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STANDARDS TAXONOMY SUPPORTING MANUFACTURING IN INDUSTRY 4.0 TOWARD 5.0

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Abstract: The article presents the approach of a taxonomy development with standards providing support to technologists and designers in manufacturing to better manage production processes. The approach is intended to consider the current manufacturing framework marked by the transition from Industry 4.0 to Industry 5.0; the taxonomy framework design approach consists of eight steps: (1) defining the scope, (2) conducting literature reviews, (3) collecting data, (4) conceptualizing the basic items, (5-8) documenting, classifying, validating, refining and maintaining the created database. Consulting various specialists during the testing and validation phase of the taxonomy highlighted the usefulness of the approach and its result in facilitating the process of navigating the complexity of standard aspects related to smart manufacturing, to boost innovation and compliance.

Keywords: Manufacturing, Standards, Taxonomy, Industry 4.0, Innovation.

1. INTRODUCTION

Production standardization is strongly influenced by the transformations generated by advances in digital technologies and the trend towards smart manufacturing. The transition from Industry 4.0 to 5.0 requires major changes involving the integration of digital and production technologies, the development of new standards and the adaptation of existing ones to meet current manufacturing requirements. Standardization requires a coherent operating framework, centered on processes and procedures that are carried out, implemented in a consistent and reliable manner [1-3].

It is interesting to synthesize the aspects that had the greatest impact and dynamics correlated with the production standardization process.

First, the integration of digital technologies into traditional or modernized manufacturing processes (aspects most often reported in the transition from Industry 4.0 to 5.0), thus generating the need for new standards that address the complexity and interoperability of new systems (e.g., International Standards Organization (ISO), IEEE Computer Society

Smart Manufacturing Standards Committee are particularly active in this field) [1, 2]. Furthermore, it should be emphasized that the shift from data standardization to the description of software capabilities for manufacturing has highlighted their evolution and standardization efforts [3].

Second, the dynamics of adoption, transfer and assimilation of international standards into national systems; different countries have already adopted standardization models related to smart manufacturing, influenced by industrial policies and levels of state involvement (e.g., China, Germany and the USA have developed comprehensive standards, roadmaps to guide the standardization of smart manufacturing) [4, 5]. In this context, ISO and IEC (International Electrotechnical Commission) have an important role in cross-border harmonization, facilitating global trade and cooperation in manufacturing [6].

Third, dynamic and participatory approaches to standardization should be considered. Adopting dynamic, participatory approaches that involve the knowledge and contributions of those who use the standards supports the

adaptability and practicality of standards to the real world of manufacturing [5-7].

The fourth aspect is related to the real concentrated production behavior, which focuses on quality and competitiveness. Thus, standardization is seen as a tool for ensuring product quality, safety and consumer satisfaction, elements that remain essential for Industry 5.0 and contribute to economic growth and global competitiveness [8, 9]. So, the new production standardization framework must help industries (organizations) to adopt new technologies and promote research and development, creating a competitive advantage in the global market [9].

These four challenges and challenges of the dynamics of standardization in the field of manufacturing in Industry 5.0 are driven by an ever-evolving agility of organizations, where technology, human factors and sustainability converge to create a more interconnected, smarter and more sustainable future. It remains only for these challenges to be accepted and for organizations to be able to position themselves for success in the extremely dynamic global market.

The summary analysis of these four challenges should be complemented by the strategic dimension of manufacturing organizations, which must find a balance between the characteristics and evolution of the internal environment vs. market opportunities. It should also be noted that there is a gap between the research and development activities of new, more comprehensive standards for smart manufacturing and the dynamics of the internal environment of manufacturing organizations. Thus, the existence of opportunities for further innovation and collaboration is highlighted [10].

Furthermore, the role of standardization as a policy tool to promote digital technologies in business is gaining recognition, with countries like the case of the “Assembly Lines In CIRCulAtion – smart digital tools for the sustainable, human-centric and resilient use of production resources” ALICIA project community [11] or the developing frameworks to enhance industrial partners digital transformation efforts [6, 7].

In this context, while the shift towards smart manufacturing and digital technologies presents

numerous opportunities for innovation and efficiency, it also poses challenges in terms of standardization. The complexity of integrating new technologies with existing systems requires a collaborative approach involving governments, industry stakeholders, and standardization organizations. As countries and industries continue to navigate these changes, the development of flexible and inclusive standards will be crucial in ensuring that the benefits of smart manufacturing are realized globally.

The aim of the present research is to design taxonomy of existing standards that could provide the framework for better piloting manufacturing processes in their transformation from Industry 4.0 to Industry 5.0. The research motivation lays in the fact that the field of manufacturing standardization is undergoing significant changes, driven by the rapid advancements of Industry 4.0 and the emergence of Industry 5.0. Thus, practitioners, as designers and manufacturers, will have a comprehensive system of standards (as a tool) for easily piloting their processes.

2. METHODOLOGY

As manufacturing evolves from Industry 4.0 to Industry 5.0, a robust and adaptable standards taxonomy becomes crucial. The proposed taxonomy should provide a clear and structured framework for understanding, implementing, and evaluating the diverse technologies and practices involved in this transformation.

The research methodology consists of eight steps as described in the logical schema of Figure 1. The establishment of a standards taxonomy in smart manufacturing is a critical aspect of advancing the field, as it provides a structured framework for integrating various technologies and processes. Several key articles contribute to this taxonomy by addressing different dimensions of smart manufacturing, including standardization efforts, reference models, and the integration of emerging technologies. These articles collectively offer a comprehensive view of the standards landscape, highlighting the importance of a systematic approach to standardization in smart manufacturing [2, 4, 10, 11-15].

Further, the analysis of the literature on the approaches of taxonomy development, some key considerations have been discovered:

- Flexibility and adaptability - The taxonomy should be flexible enough to accommodate future advancements in smart manufacturing;
- User-friendliness - The taxonomy should be easy to understand and use by a diverse range of stakeholders;
- Collaboration - engage relevant stakeholders (e.g., industry associations, research institutions, government agencies) throughout the development process;
- International alignment - consider alignment with international standards and best practices to facilitate global interoperability.

By following the research methodology stages and involving key stakeholders (from different companies in Romania, Germany), the effective standards taxonomy has been developed to support the successful implementation of smart manufacturing initiatives.

In addition, the standards taxonomy includes standards and EN (European Norms) and from the European organizations European Committee for Standardization (CEN), European Committee for Electrotechnical Standardization (CENELEC), from the International Standard Organizations (ISO), International Electrotechnical Commission (IEC), and International Telecommunication Union (ITU). Regarding the national standards, it should be mentioned that mostly they have not been considered because of linguistic obstacles.

The standards study concentrated on German standards within the framework of national standards since Germany is a pioneer in the automobile sector. The following associations were mapped to identify relevant ideas of structuring: Association of the Automotive Industry e.V. (VDA), Association for Electrical, Electronic and Information Technologies (VDE), Association of German Engineers (VDI) and Association of German Mechanical and Plant Engineering (VDMA).

In addition, there have been used the facilities offered by the standards management solution DIN Media that over 600,000 documents from German, European and international collections.

The Nautos which is a software search engine of DIN (the German Institute for Standardization) Media platform has been used for finding, recording, requesting, monitoring and licensing documents in a time-saving manner [16]. Finally, a list of more than 2000 standards were identified and analyzed to be considered for the proposed taxonomy.

The methodology described for designing a taxonomy of standards supporting manufacturing in Industry 4.0 toward 5.0 offers several advantages:

1. Clarity and Structure because it provides a clear and organized framework for understanding the complex landscape of Industry 4.0 and 5.0 standards. It helps stakeholders easily navigate and implement relevant standards;
2. Interoperability because it facilitates the integration of different technologies and systems by establishing common standards and protocols. Also, the methodology ensures seamless communication and collaboration across various platforms and devices;
3. Flexibility and Adaptability because it is designed to be flexible and adaptable to accommodate future advancements in smart manufacturing. In addition, it allows continuous evolution and incorporation of new technologies and practices;
4. Collaboration because the research approach involves relevant stakeholders throughout the development process, including industry associations, research institutions, and government agencies. It promotes collaboration and consensus-building among key players in the industry;
5. International Alignment because it aligns with international standards and best practices to facilitate global interoperability; the research approach supports global collaboration and ensures compliance with international norms;
6. The proposed methodology encourages the development and adoption of new technologies and practices that align with the best practices with industry. It fosters innovation and continuous improvement in manufacturing processes.

7. It considered risk mitigation because it helps organizations identify and address potential risks associated with the implementation of new technologies; reduces the likelihood of disruptions and enhances overall operational stability;
8. The methodology provides a framework for ongoing evaluation and improvement of manufacturing processes and systems. This ensures that manufacturing practices remain up-to-date and effective.

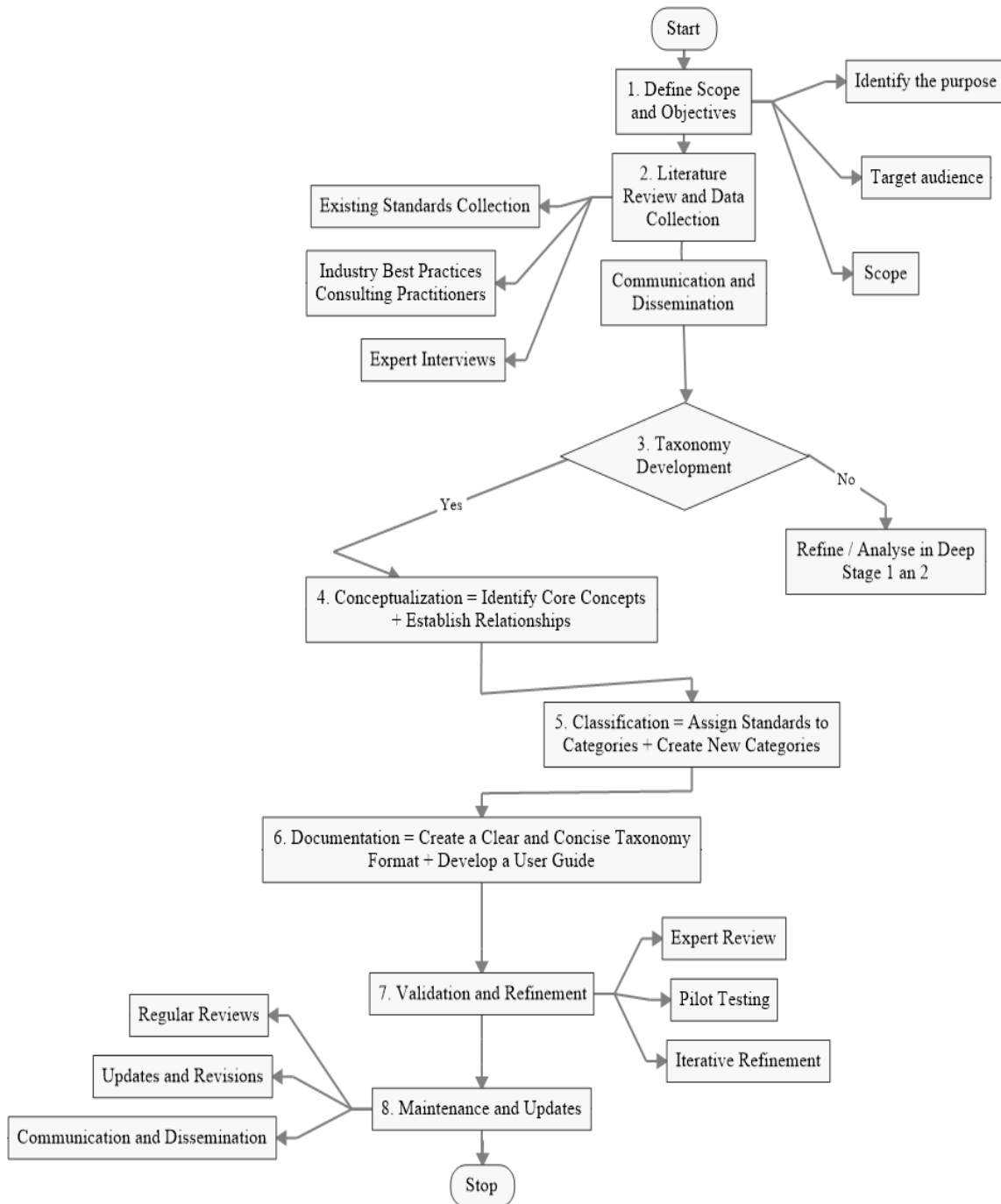


Fig. 1. The research methodology (logic schema).

Table 1

Details on the design methodology.	
Methodological step	Technical details
1. Define Scope and Objectives	- Identify the purpose by clearly articulating the goals of taxonomy. Is it for internal use, external collaboration, or a combination? - Target Audience - Determine who will primarily use the taxonomy (e.g., engineers, managers, researchers). - Scope - Define the specific area of smart manufacturing to be covered (e.g., all aspects, specific technologies like robotics or AI, or a particular industry sector).
2. Literature Review and Data Collection	- Existing Standards: Gather relevant international and national standards (e.g., ISO, IEC, ANSI, NIST). - Industry Best Practices: Analyze existing industry frameworks, guidelines, and roadmaps. - Expert Interviews: Conduct interviews with industry experts, academics, and standards organizations. - Technology Surveys: Analyze current and emerging technologies relevant to smart manufacturing.
4. Conceptualization:	- Identify Core Concepts: Determine the fundamental concepts and categories that underpin smart manufacturing (e.g., connectivity, automation, data analytics, human-centricity, sustainability). - Establish Relationships: Define hierarchical relationships between concepts (e.g., parent-child, sibling).
5. Classification	- Assign Standards to Categories: Categorize existing standards and technologies within the developed framework. - Create New Categories: Develop new categories as needed to accommodate emerging technologies and concepts.
6. Documentation	- Create a Clear and Concise Taxonomy: Document the taxonomy in a user-friendly format (e.g., diagrams, tables, online database). - Develop a User Guide: Provide clear instructions on how to use and interpret the taxonomy.
7. Validation and Refinement	- Expert Review: Seek feedback from a panel of experts to validate the taxonomy's accuracy, completeness, and usability. - Pilot Testing: Conduct a pilot test with a small group of users to identify any issues or areas for improvement. - Iterative Refinement: Continuously refine the taxonomy based on feedback and new developments in smart manufacturing.
8. Maintenance and Updates	- Regular Reviews: Conduct periodic reviews to ensure the taxonomy remains current and relevant. - Updates and Revisions: Incorporate new standards, technologies, and industry best practices as they emerge. - Communication and Dissemination: Promote the use of taxonomy within the relevant communities.

3. RESEARCH RESULTS

3.1. General overview of the standards taxonomy

In general, the proposed taxonomy structure consists of three main branches as described in the following, together with a few examples of representative standards in the second level branches topics (general result of the applied

approach with first and second level of the taxonomy):

1. Technological Foundations:

- Connectivity:** Standards related to data exchange, communication protocols, and network security (e.g., OPC UA, MQTT, 5G);
- Automation:** Standards for robotics, automation systems, and control (e.g., ISO 10218, IEC 61131);

- **Data Analytics:** Standards for data collection, storage, analysis, and visualization (e.g., ISO/IEC 27001, ISO/IEC 25010);
- **Artificial Intelligence (AI):** Standards for AI algorithms, machine learning, and deep learning (e.g., ISO/IEC 2382-15, IEEE Std 7001-2021);
- **Additive Manufacturing:** Standards for 3D printing technologies and materials (e.g., ISO/ASTM 52900);

2. Human-Centric Principles:

- **Ergonomics:** Standards for workplace design, human-machine interaction, and worker safety (e.g., ISO 6385);
- **Skills Development:** Standards for workforce training, education, and upskilling (e.g., ISO 9001:2015, Annex SL);
- **Sustainability:** Standards for environmental impact assessment, resource efficiency, and circular economy practices (e.g., ISO 14001);
- **Ethical Considerations:** Standards for data privacy, cybersecurity, and responsible AI development (e.g., ISO/IEC 27001, ISO/IEC 2382-15);

3. Business and Organizational Aspects:

- **Interoperability:** Standards for seamless integration of systems and technologies across the value chain;
- **Digital Twin:** Standards for modeling, simulation, and virtual representation of physical assets;
- **Supply Chain Management:** Standards for resilient and sustainable supply chains (e.g., ISO 28000);
- **Innovation Management:** Standards for fostering innovation, experimentation, and continuous improvement.

3.2. Particularities of the manufacturing area standards considered in the taxonomy

The establishment of the general structure of the taxonomy was achieved based on the presented methodology and by involving a considerable number of stakeholders, but the research interest was not satisfied. Therefore, the research focused on identifying the most relevant standards to be considered for the field of manufacturing in Industry 4.0 towards 5.0. As a result, research focused on identifying areas of

interest and key terms to collect current standards and organizing them into categories.

An overview of the various domains may be provided using the International Classification for Standards (ICS) fields (Figure 2); the list consists of those ICS fields that are allocated to at least 50 standards for the purposes of this design approach.

The standards are included in 19 distinct ICS fields, the most prevalent of which are ICS fields 25, 35, and 13. It is crucial to remember that a single standard may be used in many ICS domains. ICS field 25, Manufacturing Engineering, is where 53% of the standards contained in the taxonomy design method are categorized.

Information technology, or ICS field 35, contains about the same number of standards (47%) as this one. ICS field 13: Environment, Health Protection & Safety has the third-highest number of standards (26%).

Furthermore, standards have been considered at the international level. In Industry 4.0 and Industry 5.0, the primary technical committees (TC) in charge of manufacturing standards are mentioned in Figure 3 (with additional details in Figure 4) and are explained below. Only TCs that published more than five of the standards that were part of the taxonomy's formulation. Finally, in Figure 5 the considerations are presented for the actual research.

4. CONCLUSIONS

The taxonomy design approach presents a comprehensive overview of the standardization landscape in the field of “manufacturing in Industry 4.0 towards 5.0”. It has been summarized the results of a preliminary study regarding the definition and description of the standardization framework inventory. Knowing the existing standards is important for designers and technologists (be they students, beginners or long-time practitioners), because it allows developing solutions that comply with the latest standards and lead the way for bond compliance activities.

For this, a database of standards a series of conceptual maps was also created, which includes over 300 standards that could be relevant for given theme. This dashboard

provides the ability to search for and identify specific standardization gaps.

A well-defined standards taxonomy is essential for the successful transition to Industry 5.0. By providing a clear and structured framework, this taxonomy can help organizations navigate the complexities of this evolving landscape, embrace innovation, and achieve sustainable and human-centric manufacturing practices. In the research period and during its testing in different contexts (industrial, research and educational) the following benefits of this standards taxonomy have been identified:

- **Clarity and Structure** - Provides a clear and organized framework for understanding the complex landscape of Industry 4.0 and 5.0 standards;
- **Interoperability** - Facilitates the integration of different technologies and systems by

establishing common standards and protocols;

- **Innovation** - Encourages the development and adoption of new technologies and practices that align with industry best practices;
- **Risk Mitigation** - Helps organizations identify and address potential risks associated with the implementation of new technologies;
- **Continuous Improvement** - Provides a framework for ongoing evaluation and improvement of manufacturing processes and systems.

Future research will be conducted to fully define semantic maps with standards (including their description and presentation of links to the standards library or other databases that can facilitate user accessibility).

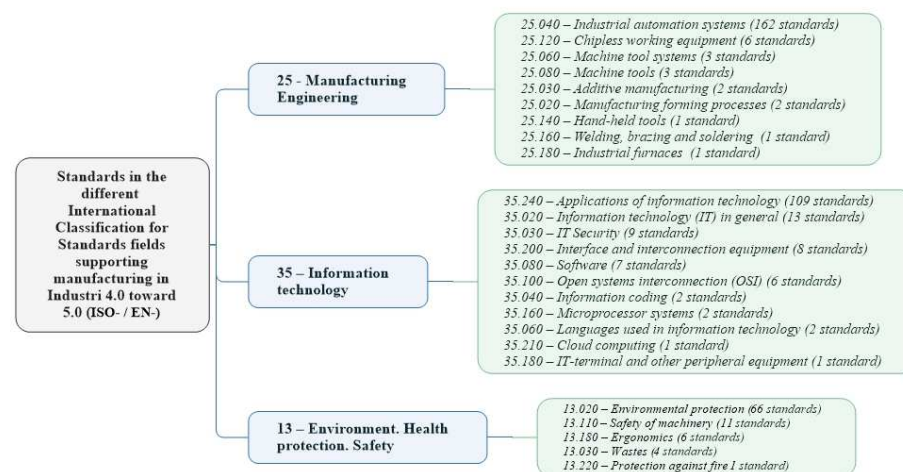


Fig. 2. Overview of the standards in the different ICS fields.

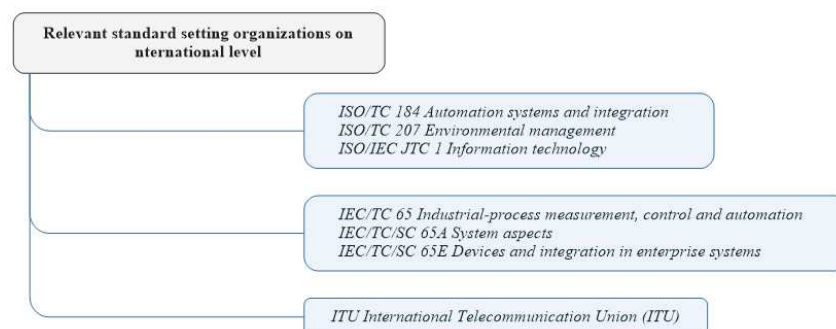


Fig. 3. Relevant standard setting organizations on an international level.

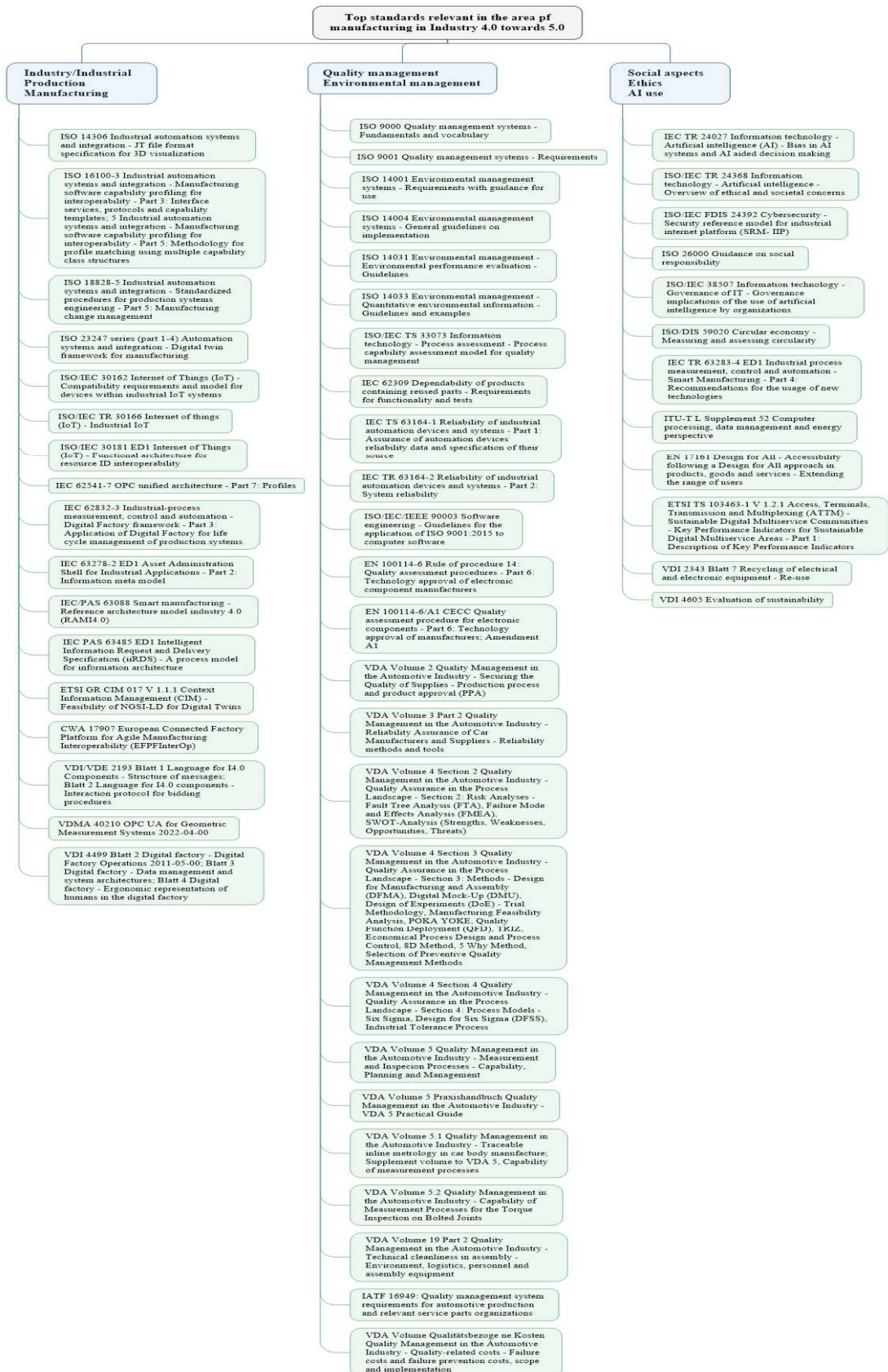


Fig. 4. List of top standards relevant in the area of manufacturing in Industry 4.0 towards 5.0.

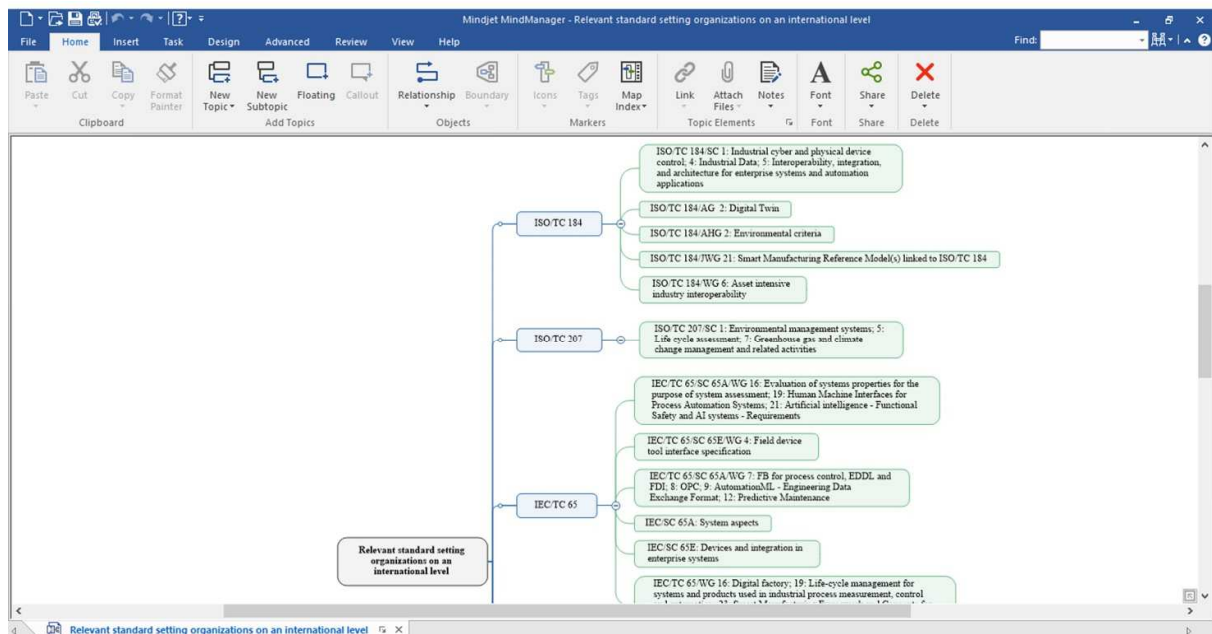


Fig. 5. Details and description of the relevant standard setting organizations on an international level (capture from the created taxonomy using MindManager software tool).

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O taxonomie de standarde ce sprijină tranziția producției din Industria 4.0 către 5.0

Articolul prezintă abordarea unei dezvoltări de taxonomie cu standarde care oferă suport tehnologiilor și designerilor în producție pentru a gestiona mai bine procesele de producție. Abordarea este menită să ia în considerare cadrul actual de producție marcat de tranziția de la Industria 4.0 la Industria 5.0; abordarea de proiectare a cadrului de taxonomie constă în opt pași: (1) definirea domeniului de aplicare, (2) efectuarea de revizuirii a literaturii, (3) colectarea datelor, (4) conceptualizarea elementelor de bază, (5-8) documentarea, clasificarea, validarea, rafinarea și menținerea bazei de date create. Consultarea diverșilor specialiști în faza de testare și validare a taxonomiei a evidențiat utilitatea abordării și rezultatul acesteia în facilitarea procesului de navigare în complexitatea aspectelor standard legate de fabricația inteligentă, pentru a stimula inovația și conformitatea.

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