Summary

Summary Statistics

Papers Sorted by Unique Keyword Counts:

Paper	Unique Keyword Count
73439ebce1faf9850d2a1c820957d36c2eac0701 An AAS Modeling Tool for Capability-Based Engineering of Fle...	4
cc7f70083823539e60190435e990515a336470f6 Semantic Interoperability of Digital Twins: Ontology-based C...	4
8b281d3a180908cacac9e13c24fbbb7c2e9b9881 Editorial: Big Data Management in Industry 4.0...	4
aac724eeecd22312a89df71d2957a5fc09f6c129 Multi-Agent Systems to Implement Industry 4.0 Components...	3
8a4abb66b52addabc9b7f930220ebfda721375d6 Enabling semantic interoperability of asset administration s...	3
bfa50108510ee6684ba9b052813fa5891688af9c Digital Twin of a Water Supply System Using the Asset Admini...	3
776888d51cedc4b324c8209cff878ab7185d7481 Automatic Fuzzing of Asset Administration Shells as Digital ...	3
395c157eb8d105457bc5974adaeac6fd95c5defb Modelling Agents in Industry 4.0 Applications Using Asset Ad...	3
ac515ecb306a7a6d5d07ea79bc519a586b1f6efb Historical Data Storage Architecture Blueprints for the Asse...	3
1aeb0c1ef6ee06683a8e984ec6faa7fae1274c56 Am I in Good Shape? Flexible Way to Validate Asset Administr...	3
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93eb9111a59c343760c98ed11db4bd147f404298 The Digital Twin Concept in Industry – A Review and Systemat...	2
ac105ceaf16483defb6985ec8d690d4ae690ee38 Insights into Mapping Solutions Based on OPC UA Information ...	2
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98267ac15d74d69f71b51ba21da39baebfec4ba4 Semantic Asset Administration Shells in Industry 4.0: A Surv...	2
cd3a8df166ba946e2200853e0ef3b32d0dfe5448 Industrial Internet of Things and Fog Computing to Reduce En...	2
c94ad2e67e261fb786931086f7c95a7478a4eb88 Enhancing Digital Twins of Semi-Automatic Production Lines b...	2
51f37d45bf9f75e6b39f50f566520c91765c8d2e Generation of Digital Twins for Information Exchange Between...	2
48c8c2a8e6b00b1d20bde6a12426330d61aac591 The AutomationML Component Description in the context of the...	2
aba4ef8b6799722665247ad7aa6b3b7d9c4c6ace On the Use of Asset Administration Shell for Modeling and De...	2
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9bdeb2e1ed7be3df49b55cb26b1428f4aaa91f09 Towards the Digitization using Asset Administration Shells...	2
06ee21fbeae1016b5ad6c23f98b775d61f66a3bf Enabling Industry 4.0 Communication Protocol Interoperabilit...	2
46d50495d99170553c68c9db2272ba3679f1854a Neuro-Symbolic AI at Bosch: Data Foundation, Insights, and D...	2
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99a1b16b265aeb42035da26a5981b8f8957e549e Efficient Control Representation in Digital Twins: An Impera...	2
5e49a137e661f3dbbd2ef11da3cf03b647e83963 Use Case Driven Digital Twin Generation...	2
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326b0126e957b02015523d9771931fe08250458d Toward a Unified Security Framework for Digital Twin Archite...	2
cdf8dafb5b0bf1a2270dee9c4e025eb1eaaea337 Digital Twin Enabled Asset Management of Machine Tools...	2
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3d6838d81550e23fe55bc1f0e4cf014a08904850 Impact of Industry 4.0 in Architecture and Cultural Heritage...	1
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c4470da19bcd86eae46523ca95d9633fff693fa5 COMPUTATIONAL MODEL OF INTERSECTIONS REPRESENTATION AS APPAR...	1
1a3882a1bf3265442cd139195cdb678d8c6c8ddd COMPUTATIONAL MODEL OF INTERSECTIONS REPRESENTATION AS APPAR...	1
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Authors

Authors with More Than 1 Paper:

Author ID	Author Name	Number of Papers
2142768259	Nico Braunisch	4
98681611	H. W. V. D. Venn	4
1791537	J. Malenfant	3
2118799456	Yining Huang	3
2024999	A. Lüder	3
145281283	P. Leitão	3
2066359511	R. Lehmann	3
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Papers by Nico Braunisch:

Paper ID	Title
776888d51cedc4b324c8209cff878ab7185d7481	Automatic Fuzzing of Asset Administration Shells a...
01f9eb1d562af8e733372edeb48cf1e07979d556	Empowering Industry 4.0 with Generative and Model-...
51f37d45bf9f75e6b39f50f566520c91765c8d2e	Generation of Digital Twins for Information Exchan...
64cdf2f084f9abe071b1e4e185f2916f6c1afa33	Generative and Model-driven SDK development for th...

Papers by H. W. V. D. Venn:

Paper ID	Title
776888d51cedc4b324c8209cff878ab7185d7481	Automatic Fuzzing of Asset Administration Shells a...
01f9eb1d562af8e733372edeb48cf1e07979d556	Empowering Industry 4.0 with Generative and Model-...
51f37d45bf9f75e6b39f50f566520c91765c8d2e	Generation of Digital Twins for Information Exchan...

64cdf2f084f9abe071b1e4e185f2916f6c1afa33	Generative and Model-driven SDK development for th...

Papers by J. Malenfant:

Paper ID	Title
8a4abb66b52addabc9b7f930220ebfda721375d6	Enabling semantic interoperability of asset admini...
cc7f70083823539e60190435e990515a336470f6	Semantic Interoperability of Digital Twins: Ontolo...
73439ebce1faf9850d2a1c820957d36c2eac0701	An AAS Modeling Tool for Capability-Based Engineer...

Papers by Yining Huang:

Paper ID	Title
8a4abb66b52addabc9b7f930220ebfda721375d6	Enabling semantic interoperability of asset admini...
cc7f70083823539e60190435e990515a336470f6	Semantic Interoperability of Digital Twins: Ontolo...
73439ebce1faf9850d2a1c820957d36c2eac0701	An AAS Modeling Tool for Capability-Based Engineer...

Papers by A. Lüder:

Paper ID	Title
4d547378091d15761e1f9546790ed9c2298429e7	Generating Industry 4.0 Asset Administration Shell...
c9c0ded35c8f50d2a918d233b399c45af15d3051	Consistent Extension of Networks of Digital Repres...
0837e5bc01a11fd7d0eeadea79e18a180a3e514e	Patterns for Reuse in Production Systems Engineeri...

Papers by P. Leitão:

Paper ID	Title
aac724eeecd22312a89df71d2957a5fc09f6c129	Multi-Agent Systems to Implement Industry 4.0 Comp...
807339238de26cae890e8f79d3b608241f0d4f63	Multi-Agent Systems to Realize Intelligent Asset A...
9bdeb2e1ed7be3df49b55cb26b1428f4aaa91f09	Towards the Digitization using Asset Administratio...

Papers by R. Lehmann:

Paper ID	Title
01f9eb1d562af8e733372edeb48cf1e07979d556	Empowering Industry 4.0 with Generative and Model-...
51f37d45bf9f75e6b39f50f566520c91765c8d2e	Generation of Digital Twins for Information Exchan...
64cdf2f084f9abe071b1e4e185f2916f6c1afa33	Generative and Model-driven SDK development for th...

Papers by Lucas Sakurada:

Paper ID	Title
aac724eeecd22312a89df71d2957a5fc09f6c129	Multi-Agent Systems to Implement Industry 4.0 Comp...
807339238de26cae890e8f79d3b608241f0d4f63	Multi-Agent Systems to Realize Intelligent Asset A...
9bdeb2e1ed7be3df49b55cb26b1428f4aaa91f09	Towards the Digitization using Asset Administratio...

Papers by S. Dhouib:

Paper ID	Title
8a4abb66b52addabc9b7f930220ebfda721375d6	Enabling semantic interoperability of asset admini...
cc7f70083823539e60190435e990515a336470f6	Semantic Interoperability of Digital Twins: Ontolo...
73439ebce1faf9850d2a1c820957d36c2eac0701	An AAS Modeling Tool for Capability-Based Engineer...

Papers by Marko Ristin-Kaufmann:

Paper ID	Title
01f9eb1d562af8e733372edeb48cf1e07979d556	Empowering Industry 4.0 with Generative and Model-...
51f37d45bf9f75e6b39f50f566520c91765c8d2e	Generation of Digital Twins for Information Exchan...

Papers by S. Biffl:

Paper ID	Title
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Papers by Luis Palacios Medinacelli:

Paper ID	Title
8a4abb66b52addabc9b7f930220ebfda721375d6	Enabling semantic interoperability of asset admini...
cc7f70083823539e60190435e990515a336470f6	Semantic Interoperability of Digital Twins: Ontolo...

Papers by Sadeer Beden:

Paper ID	Title
98267ac15d74d69f71b51ba21da39baebfec4ba4	Semantic Asset Administration Shells in Industry 4...
3614e589fcc4148bc2a10569b40c17ba5cc8ac18	Knowledge-driven Artificial Intelligence in Steelm...

Papers by F. D. L. Prieta:

Paper ID	Title
807339238de26cae890e8f79d3b608241f0d4f63	Multi-Agent Systems to Realize Intelligent Asset A...
9bdeb2e1ed7be3df49b55cb26b1428f4aaa91f09	Towards the Digitization using Asset Administratio...

Papers by Martin Wollschlaeger:

Paper ID	Title
776888d51cedc4b324c8209cff878ab7185d7481	Automatic Fuzzing of Asset Administration Shells a...
01f9eb1d562af8e733372edeb48cf1e07979d556	Empowering Industry 4.0 with Generative and Model-...

Papers by Marko Ristin:

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776888d51cedc4b324c8209cff878ab7185d7481	Automatic Fuzzing of Asset Administration Shells a...
64cdf2f084f9abe071b1e4e185f2916f6c1afa33	Generative and Model-driven SDK development for th...

Papers by F. Schnicke:

Paper ID	Title
ac515ecb306a7a6d5d07ea79bc519a586b1f6efb	Historical Data Storage Architecture Blueprints fo...
06ee21fbeae1016b5ad6c23f98b775d61f66a3bf	Enabling Industry 4.0 Communication Protocol Inter...

Papers by E. Kharlamov:

Paper ID	Title
04951cdeaf092794088b827a48b38e0664ecce3f	Semantic Digital Twins: Trends and Shortcomings (K...
46d50495d99170553c68c9db2272ba3679f1854a	Neuro-Symbolic AI at Bosch: Data Foundation, Insig...

Papers by P. Antonino:

Paper ID	Title
ac515ecb306a7a6d5d07ea79bc519a586b1f6efb	Historical Data Storage Architecture Blueprints fo...
06ee21fbeae1016b5ad6c23f98b775d61f66a3bf	Enabling Industry 4.0 Communication Protocol Inter...

Papers by Jairo Viola:

Paper ID	Title
7f9b86fb6f72d721d4b28158e694788bfc191e48	FPGA-Based Digital Twin Implementation for Mechatr...
09476cf6c0f9455d06e96ab6f8141e06a97f214e	Digital Twin-Enabled Modelling of a Multivariable ...

Papers by Kristof Meixner:

Paper ID	Title
c9c0ded35c8f50d2a918d233b399c45af15d3051	Consistent Extension of Networks of Digital Repres...
0837e5bc01a11fd7d0eeadea79e18a180a3e514e	Patterns for Reuse in Production Systems Engineeri...

Papers Details

1) The Digital Twin Concept in Industry – A Review and Systematization

Paper ID: 93eb9111a59c343760c98ed11db4bd147f404298

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Citation Count	Influential Citation Count	Reference Count
67	4	64

Keyword	Count
industry 4.0	1
digital twin	10
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This paper provides a structured review of the body of relevant literature with the specific focus on finding explicit definitions of the term "**Digital Twin**" as well as stated models characterizing the **Digital Twin** concept.

Abstract: The scientific discussion on the **Digital Twin** gained substantial momentum within the last couple of years. In the context of **Industry 4.0**, the **Digital Twin** in the broadest sense refers to the concept of a coupled virtual representation of a physical asset. The asset types may range from products and processes to whole production systems. Different authors offer a variety of interpretations on the actual nature of the **Digital Twin**, often defining it via implicit functional aspects rather than giving explicit definitions. At the same time, some authors use the term merely as a catchphrase, thus applying blur to this emerging paradigm. At this point, a comprehensive understanding as well as a unifying model of the **Digital Twin** are absent. This paper therefore provides a structured review of the body of relevant literature with the specific focus on finding explicit definitions of the term "**Digital Twin**" as well as stated models characterizing the **Digital Twin** concept. As a result, a relevance assessment provides the most important literature regarding the research questions. The found explicit definitions, being partly conflicting, are presented. Similar notions like Product Avatar and Digital Shadow are assorted accordingly. Further, depictions of **Digital Twin** models stated in the most relevant literature as well as derived **Digital Twin** purposes are provided. Thus, this paper extends the theoretical foundation, thereby setting a basis for future augmented **Digital Twin** modeling.

2) Automated Design and Integration of Asset Administration Shells in Components of Industry 4.0

Paper ID: e8ddda60e8ee15e7131cd57ada61a57fd8178197

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2382692	F. Zezulka
2321228	C. Diedrich
3478336	P. Dohnal

Citation Count	Influential Citation Count	Reference Count
40	1	64

Keyword	Count
industry 4.0	4
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: The paper discusses the AAS in terms of its structure, its components, the sub-models that form a substantial part of the shell's content, and its communication protocols (Open Platform Communication—Unified Architecture and MQTT or SW interfaces enabling vertical and horizontal communication to involve other components and levels of management systems).

Abstract: One of the central concepts in the principles of **Industry 4.0** relates to the methodology for designing and implementing the digital shell of the manufacturing process components. This concept, the Asset Administration Shell (AAS), embodies a systematically formed, standardized data envelope of a concrete component within **Industry 4.0**. The paper discusses the AAS in terms of its structure, its components, the sub-models that form a substantial part of the shell's content, and its communication protocols (Open Platform Communication—Unified Architecture (OPC UA) and MQTT) or SW interfaces enabling vertical and horizontal communication to involve other components and levels of management systems. Using a case study of a virtual assembly line that integrates AASs into the technological process, the authors present a comprehensive analysis centered on forming AASs for individual components. In the given context, the manual AAS creation mode exploiting framework-based automated generation, which forms the AAS via a configuration wizard, is assessed. Another outcome consists of the activation of a virtual assembly line connected to real AASs, a step that allows us verify the properties of the distributed manufacturing management. Moreover, a discrete event system was modeled for the case study, enabling the effective application of the **Industry 4.0** solution.

3) Insights into Mapping Solutions Based on OPC UA Information Model Applied to the Industry 4.0 Asset Administration Shell

Paper ID: ac105ceaf16483defb6985ec8d690d4ae690ee38

Authors:

Author ID	Author Name
35530716	S. Cavalieri
37811456	Marco Giuseppe Salafia

Citation Count	Influential Citation Count	Reference Count
37	0	47

Keyword	Count
industry 4.0	4
digital twin	0
digital asset management	0
interoperability	3
digital representation	0
industrial metaverse	0

TLDR: Some insights behind modelling techniques that should be adopted during the definition of OPC UA Information Model exposing information of the very recent metamodel defined for the asset administration shell are given.

Abstract: In the context of **Industry 4.0**, lot of effort is being put to achieve **interoperability** among industrial applications. As the definition and adoption of communication standards are of paramount importance for the realization of **interoperability**, during the last few years different organizations have developed reference architectures to align standards in the context of the fourth industrial revolution. One of the main examples is the reference architecture model for **Industry 4.0**, which defines the asset administration shell as the corner stone of the **interoperability** between applications managing manufacturing systems. Inside **Industry 4.0** there is also so much interest behind the standard open platform communications unified architecture (OPC UA), which is listed as the one recommendation for realizing the communication layer of the reference architecture model. The contribution of this paper is to give some insights behind modelling techniques that should be adopted during the definition of OPC UA Information Model exposing information of the very recent metamodel defined for the asset administration shell. All the general rationales and solutions here provided are compared with the current OPC UA-based existing representation of asset administration shell provided by literature. Specifically, differences will be pointed out giving to the reader advantages and disadvantages behind each solution.

4) Digital Twin and Industry 4.0 Enablers in Building and Construction: A Survey

Paper ID: bbf900cd6a7d97c1357a8345ab3c43f920e6f4c7

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Citation Count	Influential Citation Count	Reference Count
34	3	183

Keyword	Count
industry 4.0	4
digital twin	2
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: A systematic literature review of 182 papers on DT-in-construction works over the past 6 years is conducted and aims to serve as a reference for both industry and academia towards the use of DT systems as a fundamental enabler to realise the Construction 4.0 paradigm.

Abstract: With increasing interest in automatic and intelligent systems to enhance the building and construction industry, digital twins (DT) are gaining popularity as cost-effective solutions to meet stakeholder requirements. Comprising real-time multi-asset connectivity, simulation, and decision support functionalities, many recent studies have utilised **Industry 4.0** technologies with DT systems to fulfil construction-specific applications. However, there is no comprehensive review to our knowledge, holistically examining the benefits of using DT as a platform from the angles of **Industry 4.0** technologies, project management, and building lifecycle. To bridge this gap, a systematic literature review of 182 papers on DT-in-construction works over the past 6 years is conducted to address the three perspectives. In this review, a unified framework is first modelled to incorporate **Industry 4.0** technologies within the DT structure. Next, a Six M methodology (comprising of Machine, Manpower, Material, Measurement, Milieu, and Method) based on Ishikawa's Diagram with building lifecycle considerations is proposed to highlight the advantages of DT in ensuring successful construction projects. Lastly, through the identification of 11 future directions, this work aims to serve as a reference for both industry and academia towards the use of DT systems as a fundamental enabler to realise the Construction 4.0 paradigm.

5) Generating Industry 4.0 Asset Administration Shells with Data from Engineering Data Logistics

Paper ID: 4d547378091d15761e1f9546790ed9c2298429e7

Authors:

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81093575	Felix Rinker
1689732	S. Biffl

Citation Count	Influential Citation Count	Reference Count
27	4	38

Keyword	Count
industry 4.0	5
digital twin	1
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This paper introduces the I4.0AAS completion method and builds on the AutomationML standard and on the data logistics between engineering workgroups to facilitate the collection and representation of engineering data as part of the I3.5AAS.

Abstract: Advanced production systems, for example in the European automotive or steel industries, incorporate **Industry 4.0** defined structures based on **Industry 4.0** components and their asset administration shells. Several development and standardization initiatives define structures, behavior patterns, meta models, etc. These initiatives assume the **Industry 4.0** asset administration shell (I4.0AAS) as a **digital twin** of the **Industry 4.0** component to contain all relevant engineering and runtime data. However, there is only limited discussion on how to collect and represent these data effectively and efficiently. In this paper, we discuss the collection and representation of engineering data as part of the I4.0AAS. We introduce the I4.0AAS completion method to facilitate the collection of the I4.0AAS engineering data set and its export to an I4.0AAS serialization. In the multi-disciplinary engineering of production systems, the I4.0AAS completion method builds on the AutomationML standard and on the data logistics between engineering workgroups. We evaluate the I4.0AAS completion method in a feasibility study with an I4.0 measurement cell.

6) IoTwins: Toward Implementation of Distributed Digital Twins in Industry 4.0 Settings

Paper ID: 3703618d21ff43b728eb4e86ef6b6c4c40367d8a

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Citation Count	Influential Citation Count	Reference Count
26	3	53

Keyword	Count
industry 4.0	1
digital twin	4
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: The main research goals of the IoTwins project are presented and its reference architecture, platform functionalities and building components are discussed and an industry-related use case is discussed that showcases how manufacturers can leverage the potential of the IoTwins platform to develop and execute distributed DTs for the the predictive-maintenance purpose.

Abstract: : While the digital twins paradigm has attracted the interest of several research communities over the past twenty years, it has also gained ground recently in industrial environments, where mature technologies such as cloud, edge and IoT promise to enable the cost-effective implementation of digital twins. In the industrial manufacturing ■eld, a digital model refers to a virtual representation of a physical product or process that integrates data taken from various sources, such as application program interface (API) data, historical data, embedded sensor data and open data, and that is capable of providing manufacturers with unprecedented insights into the product’s expected performance or the defects that may cause malfunctions. The EU-funded IoTwins project aims to build a solid platform that manufacturers can access to develop hybrid digital twins (DTs) of their assets, deploy them as close to the data origin as possible (on IoT gateway or on edge nodes) and take advantage of cloud-based resources to off-load intensive computational tasks such as, e.g., big data analytics and machine learning (ML) model training. In this paper, we present the main research goals of the IoTwins project and discuss its reference architecture, platform functionalities and building components. Finally, we discuss an industry-related use case that showcases how manufacturers can leverage the potential of the IoTwins platform to develop and execute distributed DTs for the the predictive-maintenance purpose.

7) A Semantic-driven Approach for Industry 4.0

Paper ID: 19d07a301d837161c48548c06bd8a77bc25496d6

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Citation Count	Influential Citation Count	Reference Count
16	2	9

Keyword	Count
industry 4.0	3
digital twin	1
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This research addresses problems towards efficient integration and management of data for predictive maintenance through representation of knowledge in an ontology-based model.

Abstract: Toward **industry 4.0**, modern manufacturing companies are aiming at building digital twins to manage physical assets, processes, people, and places. Since in this environment, massive amounts of data have been generated and collected, integration and management of various data sources is of paramount importance. In this context, cloud computing as a crucial part of **Industry 4.0** facilitates distribution of computer resources without direct active management by users. Accordingly, an ontology enables efficient integration and management of data as a reference data model through representation of knowledge. Besides, data mining from massive data is very important to identify significant meaning of data, and to avoid unexpected errors through predictions from experiences described in data replica. This research addresses problems towards efficient integration and management of data for predictive maintenance.

8) Modeling and Connecting Asset Administrative Shells for Mini Factories

Paper ID: 7f0a9b2f2e525f8fcbd6ec51c47fd45d835468b0

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Citation Count	Influential Citation Count	Reference Count
14	1	25

Keyword	Count
industry 4.0	2
digital twin	1
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This paper extends the previously presented methodology meant for creating Asset Administrative Shells in Mini Factories with a focus on connectivity, and shows some of the enhanced capabilities of **Industry 4.0**.

Abstract: Abstract The supply-chain based (SCB) concept applied to Mini Factories is a very relevant approach for current manufacturing. SBC, allows a network-like interconnectivity between assets by setting up factories inside the premises of the principal manufacturer, allowing more efficient machines utilization. The aforesaid assets need a proper representation and it is there where the core of **Industry 4.0** (I4.0) comes to the rescue. According to I4.0, every asset (e.g. a machine, software, sensor or actuator, etc.), should be modeled via an Asset Administrative Shell (AAS). AAS is a knowledge structure that provides a description of the asset, its technical functionality and its relationships to other assets. It can be viewed as the as the data model from where the **digital twin** stems from. In this paper we extend our previously presented methodology meant for creating Asset Administrative Shells in Mini Factories with a focus on connectivity. By using our proposed methodology, Model Factory @ARTC has been able to quickly connect and integrate diverse assets into our factory of the future, demonstrating some of the enhanced capabilities of **Industry 4.0**.

9) Semantic Asset Administration Shells in Industry 4.0: A Survey

Paper ID: 98267ac15d74d69f71b51ba21da39baebfec4ba4

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Citation Count	Influential Citation Count	Reference Count
14	4	0

Keyword	Count
industry 4.0	2
digital twin	0
digital asset management	0
interoperability	0
digital representation	2
industrial metaverse	0

TLDR: A comprehensive survey of the scientific contributions to Semantic AASs that model the Information and Communication Layer within RAMI 4.0 is provided, and their structure, communication, functionalities, and use cases are summarized.

Abstract: The Asset Administration Shell (AAS) is a fundamental concept in the Reference Architecture Model for **Industry 4.0** (RAMI 4.0), that provides a virtual and **digital representation** of all information and functions of a physical asset in a manufacturing environment. Recently, Semantic AASs have emerged that add knowledge representation formalisms to enhance the **digital representation** of physical assets. In this paper, we provide a comprehensive survey of the scientific contributions to Semantic AASs that model the Information and Communication Layer within RAMI 4.0, and summarise and demonstrate their structure, communication, functionalities, and use cases. We also highlight the challenges of future development of Semantic AASs.

10) Multi-Agent Systems to Implement Industry 4.0 Components

Paper ID: aac724eeecd22312a89df71d2957a5fc09f6c129

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Citation Count	Influential Citation Count	Reference Count
13	4	24

Keyword	Count
industry 4.0	3
digital twin	0
digital asset management	0
interoperability	1
digital representation	1
industrial metaverse	0

TLDR: This paper explores the use of Multi-Agent Systems (MAS) to implement the AAS functionalities, taking advantage of their inherits characteristics, e.g., autonomy, intelligence, decentralization and reconfigurability.

Abstract: The fast-changing market conditions, the increased global competition and the rapid technological developments demand flexible, adaptable and reconfigurable manufacturing systems based on Cyber-Physical Systems (CPS). Aligned with CPS, the adoption of production system architectures is suitable to reduce complexity and achieve **interoperability** in the industrial applications. In this context, the Reference Architecture Model for **Industry 4.0** (RAMI4.0) provides the guidelines to develop **Industry 4.0** (I4.0) compliant solutions, considering the existing industrial standards. The so-called I4.0 components implement this model in practice, combining the physical asset with its **digital representation**, named Asset Administration Shell (AAS). This paper explores the use of Multi-Agent Systems (MAS) to implement the AAS functionalities, taking advantage of their inherits characteristics, e.g., autonomy, intelligence, decentralization and reconfigurability. In this context, the mapping between AAS functionalities and MAS characteristics is provided, as well as the challenges for this implementation. The applicability is illustrated by digitalizing an inspection cell comprising an UR3 robot and several console products by using MAS technology.

11) Patterns for Reuse in Production Systems Engineering

Paper ID: 0837e5bc01a11fd7d0eeadea79e18a180a3e514e

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Citation Count	Influential Citation Count	Reference Count
11	0	24

Keyword	Count
industry 4.0	2
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: N/A

Abstract: In Production Systems Engineering (PSE), domain experts aim at reusing partial system designs implemented as **Industry 4.0** assets and software. However, the knowledge on assets is often scattered across engineering artifacts from multiple disciplines and domain experts, making it difficult to find reusable assets and map them to requirements. In this paper, we (i) identify challenges and requirements for the representation of reuse knowledge in PSE, based on the results of a domain analysis in automotive manufacturing; (ii) refine the **Industry 4.0** Asset Network (I4AN) meta-model that integrates multi-disciplinary dependencies between the assets; (iii) introduce the I4AN reference model that exposes recurring patterns; and (iv) present basic and applied patterns for reuse in PSE that aim at improving reuse efficiency and lowering risks. We evaluate the I4AN reference model and patterns with reuse scenarios in a feasibility study in automotive manufacturing. The study results indicate that the I4AN reference model and patterns satisfy the elicited requirements and enable PSE domain experts to identify patterns for reuse and sufficiently complete sets of reusable assets in their contexts.

12) Industrial Internet of Things and Fog Computing to Reduce Energy Consumption in Drinking Water Facilities

Paper ID: cd3a8df166ba946e2200853e0ef3b32d0dfe5448

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Citation Count	Influential Citation Count	Reference Count
11	1	46

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	1
digital representation	0
industrial metaverse	0

TLDR: This paper aims to provide the next step in obtaining a proactive historian application and proposes a non-invasive decision and control solution in the context of the Industrial Internet of Things, meant to reduce energy consumption in a water treatment and distribution process.

Abstract: The industry is generally preoccupied with the evolution towards **Industry 4.0** principles and the associated advantages as cost reduction, respectively safety, availability, and productivity increase. So far, it is not completely clear how to reach these advantages and what their exact representation or impact is. It is necessary for industrial systems, even legacy ones, to assure **interoperability** in the context of chronologically dispersed and currently functional solutions, respectively; the Open Platform Communications Unified Architecture (OPC UA) protocol is an essential requirement. Then, following data accumulation, the resulting process-aware strategies have to present learning capabilities, pattern identification, and conclusions to increase efficiency or safety. Finally, model-based analysis and decision and control procedures applied in a non-invasive manner over functioning systems close the optimizing loop. Drinking water facilities, as generally the entire water sector, are confronted with several issues in their functioning, with a high variety of implemented technologies. The solution to these problems is expected to create a more extensive connection between the physical and the digital worlds. Following previous research focused on data accumulation and data dependency analysis, the current paper aims to provide the next step in obtaining a proactive historian application and proposes a non-invasive decision and control solution in the context of the Industrial Internet of Things, meant to reduce energy consumption in a water treatment and distribution process. The solution is conceived for the fog computing concept to be close to local automation, and it is automatically adaptable to changes in the process's main characteristics caused by various factors. The developments were applied to a water facility model realized for this purpose and on a real system. The results prove the efficiency of the concept.

13) Enhancing Digital Twins of Semi-Automatic Production Lines by Digitizing Operator Skills

Paper ID: c94ad2e67e261fb786931086f7c95a7478a4eb88

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Citation Count	Influential Citation Count	Reference Count
10	0	0

Keyword	Count
industry 4.0	1
digital twin	4
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This approach introduces a methodology to offer suggestions about employee rotations based on their previous performance during a shift that is integrated into a **digital twin** to perform human performance assessments to manage workers' jobs.

Abstract: In recent years, **Industry 4.0** has provided many tools to replicate, monitor, and control physical systems. The purpose is to connect production assets to build cyber-physical systems that ensure the safety, quality, and efficiency of production processes. Particularly, the concept of digital twins has been introduced to create the virtual representation of physical systems where both elements are connected to exchange information. This general definition encompasses a series of major challenges for the developers of those functionalities. Among them is how to introduce the human perspective into the virtual replica. Therefore, this paper presents an approach for incorporating human factors in digital twins. This approach introduces a methodology to offer suggestions about employee rotations based on their previous performance during a shift. Afterward, this method is integrated into a **digital twin** to perform human performance assessments to manage workers' jobs. Furthermore, the presented approach is mainly comprised of a human skills modelling engine and a human scheduling engine. Finally, for demonstrating the approach, a simulated serial single-product manufacturing assembly line has been introduced.

14) An AAS Modeling Tool for Capability-Based Engineering of Flexible Production Lines

Paper ID: 73439ebce1faf9850d2a1c820957d36c2eac0701

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1791537	J. Malenfant

Citation Count	Influential Citation Count	Reference Count
10	2	21

Keyword	Count
industry 4.0	1
digital twin	1
digital asset management	0
interoperability	1
digital representation	1
industrial metaverse	0

TLDR: This article proposes a capability-based operation and engineering approach for flexible production lines based on the AAS standard and describes the subset of AAS modelling concepts necessary for this approach, and clarifies their semantics and shows their usage through a production cell use case.

Abstract: The future intelligent manufacturing systems should possess a high degree of autonomy, which is able to monitor the entire production process, quickly re-plan operations, and respond to various unforeseen situations in a secure and safe manner. This can achieve rapid response to customers and avoid costly machine downtime, which is crucial to maintaining business success and profitability. The Asset Administration Shell (AAS) is an emerging standard in the I4.0 (**Industry 4.0**) domain. Based on the concept of digital twins, it provides concepts for describing the **digital representation** of I4.0 assets including their capabilities and skills. The AAS provides also responses to the challenge of syntactic and semantic **interoperability** that the flexible and autonomous production lines are facing. In this article, we propose a capability-based operation and engineering approach for flexible production lines. Our approach is relying on the AAS standard which is a very wide and rich specification. Consequently, we describe the subset of AAS modelling concepts necessary for our approach, we clarify their semantics and we show their usage through a production cell use case. Furthermore, we demonstrate how these modelling concepts were tooled as an extension of the open source model-driven workbench Papyrus.

15) Enabling semantic interoperability of asset administration shells through an ontology-based modeling method

Paper ID: 8a4abb66b52addabc9b7f930220ebfda721375d6

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Citation Count	Influential Citation Count	Reference Count
10	1	26

Keyword	Count
industry 4.0	3
digital twin	2
digital asset management	0
interoperability	4
digital representation	0
industrial metaverse	0

TLDR: A modeling approach is proposed that provides semantic **interoperability** for AAS-based digital twins using ontologies, because they provide formal semantics expressed using a knowledge representation language, and there are many associated mature tools for reasoning and inference.

Abstract: **Digital twin** technology establishes the future development vision for **Industry 4.0**, and is also an important exploration direction for the Model-Driven Engineering (MDE) paradigm. Because it builds a more flexible and communicative production system through models that spans life cycle, hierarchy and architecture. The standard proposed under the concept of **Industry 4.0**, the Asset Administration Shell (AAS), provides a syntactic **interoperability** interface for all assets involved in smart factories. However, there is still a need to fill the gap regarding semantic **interoperability**, in order to allow efficient interactions between **Industry 4.0** components. Ontologies are a good candidate because they provide formal semantics expressed using a knowledge representation language, and in addition, there are many associated mature tools for reasoning and inference. Therefore, we propose a modeling approach that provides semantic **interoperability** for AAS-based digital twins using ontologies.

16) Generation of Digital Twins for Information Exchange Between Partners in the Industrie 4.0 Value Chain

Paper ID: 51f37d45bf9f75e6b39f50f566520c91765c8d2e

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98681611	H. W. V. D. Venn

Citation Count	Influential Citation Count	Reference Count
9	1	25

Keyword	Count
industry 4.0	2
digital twin	3
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This work presents an approach to automatically generate the different data schemas for information exchange between partners in the **Industry 4.0** value chain, based on the intermediate representation of the formalized meta-model.

Abstract: In **Industry 4.0**, the **digital twin** is represented as an Asset Administration Shell. The Asset Administration Shell meta-model is used to develop this **digital twin**. A developer needs ready-made exchange formats and data schemas to be able to work efficiently with libraries in his programming languages. The existing representations of the metamodel in XML, JSON and RDF, in their current form, have been created manually by individual working group members. This process is error-prone and inconsistent in the enforcement of serialization rules, leading to many manual re-implementations of the Asset Administration Shell in each representation. We present an approach to automatically generate the different data schemas for information exchange between partners in the **Industry 4.0** value chain, based on the intermediate representation of the formalized meta-model. The approach enables a practical and simple development process of and is scalable across different exchange formats and their future changes.

17) The AutomationML Component Description in the context of the Asset Administration Shell

Paper ID: 48c8c2a8e6b00b1d20bde6a12426330d61aac591

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Citation Count	Influential Citation Count	Reference Count
8	1	3

Keyword	Count
industry 4.0	3
digital twin	0
digital asset management	0
interoperability	0
digital representation	1
industrial metaverse	0

TLDR: This paper describes and compares the most promising approaches to model the asset administration shell: the AAS model of the Platform I4.0, and the AutomationML component description of theAutomationML e.V.

Abstract: One of the key ideas of **Industry 4.0** is the availability of a **digital representation** of each industrial asset within an **Industry 4.0** network, the “Asset Administration Shell” (AAS). The AAS combines data related to an asset and software interfaces which provide access and explorability of the asset data in the network. Because an accepted standard is missing, component manufacturers are currently not able to economically release basic asset models for their products. This creates a deadlock situation for the widespread introduction of **Industry 4.0** driven smart factory concepts. This paper describes and compares the most promising approaches to model the asset administration shell: the AAS model of the Platform I4.0, and the AutomationML component description of the AutomationML e.V. The technical concepts are comparatively analyzed for strengths and weaknesses and a useful combination of both model worlds is proposed.

18) On the Use of Asset Administration Shell for Modeling and Deploying Production Scheduling Agents within a Multi-Agent System

Paper ID: aba4ef8b6799722665247ad7aa6b3b7d9c4c6ace

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Citation Count	Influential Citation Count	Reference Count
8	0	39

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	0
digital representation	1
industrial metaverse	0

TLDR: An AAS-based information model is proposed for the description of scheduling agents that allows multiple AI methods for scheduling, such as heuristics, mathematical programming, and deep reinforcement learning, to be encapsulated within a single agent, making it adjustable to different production scenarios.

Abstract: **Industry 4.0** (I4.0) aims at achieving the interconnectivity of multiple industrial assets from different hierarchical layers within a manufacturing environment. The Asset Administration Shell (AAS) is a pilar component of I4.0 for the **digital representation** of assets and can be applied in both physical and digital assets, such as enterprise software, artificial intelligence (AI) agents, and databases. Multi-agent systems (MASs), in particular, are useful in the decentralized optimization of complex problems and applicable in various planning or scheduling scenarios that require the system's ability to adapt to any given problem by using different optimization methods. In order to achieve this, a universal model for the agent's information, communication, and behaviors should be provided in a way that is interoperable with the rest of the I4.0 assets and agents. To address these challenges, this work proposes an AAS-based information model for the description of scheduling agents. It allows multiple AI methods for scheduling, such as heuristics, mathematical programming, and deep reinforcement learning, to be encapsulated within a single agent, making it adjustable to different production scenarios. The software implementation of the proposed architecture aims to provide granularity in the deployment of scheduling agents which utilize the underlying AAS metamodel. The agent was implemented using the SARL agent-oriented programming (AOP) language and deployed in an open-source MAS platform. The system evaluation in a real-life bicycle production scenario indicated the agent's ability to adapt and provide fast and accurate scheduling results.

19) Empowering Industry 4.0 with Generative and Model-Driven SDK Development

Paper ID: 01f9eb1d562af8e733372edeb48cf1e07979d556

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Citation Count	Influential Citation Count	Reference Count
8	0	30

Keyword	Count
industry 4.0	2
digital twin	1
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This work presents an approach for automatic generation of software libraries based on the formalized AAS meta-model and shows that the development with this approach is 5× faster for a new language and 10× fasterFor a new version of the AASMeta-model.

Abstract: Industry 4.0 developers need high-quality libraries in their preferred programming languages to efficiently and ergonomically create, edit and exchange digital twins as Asset Administration Shell (AAS). Existing specifications of the AAS can not be directly translated into programming code. This leads to many, often manual, re-implementations of the AAS in different projects and programming languages. We present an approach for automatic generation of software libraries based on the formalized AAS meta-model. This shows that the development with our approach is 5× faster for a new language and 10× faster for a new version of the AAS meta-model, respectively.

20) Documentation, Processing, and Representation of Architectural Heritage Through 3D Semantic Modelling

Paper ID: 0d2e4b6a4830f67c37d759777b9eee2eccc60581

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Citation Count	Influential Citation Count	Reference Count
7	1	24

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This chapter presents main actions achieved by the INCEPTION project, which develops key-targeted innovations in efficient 3D digitization methods, post-processing modelling tools, semantic web-based solutions, and applications to ensure a wide and aware access to digital Cultural Heritage.

Abstract: Documentation, data processing, and representation of Architectural Heritage through digital models are one of the main challenges in the field of conservation, preservation, management, and inclusive use and understanding of European heritage assets. In this framework, the impact of **Industry 4.0** is more and more crucial, since new technologies, devices, and digital environment are strongly influencing the ways in which heritage contents are explored, used, managed, and shared, also in citizens' everyday life. In this direction, the INCEPTION project – founded by the European Commission within the Horizon 2020 programme – develops key-targeted innovations in efficient 3D digitization methods, post-processing modelling tools, semantic web-based solutions, and applications to ensure a wide and aware access to digital Cultural Heritage. This chapter presents main actions achieved by INCEPTION.

21) Impact of Industry 4.0 in Architecture and Cultural Heritage

Paper ID: 3d6838d81550e23fe55bc1f0e4cf014a08904850

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Citation Count	Influential Citation Count	Reference Count
7	0	28

Keyword	Count
industry 4.0	3
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This chapter proposes an extensive analysis of the use of BIM for existing assets exploring the recent development in the area of machine learning and in theUse of ontologies to overcome the existing issues.

Abstract: Building Information Modelling (BIM) is recognized as the central mean in the digitalization process of the construction sector affecting both the technological and the organizational levels. The use of information models can empower communication capabilities thus addressing one of the main development directions of **industry 4.0**. However, several issues can be highlighted in the representation of objects through information models especially in the case of existing and/or historical buildings. This chapter proposes an extensive analysis of the use of BIM for existing assets exploring the recent development in the area of machine learning and in the use of ontologies to overcome the existing issues. It will provide a structured presentation of existing works and of perspectives in the use of ontologies, expert systems, and machine learning application in architecture and cultural heritage focusing on communication and data use in digital environments along the **industry 4.0** paradigm.

22) Towards the Digitization using Asset Administration Shells

Paper ID: 9bdeb2e1ed7be3df49b55cb26b1428f4aaa91f09

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Citation Count	Influential Citation Count	Reference Count
6	0	34

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	0
digital representation	1
industrial metaverse	0

TLDR: An analysis of the current state-of-the-art of implementing AAS is provided, discussing, amongst others, the key enabling technologies used to implement the AAS and the alignment of the research works found in the literature with the I4.0 components criteria.

Abstract: **Industry 4.0** (I4.0) is promoting the digitization of traditional manufacturing systems towards flexible, reconfigurable and intelligent factories based on Cyber-Physical Systems (CPS). In this context, the Reference Architecture Model Industrie 4.0 (RAMI4.0) provides guidelines to develop I4.0 compliant solutions based on industrial standards. As the main RAMI4.0 specification, the Asset Administration Shell (AAS) is a standard **digital representation** of an industrial asset that plays a pivotal role in enabling interoperable communication among I4.0 components across the value chain. This paper provides an analysis of the current state-of-the-art of implementing AAS, discussing, amongst others, the key enabling technologies used to implement the AAS and the alignment of the research works found in the literature with the I4.0 components criteria.

23) Generative and Model-driven SDK development for the Industrie 4.0 Digital Twin

Paper ID: 64cdf2f084f9abe071b1e4e185f2916f6c1afa33

Authors:

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98681611	H. W. V. D. Venn

Citation Count	Influential Citation Count	Reference Count
6	0	9

Keyword	Count
industry 4.0	0
digital twin	3
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This work presents an approach to automatically generate libraries based on the intermediate representation of the meta-model of the Asset Administration Shell, which allows for practical and simple development process of Industrie 4.0 components, and scales across programming environments and future changes in theMeta-model.

Abstract: Industrie 4.0 maps the **digital twin** as the Asset Administration Shell. To develop this **digital twin**, the Asset Administration Shell meta-model is used. A developer needs high-quality libraries in their programming languages to build the Asset Administration Shell in efficient and ergonomic way. The existing representations of the meta-model are inconvenient for moving from the specification to realizations in software development. This leads to many, often manual, re-implementations of the Asset Administration Shell in each programming language. We present an approach to automatically generate libraries based on the intermediate representation of the meta-model. The approach allows for practical and simple development process of Industrie 4.0 components, and scales across programming environments and future changes in the meta-model.

24) Semantic Interoperability of Digital Twins: Ontology-based Capability Checking in AAS Modeling Framework

Paper ID: cc7f70083823539e60190435e990515a336470f6

Authors:

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115727061	Luis Palacios Medinacelli
1791537	J. Malenfant

Citation Count	Influential Citation Count	Reference Count
5	1	27

Keyword	Count
industry 4.0	3
digital twin	5
digital asset management	0
interoperability	5
digital representation	1
industrial metaverse	0

TLDR: This work overcome the limitation of current syntactic-only resource matching algorithms by implementing semantic **interoperability** based on ontologies by transforming AAS-based plant models into MaRCO (Manufacturing Resource Capability Ontology) instances and then query the expanded ontology to find the needed resources.

Abstract: **Industry 4.0** currently prepares a major shift towards extreme flexibility into production lines management. Digital Twins are one of the key enabling technologies for **Industry 4.0**. However, the **interoperability** gap among **digital representation** of **Industry 4.0** assets is still one of the obstacles to the development and adoption of digital twins. If the Asset Administration Shell (AAS), the standard proposed to represent the I4.0 components, caters for syntactic **interoperability**, a more semantic kind of **interoperability** is deeply needed to develop flexible and adaptable production lines. In our work, we overcome the limitation of current syntactic-only resource matching algorithms by implementing semantic **interoperability** based on ontologies i.e., by transforming AAS-based plant models into MaRCO (Manufacturing Resource Capability Ontology) instances and then query the expanded ontology to find the needed resources. This article presents this ontology-based approach as the first step towards the design and implementation of an automated I4.0 flexible plant supervision and control system based on model-driven engineering (MDE) within the “Papyrus for Manufacturing” toolset. We show how an MDE approach can aggregate around **digital twin** modeling tools from the Papyrus platform both I4.0 technologies and AI (Knowledge Representation and Reasoning) tools. Our platform aligns modeling and ontological elements to get the best of both worlds. This method has two main advantages: (1) to provide semantic descriptions for **digital twin** models, (2) to complement model-driven engineering tools with automated reasoning. This paper showcases this approach through a robotic cell use case.

25) Variable Domain-specific Software Languages with DjDSL: Design and Implementation

Paper ID: 481eaa183680deddb020b9fc7543072d6fb4e124

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Citation Count	Influential Citation Count	Reference Count
5	1	164

Keyword	Count
industry 4.0	0
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: The distinction between modelware and grammarware is not maintained, and the development of DSMLs based on the Unified Modeling Language (UML) and/or on the Meta Object Facility (MOF) has become a popular choice.

Abstract:

26) Enabling Industry 4.0 Communication Protocol Interoperability: An OPC UA Case Study

Paper ID: 06ee21fbeae1016b5ad6c23f98b775d61f66a3bf

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Citation Count	Influential Citation Count	Reference Count
4	0	23

Keyword	Count
industry 4.0	4
digital twin	0
digital asset management	0
interoperability	2
digital representation	0
industrial metaverse	0

TLDR: The experiences in integrating OPC UA in a homogeneous communication system comprised of Create, Read, Update, Delete and Invoke primitives which improves the protocol **interoperability** and reduces integration effort are reported.

Abstract: Rapid advances in digitalization are leading the automation and manufacturing sector towards the fourth industrial revolution also known as **Industry 4.0**, whose main goal is to realize the changeable production processes, which is currently expensive and effort-intensive. The Open Platform Communications Unified Architecture (OPC UA) is an established and well-known communication protocol in the industrial domain. The Reference Architecture Model Industry4.0 (RAMI 4.0) proposes OPC UA as the core communication protocol among assets such as machines, robots, and appliances. Despite the key role of OPC UA in **Industry 4.0**, there is still a lack of technical guidance on how to integrate OPC UA with other communication protocols, especially with legacy devices that communicate through proprietary protocols. To address this challenge, we propose a solution that is characterized by a set of communication primitives, a platform-independent type system and an intermediate language. We also evaluate the overhead created through integration in terms of the round-trip time and message size imposed by metadata for abstraction. We have implemented the proposed approach in reference **Industry 4.0** projects, and in this paper, we report our experiences in integrating OPC UA in a homogeneous communication system comprised of Create, Read, Update, Delete and Invoke primitives which improves the protocol **interoperability** and reduces integration effort.

27) A METHODOLOGY FOR KNOWLEDGE DISCOVERY AND CLASSIFICATION

Paper ID: 4a7d4a04645ba76938670cd1724a6f832603fb16

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Citation Count	Influential Citation Count	Reference Count
3	0	7

Keyword	Count
industry 4.0	0
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This paper presents a methodology that has been developed to assist the discovery, classification, and capture of design knowledge and it is suggested that this methodology w ill assist the knowledge mining requirements for implementation of applications in any KBE system.

Abstract: Knowledge-based engineering (KBE) has emerged as a valuable tool for many industries seeking to harness company information and knowledge resources. Commercially available KBE systems offer a variety of development languages and interfaces for this purpose. While offering the potential for great savings, these systems frequently require substantial setup to be successful. Companies that do not succeed with KBE technologies fail either because of excessive time invested with limited return or b ecause of lack of knowledge engineering sk ills. Applying one’s knowledge comes as second nature to many. Discovering, describing, and capturing this knowledge is difficult. This paper presents a methodology that has been developed to assist the discovery, classification, and capture of design knowledge. An example problem is included and demonstrates the eleven steps of the methodology. It is suggested that this methodology w ill assist the knowledge mining requirements for implementation of applications in any KBE system. INTRODUCTION Background and Motivation Few would argue that information and knowledge are crucial to engineering design. Designing products, systems, and/or processes can require information and knowledge from a great number of resources (internal, external, digital, and otherwise). Of late, knowledge-based engineering (KBE) has emerged as a valuable tool for many industries seeking to harness and perhaps integrate company information and knowledge resources so as to automate and/or assist decision-making processes. Knowledge reuse, standardization, reduced time-to-market, and improved quality are often cited as the benefits of such systems. Knowledge collection supporting engineering design tasks at the early stage of the design process is difficult, especially when the knowledge is coming from a great number of resources. In industry, from function modeling, entity-relation information modeling to object-oriented modeling, individuals and companies are more and more concerned about how to capture knowledge and manage it efficiently. Intuitively, some knowledge capture methods have been defined using structured natural language, such is the case for G2; developed by the Gensym Company[1]. G2 is a commercial product for building applications for business operations. It uses structured natural language to capture knowledge with rules and procedures. Although it claims to enable even non-programmers to read, understand, and modify applications, it is not a formal way to systematically organize and classify data and knowledge. A more formal method to facilitate knowledge collection is UML [2] (Unified Modeling Language). UML is a graphical language for analyzing, specifying, designing, constructing, visualizing, and documenting the artifacts of a software-intensive system. But with UML, non-technical end-users, managers and business domain experts find it difficult to understand UML visual models. This may lead to problems in knowledge capture from user and domain experts. An important insight obtained from system modeling is that any modeling process, by definition, implies a modeling system one level higher. Such meta-modeling systems [3-4] represent and specify the requirements to be met by the modeling process. Meta data, which stands for data for data, is about basic concepts and terms especially for a specific domain. Meta modeling is also referred to as ontology or repository construction. For example, IDEF5 [5] is such an ontology description capture method. It is concerned with building a catalog of terms used in a domain. Ontology is similar to a data-dictionary but includes both a grammar and a model of the behavior of the domain. Nevertheless, the graphical representation of ontology mentioned in IDEF5 is too general and not very applicable to building real systems. Microsoft

Repository [6] is an example of an object-oriented meta-data management facility. It tends to be somewhat complex since it is intended to accommodate users from a wide variety of areas. The Problem Commercially available KBE systems are on the rise offering a variety of development languages and interfaces to capture and make use of company knowledge. While offering the potential for great savings in time and money with shared resources, consistency, and improved efficiency, these systems frequently have required large initial investments in time from information management personnel and/or automation experts, and senior designers within the company who possess high-level expertise and knowledge. Predominately, the companies that fail at implementing and succeeding with KBE technologies are those that do not realize the significant investment of time and knowledge engineering skills that are required to succeed. Applying one’s knowledge comes as second nature to many. Discovering, describing, and capturing this knowledge is difficult. To be successful, and to reduce the time investment in setting up and implementing KBE applications, users must be guided and supported in the processes of knowledge discovery and knowledge capture.

28) Integrated Asset Management Model based on IEC 61499 and Administration Shell

Paper ID: 010af7b677b7dedbb8105bfbf2f9b1648881a0bb

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Citation Count	Influential Citation Count	Reference Count
3	0	15

Keyword	Count
industry 4.0	0
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: An integrated model based on IEC 61499 is proposed to combine information and control to obtain a unified expression model that makes up for the lack of flexibility and dynamic reconfiguration in the industry.

Abstract: In the new round of industrial innovation, the Asset Administration Shell is proposed and gradually applied as the core element of the underlying device model. It is a digital model oriented to Industrial Cyber-Physical Systems. However, the current Administration Shell meta-model only involves the information management level of entities, which lacks associations with control. In this paper, an integrated model based on IEC 61499 is proposed to combine information and control to obtain a unified expression model. It takes advantage of the distributed and modular characteristics of Administration Shell and 61499 Function Blocks, which makes up for the lack of flexibility and dynamic reconfiguration in the industry. This integrated model is tested with an AGV and robot arm in a simulated welding product line to validate its feasibility.

29) Neuro-Symbolic AI at Bosch: Data Foundation, Insights, and Deployment

Paper ID: 46d50495d99170553c68c9db2272ba3679f1854a

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Citation Count	Influential Citation Count	Reference Count
3	0	5

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	1
digital representation	0
industrial metaverse	0

TLDR: This paper exemplifies neuro-symbolic AI with the activities of at Bosch, where semantic technologies play an essential role, including the data foundation, which relies on semantic data integration to unify heterogeneous data to uniform formats.

Abstract: Motivation. Neuro-symbolic AI [1] refers to the integration of connectionist AI (neural net-works) and symbolic AI approaches (e.g. ontology and logics). Neuro-symbolic AI in the industry becomes possible thanks to the technological advances of **Industry 4.0** [2], which bring a fast growth in volume and complexity of heterogeneous manufacturing (big) data [3]. Despite the popularity of this topic, how neuro-symbolic AI can be realised in the industry remains to be stud-ied. In this paper, we exemplify neuro-symbolic AI with the activities of at Bosch (Fig. 1), where semantic technologies play an essential role, including 1) the data foundation, which relies on semantic data integration to unify heterogeneous data to uniform formats, 2) the insights, which exploit data-driven methods especially machine learning (ML) to extract knowledge from the data, and 3) the deployment, which gives industrial examples of value generation from the data. Data Foundation: Semantic Data Integration . Bosch models industrial assets with their semantic digital counterparts as ontologies, such as resistance spot welding (welding that connects car bodies parts via welding nuggets). Bosch is also developing domain core ontology, based on manufacturing standards of ISO and harmonised with the top level ontology such as BFO to improve the Bosch applications **interoperability**. Industrial KGs. Bosch experts annotate heterogeneous manufacturing data with unified vocabularies from the ontologies, which are enhanced by the ontology reshaping method [4]

30) Digital Twins of Business Processes as Enablers for IT / OT Integration

Paper ID: 85364265d85540a482bcd4c8c52ef79db6946a9e

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Citation Count	Influential Citation Count	Reference Count
3	0	23

Keyword	Count
industry 4.0	4
digital twin	1
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: An Industrial Business Process Twin (IBPT) is proposed, allowing to apply methods of one world to another not directly but, instead, to a representation, that is in bidirectional exchange with the other world.

Abstract: The vision of **Industry 4.0** introduces new requirements to Operational Technology (OT) systems. Solutions for these requirements already exist in the realm of Information Technology (IT), however, due to the different characteristics of IT and OT, these solutions often cannot be directly used in the realm of OT. We therefore propose an Industrial Business Process Twin (IBPT), allowing to apply methods of one world to another not directly but, instead, to a representation, that is in bidirectional exchange with the other world. The proposed IBPT entity acts as an intermediary, decoupling the realms of IT and OT, thus allowing for an integration of IT and OT components of different manufacturers and platforms. Using this approach, we demonstrate the four essential **Industry 4.0** design principles information transparency, technical assistance, interconnection and decentralized decisions based on the gamified **Industry 4.0** scenario of playing the game of Nine Men’s Morris. This scenario serves well for agent based Artificial Intelligence (AI)-research and education. We develop an Open Platform Communications Unified Architecture (OPC UA) information and communication model and then evaluate the IBPT component with respect to the different views of the Reference Architecture Model **Industry 4.0** (RAMI4.0).

31) Efficient Control Representation in Digital Twins: An Imperative Challenge for Declarative Languages

Paper ID: 99a1b16b265aeb42035da26a5981b8f8957e549e

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Citation Count	Influential Citation Count	Reference Count
2	0	47

Keyword	Count
industry 4.0	1
digital twin	2
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This work analyzes the problem, proposes a modeling paradigm to solve it, and suggests how to integrate that paradigm into equation-based language compilers, and presents a Modelica/C++ library, which is released as free software, built according to the said paradigm.

Abstract: Digital twins (DTs) are enablers for the fast optimization processes required in the **Industry 4.0** context. Declarative equation-based modeling languages, in turn, enable the creation of large-scale simulation-based DTs, as they relieve the analyst from creating the solution code. However, most industrial assets are cyber-physical systems, the cyber part being their digital controls. With the available technology, a precise representation of modulating and logic controls conflicts with DT simulation performance. The result is a barrier to using DTs for system-level optimization. We analyze the problem, propose a modeling paradigm to solve it, and suggest how to integrate that paradigm into equation-based language compilers. We support our proposal by presenting a Modelica/C++ library, which we release as free software, built according to the said paradigm.

32) Use Case Driven Digital Twin Generation

Paper ID: 5e49a137e661f3dbbd2ef11da3cf03b647e83963

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Citation Count	Influential Citation Count	Reference Count
2	0	0

Keyword	Count
industry 4.0	2
digital twin	5
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This contribution presents an approach and an architecture for a model-based generation of AASs, which provides a meta model and initial submodels, each of which contains the information needed for a common use case.

Abstract: Digital twins, especially when standardized, are an essential aspect of **Industry 4.0**, because they enable in-teroperability for components of different companies, both in the engineering and operational phase. The German initiative “Plattform Industrie 4.0” considers the Asset Administration Shell (AAS) as the **Digital Twin** for **Industry 4.0**. The concept provides a meta model and initial submodels, each of which contains the information needed for a common use case. For a variety of use cases, in particular customer specific applications, the information that may need to be provided by multiple AASs to ensure the correct execution of the application must be specified by the partners involved. This contribution presents an approach and an architecture for a model-based generation of AASs. The foundation is a model containing the specification of a use case. Each partner involved in the execution of this use case uses an instance of the presented **Digital Twin** Generator to create the required AAS. The **Digital Twin** Generator analyzes the required information based on the provided model, finds it in a company's tools, in databases or on the physical twin and publishes the generated AAS on a web server.

33) Editorial: Big Data Management in Industry 4.0

Paper ID: 8b281d3a180908cacac9e13c24fbbb7c2e9b9881

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Citation Count	Influential Citation Count	Reference Count
2	0	5

Keyword	Count
industry 4.0	5
digital twin	1
digital asset management	0
interoperability	1
digital representation	1
industrial metaverse	0

TLDR: The research topic “Big DataManagement in **Industry 4.0**” includes contributions in several of the aforementioned areas, and discusses the challenge of integrating traditional enterprise software solutions.

Abstract: **Industry 4.0** represents the digital evolution of manufacturing, where emerging technologies such as Industrial Internet of Things (IIoT) Sisinni et al. (2018), data analytics, artificial intelligence, cloud computing and cyber physical systems Lee et al. (2018) enable operation of industries in a flexible, efficient, and green way. As such, it is of the utmost importance to be able to manage and analyse the huge amount of data originating from the deployed sensors and services, which can be classified as Big Data from the point of view of volume, velocity, variety, veracity, and value (5 V s). Digital factory is a fundamental notion within the **Industry 4.0** domain: it comprises a multilayered integration of the factory activities, enabling the product lifecycle stakeholders to collaborate through the use of software solutions. A digital factory can expand outside the company boundaries and offers the opportunity to collaborate on business processes affecting the whole supply chain Bicocchi et al. (2019). **Digital Twin** (DT) is one of the most prominent technologies for realizing digital factories and **Industry 4.0** Tao et al. (2018). A DT is a **digital representation** of a physical asset (e.g., a machine, a partner organization, a product), which can be employed for 1) querying its status, 2) issuing commands, 3) receiving streaming data, 4) performing prediction tasks, and 5) simulating the effect of specific usage conditions. A digital factory can be represented with the DTs involved in the manufacturing process. The result can be thought of as an heterogeneous data space, populated by the DTs, and a coordination entity in charge of pursuing specific tasks Catarci et al. (2019). Data coming from the DTs can be used by the coordination entity for a wide variety of tasks, including monitoring the status of the process, adapting to sudden or long term changes, improving the process according to specific Key Performance Indicators (KPI), and predicting the evolution of all the assets involved in the manufacturing process. The digital factory data space can include structured, semi-structured and unstructured data with different schemata, vocabularies, and data access technologies. Due to such heterogeneity and to the nature of the involved data, only a small fraction of the existing data management techniques can be directly applied in a digital factory data space. As a consequence, existing approaches struggle to capture the production goal semantic and mainly focus on specific **interoperability** aspects. Furthermore, existing data modeling frameworks for DTs (either commercial or open-source) do not provide full support for simulation and prediction. The research topic “Big DataManagement in **Industry 4.0**” includes contributions in several of the aforementioned areas. Authors in Bousdekis and Mentzas (2021) discuss the challenge of integrating traditional enterprise software solutions (e.g., Enterprise Resource Planning systems (ERPs) and Edited and reviewed by: Huan Liu, Arizona State University, United States

34) Digital Twin-Enabled Modelling of a Multivariable Temperature Uniformity Control System

Paper ID: 09476cf6c0f9455d06e96ab6f8141e06a97f214e

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Citation Count	Influential Citation Count	Reference Count
2	0	26

Keyword	Count
industry 4.0	1
digital twin	4
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: Using digital twins to represent a multivariable thermoelectric system employed for temperature uniformity distribution control with potential applications in semiconductor manufacturing indicated that using digital twins not only increases the accuracy of the system's representation but can also provide the system with novel information that can be leveraged for the design and implementation of smart control systems.

Abstract: The use of a **digital twin** as an enabling technology for **industry 4.0** provides control systems engineers with novel tools for modelling, designing, and controlling complex systems, providing a deep understanding of the physical asset based not only on its physics but also the real system's response. It is particularly critical for uniformity temperature control applications, where providing a reasonable model of the system's diffusion is always affected by the physical behavior of the system's components required for heating, cooling, or power distribution. In this paper, a **digital twin** is used to represent a multivariable thermoelectric system employed for temperature uniformity distribution control with potential applications in semiconductor manufacturing. The modelling employs a five-step methodological framework consisting of the stages: target system definition, system description, multiphysics and data-driven simulation, behavioral matching, and implementation to represent the system's temperature distribution accurately. The temperature distribution is measured using an infrared thermal camera to perform model behavioral matching on heating and cooling temperature uniformity applications. The obtained results indicated that using digital twins not only increases the accuracy of the system's representation but can also provide the system with novel information that can be leveraged for the design and implementation of smart control systems.

35) Digital Twin of a Water Supply System Using the Asset Administration Shell

Paper ID: bfa50108510ee6684ba9b052813fa5891688af9c

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Citation Count	Influential Citation Count	Reference Count
1	0	46

Keyword	Count
industry 4.0	3
digital twin	6
digital asset management	0
interoperability	0
digital representation	2
industrial metaverse	0

TLDR: N/A

Abstract: The concept of digital twins is one of the fundamental pillars of **Industry 4.0**. **Digital twin** allows the realization of a virtual model of a real system, enhancing the relevant performance (e.g., in terms of production rate, risk prevention, energy saving, and maintenance operation). Current literature presents many contributions pointing out the advantages that may be achieved by the definition of a **digital twin** of a water supply system. The Reference Architecture Model for **Industry 4.0** introduces the concept of the Asset Administration Shell for the **digital representation** of components within the **Industry 4.0** ecosystem. Several proposals are currently available in the literature considering the Asset Administration Shell for the realization of a **digital twin** of real systems. To the best of the authors' knowledge, at the moment, the adoption of Asset Administration Shell for the **digital representation** of a water supply system is not present in the current literature. For this reason, the aim of this paper is to present a methodological approach for developing a **digital twin** of a water supply system using the Asset Administration Shell metamodel. The paper will describe the approach proposed by the author and the relevant model based on Asset Administration Shell, pointing out that its implementation is freely available on the GitHub platform.

36) Automatic Fuzzing of Asset Administration Shells as Digital Twins for Industry 4.0

Paper ID: 776888d51cedc4b324c8209cff878ab7185d7481

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Citation Count	Influential Citation Count	Reference Count
1	0	36

Keyword	Count
industry 4.0	2
digital twin	4
digital asset management	0
interoperability	1
digital representation	0
industrial metaverse	0

TLDR: This work surveys different methods for the automated generation of AAS instances for testing and evaluates their applicability in the context of the AAS resulting in a set of recommendations for their future usage in the AAS community.

Abstract: Digital twins drive the digitization of industrial value chains, the goal of **Industry 4.0**. While digital twins are only a concept, with the Asset Administration Shell (AAS) a standard has been published which describes a concrete meta-model and interfaces for AAS digital twins. As the AAS standard and the corresponding ecosystem are growing at rapid pace, novel methods for quality assurance are required to maintain **interoperability** between all components of the ecosystem and to keep up with the high pace. Therefore, in this work, we survey different methods for the automated generation of AAS instances for testing. Here, we focus on fuzzing approaches, as they require the least manual effort and offer a high degree of automation and coverage. We evaluate their applicability in the context of the AAS resulting in a set of recommendations for their future usage in the AAS community.

37) Modelling Agents in Industry 4.0 Applications Using Asset Administration Shell

Paper ID: 395c157eb8d105457bc5974adaeac6fd95c5defb

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Citation Count	Influential Citation Count	Reference Count
1	0	9

Keyword	Count
industry 4.0	2
digital twin	0
digital asset management	0
interoperability	1
digital representation	1
industrial metaverse	0

TLDR: This work proposes the usage of the AAS for creating information models of software agents and suggests a generic approach to apply the AAS meta-model to ensure semantic **interoperability** between them and outlines a structure and a set of submodels to group agent attributes.

Abstract: : Within **Industry 4.0**, more applications include multi-agent systems and integrated software agents in the newly developed solutions, as they can provide a valuable contribution to the manufacturing processes. This makes it important to create a **digital representation** of those virtual assets, similar to how this is done for physical ones. The Asset Administration Shell (AAS) has been designed for just this purpose - to create models of assets, containing all the relevant information. Currently, this is standard for physical assets, however, it could be of value to extend it beyond. We propose the usage of the AAS for creating information models of software agents and suggest a generic approach to apply the AAS meta-model to ensure semantic **interoperability** between them. For this purpose, we outline a structure and a set of speci■c submodels to group agent attributes, which can provide a description of all relevant information for a given task. We provide two examples of concrete agents and outline how this approach will be further validated within future use cases.

38) Digitalization of the Components of a Mini Factory with the Implementation of RAMI 4.0 Asset Administration Shell

Paper ID: 372635c2e3c47576bc9e259c5c7cc001f314ddef

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Citation Count	Influential Citation Count	Reference Count
1	0	31

Keyword	Count
industry 4.0	2
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: The implementation of the Asset Administration Shell (AAS), recognized as pivotal in integrating the vertical dimensions of the Reference Architecture Model for **Industry 4.0**, is explored, underscoring its scalability for wider adoption across the industry.

Abstract: In the era of **Industry 4.0**, characterized by the paradigm shift towards Smart Manufacturing, the traditional hierarchical and rigid control system architectures and information silos are being redefined to realise a vision of dynamic system reconfiguration through the seamless integration of Operational Technology (OT) and Information Technology (IT) systems. This paper explores the implementation of the Asset Administration Shell (AAS), recognized as pivotal in integrating the vertical dimensions of the Reference Architecture Model for **Industry 4.0** (RAMI 4.0). The study demonstrates the deployment of AAS across various hierarchical levels, showcasing the digitalization of diverse production facility assets and their standardized representation in a technology-neutral manner. A use-case is presented to illustrate the concept of dynamic process execution facilitated by Manufacturing Execution System (MES) and Manufacturing Operations Management (MOM), leveraging the capabilities offered by digitalized assets. The implementation adheres to current standards and companion specifications, underscoring its scalability for wider adoption across the industry.

39) FPGA-Based Digital Twin Implementation for Mechatronic System Monitoring

Paper ID: 7f9b86fb6f72d721d4b28158e694788bfc191e48

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Citation Count	Influential Citation Count	Reference Count
1	0	17

Keyword	Count
industry 4.0	1
digital twin	7
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This work proposes an FPGA-based **digital twin** implementation where the datasets are taken directly from the physical asset running parallel to the digital asset, eliminating the need for big data and cloud upload, ensuring data privacy and faster, efficientdigital twin implementation and update.

Abstract: **Digital Twin** is a driving technology for **Industry 4.0** that enables novel capabilities like smart process control, fault detection, or remaining useful life estimation. Since a **Digital Twin** is an up-to-date representation of an actual physical process, building this model requires exchanging many datasets from the physical assets. Usually, it is performed on external servers within a cloud-computig architecture that communicates physical assets with the **digital twin** model. However, the cloud exchange introduces transmission delays and security and data privacy issues that hamper digital asset updates and create safety concerns. Hence, we propose an FPGA-based **digital twin** implementation where the datasets are taken directly from the physical asset running parallel to the digital asset. This setup eliminates the need for big data and cloud upload, ensuring data privacy and faster, efficient **digital twin** implementation and update. A case study is implemented to demonstrate embedded **Digital Twin** capabilities for monitoring mechatronic systems under fault events.

40) Historical Data Storage Architecture Blueprints for the Asset Administration Shell

Paper ID: ac515ecb306a7a6d5d07ea79bc519a586b1f6efb

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Citation Count	Influential Citation Count	Reference Count
1	0	21

Keyword	Count
industry 4.0	2
digital twin	1
digital asset management	0
interoperability	1
digital representation	0
industrial metaverse	0

TLDR: This work presents multiple blueprints for data storage and retrieval motivated by use cases from **Industry 4.0**, healthcare, and civil construction, and showcases how the data model of the AAS can be utilized for a unified retrieval of historical data.

Abstract: The concept of the **Digital Twin** (DT) and its implementation as Asset Administration Shell (AAS) is one of the key technologies for implementing **Industry 4.0**. By utilizing the AAS, use cases can be implemented with high **interoperability**. These use cases include optimizations and improvements of physical systems, like predictive maintenance or other artificial intelligence applications. For these use cases, historical data is key. However, there exists no guidance on how to handle historical data with the AAS. Furthermore, no integrated architecture exists that enables seamless storage and retrieval of historical data using the unified AAS meta-model and interface. Thus, we bridge this gap between use case and unified implementation by presenting multiple blueprints for data storage and retrieval motivated by use cases from **Industry 4.0**, healthcare, and civil construction. These data storage blueprints range from a mandatory change in the AAS infrastructure to augmentations of the existing AAS concepts. Furthermore, we showcase how the data model of the AAS can be utilized for a unified retrieval of historical data. In consequence, practitioners can quickly realize use cases that require historical data by tailoring and implementing the presented blueprints. Additionally, researchers can extend the presented guidance to further use cases, possibly from other domains.

41) Am I in Good Shape? Flexible Way to Validate Asset Administration Shell Data Entry via Shapes Constraint Language

Paper ID: 1aeb0c1ef6ee06683a8e984ec6faa7fae1274c56

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Citation Count	Influential Citation Count	Reference Count
1	0	23

Keyword	Count
industry 4.0	1
digital twin	1
digital asset management	0
interoperability	1
digital representation	0
industrial metaverse	0

TLDR: This paper shows that Shapes Constraint Language (SHACL) is not only possible to be used for schema compliance checks but also for data entry validation in AAS, and shows the flexibility of the solution, which is also platform independent.

Abstract: Digital Twins and their adoption in **Industry 4.0** are trending topics. Asset Administration Shell (AAS) has been introduced as a standard metamodel and application programming interface (API) to cope with **interoperability** issues. The specification discusses possibilities of serializing the AAS meta-model to various formats such as XML, JSON, and RDF. It also introduced various schemas to check the compliance of serialized content with the specification. In this paper, we show that Shapes Constraint Language (SHACL) is not only possible to be used for schema compliance checks but also for data entry validation. Within our use case, we show the flexibility of our solution, which is also platform independent.

42) Design of Heterogeneous Cyber-Physical Systems Employing Category Theory

Paper ID: 0f9b7400793a7049e10129c97bd5d9418b04a698

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Citation Count	Influential Citation Count	Reference Count
1	0	0

Keyword	Count
industry 4.0	1
digital twin	1
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: The paper proposes approaches to formalization and subsequent automation of solving direct and inverse problems of heterogeneous cyber-physical systems design and outlines the design of energy-efficient robotic production lines represented from the behavior viewpoint as discrete-event simulation models.

Abstract: Heterogeneous cyber-physical control systems based on digital twins are in demand by **Industry 4.0**. In accordance with the contemporary systems engineering methodology, such systems are designed at the level of digital models. The paper proposes approaches to formalization and subsequent automation of solving direct and inverse problems of their design. To unify descriptions of heterogeneous components, we follow a viewpoint-based approach to architecture design recommended by the international standard ISO/IEC/IEEE 42010. Following recent trends, we employ category theory as a mathematical framework for the formal description and solution of design problems. Indeed, category theory is a branch of higher algebra specifically aimed at a unified representation of objects of different nature and relationships between them. The design space of a heterogeneous cyber-physical system is constructed as a subcategory of the multicomma category, the objects of which describe possible system architectures with a fixed structural hierarchy represented from a certain viewpoint as diagrams, and morphisms denote actions associated with the parts selection and replacement during the system design. Direct design problems consist in evaluating the properties of the system as a whole by its architecture and are solved using a universal category-theoretic construction of the colimit of the diagram. The solution of inverse problems that require finding variants of the system architecture, which are (sub-, Pareto-) optimal according to the consumer quality criteria, consists in reconstructing diagrams by their colimit edges. For such reconstruction, optimization algorithms of gradient descent type are reasonable to employ, which navigate along the system design space morphisms calculating the path by means of computer algebra. Typical techniques of assembling cyber-physical systems, such as modular composition and aspect weaving, are described in the language of category theory and illustrated. As an example, we outline the design of energy-efficient robotic production lines represented from the behavior viewpoint as discrete-event simulation models.

43) Consistent Extension of Networks of Digital Representations of Production System Assets

Paper ID: c9c0ded35c8f50d2a918d233b399c45af15d3051

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Citation Count	Influential Citation Count	Reference Count
1	0	25

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	0
digital representation	2
industrial metaverse	0

TLDR: The PPRplus modeling method is introduced to facilitate the **digital representation** of a product along the product lifecycle, including PPR dependencies, and knowledge about performance indicators.

Abstract: **Industry 4.0** use case on products along the production lifecycle require an extensible representation of PPR dependencies, which are distributed on PLM, CRM, and production system assets. This paper introduces the PPRplus modeling method to facilitate the **digital representation** of a product along the product lifecycle, including PPR dependencies, and knowledge about performance indicators. We initially evaluated the feasibility and effectiveness of the PPRplus modeling method with two use cases on work lines for metal processing.

44) Multi-Agent Systems to Realize Intelligent Asset Administration Shells

Paper ID: 807339238de26cae890e8f79d3b608241f0d4f63

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Citation Count	Influential Citation Count	Reference Count
1	1	0

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	0
digital representation	1
industrial metaverse	0

TLDR: This paper discusses how Multi-Agent Systems (MAS) technology can be used to realize the AAS, mapping their inherits characteristics into AAS functionalities and also extending them, introducing intelligence and data analytics capabilities.

Abstract: The digital transformation driven by the fourth industrial revolution is promoting the transition of traditional manufacturing systems towards flexible, reconfigurable and intelligent factories based on Cyber- Physical Systems (CPS), bringing new opportunities and innovative solutions for modern manufacturing systems. However, this condition imposes complex planning across the production chain and lifecycle of the industry. In this context, the Reference Architecture Model Industrie 4.0 (RAMI4.0) provides guidelines to develop **Industry 4.0** (I4.0) compliant solutions based on industrial standards. As the main specification of RAMI4.0, the Asset Administration Shell (AAS) is a standardized **digital representation** of an asset that represents an object of value for the industry. This paper discusses how Multi-Agent Systems (MAS) technology can be used to realize the AAS, mapping their inherits characteristics into AAS functionalities and also extending them, introducing intelligence and data analytics capabilities.

45) BACK TO 4.0: RETHINKING THE DIGITAL CONSTRUCTION INDUSTRY

Paper ID: 52f5cb90cb3457f486219554625af774e67663b9

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Citation Count	Influential Citation Count	Reference Count
1	0	31

Keyword	Count
industry 4.0	0
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: The Careggi University Hospital, given its particular territorial and building characteristics, the energy systems involved and the computer-aided methodology implied in the management of structural/systems/organizational assets, was chosen as a case study for assessing the final feedback for the expected outcomes during the demonstration and validation phases.

Abstract: STREAMER is a research funded under the 7 th Framework Programme, aimed at achieving “Energy-efficient Buildings (EeB)” integrated in healthcare districts. The scope of the research project at issue is to define and develop integrated technologies applicable to Computer Aided Facility systems through the combination of BIM and GIS systems to achieve semantic models for optimising the design and management of hospital buildings, in order to reduce the energy needs of the same throughout their entire lifecycle. The research involves 20 partners coming from different sectors (university, industry, design engineering and construction). The Careggi University Hospital (AOUC), given its particular territorial and building characteristics, the energy systems involved and the computer-aided methodology implied in the management of structural/systems/organizational assets, was chosen as a case study for assessing the final feedback for the expected outcomes during the demonstration and validation phases. In the first place, a modeling methodology for the territorial ambits of the case studies was defined, with the assessment of the levels of detail and methods of representation of the transport network systems and types of energetic distribution connections. The BIM models for the pavilions were created based on such territory models

46) Asset Modelling for Efficient Data Representation in Industry 4.0

Paper ID: 0c0a7a9b03cda441aab6e733dce1e753134e233e

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Citation Count	Influential Citation Count	Reference Count
0	0	11

Keyword	Count
industry 4.0	5
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This research proposes an asset model inspired from Asset Administration Shell to better represent the ever-evolving digital data as a valuable asset within the **Industry 4.0** framework.

Abstract: **Industry 4.0** presents considerable challenges in data unification. The Asset Administration Shell is a key concept introduced by Reference Architecture Model **Industry 4.0** to enable the storage and communication of data between assets. The current conceptualization of the Asset Administration Shell exhibits limitations when it comes to representing digital data. It lacks an effective methodology for categorizing and defining existing data as an asset and this can potentially hinder the full utilization of digital data as an integral asset within the **Industry 4.0** infrastructure. This research proposes an asset model inspired from Asset Administration Shell to better represent the ever-evolving digital data as a valuable asset within the **Industry 4.0** framework.

47) Leveraging Digital Asset Management and Meta-Data Integration for Enhanced Asset Management

Paper ID: 827537528a42aba72772deadba01cac5cabf54c9

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Citation Count	Influential Citation Count	Reference Count
0	0	0

Keyword	Count
industry 4.0	0
digital twin	0
digital asset management	3
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: The challenge of integrating metadata from a repository of 2340 reported asset problems at one of the public schools in Saudi Arabia over 2 years is addressed and a compelling blueprint for leveraging metadata integration for effective asset management strategies is presented.

Abstract: **Digital Asset Management** (DAM) has emerged as an advanced approach to empower asset managers in controlling and optimizing asset operations. This study addresses the challenge of integrating metadata from a repository of 2340 reported asset problems at one of the public schools in Saudi Arabia over 2 years. The data, obtained in .xls format from the existing asset/facility information management system, was meticulously unified to visualize digital assets enriched with relevant data. Findings showed, among others, repeated data/records, incomplete/inaccurate data, language issues, lack of time reporting a problem, absence of status reports, and confusion between asset and facilities data. The primary aim is to explore the integration of this metadata into an Asset Information Model (AIM) for more efficient asset management. The proposed integrated strategy for supporting metadata in AIM analysis emphasizes effective metadata management. By defining metadata requirements, establishing robust standards, implementing efficient capture and storage processes, seamlessly integrating metadata into the AIM model, establishing governance procedures, leveraging metadata in analysis, and continuously monitoring and optimizing the strategy, organizations enhance the accuracy, consistency, and integrity of AIM analysis. This comprehensive approach fosters improved decision-making in asset and facility management, leading to enhanced overall efficiency. Successful implementation and further research on this strategy contribute to AIM analysis advancement and metadata utilization optimization, elevating asset management practices in the evolving construction and infrastructure industry. This research provides valuable insights into **digital asset management** and presents a compelling blueprint for leveraging metadata integration for effective asset management strategies.

48) Transforming high-rise residential maintenance: a 3D spatio-temporal model utilizing Industry 4.0 and lean principles

Paper ID: 98a9bd7395c0e29389369e2aa7a67796b7c52289

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Citation Count	Influential Citation Count	Reference Count
0	0	34

Keyword	Count
industry 4.0	3
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: N/A

Abstract: Purpose The purpose of this paper is to develop and demonstrate a comprehensive 3D spatio-temporal maintenance management model for high-rise residential buildings by integrating Industry 4.0 technologies and lean maintenance principles. This model aims to optimize maintenance scheduling, enhance resource utilization and improve decision-making processes. By leveraging advanced data visualization and predictive analytics, this study seeks to address the complexities of building maintenance, ensure timely interventions, reduce downtime and extend the lifespan of building assets, ultimately leading to more efficient and sustainable maintenance management practices. Design/methodology/approach Integrating state-of-the-art technologies such as big data analytics and artificial intelligence into the proposed model is geared towards benefiting from optimized maintenance scheduling and resource allocation, hence achieving minimum asset downtime and extension in asset life. This is being done through the digitization of paper maps, the development of 3D building models in AutoCAD and SketchUp and the placing of the developed models into ArcGIS Pro. The PostgreSQL database with PostGIS extension supports optimal storage and management of spatial data towards real-time updates and advanced analyses. Findings The results revealed that the model enhances maintenance planning considerably better than traditional methods due to the revelation of meaningful patterns and trends that are not visible in conventional visualization methods. Temporal analysis indicates increasing needs for maintenance through time, whereas spatial analysis can point out the units that require special attention. The spatiotemporal analysis is needed to determine overall maintenance requirements for better decision-making. The work demonstrated that 3D visualization of maintenance activities performed over building representation helps facility managers in better decision-making related to task planning for performance improvement concerning building and tenant satisfaction. Research limitations/implications The study’s current limitations include the reliance on specific datasets and technologies, which may need adaptation for broader applications. Future research could explore further integration with additional building types and longitudinal studies to assess long-term impacts. Practical implications The 3D visualization of maintenance activities over building representation aids facility managers in better decision-making related to task planning, improving building performance and tenant satisfaction. This integrated approach provides significant benefits in efficiency, resource use and sustainability. Originality/value The originality of this paper lies in its innovative integration of 3D spatio-temporal data with Industry 4.0 technologies and lean maintenance principles to create a comprehensive maintenance management model for high-rise residential buildings. Unlike traditional approaches, this model combines advanced data visualization, real-time analytics and predictive maintenance strategies within a unified geographic information system framework. This holistic approach not only enhances maintenance planning and resource allocation but also provides a proactive, data-driven methodology that significantly improves the efficiency and effectiveness of maintenance management, addressing the unique challenges of high-rise residential building maintenance.

49) Enhancing Intralogistics 4.0: Integrating Asset Administration Shell for Improved Navigation, Safety, and Risk Management across Stationary and Mobile Transport Systems

Paper ID: cfcd819fc256c3259d356070ecadf476e4209c38

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Citation Count	Influential Citation Count	Reference Count
0	0	36

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	0
digital representation	1
industrial metaverse	0

TLDR: This paper analyzes existing information models and develops new models that are necessary for the development of an intralogistics structure that includes a comprehensive **digital representation** of autonomous mobile robots and the information needed for individual handling to improve the overall production efficiency.

Abstract: Intralogistics 4.0, a central aspect of **Industry 4.0**, poses several challenges for Driverless Transport Systems, especially for Autonomous Mobile Robots, which have to navigate in complex environments. The increasing variety of goods with different physical properties is pushing today's intralogistics systems to their limits. A modular production environment with dynamic obstacles, reconfigurable production systems and human influences such as worker interaction, unpredictable movements and manual handling of goods requires the processing of specific information to ensure safe handling and efficient navigation. Furthermore, it requires a classification of products into categories, including those classified as hazardous goods, for individual handling to achieve greater production efficiency. The Asset Administration Shell concept provides a comprehensive virtual representation of these environments and enables the management of safety and hazard information. This paper analyzes existing information models and develops new models that are necessary for the development of an intralogistics infor-mation structure. This structure will include a comprehensive **digital representation** of autonomous mobile robots and the information needed for individual handling. It demonstrates how this information can be used within an architecture to optimize navigation strategies and hazard handling across stationary and mobile transportation systems to improve the overall production efficiency.

50) An Object-oriented Approach to Ontological Engineering of Complex Cyber-physical systems Based on Meta-associative Graphs

Paper ID: ec61065569465cc0c3ed13cdd974bc498c21fe1d

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Citation Count	Influential Citation Count	Reference Count
0	0	17

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	1
digital representation	0
industrial metaverse	0

TLDR: The article posits meta-associative graphs as a superior ontological engineering tool for cyber-physical systems compared to the Web Ontology Language (OWL) and frames, particularly due to their flexibility in representing quasi-hierarchical structures and dynamic relationships.

Abstract: This article delves into the pivotal role of cyberphysical systems in the fabric of modern digital and automated environments, serving as a cornerstone of the Industrial Internet of Things and the **Industry 4.0** revolution. These systems represent a synthesis of computational algorithms and physical processes, resulting in intelligent, autonomous systems equipped for self-correction and adaptation. The ability of cyber-physical systems to monitor environmental changes, adapt to the physical world, and manage complex tasks marks a significant leap in automating production and ensuring safety in intelligent transportation, among other applications. At the heart of developing and deploying cyber-physical systems is the ontological approach, which employs structured frameworks to delineate the interactions between cyber and physical elements. Ontologies, by categorizing and organizing knowledge, are vital for modeling relationships within cyber-physical systems, enhancing **interoperability** and communication across various domains. The quasi-hierarchical structure of cyber-physical systems ontologies, where a child node may link to multiple parents, introduces a nuanced representation of complex system interdependencies, surpassing the capabilities of traditional hierarchical models. Ontological engineering for cyber-physical systems merges object-oriented and structural analysis methodologies, focusing on key entity classes and their interrelations to dictate system evolution and behavior. The object-oriented approach divides into structuring data and knowledge, organizing system data, and developing user interfaces that support cyber-physical systems business processes, culminating in a coherent, functional system model. The article posits meta-associative graphs as a superior ontological engineering tool for cyber-physical systems compared to the Web Ontology Language (OWL) and frames, particularly due to their flexibility in representing quasi-hierarchical structures and dynamic relationships. An ontological framework enables developers to create a software instrumental environment where domain experts can independently construct ontologies and business processes, bridging the semantic gap between experts and developers.

51) Digitalization of Industrial Inspection Assets through the Asset Administration Shell

Paper ID: 34ff2dd2d64d5605bd02bd68aa7bbe995b957bd7

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Citation Count	Influential Citation Count	Reference Count
0	0	25

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	1
digital representation	1
industrial metaverse	0

TLDR: A critical opinion is given on the current status of the technologies associated with AAS in I4.0 by modelling geometric inspection assets on an automotive assembly line using AAS standards.

Abstract: Developments in industrial manufacturing systems, through the use of new digital technologies, are revolutionizing the traditional means by which companies operate in terms of productivity and competitiveness. The adoption of technologies related to **Industry 4.0** (I4.0) has led to the possibility of digitizing industrial assets to achieve more responsive, reconfigurable and efficient production systems. The Asset Administration Shell (AAS) corresponds to a form of **digital representation** of a physical asset, such as, a machine or device, that describes its properties, functionalities, and behaviours, as well as guarantee **interoperability** between different systems. Implementing AAS in the industrial environment allows the creation of a standard for digitalising asset scenarios, which can be used for intelligent and non-intelligent products. This paper explores modelling geometric inspection assets on an automotive assembly line using AAS standards. Once modelled, the AAS of the assets are applied to a new approach for reactive AAS based on a REST API for real-time data transmission to a framework focused on Zero Defects Manufacturing. The implications associated with the asset modelling and the creation of the AAS server are presented and discussed, giving a critical opinion on the current status of the technologies associated with AAS in I4.0.

52) Logical-semantic models and methods of knowledge representation: cases for energy management systems and SMR digital infrastructures

Paper ID: f015a63b09fda514c68472a7ca520fe95a9d6afc

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Citation Count	Influential Citation Count	Reference Count
0	0	0

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: It was determined that the advantage of using existing knowledge representation methods is that an expert can independently form such a knowledge model, and the application of logical-semantic knowledge representation models for alternative energy-source management systems will ensure increased energy efficiency.

Abstract: The subject of this article is the development of information technologies at the end of the 20th and the beginning of the 21st century for the Fourth Industrial Revolution in the form of **Industry 4.0**, i.e., Internet of Things (IoT) technologies. Successes in the implementation of this technology have led to the development of new applications in the energy sector, such as energy management systems, small modular reactor (SMR) management systems, and alternative power supply systems based on renewable energy sources. The digital infrastructure of these management systems is characterized by a high "density of knowledge", which requires clarification of fundamental concepts in information theory, namely the content of the concepts "data", "information", "knowledge" and "meaning of knowledge". Special attention was given to defining the role of knowledge. The aim of this study is to further develop methods and models of semiotic theory by determining the role and place of logical as well as eight- and four-factor logical-semantic models of knowledge bases in semiotic space. The tasks: comparing existing knowledge representation methods and models. Research results: We found that the logical models used in the development of knowledge bases are based on the principles of artificial intelligence theory, which relies on sign system hypotheses and formal logic theory. The main drawback is the complexity of practical implementation in the form of expert systems. For logical-semantic models in the form of eight-vector graphic models, it was found that there is currently no theoretical justification for defining the vectors that form the coordinate axes, making these models unique to specific subject areas. It was determined that the advantage of using these methods is that an expert can independently form such a knowledge model. For logical-semantic models in the form of four-factor graphic models, there is a theoretical justification for defining the factors of the model that form the coordinate axes, making these models universal for specific subject areas. It was established that the advantage of these models is that they can be developed by experts without the involvement of a knowledge engineer. Therefore, it is proposed to use four-factor logical-semantic knowledge representation models for further application. It is also proposed to split the element "logical-semantic models" into two elements in the semiotic spatial model in vector K8 "Knowledge Representation Models", namely: "logical-semantic eight-vector models" and "logical-semantic four-factor models". Additionally, it is proposed to add the element "post-Cartesian representation of meta-knowledge" to the element "geometric" in vector K5 "Ideal Models". Conclusions: The theoretical basis for developing eight-factor logical-semantic knowledge representation models is the form of connections between adjacent vectors in the form of Cartesian products on elements of the corresponding inter-coordinate matrices. The theoretical basis for the methodology of developing four-factor logical-semantic knowledge representation models is the form of connections between adjacent vectors in the form of Cartesian products for elements of the corresponding inter-coordinate matrices, as well as for diametrically opposite pairs

of factors in the form of dialectical unity of the concepts "general" and "particular." The application of logical-semantic knowledge representation models for alternative energy-source management systems will ensure increased energy efficiency. Other cases related to the development of databases for SMR digital infrastructure are discussed.

53) Toward a Unified Security Framework for Digital Twin Architectures

Paper ID: 326b0126e957b02015523d9771931fe08250458d

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Citation Count	Influential Citation Count	Reference Count
0	0	30

Keyword	Count
industry 4.0	1
digital twin	2
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This study examines a cross-platform DT reference architecture that adapts to various DT architectures in terms of functionality, reliability, and life cycle and proposes a unified security framework that incorporates attack-defense layers and a model checker that scrutinizes various inputs from the DT architecture to assess its security and privacy.

Abstract: Digital Twins (DTs) stand as the most dominant representation of cyber-physical integration made possible through the advent of **Industry 4.0**. Their utilization is gaining precedence across various application domains for the implementation and analysis of complex systems. However, despite the numerous architectures proposed to develop and describe DTs setup in these applications, most of them fail to address the security and privacy challenges specific to each architecture. In this study, we examine a cross-platform DT reference architecture that adapts to various DT architectures in terms of functionality, reliability, and life cycle. We then explore the specific cybersecurity challenges of this reference architecture. As a result of our study, we propose a unified security framework that incorporates attack-defense layers and a model checker that scrutinizes various inputs from the DT architecture to assess its security and privacy. Finally, we present the security solutions that this framework can provide.

54) Digital Twin Enabled Asset Management of Machine Tools

Paper ID: cdf8dafb5b0bf1a2270dee9c4e025eb1eaaea337

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Citation Count	Influential Citation Count	Reference Count
0	0	44

Keyword	Count
industry 4.0	1
digital twin	2
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This work examines the potential benefits of applying DTs to AM, examples in the literature of applying AM methods to MTs using DT, and how advanced AM strategies can be deployed using DT.

Abstract: Machine tools (MT) are essential equipment in modern manufacturing. They are a large investment which yields great returns to productivity and profitability. MTs enable the high throughput manufacturing of high precision components. Given their great importance, and their large cost, it is beneficial to implement asset management (AM) strategies such as condition monitoring, fault detection and predictive maintenance. Implementing these processes and methods can improve reliability and performance of MTs, while extending their lifetime and reducing operating expenses. Digital twins (DT) are an emerging technology within the **Industry 4.0** landscape. They represent a connection between a physical system, object, or process and it's virtual representation. DTs can be leveraged for AM implementation in MTs. This work examines the potential benefits of applying DTs to AM, examples in the literature of applying AM methods to MTs using DT, and how advanced AM strategies can be deployed using DT. From examining the literature it was clear that DTs are well suited for AM in MTs. DTs enable improved data collection and processing, modeling and model retention, and historical analysis and trend prediction. DTs have been applied to a variety of application scenarios for MTs such as in cutting tools, spindles, and feed drives. DTs can additionally enable more advanced modeling solutions such as physics informed machine learning which can overcome some issues with traditional data-driven and physics-based modeling strategies. These advanced methods can improve overall AM across the MT's life-cycle and enable effective prognostic health management.

55) Development of Asset Administration Shell for the components of EBMR plant

Paper ID: 97059a1c3c822c25f449c8e97d69d64b8a604123

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0	0	11

Keyword	Count
industry 4.0	2
digital twin	1
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: A semantic approach for development of AAS is represented, which presents the data model through ontology, which allows for the presentation of facts, data schemes and meta-data in a unified way, using a global identification scheme.

Abstract: The use of reference architectures and frameworks is an important prerequisite for dealing with the complexity, diversity and heterogeneity of cyber-physical systems. One of the most popular architectures is RAMI 4.0, suggested by the **Industry 4.0** Working Group. According to RAMI 4.0, the Asset Administration Shell (AAS) is a digital copy of assets, an implementation of the **digital twin** for **Industry 4.0**. The paper represents a semantic approach for development of AAS, which presents the data model through ontology. The semantic model allows for the presentation of facts, data schemes and meta-data in a unified way, using a global identification scheme. An example from the development of AAS for I4.0 components of an EBMR plant illustrates the approach.

56) Model-Driven Realization of IDTA Submodel Specifications: The Good, the Bad, the Incompatible?

Paper ID: 3c49589dff20d88d4605fe1e1bbe6750beeed1f8

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Citation Count	Influential Citation Count	Reference Count
0	0	16

Keyword	Count
industry 4.0	1
digital twin	1
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: A model-driven approach is presented, which transforms extracted information from IDTA specifications into an intermediary meta-model and, from there, generates API code and tests and shows it can process all current IDTA specifications successfully leading in total to more than 50000 lines of code.

Abstract: Asset Administration Shells are trending in **Industry 4.0**. In February 2024, the Industrial **Digital Twin** Association announced 84 and released 18 AAS sub model specifications. As an enabler on programming level, dedicated APIs are needed, for which, at this level of scale, automated creation is desirable. In this paper, we present a model-driven approach, which transforms extracted information from IDTA specifications into an intermediary meta-model and, from there, generates API code and tests. We show we can process all current IDTA specifications successfully leading in total to more than 50000 lines of code. However, syntactical variations and issues in the specifications impose obstacles that require human intervention or AI support. We also discuss experiences that we made and lessons learned.

57) Knowledge-driven Artificial Intelligence in Steelmaking: Towards Industry 4.0

Paper ID: 3614e589fcc4148bc2a10569b40c17ba5cc8ac18

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Citation Count	Influential Citation Count	Reference Count
0	0	0

Keyword	Count
industry 4.0	3
digital twin	0
digital asset management	0
interoperability	3
digital representation	0
industrial metaverse	0

TLDR: This thesis discovers that a clear under-standing of semantic-based asset administration shells, an international standard within the RAMI 4.0 model, was lacking, and provides an extensive survey on semantic-based implementations of asset administration shells, and focuses on literature that utilises semantic technologies to enhance the representation, integration, and exchange of information in an industrial setting.

Abstract: With the ongoing emergence of the Fourth Industrial Revolution, often referred to as Indus-try 4.0, new innovations, concepts, and standards are reshaping manufacturing processes and production, leading to intelligent cyber-physical systems and smart factories. Steel production is one important manufacturing process that is undergoing this digital transfor-mation. Realising this vision in steel production comes with unique challenges, including the seamless **interoperability** between diverse and complex systems, the uniformity of het-erogeneous data, and a need for standardised human-to-machine and machine-to-machine communication protocols. To address these challenges, international standards have been developed, and new technologies have been introduced and studied in both industry and academia. However, due to the vast quantity, scale, and heterogeneous nature of industrial data and systems, achieving **interoperability** among components within the context of **Industry 4.0** remains a challenge, requiring the need for formal knowledge representation capabilities to enhance the understanding of data and information. In response, semantic-based technologies have been proposed as a method to capture knowledge from data and resolve incompatibility con■icts within **Industry 4.0** scenarios. We propose utilising fundamental Semantic Web concepts, such as ontologies and knowledge graphs, speci■cally to enhance semantic **interoperability**, improve data integration, and standardise data across heterogeneous systems within the context of steelmaking. Addition-ally, we investigate ongoing trends that involve the integration of Machine Learning (ML)techniques with semantic technologies, resulting in the creation of hybrid models. These models capitalise on the strengths derived from the intersection of these two AI approaches.Furthermore, we explore the need for continuous reasoning over data streams, presenting preliminary research that combines ML and semantic technologies in the context of data streams. In this thesis, we make four main contributions: (1) We discover that a clear under-standing of semantic-based asset administration shells, an international standard within the RAMI 4.0 model, was lacking, and provide an extensive survey on semantic-based implementations of asset administration shells. We focus on literature that utilises semantic technologies to enhance the representation, integration, and exchange of information in an industrial setting. (2) The creation of an ontology, a semantic knowledge base, which speci■cally captures the cold rolling processes in steelmaking. We demonstrate use cases that leverage these semantic methodologies with real-world industrial data for data access, data integration, data querying, and condition-based maintenance purposes. (3) A frame-work demonstrating one approach for integrating machine learning models with semantic technologies to aid decision-making in the domain of steelmaking. We showcase a novel approach of applying random forest classi■cation using rule-based reasoning, incorporating both meta-data and external domain expert knowledge into the model, resulting in improved knowledge-guided assistance for the human-in-the-loop during steelmaking processes. (4) The groundwork for a continuous data stream reasoning framework, where both domain expert knowledge and random forest classi■cation can be dynamically applied to data streams on the ■y. This approach opens up possibilities for real-time condition-based monitoring and real-time decision support for predictive maintenance applications. We demonstrate the adaptability of the framework in the context of dynamic steel production processes. Our contributions have been validated on both real-world data sets with peer-reviewed conferences and journals, as well as through collaboration with domain experts from our industrial partners at Tata Steel.

58) Application of Multi-agent Technologies for Transforming Network Engineering Education

Paper ID: 8a2c6b6c0c770b640dafcc8fa174bf716d4cdab3

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Citation Count	Influential Citation Count	Reference Count
0	0	29

Keyword	Count
industry 4.0	1
digital twin	1
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR:

Abstract: The article substantiates the possibilities of implementing network programs of higher and additional professional education based on multi-agent technologies that transform all basic educational processes, ensuring their flexibility and adaptability to the dynamic needs of the labor market. The use of multi-agent technologies for engineering education, which is characterized by the use of complex and high-cost software, hardware and engineering systems that require the organization of collective sharing of resources, is becoming especially relevant. For multi-agent technologies, a method is chosen for representing agents in the form of asset administrative shells of fourth-generation industry systems, representing digital twins of information, educational, software, technical and organizational-methodological resources. The article proposes the structure of a multi-agent networked learning system; requirements for information representation of educational processes and the composition of key services in the asset administrative shells are defined. It introduces a multi-agent technology for the interaction of participants in the creation of networked educational programs. The software implementation of a multi-agent networked learning system based on the FIPA (Foundation for Intelligent Physical Agents) standards and the specifications of the asset administrative shells of the Platform **Industry 4.0** project will enhance the adaptability of networked educational programs. This will be achieved through the individualization of the learning process, with the real-time involvement of resources from various educational institutions and the collective use of software, technical, and engineering complexes. The collection of big data on the execution of educational processes in the asset administrative shells will contribute to both the real-time adjustment of the multi-agent system to the evolving competency model of learners and the improvement of the educational content throughout the entire system. The research results presented in the article will be applicable in teaching the courses “Design of Intelligent Information Systems” (bachelor’s degree) and “Knowledge Engineering” (master’s degree) in the field of study “Applied Informatics.”

59) COMPUTATIONAL MODEL OF INTERSECTIONS REPRESENTATION AS APPARATUS OF CONTENTS MULTI-SCALAR, RETROSPECTIVE AND RESILIENT FOR THE RESEARCH OF CONNOTATIONS, SIMULATIONS AND SUSTAINABILITY IN THE LANDSCAPE ASSETS

Paper ID: c4470da19bcd86eae46523ca95d9633fff693fa5

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Citation Count	Influential Citation Count	Reference Count
0	0	33

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This research project's objective, based on defining a "Computational Model of Intersections Simulation/Representation" as complex digital cultural infrastructure and computational knowledge, acquires the identity characteristics of the Computational Representation to promote for landscape and Cultural Heritage.

Abstract: The research project's objective, based on defining a "Computational Model of Intersections Simulation/Representation" as complex digital cultural infrastructure and computational knowledge, acquires the identity characteristics of the Computational Representation (phenomenological, geometry, visual, resilience, scalability analytical-interpretative knowledge) to promote for landscape and Cultural Heritage (CH): a) of systematize environmental information and protective by intersections of resilience's categories in the "thematic systems of families and types" of the landscape; b) a model of Smart CH for **Industry 4.0** – 2021. The same time favors: a) thematic and retrospective intersections between formal and interpretative layers for the return of information from a spatial and functional; b) innovation by introduction of professional figures of the contemporary digital. The methodology is articulated on following intersection models: Connotations, Composition, Development (combination of complex formal, structural and geometric factors); Morphogenesis (innovative concepts of transformations form), Sustainability. From the point of view the results and conclusion the study allowed to highlight: a) "network of multi-scalar discrete relationships" with sequences of digital models for the relative tessellation of the surfaces; b) "resilience measure" by "building a digital model of morphogenesis"; c) systematize environmental information and protective by intersections of resilience's categories in the "thematic systems of families and types" of the landscape; d) "operative and phenomenological reading" of the changing complexity of environmental reality with connections between the behavioural and physical structures of the place.

60) COMPUTATIONAL MODEL OF INTERSECTIONS REPRESENTATION AS APPARATUS OF CONTENTS MULTI-SCALAR, RETROSPECTIVE AND RESILIENT FOR THE RESEARCH OF CONNOTATIONS, SIMULATIONS AND SUSTAINABILITY IN THE LANDSCAPE ASSETS

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Citation Count	Influential Citation Count	Reference Count
0	0	0

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: This research project's objective, based on defining a "Computational Model of Intersections Simulation/Representation" as complex digital cultural infrastructure and computational knowledge, acquires the identity characteristics of the Computational Representation to promote for landscape and Cultural Heritage.

Abstract: Abstract. The research project's objective, based on defining a "Computational Model of Intersections Simulation/Representation" as complex digital cultural infrastructure and computational knowledge, acquires the identity characteristics of the Computational Representation (phenomenological, geometry, visual, resilience, scalability analytical-interpretative knowledge) to promote for landscape and Cultural Heritage (CH): a) of systematize environmental information and protective by intersections of resilience's categories in the "thematic systems of families and types" of the landscape; b) a model of Smart CH for **Industry 4.0** – 2021. The same time favors: a) thematic and retrospective intersections between formal and interpretative layers for the return of information from a spatial and functional; b) innovation by introduction of professional figures of the contemporary digital. The methodology is articulated on following intersection models: Connotations, Composition, Development (combination of complex formal, structural and geometric factors); Morphogenesis (innovative concepts of transformations form), Sustainability. From the point of view the results and conclusion the study allowed to highlight: a) "network of multi-scalar discrete relationships" with sequences of digital models for the relative tessellation of the surfaces; b) "resilience measure" by "building a digital model of morphogenesis"; c) systematize environmental information and protective by intersections of resilience's categories in the "thematic systems of families and types" of the landscape; d) "operative and phenomenological reading" of the changing complexity of environmental reality with connections between the behavioural and physical structures of the place.

61) Matters of assuring functional dependability compliance of digital manufacturing

Paper ID: c0dffd5020184ec65146069aa350efb39cd5087f

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Citation Count	Influential Citation Count	Reference Count
0	0	0

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: It was shown that the deployment of SMART standards improves the stability of interaction between information management systems and the functional dependability of production lines and the presented approach is focused on the methodology for developing standards that take into account requirements from various subject areas.

Abstract: Aim. To propose a methodological approach to ensuring the functional dependability of industrial facilities using SMART documents in the context of import-independent digital processes. Methods. The evolving applicability of the dependability theory and information systems design has defined the methodological provisions for algorithmising the application of SMART standards for minimising functional faults and failures of industrial processes. Digital models of production lines were examined as tools for machine-recognisable representation of standards. The proposed form of regulatory documents is intended to enable the transition from machine-readable data to machine-understandable content. Findings. The application of the proposed methods of content systematisation in the context of manufacturing process standardisation shows that the classification of process data based on standardised characteristics of digital information exchange processes is one of the key methodological provisions ensuring unambiguous interpretation of regulatory requirements. Specialised projects often use individual provisions rather than complete regulatory documents. In this case, in order to ensure machine-understandability of the developed content, it is proposed using special identifiers, e.g., «paragraph», «graphic object», «table cell». The deployment of such identification tools will allow creating a class of SMART standards that collect into a single document the provisions regarding the delivery of intended results in situations when the operating equipment is diverse. Publications created using intelligent processing of SMART documents are considered as containers of structured and unstructured data that take into account the conditions of particular projects. The existing dynamics of the demand for advanced industrial products often determines the admissibility of its industrial production by various companies with the parallel use of unique technologies. The conditions of such an organisation impose their limitations on the comparability of various process requirements, therefore, it is proposed to harmonise the presentation of the results of managerial, design, and process engineering solutions using the term «manufacturing system asset». The introduction of relative result estimates as part of the digital format is an efficient mechanism for ensuring management consistency. In this context, the importance of a uniform regulatory framework as the foundation for such assessments is growing. As one of the ways of minimising faults and failures of industrial equipment, it is proposed to create a situation centre with a decision support system based on the regulatory data with harmonised manufacturing system asset requirements. An experience of **Industry 4.0** regulation is described in the review of the ISA digital manufacturing series of standards. It was shown that the deployment of SMART standards improves the stability of interaction between information management systems and the functional dependability of production lines. The introduction of provisions regulating the use of algorithms for the development, editing, and examination of draft regulatory documents into the content machine-understandability facilities is an important factor in ensuring the functional dependability of products. Conclusions. The presented approach is focused on the methodology for developing standards that take into account requirements from various subject areas. In the context of ongoing import substitution in manufacturing, the paper examines the feasibility of minimizing digital process faults and failures caused by the use of regulatory frameworks that are not equivalent to the provisions of international documents and take into account the specificity of Russian industrial systems.

62) Digital Twins in Engineering Education, Preparing Students for Industrial Digital Transformation

Paper ID: b829ef90bed6916bc60d695342e88721d4c7013c

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Citation Count	Influential Citation Count	Reference Count
0	0	17

Keyword	Count
industry 4.0	1
digital twin	4
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: A **digital twin** is a virtual model designed to accurately reflect a physical object and is connected to the real asset with a bi-directional digital thread to unify general architectural solutions, speed up design processes and provide reliable tools to provide safe, reliable and secure solutions for running physical systems.

Abstract: Digital twins, one of the new important technologies which started to be omnipresent in literature since **Industry 4.0** got started, are becoming an essential part of the digital transformation processes in industry. Simply put, a **digital twin** is a virtual model designed to accurately reflect a physical object and is connected to the real asset with a bi-directional digital thread. Despite the different soft- and hardware architectures and applied fields digital twins are aimed to unify general architectural solutions, speed up design processes and provide reliable tools to provide safe, reliable and secure solutions for running physical systems. At the same time it is can be used as an educational tool, a framework to connect different technologies and it could be a bridge between Industry and Academia.

63) Impact of Topology Manipulation on Digital Thread Functionality: A Case Study on Aerospace Engineering

Paper ID: 93b80d4a2998e0403b2804dc447d410cdb04f18f

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Citation Count	Influential Citation Count	Reference Count
0	0	22

Keyword	Count
industry 4.0	1
digital twin	2
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: A graph representation of the digital thread is analyzed and one candidate scenario for reducing the network distance, which is the average path connecting two network nodes, will be studied as a use case.

Abstract: The emergence of **Industry 4.0** has necessitated the integration of technologies like Internet of Things (IoT) concepts into the production, operation, and processes of industries and institutions. Industry with the growing amount of data generated in facilities, digital models such as **digital twin** and the digital thread representing the communication between the devices can be leveraged to efficiently execute and monitor the processes. Linking different contributing assets to their counterpart digital twins is one of the main roles of the digital thread. Creating a digital thread for any product or the set of operations to manage a procedure during the life cycle of a product has been a major focus in the last few years. It eliminates a lot of difficulties (such as errors and delays) and optimizes the operations in every stage of designing products, services, and so on. Considering the numerous advantages of implementing the digital thread, there is still space to further improve the technology. Digital thread, as an infrastructure of data flow, can be optimized by mitigating problems such as latency in the communication between the interconnected nodes. This thread of communication between nodes can be shown as a mathematical graph made of vertices and edges so that the set of edges realizes the digital thread concept. Viewing a digital thread as a graph emerges the idea of exploiting well-known graph theory knowledge to figure out the problems of communication. In this paper, a graph representation of the digital thread is analyzed and one candidate scenario for reducing the network distance, which is the average path connecting two network nodes, will be studied as a use case. This approach intends to optimize the performance with latency as the key performance metric, by manipulating network distance as an independent variable.

64) A token-based operating model unifying traditional and token-based operations for security services

Paper ID: b9d2904414a6718a752c0e2ecf853a4d4abe6d4d

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Citation Count	Influential Citation Count	Reference Count
0	0	0

Keyword	Count
industry 4.0	0
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: The necessity for traditional custodians to enter tokenised markets to propose a future operating model for traditional custodians is examined and a proposed schematic architecture for the technical implementation of the operating model is proposed.

Abstract: Asset tokenisation is expected to have an impact on the financial services industry in the future. This paper examines the necessity for traditional custodians to enter tokenised markets to propose a future operating model for traditional custodians. We explore the advantages, such as leveraging regulatory expertise and existing customer bases and challenges, including the adoption of new technology stacks involved in such a model. Our proposed operating model utilises a blockchain infrastructure that relies on the use of tokens that spans both traditional and digital assets to create an automated platform. This platform can include the automation of credit risk and liquidity across multi-asset classes and multi-jurisdictional operations. Notably, our model introduces two types of tokens: value tokens (the fully digital or tokenised assets as well as tokenised money) and proxy tokens (among others, representing traditional assets). While value tokens carry value and represent tokenised assets, proxy tokens do not carry value. These proxy tokens are an internal representation of traditional assets that can facilitate managing the intra-day liquidity and extended credit lines offered to customers. Within our proposed operating model, all transaction instructions, whether in the traditional or tokenised realm, are streamlined through a unified ‘instruction worklist’. We conclude the paper with a proposed schematic architecture for the technical implementation of the operating model.

65) Metaverse: Accelerates Upstream Growth with the Power of Immersive Collaboration

Paper ID: 95f8d14b420cf013fadc86b100aecc18b17b4e88

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Citation Count	Influential Citation Count	Reference Count
0	0	19

Keyword	Count
industry 4.0	0
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: A comprehensive immersive platform that enables multidisciplinary teams and management to make decisions, and connects professionals to collaboratively demonstrate and share findings, run cross-functions business processes in an intuitive way capitalizing on artificial intelligence and cognitive capabilities is presented.

Abstract: The global transition towards sustainable future influenced industries to create a fundamental shift in the way they conduct the business to improve sustainability. This paper presents a comprehensive immersive platform that enables multidisciplinary teams and management to make decisions. It connects professionals to collaboratively demonstrate and share findings, run cross-functions business processes in an intuitive way capitalizing on artificial intelligence and cognitive capabilities. All of this is under a unified platform that we called the Upstream Metaverse. There are four pillars for the Upstream Metaverse: digital assets, real-time collaboration, intelligence, and venues. First digital assets, which include visualization of reservoir simulation static and dynamic properties (e.g., porosity, permeability, water, oil saturation, etc.), other datatypes such as core and well log data. Second is the collaboration and interactive capabilities that allows engineers to be immersed into their models, and run different scenarios. Third is the intelligent layer, which capitalizes on available Industrial Revolution 4.0 (IR4.0) solutions. Fourth is the collaboration venues represented by the Upstream collaboration centers to maximize the user experience. A synthetic model was used in this paper to demonstrate well placement process, which is one of the Upstream complex processes as it involves many stakeholders. Upstream Metaverse streamlined the process by integrating the key data, and workflows needed for the decision process in a single platform. It enables multiple intuitive visualization methods of well logs to address the complexity. In addition, it provides the visualization of structured data including reservoir models that can be cross-referenced with well logs. Moreover, it provides seamless integration with an intelligent voice assistant to enrich the user experience. These capabilities allow multidisciplinary teams to run different business scenarios, conduct effective field reviews, and collaboratively discuss their findings in an interactive and immersive platform. This allows real-time collaboration around the data for all participants. Furthermore, coupling Upstream Metaverse with digital transformation solutions provides a rich platform that is capable to effectively facilitate the meetings. Also, capitalizing on the integrated data sources, and cross-organization functions combined with streamlined IR4.0 processes enabled on spot decision making. The Upstream Metaverse established the main building blocks that are fully integrated with data repositories to address current and future challenges. This will directly increase the efficiency of conducting Upstream cross-functions operations through a single, unified, immersive, and collaborative platform. Upstream Metaverse is a sustainable environment that reduces the need for sequel meetings, supplemental silo efforts, and computation resources.

66) Digital Oil Field; The NPDC Experience

Paper ID: 52c016b5e4accb21c06cf690bb302ab74d745d32

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Citation Count	Influential Citation Count	Reference Count
0	0	5

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	0
digital representation	1
industrial metaverse	0

TLDR: The Oredo Digital Oil Field represents a future of the oil and gas industry in tandem with the **industry 4.0** attributes of using digital technology to drive efficiency, reduce operating expenses and apply surveillance best practices which is required for the survival of the Oil and Gas industry.

Abstract: This paper presents an overview of the implementation of a Digital Oilfield (DOF) system for the real-time management of the Oredo field in OML 111. The Oredo field is predominantly a retrograde condensate field with a few relatively small oil reservoirs. The field operating philosophy involves the dual objective of maximizing condensate production and meeting the daily contractual gas quantities which requires wells to be controlled and routed such that the dual objectives are met. An Integrated Asset Model (IAM) (or an Integrated Production System Model) was built with the objective of providing a mathematical basis for meeting the field's objective. The IAM, combined with a Model Management and version control tool, a workflow orchestration and automation engine, A robust data-management module, an advanced visualization and collaboration environment and an analytics library and engine created the Oredo Digital Oil Field (DOF). The Digital Oilfield is a real-time **digital representation** of a field on a computer which replicates the behavior of the field. This virtual field gives the engineer all the information required to make quick, sound and rational field management decisions with models, workflows, and intelligently filtered data within a multi-disciplinary organization of diverse capabilities and engineering skill sets. The creation of the DOF involved 4 major steps; DATA GATHERING considered as the most critical in such engineering projects as it helps to set the limits of what the model can achieve and cut expectations. ENGINEERING MODEL REVIEW, UPDATE AND BENCHMARKING; Majorly involved engineering models review and update, real-time data historian deployment etc. SYSTEM PRECONFIGURATION AND DEPLOYMENT; Developed the DOF system architecture and the engineering workflow setup. POST DEPLOYMENT REVIEW AND UPDATE; Currently ongoing till date, this involves after action reviews, updates and resolution of challenges of the DOF, capability development by the operator and optimizing the system for improved performance. The DOF system in the Oredo field has made it possible to integrate, automate and streamline the execution of field management tasks and has significantly reduced the decision-making turnaround time. Operational and field management decisions can now be made within minutes rather than weeks or months. The gains and benefits cuts across the entire production value chain from improved operational safety to operational efficiency and cost savings, real-time production surveillance, optimized production, early problem detection, improved Safety, Organizational/Cross-discipline collaboration, data Centralization and Efficiency. The DOF system did not come without its peculiar challenges observed both at the planning, execution and post evaluation stages which includes selection of an appropriate Data Gathering & acquisition system, Parts interchangeability and device integration with existing field devices, high data latency due to bandwidth, signal strength etc., damage of sensors and transmitters on wellheads during operations such as slickline & WHM activities, short battery life, maintenance, and replacement frequency etc. The challenges impacted on the project

schedule and cost but created great lessons learnt and improved the DOF learning curve for the company. The Oredo Digital Oil Field represents a future of the oil and gas industry in tandem with the **industry 4.0** attributes of using digital technology to drive efficiency, reduce operating expenses and apply surveillance best practices which is required for the survival of the Oil and Gas industry. The advent of the 5G technology with its attendant influence on data transmission, latency and bandwidth has the potential to drive down the cost of automated data transmission and improve the performance of data gathering further increasing the efficiency of the DOF system. Improvements in digital integration technologies, computing power, cloud computing and sensing technologies will further strengthen the future of the DOF. There is need for synergy between the engineering team, IT, and instrumentation engineers to fully manage the system to avoid failures that may arise from interface management issues. Battery life status should always be monitored to ensure continuous streaming of real field data. New set of competencies which revolves around a marriage of traditional Petro-technical skills with data analytic skills is required to further maximize benefit from the DOF system. NPDC needs to groom and encourage staff to venture into these data analytic skill pools to develop knowledge-intelligence required to maximize benefit for the Oredo Digital Oil Field and transfer this knowledge to other NPDC Asset.

67) Semantic Digital Twins: Trends and Shortcomings (Keynote)

Paper ID: 04951cdeaf092794088b827a48b38e0664ecce3f

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Citation Count	Influential Citation Count	Reference Count
0	0	0

Keyword	Count
industry 4.0	2
digital twin	15
digital asset management	0
interoperability	0
digital representation	1
industrial metaverse	0

TLDR: This talk discusses the current practices and trends in the development and use of Digital Twins in smart manufacturing with a particular focus on approaches that are rooted in semantic technologies, that is, ontologies, constraints, knowledge graphs and different research directions for Semantic Digital Twins.

Abstract: During the last decade the concept of Digital Twins, as **digital representation** of a physical object or system, has become one of the key building blocks towards digitalization and automation in the whole production value chain. In particular, Digital Twins are popular in manufacturing since they allow to seamlessly capture the entire manufacturing environment including facilities, processes, materials, personnel, etc. In the keynote talk we discuss the current practices and trends in the development and use of Digital Twins in smart manufacturing with a particular focus on approaches that are rooted in semantic technologies, that is, ontologies, constraints, knowledge graphs. We also discuss what are the limitations of existing solutions and requirements for the next-generation Semantic Digital Twins. First, we discuss the vision of the concept of a **digital twin** will be analyzed based on the perspective from the industry. In this scenario, the main challenge still remains to have isolated information silos, and digital twins can support the aggregation of information from such silos. This goes beyond conceptual modelling, i.e. just interlinking the physical and digital conceptual models, but also connecting information across the project life cycle and solving the particular needs from industry. Then, we deep dive into the analysis of the **digital twin**-powered **industry 4.0**, from vision to the main trends and current practices. **Industry 4.0** can be enhanced with semantic digital twins and industrial knowledge graphs, which will enable applications to be built on top of such digital twins and the underlying knowledge graph they expose. The existing **digital twin** solutions provide flexible linking and integration of heterogeneous data across information silos, and having ontology-based solutions simplifies data access. The **digital twin** concept enables heterogeneous industrial asset data to be dis-coverable, presented in a homogeneous language, and understood by domain experts. Furthermore, diagnosis and analytics require specialised semantic languages to enable native analyses over semantic data models and combine data extraction and data analysis. Finally, in the keynote we present different research directions for Semantic Digital Twins. The research community has a good room for improvement on topics such as the combination of ontologies and constraints, the use of modelling patterns and standards, the provision of quality management mechanisms, the construction of user-orientated solutions, and the enhancement of Digital Twins with machine learning, analytics, and simulation. Addressing these topics will give us the next generation of Semantic Digital Twins that are enhanced with modelling patterns, constraints, reasoning

68) The 2nd Learning from Limited Labeled Data (LLD) Workshop: Representation Learning for Weak Supervision and Beyond

Paper ID: 6461d1abbacc2afe26cfebf10cc5d0fe8fcc2e38

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Citation Count	Influential Citation Count	Reference Count
0	0	32

Keyword	Count
industry 4.0	0
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: It was demonstrated that loss gradients from adversarially trained DNNs align better with human perception because adversarial training restricts gradients closer to the image manifold, and under the adversarial training framework, there exists an empirical trade-off between test accuracy and loss gradient interpretability.

Abstract: s (3): Abstract 5: Misleading meta-objectives and hidden incentives for distributional shift in Safe Machine Learning: Specification, Robustness, and Assurance, Krueger 12:00 PM5: Misleading meta-objectives and hidden incentives for distributional shift in Safe Machine Learning: Specification, Robustness, and Assurance, Krueger 12:00 PM David Krueger, Tegan Maharaj, Shane Legg and Jan Leike. Decisions made by machine learning systems have a tremendous influence on the world. Yet it is common for machine learning algorithms to assume that no such influence exists. An example is the use of the i.i.d. assumption in online learning for applications such as content recommendation, where the (choice of) content displayed can change users' perceptions and preferences, or even drive them away, causing a shift in the distribution of users. A large body of work in reinforcement learning and causal machine learning aims to account for distributional shift caused by deploying a learning system previously trained offline. Our goal is similar, but distinct: we point out that online training with meta-learning can create a hidden incentive for a learner to cause distributional shift. We design a simple environment to test for these hidden incentives (HIDS), demonstrate the potential for this phenomenon to cause unexpected or undesirable behavior, and propose and validate a mitigation strategy. Abstract 8: Bridging Adversarial Robustness and Gradient Interpretability in Safe Machine Learning: Specification, Robustness, and Assurance, Kim 03:20 PM8: Bridging Adversarial Robustness and Gradient Interpretability in Safe Machine Learning: Specification, Robustness, and Assurance, Kim 03:20 PM Beomsu Kim, Junghoon Seo and Taegyun Jeon. Adversarial training is a training scheme designed to counter adversarial attacks by augmenting the training dataset with adversarial examples. Surprisingly, several studies have observed that loss gradients from adversarially trained DNNs are visually more interpretable than those from standard DNNs. Although this phenomenon is interesting, there are only few works that have offered an explanation. In this paper, we attempted to bridge this gap between adversarial robustness and gradient interpretability. To this end, we identified that loss gradients from adversarially trained DNNs align better with human perception because adversarial training restricts gradients closer to the image manifold. We then demonstrated adversarial training causes loss gradients to be quantitatively meaningful. Finally, we showed that under the adversarial training framework, there exists an empirical trade-off between test accuracy and loss gradient interpretability and proposed two potential approaches to resolving this trade-off. Abstract 9: Uncovering Surprising Behaviors in Reinforcement Learning via Worst-Case Analysis in Safe Machine Learning: Specification, Robustness, and Assurance, Ruderman 03:40 PM9: Uncovering Surprising Behaviors in Reinforcement Learning via Worst-Case Analysis in Safe Machine Learning: Specification, Robustness, and Assurance, Ruderman 03:40 PM Avraham Ruderman, Richard Everett, Bristy Sikder, Hubert Soyer, Charles Beattie, Jonathan Uesato, Ananya Kumar and Pushmeet Kohli Reinforcement learning agents are typically trained and evaluated according to their performance averaged over some distribution of environment settings. But does the distribution over environment settings ICLR 2019 Workshop book Generated Fri Apr 19, 2019 Page 9 of 12 contain important biases, and do these lead to agents that fail in certain cases despite high

average-case performance? In this work, we consider worst-case analysis of agents over environment settings in order to detect whether there are directions in which agents may have failed to generalize. Specifically, we consider a 3D first-person task where agents must navigate procedurally generated mazes, and where reinforcement learning agents have recently achieved human-level average-case performance. By optimizing over the structure of mazes, we find that agents can suffer from catastrophic failures, failing to find the goal even on surprisingly simple mazes, despite their impressive average-case performance. Additionally, we find that these failures transfer between different agents and even significantly different architectures. We believe our findings highlight an important role for worst-case analysis in identifying whether there are directions in which agents have failed to generalize. Our hope is that the ability to automatically identify failures of generalization will facilitate development of more general and robust agents. Representation Learning on Graphs and Manifolds Will Hamilton, Fred Sala, Peter Battaglia, Joan Bruna, Thomas Kipf, Yujia Li, Razvan Pascanu, Adriana Romero, Petar Veli■kovi■, Marinka Zitnik, Maximilian Nickel, Beliz Gunel, Albert Gu, Christopher Re Room R07, Mon May 06, 09:45 AM Many scientific fields study data with an underlying graph or manifold structure—such as social networks, sensor networks, biomedical knowledge graphs, and meshed surfaces in computer graphics. The need for new optimization methods and neural network architectures that can accommodate these relational and non-Euclidean structures is becoming increasingly clear. In parallel, there is a growing interest in how we can leverage insights from these domains to incorporate new kinds of relational and non-Euclidean inductive biases into deep learning. Recent years have seen a surge in research on these problems—often under the umbrella terms of graph representation learning and geometric deep learning. For instance, new neural network architectures for graph-structured data (i.e., graph neural networks) have led to state-of-the-art results in numerous tasks—ranging from molecule classification to recommender systems—while advancements in embedding data in Riemannian manifolds (e.g., Poincaré embeddings, Hyperspherical-VAEs) and optimization on Riemannian manifolds (e.g., R-SGD, R-SVRG) have demonstrated how non-Euclidean geometries can provide powerful new kinds of inductive biases. Perhaps the biggest testament to the increasing popularity of this area is the fact that five popular review papers have recently been published on the topic [1-5]—each attempting to unify different formulations of similar ideas across fields. This suggests that the topic has reached critical mass and requires a focused workshop to bring together researchers to identify impactful areas of interest, discuss how we can design new and better benchmarks, encourage discussion, and foster collaboration. The workshop will consist of contributed talks, contributed posters, and invited talks on a wide variety of methods and problems in this area, including but not limited to: Deep learning on graphs and manifolds (e.g., graph neural networks) Riemannian optimization methods Interaction and relational networks Unsupervised geometric/graph embedding methods (e.g., hyperbolic embeddings) Generative models with manifold-valued latent variables Deep generative models of graphs Deep learning for chemical/drug design Deep learning on manifolds, point clouds, and for 3D vision Relational inductive biases (e.g., for reinforcement learning) Optimization challenges due to the inherent discreteness of graphs Theoretical analyses of graph-based and non-Euclidean machine learning approaches Benchmark datasets and evaluation methods We welcome and encourage position papers under this workshop theme. We are also particularly interested in papers that introduce benchmark datasets, challenges, and competitions to further progress of the field, and we will discuss the challenge of designing such a benchmark in an interactive panel discussion. [1] Bronstein, M. M., Bruna, J., LeCun, Y., Szlam, A., & Vandergheynst, P. (2017). Geometric deep learning: going beyond euclidean data. IEEE Signal Processing Magazine, 34(4), 18-42. [2] Hamilton, W. L., Ying, R., & Leskovec, J. (2017). Representation learning on graphs: Methods and applications. IEEE Data Engineering Bulletin. [3] Battaglia, P. W., Hamrick, J. B., Bapst, V., Sanchez-Gonzalez, A., Zambaldi, V., Malinowski, M., ... & Gulcehre, C. (2018). Relational inductive biases, deep learning, and graph networks. arXiv preprint arXiv:1806.01261. [4] Goyal, P., & Ferrara, E. (2018). Graph embedding techniques, applications, and performance: A survey. Knowledge-Based Systems, 151, 78-94. [5] Nickel, M., Murphy, K., Tresp, V., Gabrilovich, E. (2016). A review of relational machine learning for knowledge graphs. Proceedings of the IEEE. 104.1, 11-33. Reproducibility in Machine Learning Nan Rosemary Ke, Alex Lamb, Anirudh Goyal Alias Parth Goyal, Aaron Courville, Yoshua Bengio Room R08, Mon May 06, 09:45 AM Papers from the Machine Learning community are supposed to be a valuable asset. They can help to inform and inspire future research. They can be a useful educational tool for students. They are the driving force of innovation and differentiation in the industry, so quick and accurate implementation is really critical. On the research side they can help us answer the most fundamental questions about our existence what does it mean to learn and what does it mean to be human? Reproducibility, while not always possible in science (consider the study of a transient astrological phenomenon like a passing comet), is a powerful criteria for improving the quality of research. A result which is reproducible is more likely to be robust and meaningful and rules out many types of experimenter error (either fraud or accidental). There are many interesting open questions about how reproducibility issues intersect with the Machine Learning community: -How can we tell if papers in the Machine Learning community are ICLR 2019 Workshop book Generated Fri Apr 19, 2019 Page 10 of 12 reproducible even in theory? If a paper is about recommending news sites before a particular election, and th

69) Cyber-physical System Control via Industrial Protocol OPC UA

Paper ID: d5a11f341af53b51b0cfeba57b2cdf3f5d694b8e

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Citation Count	Influential Citation Count	Reference Count
0	0	31

Keyword	Count
industry 4.0	1
digital twin	0
digital asset management	0
interoperability	0
digital representation	1
industrial metaverse	0

TLDR: A system is described that enables the control of a 3D printer via the industrial standardized Machine-to-Machine (M2M) communication protocol Open Platform Communications Uni■ed Architecture (OPC UA) and facilitates research in 3D printing control structures and industrial application.

Abstract: —The integration of cyber-physical systems (CPS) is gaining more and more momentum due to the advent of **Industry 4.0**. Thereby, one of the main challenges is to facilitate the connection to arbitrary machinery in order to monitor and control these automatically. Such a control ■exibilizes production processes by enabling quick adaptions of production steps. Therefore, in this work, a system is described that enables the control of a 3D printer via the industrial standardized Machine-to-Machine (M2M) communication protocol Open Platform Communications Uni■ed Architecture (OPC UA). The system is implemented on the basis of a micro computing platform, in this case a Raspberry Pi 2, and utilises open-source libraries and tools. The implementation creates a cyber-physical system, consisting of a 3D printer, its control system, sensor data acquisition systems and their respective **digital representation**. With this control system, the usage of consumer-centric 3D printers, such as Fused Deposition Modeling (FDM) printers, in enterprise-like scenarios is enabled. This abstract and universal control mechanism facilitates research in 3D printing control structures and industrial application.

70) Towards a Well-Founded Domain Ontology for Offshore Petroleum Production Plants

Paper ID: f5680ed319d6d5cf660b4307bdfd69b19337e1f7

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Citation Count	Influential Citation Count	Reference Count
0	0	0

Keyword	Count
industry 4.0	0
digital twin	1
digital asset management	0
interoperability	2
digital representation	0
industrial metaverse	0

TLDR: A domain ontology of offshore petroleum production plants to address the lack of a uniform vocabulary for entities involved in the production process and expand the semantics involved in machine learning applications is built.

Abstract: The petroleum industry has many challenges to address when it comes to data handling. The vast number of companies that perform specialized services and use their proprietary software creates a challenging environment for managing whole chain field data. Thus, a significant effort has been made to provide a semantic framework for **interoperability** in the oil and gas industry, such as the ontology provided by ISO 15926, the integrated data platform from the Open Subsurface Data Universe Forum (OSDU), and standard glossaries such as the Professional Petroleum Data Management (PPDM) What is a Well?. Despite such an effort, accessing integrated data and reasoning over it remains an issue in the offshore environment. Service companies, operators, and platform leasing companies usually work together, each with its own siloed systems. Besides several **interoperability** problems, the lack of a uniform vocabulary for entities involved in the production process shows a problematic issue. Our work aims to build a domain ontology of offshore petroleum production plants to address this issue. The initial scope is material entities and their inhering properties, connecting the subsurface reservoir and topside equipment. By building the ontology, we intend to help solve modeling challenges common to ontologies in the industrial domain. The development of the domain ontology is following the NeOn Methodology. In this proposal, we consider a collection of requirements defined in the format of competence questions. The ontology uses BFO as a top-level ontology and employs the core ontology produced by the Industry Ontology Foundry (IOF) and GeoCore as middle-level ontologies. We build the ontology after textual definitions for the terms of the domain provided by ISO 15926-4 and other publications or glossaries from the oil and gas industry (e.g., Petrowiki, SPE, API, PPDM). The ontology will provide first-order logic definitions of concepts from the domain and enables query answering related to production and injection data from wells. We intend the ontology to rule the tag definitions on monitoring systems, provide labels for annotating databases from different providers, allow unified queries over various sources, and expand the semantics involved in machine learning applications. FOIS 2021 Early Career Symposium (ECS), held at FOIS 2021 12th International Conference on Formal Ontology in Information Systems, September 13-17, 2021, Bolzano, Italy " nicolau.santos@inf.ufrgs.br (N. O. Santos) ~ https://github.com/nos4397 (N. O. Santos) 0000-0003-0901-2465 (N. O. Santos) © 2021 Copyright for this paper by its authors. Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0). CEUR Workshop Proceedings http://ceur-ws.org ISSN 1613-0073 CEUR Workshop Proceedings (CEUR-WS.org) Up to now, we have performed a meta-property analysis following OntoClean methodology to guide the initial taxonomy construction. The author acquired 59 competence questions (at present) and 26 initial modeling terms after eight initial one-and-a-half-hour interviews with professionals from the partner industry. Formal definitions for the terms are in development. The author started classifying each of the acquired terms following BFO guidelines and associating the terms with possible specializations of GeoCore and IOF-Core. This research is part of a joint industry-university project to develop a **digital twin** for production optimization for the petroleum industry. The ontology is under the process of formalization and logical consistency validation. We have scheduled a new round of interviews with stakeholder groups to validate the definitions. The further validation step corresponds to applying the developed ontology to a use case from a production facility plant located offshore of Southeast Brazil.

71) [redacted]

Paper ID: bd8814a4fea3f161bc1098d0e398a19ed2d41b71

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Citation Count	Influential Citation Count	Reference Count
0	0	0

Keyword	Count
industry 4.0	0
digital twin	0
digital asset management	0
interoperability	0
digital representation	1
industrial metaverse	0

TLDR: Analysis of recent research and publications showed that the prospects for the introduction of geographic information technology for administrative and economic asset management of Ukrainian airports need further research, as these issues are very important and relevant, given the rapid growth of digital society, environment and infrastructure.

Abstract: In accordance with the State Target Program for Airport Development for the period up to 2023, in order to increase the efficiency of state property management and meet the needs of the state in ensuring the stable development of the aviation industry, a number of theoretical studies and practical stages of creating a subsystem for managing engineering networks. According to the tasks and measures of this program, the development of a subsystem for the management of engineering networks at the airport is a relevant and promising area. Engineering networks to ensure the smooth operation of the airport complex may include units that perform the functions of operation of utility networks of different types of planning of current and future development. This is a complex territorial and technological complex, for the optimal functioning of which requires no less complex management information system, which in turn requires laying already at the stages of developing capabilities to perform two communicative functions: the first one - to unite all airport subsystems, the second one - to coordinate relations with other airport systems, management and its divisions. The paper analyzes and summarizes publications on methods of geospatial data generation, introduction of geoinformation technologies for administrative and economic management of airports, as well as publications on information systems of branched areas of public utilities as a system of economic work of the airport, in particular, water supply and sewerage, energy and heat supply, outdoor lighting of the airport and runways, sanitation, etc. Analysis of recent research and publications showed that the prospects for the introduction of geographic information technology for administrative and economic asset management of Ukrainian airports need further research, as these issues are very important and relevant, given the rapid growth of digital society, environment and infrastructure. The main purpose of the study is to develop models for the formation of geospatial data subsystem management utilities airport, their processing and visualization, application of geographic mapping systems and the formation of conceptual approaches to the creation, operation and application of geographic information systems and technologies to solve administrative problems. The structure of the subsystem was determined and the basic sets of geospatial data of the airport were established, which include a single cartographic basis for the location of profile sets of engineering infrastructure. The formation of geospatial data sets is in accordance with the international standards ISO 19100 «Geographic Information / Geomatics», which provides the use of data in various software, access to open data, services and programs that can be easily integrated without the need for refinement and based on common standards and concepts of modern information technologies. Using the classifier of topographic information of scales 1:500 - 1:5 000, the list of names of objects of classification of subsystem of management of engineering communications of GIS, classification groups and their code designations from a class of objects 51300000 «Communications» is formed. **Digital representation** of objects is performed in accordance with the set of standards «Topographic Database», which allows to unify the structure and composition of digital terrain models in topographic databases for compatibility of geospatial data of different manufacturers. On the basis of the conducted research, the theoretical bases of cartographic maintenance of functioning of GIS for successful management of operational services of various types of engineering networks of a complex of the airport are developed. This is done taking into account the specifics of the object of study (airport) and the capabilities of modern GIS, the main function of

which is to conduct cartographic modeling based on geoinformation analysis of geospatial and attributive data of engineering communications of an airport.

72) CREATION OF A DOMAIN ONTOLOGY IN CIDOC CRM OWL FORMAT USING HETEROGENEOUS TEXTUAL DATA RELATED TO INDUSTRIAL HERITAGE

Paper ID: c69cd9aa202eca3ec761216ab3732f969af996f7

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Citation Count	Influential Citation Count	Reference Count
0	0	1

Keyword	Count
industry 4.0	0
digital twin	0
digital asset management	0
interoperability	2
digital representation	0
industrial metaverse	0

TLDR: The originality of the project is to adopt a multidisciplinary approach to provide stakeholders, experts and non-experts, help them in the discovery of knowledge specific to their heritage, thanks to the extraction, structuring and visualization of knowledge from heterogeneous digital corpora.

Abstract: An important social issue in the cultural heritage domain is related to collection, analysis, publication and enhancement of collective history and memory of the stakeholders, be they spoken or written. This kind of information about cultural heritage presents a real challenge for their formalization because of the data diversity and incompleteness. Moreover, the data about cultural heritage are sparse and distributed, and can be found in different sources: online, in databases, in libraries, museums, in press papers, in the memories of stakeholders, etc. Thus, we are witnessing a prodigious rise of the volume of digital and physical contents describing this heritage and the increase of the production power associated with dissemination techniques, at different scales, and especially at the regional level. This diversity of resources brings many problems such as data documentation, representation, integration and **interoperability** within the same knowledge base. Most of the attempts to resolve semantic **interoperability** problems focus on standardization and development of shared structures like FRBR, FRBRoo, CIDOC CRM etc. Among those technologies, the CIDOC CRM is an ontology format specifically designed to model cultural heritage domains. This model offers a common meta-data schema making it understandable and interrelated by implicit and explicit relationships. Those ontology schemas are meant to promote a common data comprehension about cultural heritage by providing a common and extensible semantic framework in which all information can be mapped. In our project, the objective is to provide a knowledge representation that interconnects all of these data, thanks to the semantic web technologies, in order to assist domain experts in producing and providing digital content. The originality of the project is to adopt a multidisciplinary approach to provide stakeholders, experts and non-experts, help them in the discovery of knowledge specific to their heritage, thanks to the extraction, structuring and visualization of knowledge from heterogeneous digital corpora. According to UNESCO, which has contributed significantly to the definition of the heritage (UNESCO, 1954, 1970, 1982), and then to The International Committee for the Conservation of Industrial Heritage (TICCIH, 2003), the industrial heritage can be defined as: Material assets: buildings, machinery, equipment, workshops, factories, processing and refining sites, shops, production centers and social activities related to the textile industry; Immaterial assets: memories, events, festivals, collective images, intellectual production transmitted by know-how which can be a succession of gestures dictated and displayed in production centers. In our work, the main efforts are focused on modeling of the domain stakeholders, the spatial entities and thematic, which belong to both of the assets. In this paper, we first provide a brief description of existing studies which aim at building of domain ontologies related to several fields in the cultural heritage area using semantic web technologies. Then, we present a three step methodology for semi-automatic building of semantic representation of the studied domain from heterogeneous documents. During the first step, we collect and formalize the history through interviews with

stakeholders. In addition to the collected information, we also exploit a web mapping/visualization? of stakeholders organized by their type (Kergosien et al, 2015). During the second step, we describe our methodology for identification and extraction of information related to industrial cultural heritage from heterogeneous textual documents (interviews, numerical documents from libraries, newspapers, etc.). The proposed approach combines lexicon projection with text mining methods to improve the identification of relevant data. Lexica of spatial entities initially cover regional municipalities. The lexicon of the domain's stakeholders was built semi-automatically with experts. To create a thematic lexicon, existing specialized resources defined by experts (Joconde created by French museums, Rameau created by the National Library of France, Wiktionnary, and other) were analyzed and filtered manually. Text mining approach is based on the Word2vec algorithm and is exploited for identification of new terms from the processed corpus. The main purpose is to build a semantic representation of the studied domain as precise as possible. The indexed documents are structured in XML MODS format [1] , which is a document indexing format created by the Congress Library in the United States. This standard is a compromise between the complexity of the MARC format used by libraries and the extreme simplicity of the Dublin Core metadata. Then, during the third step, we present a first ontology built automatically in the OWL CIDOC CRM format to merge together all our lexica. In this phase, it is important to filter the CIDOC CRM model to obtain a sub-model with the relevant concepts and properties. The experiments were carried out on a corpus of thousands heterogeneous documents (newspaper articles from LaVoixDuNord, documents with metadata from libraries and interviews) related to the Textile Industrial Heritage (TIH) on the territory of Nord of France. The ontology built is tested and validated by experts using the Protege tool. In future, we propose to extend our work and design a generic and semi-automatic approach for building semantic representation related to industrial heritage. Besides, we propose to test our method on heterogeneous data related to industrial and mining heritage, collected within the framework of the MemoMines project. [1] http://www.loc.gov/standards/mods/ E. Kergosien, B. Jacquemin, M. Severo et S. Chaudron, Vers l'interoperabilite des donnees heterogenes liees au patrimoine industriel textile, In 18eme colloque international sur le document numerique (CIDE'18) , pp.15, Montpellier, 2015

73) Fake news and the mediatised imagination

Paper ID: 8406fe0210f26e3d78d3f63083d73569b77bc66c

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Citation Count	Influential Citation Count	Reference Count
0	0	20

Keyword	Count
industry 4.0	0
digital twin	0
digital asset management	0
interoperability	0
digital representation	0
industrial metaverse	0

TLDR: N/A

Abstract: The mass media provide the auditoria with the attractive texts aiming mainly or solely at the powerful emotional and sensual stimulation. To the auditoria, these texts constitute the source of the narratives, heuristics, and interpretations handy in the description and representation of the world. Such a mediatised imagination facilitates spreading stereotypes, hearsay, and fake information. It is possible to describe a certain type of people's cultural experiences in the mediatised society by means of a metaphor of the shock caused by the electric eel. The experience thus described is short and intense, composed of poignant sensations and strong emotions, still, devoid of any significant intellectual content. Such experiences provide a sense of detachment from reality and immersion into the alternative world, and participation in this world together with a large crowd of others. One can surmise that the experiential participation in culture contributes to the reshaping of social representations of various social phenomena, their altered evaluation, diffusion, and hierarchisation. It may be therefore co-responsible for the faith in the so-called post-truth, the dissemination of superstitions, the cultivation of stereotypes and prejudices, and the mediatisation of the imagination. The logic of suspicion and eclecticism of methodology The word "surmise" is being used consciously here, with the perfect awareness that in the academic discourse the conjectures need only be the basis for hypotheses empirically confirmable through an intersubjectively valid methodology. Hopefully, sometime such a methodology will be built. Meanwhile, the conjectures allow for the construction of an essay. It might be contributive to the discussion about the deep causes of the calamity that the massmediated distribution of fake news and the dissemination of post-truth has become in recent years. The distribution of fake news ruins the public sphere, distorts political choices of citizens, diminishes the prestige of science while bolstering the spreading of the common knowledge, and, releases demons hidden inside social stereotypes and prejudices. Technological explanations of this phenomenon lead to the easy attribution of blame to the social media tools: lo and behold, the reason fetched away as a result of the technical solutions enabling mass distribution and authentication of every, even the most absurd information both by humans and by the human-emulating algorithms. Sociological explanations point to the collapse of the social trust and the post-modern crisis of the worldordering "great narratives". Political scientists describe the dangerous connections between the economic deprivation of the large groups of people and populism that uses their frustration to spread the totalitarian vision of reality. Each of these explanations touches the heart of the problem, but only to a certain extent. Media scholar/semiotician (which is the position of the author of this essay) is also unable to provide the key to its complete understanding. However, the media-socio-semiotic perspective may help to diagnose how the mediatised culture produces not only fake news on their own, but also the context incentivising their distribution, paired with people's emotional and cognitive attitudes conducive to it. It can also indicate the cultural forces enabling the resistance against the posttruth invasion. The awareness of the inability to fully empirically validate the theses expressed in this essay has to lead to the partial scepticism as to the adopted heuristic and cognitive procedures. However, it does not have to lead to the complete disqualification of the applied methodology. It is instead useful to remind that its explicatory power is not absolute, so the used methods should be triangulated with the sociological, political and anthropological methodologies. Hence the methodological eclecticism: the use of socio-semiotic tools, sociological concepts and the achievements of communication science. The media studies, as a young discipline lacking a single unified Great Theory, feed on these encounters. Experiences and practices The metaphor of electric eel used at the beginning of this essay refers to the particular type of the experience of the media users, resulting from the comprehensive, very intense stimulation of their senses. It is based on the illusion of an intimate, direct physical reception of the cultural text, but in reality, it cannot do without the use of sense-enhancing technology. The technological mediation

is also the source of the sense of togetherness, the co-participation in large aggregative processes, a kind of initiation binding the participants of the particular cultural event against the rest of the world. In concert with the character of our current culture such experiences happen to us incessantly during a concert, performance, match, exhibition, election rally, at the shopping mall and in front of a TV. They are pleasurable because of providing users with the emotional and sensory stimulations, even though they do not have to be joyful or cheerful, and sometimes they rely on arousing anger, fear or disgust. Although very strong, they are transient and temporary. They are basically unrepeatable, although the recipients can try to reprise them, and they have at their disposal the text and image registration devices allowing to do it to some extent. Media science theories of media dependency and the newer versions of the cultivation theory suggest that the recurring, longterm technologically mediated cultural experiences of this kind generate the particular reception attitudes. This can influence the acquirement of knowledge or shape various 1 S.J. Ball-Rokeach, J.Y. Jung, The evolution of media system dependency theory [in:] Sage handbook of media processes and effects, ed. R. Nabi, M.B. Oliver, Thousand Oaks 2009, pp. 531–544. 2 M. Morgan, J. Shanahan, Two decades of cultivation research: An appraisal and meta-analysis, “Annals of the International Communication Association”, 1997, 20, pp. 1–45, doi: 10.1080/23808985.1997.11678937 [access: 1.07.2018]. Also: M. Morgan, J. Shanahan, N. Signorelli, Yesterday's new cultivation, tomorrow, “Mass Communication and Society”, 2015, 18/5, pp. 674–699, doi:10.1080/15205436.2015.1072725 [access: 1.07.2018]. people’s choices not only in the sphere of culture, but also in politics, education, consumption, or lifestyle. The experiential model of cultural reception is based on the synthesis of technologies and market mechanisms of the mediatised culture, mass-producing spectacular texts devoid of intellectual depth which then become powerful, collective experiences of large audiences. While pondering this type of media experiences, it is worth looking for a perspective allowing for the description of their social dimensions. The socio-semiotic theories of reception seem to be useful and applicative in this respect. Not without reason, Nick Couldry's work on media practices has been in recent years widely cited in Western academia and applied to explain various phenomena in the realm of social communication. The British communication sociologist, drawing on Ludwig Wittgenstein and Teodor Schatzky, perceives the media use as a kind of social practice: the set of recurring human activities of universal, repetitive, routine, ritualised character, incident to the human needs of communication and interaction, cooperation, trust and freedom. Each time, they consist of the activity, co-related communication (production of discourse) and the re-ordering of the world knowledge, hierarchisation of the issues, establishment of the criteria of truth and accuracy of the collective interpretations of the various social phenomena. This clearly entails that practices are related to power, social hierarchy and knowledge production processes. Their repeatability and universality in our life lead to specific collective attitudes and values. Therefore, the collective and repetitive nature of media practices has considerable practical import. They enable the dissemination of certain types of discourse, shape the construction and transfer of knowledge, lead to naturalisation of particular representations of social life. The media practices constantly interact with the consumption, political, religious, health, educational and family practices which leads to the changes in the collective evaluation of the social phenomena, and in the uses of culture, the tastes, and preferences, consumer and political choices, and private decisions of people. Therefore the character of the media texts serving as the background for the most prevalent practices is of enormous importance. 3 N. Couldry, Media, society, world. Social theory and digital media practice, Cambridge 2012. See, by the same author: Media w kontek■cie praktyk. Próba teoretyczna [Theorising Media as Practice], “Kultura Popularna” 2010, 27/1, pp. 96–113. 4 T.R. Schatzky, Social practices: a Wittgensteinian approach to human activity and the social, New York 1996. 5 N. Couldry, Media, society, world..., op. cit., p. 34 et seq. 6 E. Shove, M. Pantzar, M. Watson, The dynamics of social practice: Everyday life and how it changes, London 2012. Convergence and unity The metaphor of an electric eel culture relates to the era of industrial production and distribution of experiences. Despite their repetitive nature, they are promoted by the cultural industry as unique, perception-altering, and unforgettable, whereas the technologicallysupported communication gives the access to the same “unique” experience to large numbers of people. Paradoxically, the cultural industry itself, while promoting the uniqueness of its products, uses different content, formal and distribution solutions to emphasise the collective character of the experiences of large human aggregates and encourage us to communicate with other users by means of the convergent interactive media. Such e