Structuring the Industry 4.0 Landscape

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***Abstract*—The industry and research efforts to standardize Industry 4.0 related developments have merged into an unmanageable amount of reference models, architectures and specification activities. As these efforts have only been roughly coordinated, am incomprehensible and confusing landscape occurred. These developments contradict the initial need for more clarity and structure, especially as many different aspects are framed under the same terminology.**

We contribute to this challenge by providing a structured overview of the current state of standardization. We create a graphical landscape of Industry 4.0 specifications and standards based on an integrated knowledge graph. Various views provide different illustrations for several information needs. Explicitly stated relations between Industry 4.0 frameworks and technical standards enable the flexible discovery of related information. In addition, we use machine inference techniques to add new links and to further extend the knowledge graph.

***Index Terms*—Industry 4.0, standardization, digital manufacturing, knowledge graphs, visualization**

I. Introduction

The expected disruptive developments arising from Industry 4.0 have drawn a significant amount of attention from many communities. However, due to its vague meaning, the term has become widely used for nearly any technology related to industrial manufacturing, leading to a high demand for defining and standardizing the topic. In the recent years, many initiatives and consortia have been formed, each propagating their own interpretation and guidelines. As a result, important aspects are hidden in the high volume of publications and differing models. Even more, widely accepted conventions are not sufficiently visible, therefore hindering the formation of real interoperable solutions.

We view the Industry 4.0 environment as categorized by several groups of stakeholders. Experts have organized themselves in various consortia and standardization organizations in order to create reference frameworks and technical standards. Experienced developers and system architects are familiar with parts of the related technologies but search for more detailed information for their specific challenges. Newcomers require a structured introduction to the field in order to recognize key players and to effectively gain a first overview.

All involved stakeholders face the challenge of searching the already existing works relevant to their current situation. Traditional mechanisms, for instance based on personal communication, media articles or professional training, cannot face the speed and complexity of the developments. Furthermore, an individual examination is very time consuming and bears the risk of missing important aspects as of unknown terminology or biased search strategies. While specific problems require in-depth knowledge, only a certain degree of familiarization with the Industry 4.0 topics allows the contextualization of information, bridging the gap from knowing facts to being able for reasonable decision-making.

In the following, three use cases outline possible applications of the knowledge graph and views presented in this paper. First, the IT manager Alice is responsible for a project to make her company "Industry 4.0 ready". The challenge is to efficiently and effectively enable Alice to reach a sufficient knowledge on the Industry 4.0 landscape and to put the requirements of her project into context. Second, the system architect Bob wants to implement a future-proven Industry 4.0 architecture and searches for the best-fitting guidelines and technologies for this task. Bob must consider the established technology stack of his company but wants to follow the agreed best practices and guidelines as much as possible. Therefore, he must find the most suited Industry 4.0 reference framework and standards showing him how to continue. Third, Charlie is a well-known IT expert. He contributes to an Industry 4.0 reference framework and wants to publish the outcome in form of an international standard. Even though he his aware of the most relevant activities related to his Industry 4.0 topic, he must not miss any.

Collecting the state of the art of Industry 4.0 reference frameworks is crucial to prevent the further fragmentation of the field. As the value of new applications highly depends on their interoperability with other systems, following best practices and relying on wide-spread patterns is essential. In contrast to that, the wide-spread interest into the topic led to an overwhelming variety of usages, interpreted in different ways and regarded from different perspectives. This heterogeneity needs to be structured in order to first identify challenges, then discover relevant information material and finally best practices and common methods. An approach targeting this challenge needs to consider the variety of interest groups. For instance, decision makers require a detailed knowledge on objectives and risks. System architects need a structured reference point to distill guidelines relevant to their use cases. Developers have to be able to identify suitable software artifacts and their capabilities.

In contrast to the amount of publications reviewing Industry 4.0 as well as other digitization initiatives, significantly less work can be found on approaches that actually introduce the concepts into usable guidelines for the industry. While the existing literature repetitively outlines the key technologies and

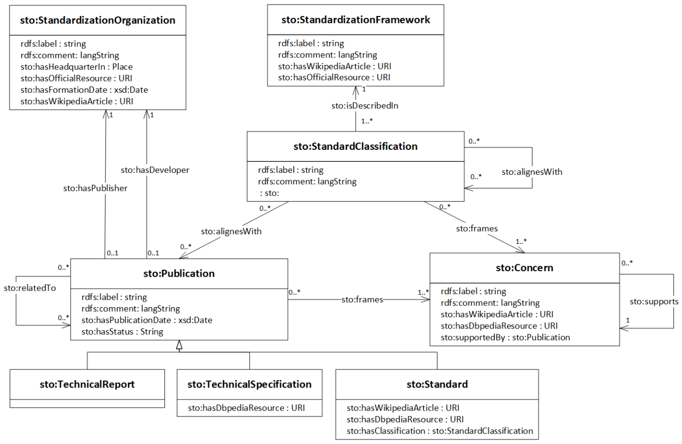

Fig. 1. **Industry 4.0 Reference frameworks are described by publications and concerns.** Reference frameworks describe the Industry 4.0 topics through several classification categories. Technical publications, like standards, explain the implementation details.

abstract processes, the efforts on transforming those ideas to appropriate guidelines and specifications is hardly investigated.

We propose three directions to sort the landscape: First, we structure the landscape by grouping the standards by the Industry 4.0 reference frameworks which promote their usage. Readers are thereby enabled to start with the frameworks they heard about and discover the technical specifications behind them. Another set of views examines dependencies and connects related standards. This approach is inspired by the already informed expert who is aware of a number of relevant specifications. We enable him to broaden his view and to find new supporting documents for his tasks. Finally, we created a list of potential requirements for an Industry 4.0 system. The interested user is directly guided to the relevant sections of the Industry 4.0 reference frameworks but also the respective standards.

We created a structured, extendable knowledge graph with typed links. Based on RDF, we created data points for all relevant standards, standardization organizations, Industry 4.0 reference frameworks and their classifications. Further, we formalized their relations by adding semantic links and attributes among the aforementioned entities. In order to enable meaningful insights, we provide several views and illustrations as dynamically created Web UIs.

The remaining of this paper is structured as follows: Section 2 gives a brief overview on the foundations of our work. Section 3 explains the most important aspects and outlines the created knowledge graph. This is followed by the description of usage scenarios, before the paper is concluded with a discussion of the limitations and an outlook on future work.

II. State of the Art

Representing knowledge in a structured and at the same time extensible manner requires methods to unambiguously model entities, attributes and relations. Ontologies have proven their value for representing formalized knowledge. They allow the formalization of facts and axioms, and their integration into bigger knowledge bases. The logical foundation behind ontologies further enables the automated inferencing of new facts, a process often referred to as automated reasoning.

The Resource Description Framework (RDF) provides the general structure for the modeling of ontologies. The resulting knowledge representation models entities, attributes and relations in the structure of extensible graphs, so-called knowledge graphs. Distributed over the Web and with countless interlinks, openly accessible RDF knowledge graphs form a network of so-called Linked Data [1]. The biggest openly accessible knowledge graph consists of more than one thousand data sets federated over the internet. This Linked Open Data Cloud[1] provides structured and interlinked facts for many domains with DBpedia, a knowledge graph representation of Wikipedia, at its heart.

Still, the volume and variety makes it hardly possible for the non-expert user to efficiently find relevant information. The problem of presenting and interacting with such big structures has drawn a lot of attention, for instance, in the biomedical domain where information about genes, drugs, and drug interactions need to be displayed effectively. As a result, several studies examine best suited templates for the different kinds of information representation.

Classical knowledge engineering is usually not targeted to direct visual presentations. In a typical setting, the ontologies or knowledge graphs are maintained in back-end systems and accessed through tailored applications and clients. Nevertheless, several tools have been created with visualizers and visual editing capabilities. Protégé [2] is likely the most prevalent editor for ontologies, featuring several plugins for ontology visualization and knowledge inferencing, among others. VoCol [3] and WebVOWL [4] are two visual approaches intended to simplify the creation, maintenance and analysis of RDF-encoded ontologies. However, most tools focus on the support of schema-level entities like classes and relations. Proper illustrations and filtering mechanisms for data instances are hardly provided.

A different approach for accessing RDF data is followed by collaborative tools like OntoWiki [5] and Semantic MediaWiki [6]. The graph structure is partly hidden behind forms and templates, allowing also non-experts to work together on the graph models. However, the presentation of the RDF graph is not possible out of the box and requires the application of further tools.

Searching for technical information in the internet is mainly executed through the established search engines. Even though more and more queries are answered by directly returning related information, for instance by displaying Wikipedia abstracts, in general only collections of web sites are provided. The user then has to manually discover the sources. Especially for technical information needs, this approach is highly inefficient as it is very time-consuming and requires considerable prior knowledge. Lafia, Turner and Kuhn [7]

[1]https://lod-cloud.net

show how semantic annotations and mappings on open data improves the discovery process. On the other hand, Xiong, Power and Callan [8] discuss embedding techniques on open knowledge graphs to measure the similarity between entities in a high-dimensional vector space.

Several works have been accomplished to address the challenge of structuring the landscapes of standards focused on the industrial domain. For instance Lu et al. [9] describe a landscape of Smart Manufacturing Systems. Similarly, Andreev et al. [10] provide several visual comparisons of radio connectvity standards and technologies. However, none of these surveys is published in an accessible data set as the contributions and insights are only represented written text.

Grangel et al. [11] proposed an ontology for structuring the necessary information and providing it as open information. We extend their work both on the level of schema extensions but also significantly added content information in terms of more entities but also new data dimensions to create a significantly improved picture of the Industry 4.0 landscape.

III. Knowledge Graph for Industry 4.0

The collected information is modeled according to RDF. Its triple-based syntax natively supports the network structure of a knowledge graph by connecting a subject (source node) and object (target node) through a typed relation. As all three types can be encoded by URIs, the RDF model is highly integratable with other Web resources and websites. The entity of the proposed Industry 4.0 knowledge graph are further grouped into classes and relations as seen in Fig. 1. In the following, the central classes and their most important representations are explained.

A. Industry 4.0 Reference Models

Several consortia have been formed in the context of Industry 4.0. One of the most prominent is the Industrial Internet Consortium (IIC), which developed the so-called Industrial Internet Reference Architecture (IIRA) [12]. Based on the structure of ISO 42010, the IIRA categorizes the outlined content in four viewpoints for business-, usage-, functional-, and implementation-related topics. Additional relevant documents in-depth examine methods of connectivity [13] and security [14]. The main scope of the IIC publications is in providing an overview of reasonable patterns and methods for the Industry 4.0 domain and providing a framework to reach a shared understanding. Therefore, the specifications are less restrictive than other guidelines.

The Reference Architecture Model for Industry 4.0 (RAMI4.0), developed by the Plattform Industrie 4.0, promotes a three-dimensional, layered model with additional dimensions regarding IEC 62890 life cycle phases and asset hierarchies according to IEC 62264. The first-class citizen in terms of RAMI4.0 are asset of any kind, for instance production plants, machines, components, materials, but also software or services. The information carrier is the Asset Administration Shell (AAS) [15], which serves as a digital model of the asset itself. The strong focus on the AAS concept underlines the manufacturing oriented view of the model. Led by the necessity to seamlessly integrate assets, RAMI4.0 specifies Industry 4.0 concepts close to standards and norms to detail technical characteristics.

The International Data Space (IDS) [16] specifies components for a sovereign and privacy-preserving data exchange. Trust between participants is established through technical measures. The IDS does not focus on machine or production-related data but defines general principles to create secure and trustworthy communication from data creation to its processing and usage in distributed settings. The governance and transparent control of data flows and usages shall enable innovative data-driven business cases between different participants while minimizing the risk of data misuse.

The presented list of reference models is only an extract of the available guidelines. The created knowledge graph includes several more specifications, among others are for instance guidelines form FIWARE[2], Edgecross [17], Industrial Value Chain Initiative [18], X-Road[3], and more.

B. Industry 4.0 Classification Categories

Reference models like RAMI4.0 or the IIRA consist of several layers, views, perspectives and other selection categories to better depict the topic of interest. For instance, RAMI4.0 is organized in six layers, seven hierarchy levels and four basic life cycle and value stream phases. The various dimensions are collected as entities of the classification class and interlinked with the entities representing their frameworks but also the standards and publications which they refer to (cf. Fig. 1).

The classifications are also the entities which link the reference frameworks with the concerns and requirements they target. Concerns represent issues or challenges which are relevant for a respective scenario. For instance, the connectivity and interoperability of devices is central to the Industrial Internet Consortium, therefore the IIRA classifications discuss related topics in detail. Data sovereignty and data description are more in the focus of the the IDS, resulting in more linked concerns of these categories. In general, the classifications play a major role in the data model of the knowledge graph and interlink and group the entities of the other classes.

C. Standards and Technical Specifications

Industry 4.0 relies on shared technologies and the seamless exchange of data. Integration of systems and the connectivity of facilities requires clear technical specifications and supporting manuals. Established standardization organizations meet this demand by developing standardization documents and technical specifications. Among the ones with the highest reputation are the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), the American National Institute of Standards and Technology (NIST), and the German Institute for Standardization (DIN).

[2]https://www.fiware.org/

[3]https://www.ria.ee/en/state-information-system/x-tee.html

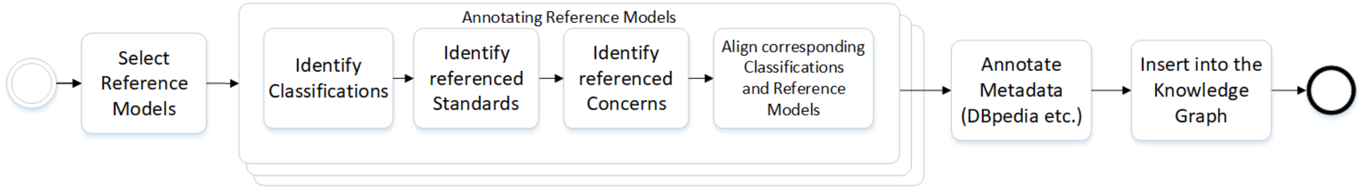

Fig. 2. **Extraction process**

TABLE I
STATISTICS OF THE KNOWLEDGE GRAPH POPULATION

Class	Number of Entities	Entities with applied Reasoning
Reference Frameworks	20	20
Classifications	155	169
Standards and Specifications	302	317
Total numbers of facts (RDF triples)	13 577	25 679

We structure our ontology according to classes of standards, reference frameworks and their promoted classification models. Each standard is annotated with a rich set of attributes, for instance the corresponding creator and publisher, its publishing date and a short description. Overlaps and similar scopes with other standards are explicitly presented through relatedTo predicates. Even further information is accessible by following outgoing links to the original publication but also to respective resources in the Linked Open Data Cloud. Thereby, the interested user can directly access additional information from the whole Web and benefit from the constantly growing volume of available knowledge.

Similar to the modelling of standards, the frameworks and reference models are directly annotated with relevant context information and also link to additional resources in the Web. Furthermore, we divide the reference framework into classifications based on the structure of their reference architecture. The combined and interlinked data is hard to analyze, especially for users who are not familiar with knowledge graphs. We argue that for the outlined use cases, several types of illustrations are necessary to optimally target the respective information needs. Relying on the knowledge graph, several Web-based views have been developed. Each one uses a different visualization pattern in order to present the information in the most intuitive manner.

D. Extraction Process

As mentioned, this work relies on the work published in [11] and therefore follows a similar data extraction and integration process (cf Fig. 2). The manual collection and filtering of relevant reference models is followed by the iteratively identification of referred standards and concerns. Furthermore, similarities and matches in the structure of the identified reference models and standards are encoded through alignment relations between the respective graph nodes (cf. Fig. 4). Additional meta-data like links to external information sources and annotations including title, short descriptions and references to the original documents are applied before the data objects are inserted into the knowledge graph.

E. Logical Reasoning

The formalized structure of the graph and its defined semantics allow a further population by explicitly stating implicitly encoded facts. For instance, the information that the Common Data Dictionary (IEC 61360) is referenced by AutomationML (IEC 62714) and the fact that AutomationML is also related to eCl@ss indicates that also the Common Data Dictionary is related to eCl@ss. A semantic reasoner can automatically discover such connections and add them to the knowledge graph as long as the respective knowledge is supplied in the form of axioms. Axioms are rules which encode the relationships as logical formulas (cf. Tab. II).

Regarding the example of the Common Data Dictionary (IEC 61360), 65 atomic statements are present in the original graph. After the reasoning process, 53 more explicit facts could be added.The reasoning itself was conducted with the Linked Data-Fu streaming engine [19] before the data was loaded into the endpoint. The execution time for the whole process is in all cases lower than tow seconds, which is especially remarkable regarding the high number of inferred facts (cf. Tab. I). A noteworthy fact is the explicit decision to *not* apply the full expressiveness of possible reasoning rules. For instance, the well-known rule sets OWL Full and OWL DL could further increase the resulting dataset. Still, the trade of is a significantly worse computation time but mostly only syntactically and not semantically relevant additional facts.

```
PREFIX sto: <https://w3id.org/i40/sto#>
SELECT ?class ?relatedClass
WHERE{
  # $classType = sto:Standard, sto:Concern
  ?class a $classtype .
  OPTIONAL{
  # $relation = sto:relatedTo, sto:frames
          ?class $relation ?relatedClass .
    }
}
```

Fig. 3. **Configurable SPARQL Query**. Parameters are provided by a set of configurable queries.

TABLE II
LOGICAL AXIOMS AS SWRL RULES.

	Rule	Description
1	*sto:relatedTo(?s1, ?s2) -> sto:relatedTo(?s2, ?s1)*	Symmetry of the sto:relatedTo property
2	*sto:relatedTo(?s1, ?s2) ∧ sto:relatedTo(?s2, ?s3) -> sto:relatedTo(?s1, ?s3)*	Transitivity of the sto:relatedTo property
3	*rdfs:subClassOf(?c1, ?c2) ∧ rdf:type(?x, ?c1) -> rdf:type(?x, ?c2)*	Class inheritence of entities
4	*sto:frames(?class, ?con) ∧ sto:isDescribedin(?class, ?fram) -> sto:hasTargetConcern(?fram, ?con)*	Reference frameworks refer to the concerns of their classifications
5	*sto:supports(?con1, ?con2) ∧ sto:frames(?class, ?con1) -> sto:frames(?class, ?con2)*	Transitive nature of framed concerns

TABLE III
DETAILS OF THE INDUSTRY 4.0 KNOWLEDGE GRAPH. THE TABLE SHOWS A SUMMARY OF THE *Industry 4.0 knowledge graph* IN ASPECTS SUCH AS GENERAL DETAILS, REUSED ONTOLOGIES, DOCUMENTATION, NAMING CONVENTIONS, MULTILINGUALITY, AND AVAILABILITY.

General	**Name**	Industry 4.0 knowledge graph
	Size	62 classes, 33 object properties, 20 data properties, 1075 individuals
	DL Expressivity	SHOIF(D)
Reuse	**Reused Ontologies**	DCTERMS, PROV, DUL, FOAF, RAMI4.0, OM
Documentation	**Every element documented**	By means of `rdfs:label`, `rdfs:comment`, `skos:prefLabel` and `rdfs:isDefinedBy`
Naming Conventions	**Naming conventions for schema and instance**	CamelCase notation for the schema and Ada for instances
Multilinguality	**English labels for all terms**	`rdfs:label` and `rdfs:comment` with the @en notation
Availability	**PersistentURI**	https://w3id.org/i40/sto
	GitHub	https://github.com/i40-Tools/StandardsOntology
	LOV	http://lov.okfn.org/dataset/lov/vocabs/sto
	OntoPortal	http://iofportal.ncor.buffalo.edu/ontologies/STO
	Licence	Creative Commons 3.0
	VoCol Instance	http://vocol.iais.fraunhofer.de/sto/

IV. INTERACTIVE PRESENTATION AND INFORMATION SELECTION

A public SPARQL endpoint[4] provides a Web interface to the Industry 4.0 knowledge graph. In addition to the pre-processed reasoning with the axioms of Tab. II, another reasoning mechanism comes into place through the SPARQL queries. Fig. 3 shows one of the applied query templates. The query here looks for relations between classes. Parameter *$classType* can have values `sto:Standard` or `sto:Concern` while *$relation* can have values `sto:relatedTo` or `sto:frames`. The respective information is not necessarily stated in the knowledge graph and can be discovered during the query execution phase (cf. Fig. 4). As most users are not familiar with this query language, nor with analyzing the raw knowledge graph in plain RDF, a set of web views has been created[5]. Each view generates unique projections of the knowledge graph by converting user inputs to customized SPARQL templates. The respective query results are rendered using the D3 JavaScript library[6].

The hierarchical relations between the Industry 4.0 reference models, their classifications, and the related standards are depicted by zoomable circle diagrams (cf. Fig. 5). Thereby, a fast and easy to grasp discovery of each technical reference is achieved. The zooming intuitively orders the entities for the user without further explanations. Concepts of the same class are positioned on the same level and ordered by their upper level affiliation, for instance the RAMI4.0 layers and dimensions are presented next to each other, containing the respective standards and technical specifications.

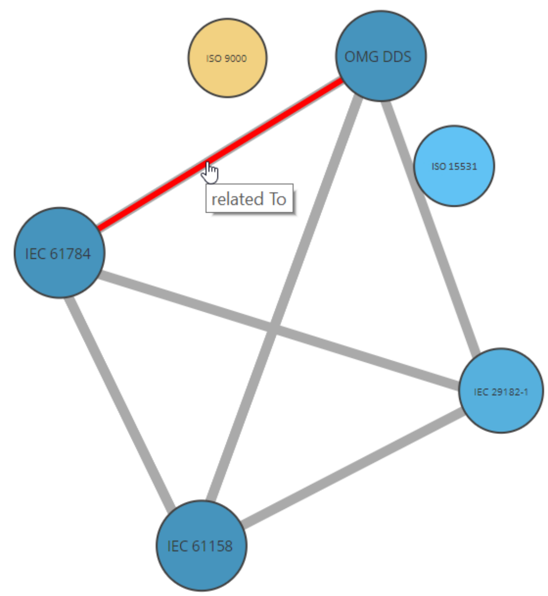

Fig. 4. **Network Visualization**. The SPARQL Query in Figure 3 helps to generate this network diagram depicting the relation `sto:relatedTo` between instances of the class `sto:Standard`.

However, a plain, unfiltered view on the whole knowledge graph has only minor usage possibilities. Still, the traversal of connections between a filtered set of nodes might uncover unknown relations. We experienced that instances of one or at maximum two classes can still be visualized properly even though a rising number of connections impacts the readability.

[4]https://vocol.iais.fraunhofer.de/sto/querying
[5]https://i40-tools.github.io/StandardOntologyVisualization/
[6]https://github.com/d3/d3

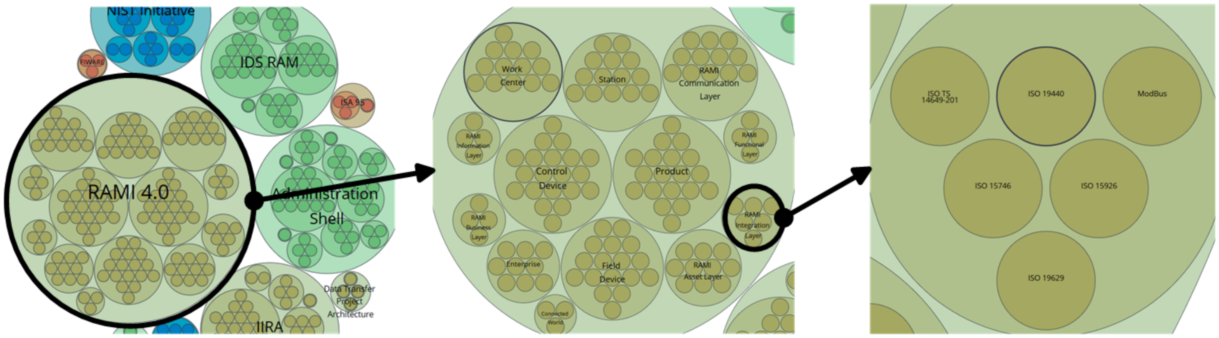

Fig. 5. **Visualizing reference models and their associated standards**. The three zooming stages visualize the Industry 4.0 reference models, their according classification categories and the referred standards.

Especially for classes with a limited number of relations per instance, as e.g. standards and classifications, the plane graph visualization can be still feasible.

Set-related coherences are illustrated in the form of Venn diagrams (cf. Fig. 7). While the hierarchical representation of Fig. 5 can put several levels of relations into context (reference frameworks to classifications to standards), Venn diagrams are limited to two dimensions. However, the representation of overlaps and disjunctions is directly presented be the later. One has to notice that due to the chosen rendering algorithm only up to three circular sets can be drawn without a potential loss of information. A fourth set, having intersections with all previously drawn areas, will result in areas which can not be positioned in the two dimensional view anymore. While this is still theoretically possible, no feasible rendering engine known to the authors solves this issue.

Similar to Venn diagrams, co-occurrence matrices compare the relations between two classes of entities (cf. Fig. 8). Co-occurrence matrices are better suited when high numbers of relations appear the hierarchy of the entities or directions of the relations is less relevant. Therefore, we selected co-occurrence matrices to illustrate the relations of the concerns class with the other classes. Utilizing this table-like structure enables the user to interpret the view in two ways, either comparing the identified concerns with their related reference frameworks or vice versa.

V. Using the Industry 4.0 Landscape

In the following, we present three scenarios to outline potential use cases. Alice, Bob and Charlie represent three typical users, each with a different background and information need in the context of Industry 4.0.

Alice, who is just starting with Industry 4.0 applications, needs to quickly gain an overview on the most influential reference frameworks. She has to communicate with consultants and potential suppliers using the correct terms in order to effectively manage her resources. Alice looks through the hierarchy view (Fig. 5), learning which frameworks contain which categories and standards. Focusing on any of the entities allows her to learn more about it in the sidebar. She makes notes about them, as well as a quick overview of which standards are the most prevalent in almost all the frameworks. Next, she finds the relations between the classification categories and follows the links to relevant standards or other publications but also to other, less well-known reference frameworks. This view gives a general impression on the structure of the reference frameworks. The categories of each framework are interactively displayed, allowing to discover standards at the relevant position.

Bob, a senior system architect, is aware of the concerns and requirements of the system he needs to implement. With the aim to ensure the effectiveness and reliability of his architecture, he searches for best practices for implementing upcoming technologies and to check the suitability of the latest trends (cf. Fig. 6).

The co-occurrence matrix (cf. Fig. 8) depicts which reference frameworks and which respective classifications frame Bob's concerns. He is directed to the most suitable models and can find the necessary guidelines to cope with his concerns. In addition, he is able to analyze whether a framework of his preference misses any important aspects and which alternative models might have the required specifications.

The third stakeholder using the application is Charlie, a collaborator of a standardization framework. He knows his

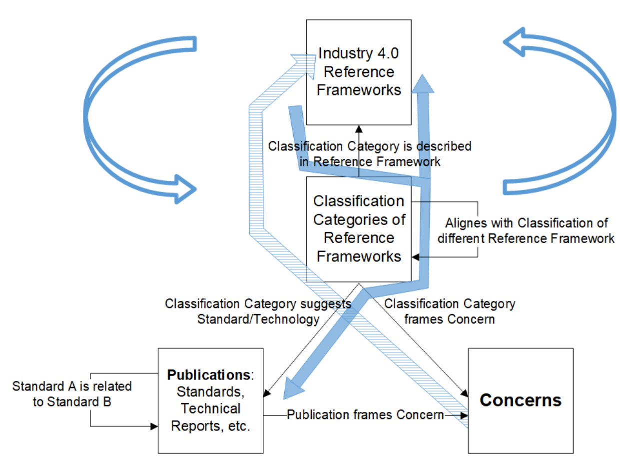

Fig. 6. **Workflows as depicted in the use cases**. Alice (filled), Bob (stripes) and Charlie (not filled) traverse the graph on different paths.

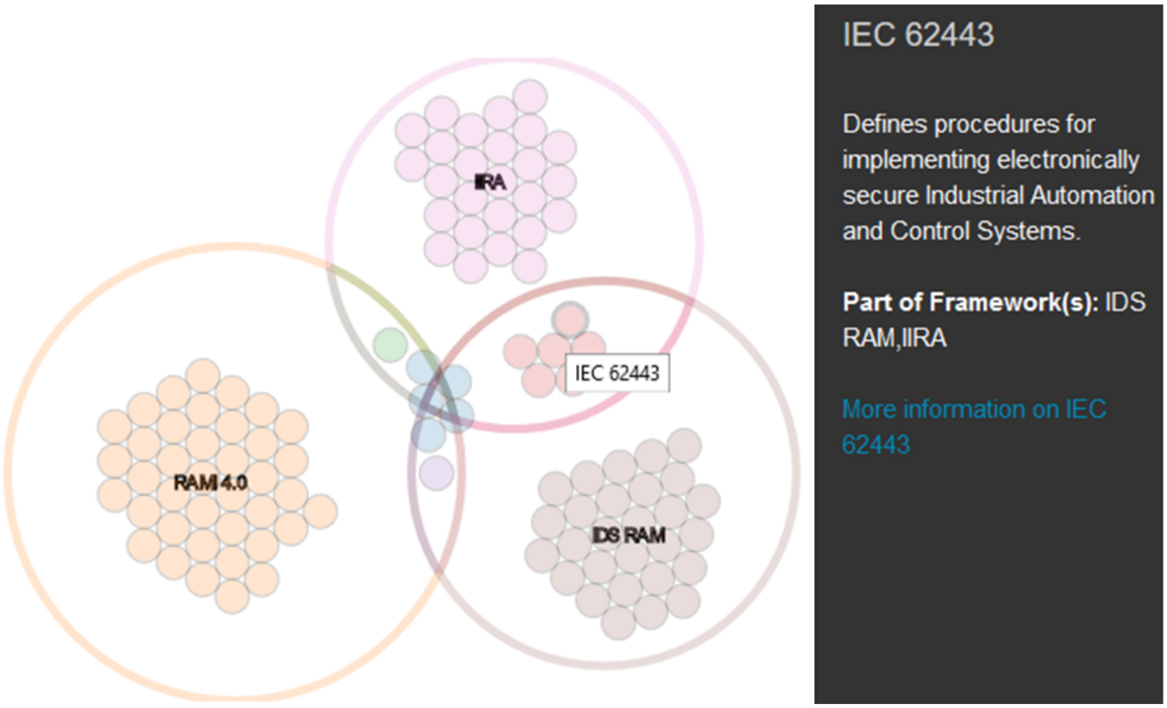

Fig. 7. **Venn diagrams for reference frameworks and standards**. The Venn diagrams localise the standards in regard to the reference frameworks. That way, a user can instantly recognize the overlaps and unique areas.

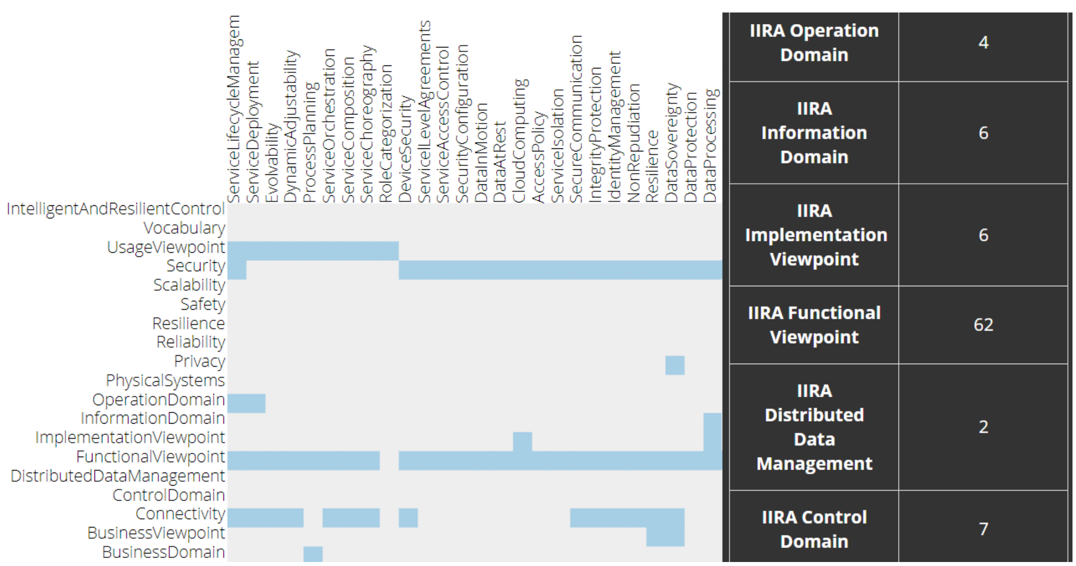

Fig. 8. **Co-occurrence matrix between concerns and classification categories**. The co-occurrence matrix enables insights which concerns are targeted by which classification categories of the presented frameworks.

own reference framework in detail and is informed on the implicit and explicit concerns, which led to proposed solutions of his framework. Now, Charlie wants to know what the other frameworks are proposing and whether there are similar views in order to find existing and/or superior recommendations. Furthermore, Charlie searches for good ideas for his own standardization work.

Charlie takes a look at the framework and standards overlap visualization, notices his framework has many standards in common with another framework (cf. Fig. 8). This leads to an investigation of the other standardization framework and the collaboration possibilities, or coming up with new ideas for his own work.

VI. Conclusion and Outlook

In this paper, we presented several views and applications on top of an integrated knowledge graph about Industry 4.0 reference frameworks, their classifications as well as standards and technical reports. The formalized semantics of the knowledge graph and the extensibility of its structure support the representation of the interlinked information of the domain. The different graphical presentation methods enable intuitive examinations of the encoded facts without insights on the underlying technology stack.

The outline usage scenarios of the developed views explain how we intend to reduce one of the most crucial obstacles hampering a further dissemination of Industry 4.0 concepts: The complicated and cumbersome search for information and establishing of a mental structure of the landscape. We argue that a graphical approach through a web application supports the necessary scalability in order to reach the required target group.

We plan to further extend and update the presented knowledge graph and further connect the contained entities with additional, external knowledge. The Linked Open Data Cloud is an ideal candidate to further annotate the graph. Also, the knowledge graph itself can, by the dynamic nature of the topic, never present a complete picture. Still, crawler in combination with automated text mining agents have the potential to independently extract facts and relations from reports and publications in real time. In addition, further logical reasoning on already existing patterns and other rule-based AI systems may lead to faster results in order to further populate the available encoded information.

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