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Review

Narrative review on key technologies of digitalization of standards transformation

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Abstract: As the technical support for economic activities and social development, standards play a great role in modern society. However, with the increasing digitization of various industries, the traditional form of standards can no longer meet the needs of the new era, and there is an urgent need to digitally transform standards using advanced technologies. The digital transformation of standards involves the standard itself and all stages of its life cycle, is a very complex systematic project, in the transformation process, technology plays a key role. Therefore, this paper summarizes the key technologies involved in the process of digital transformation of standards, sorted out and evaluated them according to different purposes for which they were used, while giving the digitalization of standards transformation technology development trends and planning as well as typical cases, hoping to provide a comprehensive and clear perspective for those engaged in the related work, as well as reference for the subsequent research and application of digital transformation of standards.

Keywords: standard digital transformation; key technologies; trends and planning; typical cases; digital

1. Introduction

With the wave of digital transformation sweeping the world, the degree of digitization in various industrial fields is deepening, new technologies, new products, and new business forms are becoming the new global economic growth point. At the same time, the standard is an important type of documents related to the national economy and people's livelihood (SAC, 2014), and it is also facing new requirements of digital transformation, because the traditional paper text standards can no longer meet the needs of various industries in today's era. Through the digital transformation of standards, the standard itself, as well as the whole process of its life cycle can be empowered, so that the rules and characteristics it carries can be read, transmitted and used through digital devices (Liu et al., 2021), so as to get rid of the limitations of paper standards, realizing the flexibility, efficiency and interactivity of the standards development process, creating a new model of machine-readable standards for the structure and content of the standard, and expanding the scope of use of the standard digital intelligent services (Tao, 2022). Technology plays an important role, and the study of key technologies for digital transformation of standards is the foundation and prerequisite for follow up work. Therefore, this study introduces the key technologies in the process of digital transformation of standards, with a view to providing a comprehensive and clear perspective for those engaged in the related work, so that they can better understand

the knowledge related to the key technologies of standard digital transformation, and thus be more informed in choosing the technologies, and also provide reference for the subsequent research application and innovation of digital transformation of standards, and proposing new technologies and new methods for digital transformation of standards.

2. Key technologies of digitalization of standards transformation

The digitalization of standards transformation technology system aims to improve the efficiency and quality of different industries, with the integration of emerging digital technologies with the original technology system of each industry as the main means to promote the digital change and upgrading in different industries. Key technologies of digitalization of standards transformation are those that play a central and essential role in the entire transformation process. According to the different purposes of using technology, this study divides the standard digital transformation technology system into three categories: namely, the key technology for standard development, the key technology for standard management, and the key technology for standard application. It should be noted that the boundaries of the key technologies included in the three are not very clear in some cases, which means that the same key technology may appear in different categories of key technology systems.

2.1. Key technologies of standard development layer

Key technologies at standard development layer mainly refer to technologies applied in the whole standard development process, which are crucial to the standard-developing process.

2.1.1. Natural language processing technology

Natural Language Processing (NLP) is a science that integrates linguistics, computer science, mathematics and other disciplines, and its research content is to realize the various theories and methods of effective communication between human beings and computers using natural language, with the aim of allowing computers to understand the natural language used by human beings, so as to achieve human-computer interaction and improve the efficiency of users. NLP can be divided into two parts: natural language understanding and natural language generation, which correspond to the tasks of understanding text and generating text, respectively (Ding et al., 2022; Li, 2013; Sarzaeim et al., 2023; Zhao et al., 2024). Standard documents often contain a large number of terminology, in the process of digital transformation of standards, standard documents can be decomposed into standard information units, based on which the use of natural language processing technology, on the basis of effective parsing and understanding of human language, through training, can help computers to understand and analyze the content of these texts, thus helping the standard-developers to efficiently extract key information from a large amounts of textual data, identifying and analyzing the potential problems and needs, and providing data support for standard-developing(Wang, 2020).

2.1.2. Ontology modeling technology

Ontology is an abstract and normalized description of domain knowledge, which can combine abstract conceptual description with concrete instance analysis, ontology modelling standardizes domain knowledge (Zhang et al., 2024); ontology models have good performance in semantics, information retrieval and so on. The reusability and extensibility of the model structure can be improved through ontology modeling (Sabrina et al., 2023; Sun, 2019; Wang and Zhang, 2009). Ontology modeling techniques enable the provision of a clear, consistent and reusable conceptual framework for standards development by providing a formal description of the concepts, relationships and rules involved in the standards.

2.1.3. Optical character recognition technology

Optical Character Recognition (OCR) technology refers to the mechanical or electronic means of analyzing and recognizing the image files of textual information for processing, and then converting them into machine-encoded text. Using OCR technology, standards of electronic text can be converted into editable digital text, which is one of the key technologies used for digital standards development in the process of digital transformation of standards (Cao, 2016; Su et al., 2024; Shi and Cui, 2019). Using OCR recognition technology to convert scanned documents or images into editable and searchable text format can improve the efficiency and accuracy of information acquisition and provide a convenient way of data input and processing for standards development.

2.2. Key technologies of standard management layer

Key technologies of standard management layer mainly refer to the technologies involved in the management of standards at different stages and in different forms throughout their life cycle. The use of these technologies can improve management efficiency.

2.2.1. Big data technology

Big data is a product of informationization in the high-tech era, and big data technology is a general term for the technologies of in-depth development of the massive amount of data that is increasing dramatically in the society (Han, 2020). Through the use of it, it is more convenient to obtain various types of massive data, and to process, store and manage them, on the basis of which further analysis and mining can be carried out, and finally the results can be presented by means of visualization. The application of big data technology will release the vitality and potential value of standard data to a greater extent (Meng et al., 2022; Wu, 2022), through the collection, storage, processing and analysis of massive standard data, mining the value information therein, providing scientific basis for standard development, implementation, supervision and evaluation, providing data basis and decision support for standard revision, update and promotion, and improving the scientificity and effectiveness of standard management.

2.2.2. Life cycle management technology

Life cycle management refers to the management of information and processes throughout the life cycle of a product, from demand to recycling and disposal.

Through life cycle management techniques, the processes of standard development, issuance, implementation, revision and abolition can be systematized, standardized and automated to ensure that standards are properly managed and controlled at all stages of their life cycle (Shen, 2003).

2.3. Key technologies of standard application layer

Key technologies of standard application layer mainly refer to the technologies that need to be used in the process of using the standard in order to achieve the purpose of better application of the standard.

2.3.1. Artificial intelligence and big model technology

Artificial intelligence (AI) technology refers to the science and technology that allow machines to simulate human perception, cognition, reasoning and decision-making processes by human means, so that they can achieve the purpose of autonomous learning, autonomous adaptation and autonomous innovation (González-Rodríguez et al., 2024; Tao, 2023). Artificial intelligence methods in the standard application process can improve the production efficiency of digitalization of standards, reduce the digital operating costs of standards, improve the customer experience of digitalization of standards, and promote the innovation of technologies on the digitalization of standards (Li et al., 2020). The use of big model technology can improve the intelligence of the computer, so that the computer is oriented to the problem can make decisions similar to human beings. With the gradual increase of standard data, there are higher requirements for the efficiency of standard data processing and analysis, and the efficiency of solving the standard management process can be improved by choosing appropriate technical methods (Barbierato and Gatti, 2024; Xu et al., 2020; Zhang and Wang, 2016). Artificial intelligence and big model technology realizes automated analysis, reasoning, interpretation and execution of standards by simulating human intelligence to realize automated application, intelligent interpretation and execution of standards.

2.3.2. Knowledge graph technology

Knowledge graph is essentially a structured knowledge database, a knowledge network that associates and organizes entities and attributes through relationships, with good knowledge expression and reasoning capabilities. With rich background knowledge, domain knowledge graph can be constructed to realize rapid response and reasoning by effectively processing intricate document data and transforming them into simple and clear ternary groups, and finally aggregating a large amount of knowledge (He et al., 2023; Zhang et al., 2023; Zou, 2017). The use of knowledge graph techniques enables standards users to manage and retrieve standards documents more efficiently, understand and interpret standards content more accurately, and analyze and mine the relevance and complexity of standards more deeply.

2.3.3. Cloud computing technology

Cloud computing technology is a new type of Internet-based data processing system that is widely used in various fields based on key technologies such as network storage, distributed computing and network computing. Using cloud

computing technology, standard stakeholders can obtain the required resources from the cloud at any time according to their needs, which can save a lot of data space and reduce resource consumption for them (Feng, 2016). At the same time, according to the actual demand, cloud computing technology can be used together with other technologies to further improve efficiency. For example, standard-related data and systems can be deployed in the cloud, and through the comprehensive use of cloud computing technology and big data technology, different types of standards can be analyzed, and on this basis, multi-business, multi-dimensional evaluation of standardization work and standardization effectiveness can be carried out, which can provide support for standardization management decision-making and higher-level management decision-making (Lv et al., 2023). The use of cloud computing technology enables faster and more cost-effective storage, processing and sharing of large quantities of standards documents and related data, while at the same time supporting cross-regional and cross-platform standards collaboration and management, and enhancing the accessibility and interoperability of standards.

2.3.4. Visualization analysis technology

Visual analytics refers to the methods and techniques used to represent data and information graphically and analyze them using computer technology. Using visualization technology can help people understand the law and meaning of data more deeply, so as to realize more scientific, accurate and effective decision-making. Using visualization analysis technology can display the results of data analysis intuitively, which helps managers to make top-level design and strategic decisions (Ma and Song, 2023; Yang, 2023). The use of visualization analysis technologies can transform complex standards information and data into intuitive, easy-to-understand graphics or images, helping users to understand and interpret standards content more quickly and accurately.

2.3.5. Knowledge reasoning technology

Knowledge reasoning is a mechanism that simulates the human thought process to control and execute the solution of a problem, identifying, selecting, and matching rules in a knowledge base based on current knowledge to get the result of the problem. Knowledge reasoning techniques rely on a good representation of knowledge (Zhang et al., 2013). By using knowledge reasoning technology, it is possible to fuse multi-paradigm information of standards, study machine language expression methods for standards and natural-machine language conversion rules, design standard machine language representation models based on multimodal knowledge expression, semantic mapping and other techniques, define a neutral format for the exchange of machine-readable standard information, and propose multi-algorithm fusion intelligence that takes into account qualitative and quantitative reasoning, so as to make the standard more understandable and easy to use. Knowledge reasoning technology simulates the human reasoning process to automatically analyze, interpret, and enforce the rules, constraints, and relationships in the standard, which helps to improve the accuracy, efficiency, and intelligence of the standard application.

3. Development trends and planning of digitalization of standards transformation technologies

3.1. Development trends of digital of standards transformation technologies

In the long run, digitalization of standards is an inevitable trend for standardization work to adapt to the global digital development. At present, the standardization community worldwide is actively laying out the strategy of standard digitization, exploring and researching the concepts, principles and methods, technologies and management modes related to standard digitization (Zhao, 2022).

3.1.1. International level

Standardization organizations at the international level are those non-governmental bodies responsible for the development, publication and promotion of standards at the global level. At the international level, ISO/IEC has respectively written the digitalization of standards into their development strategies and a new standards concept called SMART (standards machine applicable, readable and transferable) standards was proposed officially in 2019. According to the degree of digitalization, structuring and intelligence, ISO/IEC divides SMART standards into 0-4 levels, with five different stages, namely, standards available in paper, standards for open digital format, standards for machine readable document, standards for machine readable content and standards for machine interpretable content, with each stage progressively deeper in the use of digital technology. Around the concept, ISO/IEC has conducted research from the dimensions of use case collection, business model analysis, and technical solutions (Liu et al., 2021; Zhao, 2022).

3.1.2. Regional level

Standardization organizations at the regional level are standardization bodies within a given geographical area, established with the participation of several countries, regions or economies, which are responsible for developing, coordinating and promoting standardization policies and practices applicable to the region. At the regional level, CEN and CENELEC launched a number of standards digitization pilot projects in 2018 to conduct specific research and practice, focusing on the "online collaborative writing" platform of standards, the new "future standards", and the "open source innovation" in standards. In addition. At the same time, in-depth legal analysis of intellectual property protection of digital standard content has been carried out to promote the construction of relevant laws and regulations (Ma, 2023; Wang et al., 2021).

3.1.3. Level of developed countries

At the level of developed countries, Germany binds the development of standard digitization with the process of industrial digitization (Industry 4.0), takes the lead in promoting standard digitization from the decision-making mechanism, realization mode, and industrial application synchronously, and achieves considerable results, and puts forward the concept of asset management shells similar to digitalization of standards in 2016. The ANSI started to implement the ISO SMART standard with industry partners in 2019. The BSI formally proposed the BSI

Flex standard in 2020, which includes a new standard form that supports online editing and modification, as well as a set of agile rule-based online standard development processes. The standard and methodology are now being applied in practice and a range of standards have been developed, such as BSI Flex 5555 v2.0 Community face coverings—Specification v.2 (BSI, 2024a; BSI, 2024b; Liu et al., 2021; Ma, 2023).

3.2. Development stages and characteristics of standard digitalization

Generally, it is believed that the digitalization of standards can be divided into five stages from 0 to 4. Level 0 is traditional text format, the most typical is the paper version of the standard; level 1 refers to the open digitization format, such as PDF, which the standard content can be displayed and retrieved; level 2 for the machine-readable documents, such as XML format standard, contains the structured content of the standard text, which can be used by the relevant software to identify the structure of text and perform basic actions (Cai, 2022; Wang et al., 2021). Level 1 and level 2 can be considered as the primary digitalization of standards, this stage solves the "machine readability" of standards. Starting from level 3, it can be regarded as the realization of intelligent standards on the basis of standard digitalization, in which level 3 means that the machine can understand and execute the standard, and can selectively access the semantic standard content according to the application scenarios, and perform complex operations in combination with the standard content; for level 4, it will realize the complete machine parsable content, and the standard contains the model of the interrelationships between the standard content units, and even has the functions of self-learning, self-verification, etc., which can actively and predictively provide the required standard content. It should be noted that "machine" in machine-readable is a generalized concept, which can be understood as a collection of hardware devices, software systems and auxiliary tools. Different levels of SMART standards are shown in **Figure 1** (ISO, 2024b; Liu et al., 2021; Wang et al., 2021; Zhao, 2022).

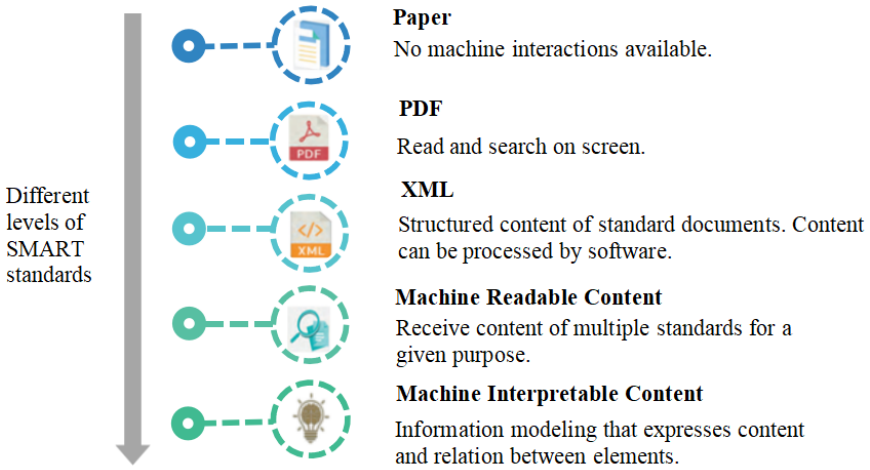

Figure 1. Different levels of SMART standards.

3.3. Planning of digitalization of standards transformation technologies

3.3.1. International level

Since 2017, ISO and IEC have been making forward-looking plans for the digital transformation of standards.

With ISO Deputy Secretary General stating in his "Standards and digitalization: Embracing change" that the future of standardization under the influence of digitization includes "Structured content to create added value products" and "Create machine-readable standards (Chen et al., 2023; Ma, 2023). The ISO Strategy 2030 identifies digital transformation including exploring new models of relevant work and providing innovative solutions, as an important thread running through the new version of the ISO Strategy. The main work carried out includes: The inclusion of "digital technologies" as a key element in the ISO Strategy 2030. The development of the ISO STS for defining and standardizing the markup and rules for standards structures, text, tables, formulas, graphics, images, terminology, reference citations, etc., and the improvement of the ISO standards publishing system. In 2018, in accordance with TMB Resolution 94/2018, the ISO Strategic Advisory Group on Machine Readable Standards (SAG-MRS) was formed, identifying six priority pilot projects for SMART standards. ISO launched the ISO SMART project in May 2021, which is divided into three sub-projects, i.e., use cases, business models, and technical solutions (Wang et al., 2021; ISO, 2024j).

The IEC attaches great importance to digital transformation, and its assembly board has included "machine-readable standards" in the objectives of the IEC's plan implementation program. The Market Strategy Board (MSB) has published a white paper entitled "Semantic interoperability: Challenges in the digital transformation age", which analyzes the importance of semantic information modeling for digital transformation (IEC, 2022). The Standardization Management Board (SMB) has relaunched SG12, with a scope of work that includes defining aspects of digital transformation relevant to the IEC and its standardization activities, and researching digital transformation methods for international standardization work (Wang et al., 2021). In the master plan released by the IEC in June 2018, which states in Agile Operations: to adopt new ways of working, suggesting that given the rapidly changing dynamics of today's world and the digital transformation of the industry, the IEC needs to be open to new ideas, technologies and working practices, including innovative ways of developing, disseminating and selling standards. The IEC will continue to be prepared for fundamental changes affecting its core businesses, such as open source and open data trends, and new forms of digital standards used directly through machines (Zhang, 2021). For state-of-the-art IT tools, IEC will have IT tools that improve the quality and speed of its work, help to reduce the cost of engagement, easy to use and support the development of new products and services, and will use digitalization opportunities as a mechanism for making IEC a global leader in the future of ways of working, the IEC should consider on a case-by-case basis opportunities to collaborate with other organizations to develop new IT tools to optimize resources.

3.3.2. Regional level

At the regional level, CEN and CENELEC's research on the digitalization of standards predates that of ISO, with three projects launched in 2018, namely "Online standardization", "Future Standards" and "Open Source Innovation", all of which are

directly related to the digitalization of standards. Differences among different projects are shown in **Table 1**. In 2019, CEN and CENELEC conducted a legal analysis of intellectual property rights (IPR) protection for digital standards content, aiming to address the legal issues arising from the transformation of standard texts into machine-readable/translatable content, and the IPR issues related to open source and online standards platforms. Moreover, the digitalization of standards has been addressed at the level of strategic planning. With the CEN and CENELEC Strategy 2030, published in 2020, aiming to provide digital solutions for customers, which require adjustments to evolving customer needs and expectations, and which result in the timely provision of digital standards that are relevant to the market (Liu et al., 2021; CEN-CENELEC, 2024). CEN and CENELEC have published a CEN-CENELEC Digital Transformation Strategic Plan, working closely with ISO and IEC on three Digital Transformation projects, namely the Online Standardization Project, the Collaboration Tools Project, and the Future Standards Project, in accordance with their CEN-CENELEC Digital Transformation Strategic Plan (CEN-CENELEC, 2017; Wang et al., 2021). In February 2021, CEN and CENELEC published the Strategy 2030, which is a joint strategy of CEN and CENELEC for the next ten years, centered on two core policies: Green Transformation and Digital Transformation (Zhu and Xu, 2021).

Table 1. Differences among the projects.

No.	Projects	Purposes
1	Online standardization	Supporting the modernization and digital transformation of CEN and CENELEC standard development, the main work is centered on the "Online Collaborative Writing" platform, which aims to provide high-end customized writing environment for CEN and CENELEC technical institutions in conjunction with ISO/IEC; completing the technical assessment and pilot preparation in 2019; and launching the formal implementation in 2020. The technical evaluation and pilot preparation were completed in 2019, and the implementation will be officially launched in 2020.
2	Future standards	Supporting CEN and CENELEC in reconstructing the content of the standard using XML to make it machine-readable and translatable, and initiated pilot work on the application of the standard in the construction and petroleum sectors.
3	Open source innovation	Fully exploiting the application potential of open source technologies in the field of standardization and providing potential innovative technical support for the digitization of standards.

3.3.3. Level of developed countries

The British Standards Institution (BSI) has initiated an agile process for collaborative standards development in the digital environment, which can result in deliverables in a matter of weeks, significantly reducing the standards development cycle (Lu et al., 2022). Based on the above research, BSI formally proposed the BSI Flex standard in 2020 as a complement to the BS and PAS standards to respond to rapidly changing market needs.

The American National Standards Institute (ANSI) considers that there are 3 main directions for digitalization of standards work: creating new tools and methods to develop standards, involving more people in standardization work, and forming new types of standards deliverables. Exploring different publishing formats, such as the more flexible and stable XML technology. And integrating standards into products, systems, and services directly. In 2018, the Center for Strategic and International Studies (CSIS) released a report on A National Machine Intelligence

Strategy for the United States that argued that the U.S. government could start by harmonizing its own data structure and tagging standards and should work with the private sector to develop standards to enable data sharing between government and industry and to drive standards digitization efforts (Carter et al., 2018). In 2019, ANSI and U.S. industry collaborators began implementing the ISO SMART standard. In 2020, ANSI listed the ISO SMART standard in its annual report as one of six emerging cutting-edge technologies collaborating on technology solutions.

Germany's development of digitalization of standards is inseparable from the Industry 4.0 strategy, and is comprehensively related to the industrial digitalization process from the perspectives of decision-making mechanism, realization mode, and industrial application. At this stage, Germany has gradually shifted the focus of digialtization of standards to the field of digital twins, in order to meet the rapidly developing demand for digital twin research and application. The German Standardization Strategy released in 2016 calls for the incorporation of digital technology into the standardization development process and the full use of digital resources in the work of committees (Ma, 2023).

Russian has also made clear in its standardization strategy the requirements for the development of "machine-readable standards", the transformation of national standards into "machine-readable standards", and the transformation of national standards into "machine-readable formats" (Liu et al., 2021; Wang et al., 2021).

4. Typical cases of key technologies for digitalization of standards transformation

Currently, different standardization organizations, countries, enterprises, etc. are conducting explorations and practices related to the key technologies for digitalization of standards transformation (Zhao, 2022).

4.1. Online standards development (OSD) platform jointly developed by ISO/IEC

In order to promote more efficient collaborative work in standards developing groups, improve the quality of standardization documents, and facilitate the commenting and compilation of resolutions, CEN and CENELEC, jointly with ISO and IEC, have developed a new online standards development (OSD) platform aims to provide a unified online standards development platform for technical organizations to develop standards from the preparatory stage to the release stage. The platform is designed to: Enable more organized and efficient collaborative work from the beginning of the standards creation process; improve/simplify the quality of content in the early stages of standards development; improve the overall quality of content; Facilitate commenting and eventual compilation of resolutions; System development (i.e., NISO STS) based on standard content; and unify ISO/IEC standards development and processes. The OSD platform is a Word-like tool, which can be used by technical bodies to develop standardization documents. It has many advantages over word, such as co-editing (clauses can be locked and unlocked), tagging and filtering of comments, normative referencing, guidance on structure according to standards writing rules as well as automated numbering and quality

checking, and different access right for leaders and staff of technical organizations, specialists, editors of standards bodies, and users of standards. The OSD platform provides standards developers with an online environment in which they can work efficiently and collaboratively. Instead of experts in standards drafting groups saving and working on documents individually and sending changes to each other via e-mail to be merged, all changes are made securely online through OSD platform (ISO, 2024a; ISO, 2024h; ISO, 2024i; NISO, 2024).

4.2. Language and terminology content structuring standard of ISO/TC 37

The ISO/TC 37 Technical Committee on Language and Terminology is one of the earliest technical committees established by ISO. The committee has developed a large number of standards related to the structured processing of text content, mainly including: Standard terminology structuring methods, such as ISO 30042:2019 Management of terminology resources—TermBase eXchange (TBX), which has been adopted by ISO and IEC for the representation, storage and management of terminology in ISO and IEC standards, and has also been incorporated into the NISO STS (ISO, 2024f); Methods for structuring the content of linguistic resources, such as ISO 24613-2:2020 Language resource management—Lexical markup framework (LMF)—Part 2: Machine-readable dictionary (MRD) model (ISO, 2024c) and other more than 20 standards (ISO, 2024d; ISO, 2024e). These standards provide important references for standard parsing, semantic annotation and management from the perspective of text content, and play an important role in the digital processing and handling of standards (ISO, 2024g).

4.3. The standards development portal of BSI in the United Kingdom

The standard development process is constrained by the process model in the background of the system to control the standardization, effectiveness and timeliness of the standard development process; the consultation is open to all members of the public, who can comment directly on the online standardized text; from draft to publication, the standard has gone through several iterations of "document use—feedback—document update" to ensure that the content of the standard is fully consensual and has good practicability; various types of information in the standard developing process are rigorously recorded by the system and can be processed using data analytics (e.g., comment filtering and screening) (BSI, 2024c; Zhao, 2022).

4.4. The SWISS of XSB company in the United States

SWISS, developed by XSB, Inc. is a neutral interoperable standard data content platform supported by standardization organizations such as ASTM, ASME, IEEE and the U.S. Department of Defense. The SWISS Interoperable Semantic Web transforms static product, material, process specifications and engineering documents into interoperable, intelligently interconnected data collection models that form a continuously updated, authoritative and consistent cloud services platform, while providing powerful APIs to automate the transfer of critical data to PLM, CAD and other software systems to support more efficient design, manufacturing and

maintenance assurance (Li et al., 2018; NIH, 2024; XSB, 2023).

5. Discussion

Based on the literature review method, this study has sorted out the key technologies of standard digital transformation, summarized the development trend and planning of standard digital transformation technology, and listed the typical cases of key technologies of standard digital transformation. Through the study, we found that the digital transformation of standards is the inevitable direction of future development in the field of standardization. Although the digitization level of different national standards is at different stages, with the gradual deepening of the use of digital technology, the global standard digitization level will be improved as a whole. To this end, in-depth research on key technologies for digital transformation of standards is needed.

Although the key technologies sorted out in this study have been widely used in various industries, they are indispensable in the process of standards digital transformation because they basically match our current standards digitization level needs. At the same time, our current standard digitization level has not yet reached the highest stage, so with the continuous development of the standard digitization level, there is a need for further research on more advanced technologies in the future to meet the higher demand.

The key technologies sorted out in this study and the typical cases cited can provide references in terms of methods and scenarios for studying more advanced technologies. Based on the discussion and analysis in this review, we suggest that new technologies in the future can be derived from further research on the basis of existing technologies according to different scenario requirements.

6. Conclusions

In today's digital era, businesses and organizations face unprecedented opportunities and challenges. In order to adapt to the rapid changes in the market and to meet the escalating needs of their customers, digital transformation, including standards digital transformation, is a must for business and social development (Ding, 2022; Yang et al., 2024). Through the use of digital technologies, digital transformation can increase productivity and reduce costs. As digital transformation continues, there will be more and more technologies used for digital transformation. This paper just summarizes some of the key technologies that are commonly used in the standard digital transformation process and evaluates them by the purpose of their use. It should be noted that the technologies in each category are not static, and there is no obvious definition between different categories for the same technology (i.e., a technology may be used at both the standards development layer and the standards application layer, with no obvious boundary between the two). In addition, the key to digital transformation is how to use the technology to realize the improvement of the quality of life in the society and promote the development of industry. Although this paper describes the key technologies for standard digital transformation, other industries can also refer to it when choosing technologies for digital transformation.

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