

Article

Long-Lived Sustainable Products through Digital Innovation

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Abstract: Digitalization is key for an organization to achieve sustainability leadership, to be able to conform with sustainability objectives, support claims, and inform consumers and consecutive stakeholders. However, there is no impartial, credible, and universal market platform where market competition favors data exchange and traceability of products and materials. This paper addresses the question of how to utilize digital tools to meet the challenges at the interface between the producer and the consumer. The methodology of the study is action research, which includes various qualitative and quantitative research methods. The research results in the creation of an information system platform, which shows how to merge digital information with a product to provide credibility to consumers and support their purchasing decision based on the claimed lifetime of the product, the sustainability requirements met, how the consumer will find service and spare parts, as well as the design of a universal digital twin. This research contributes to the transparency and traceability aspects by showing how organizations can work and cooperate to create verifiable information and establish claims that support resource efficiency decisions, as well as demonstrating how a traceability system can facilitate the efficient use of materials and energy resources.

Keywords: circular economy; consumer engagement; producer guidelines; certification; long-lived products; accessibility; sustainability; transparency



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1. Introduction

Digitalization of products and services is an emerging market potential and consequently permeates all aspects of industrial production, products, business, and markets. Digitalization is key for an organization to achieve sustainability leadership, to be able to conform to sustainability objectives, and to support claims, as well as to inform consumers and consecutive circular life cycle stakeholders. For many companies, the first major step toward sustainability and circularity comprises an assessment of how their products can become more sustainable and circular by adopting strategies that aim at slowing, narrowing, closing, and regenerating loops [1,2]. By employing strategies such as changing product design and materials, working with suppliers, providing spare parts to consumers and repairers, and informing customers about optimal use, more circular and sustainable offerings can be developed (e.g., [3]). The traceability of products and materials and the transparency of information are crucial aspects of the organizations' sustainability management, especially with increased demand from consumers with an interest to make informed choices. It is also important to manage the increasingly complex and fragmented supply and value chains, where there are risks of unsustainable practices, poor labor conditions, and counterfeit products [4–6]. To navigate the most sustainable and circular way for a product's life cycle, each user and stakeholder will need access to relevant information about the product itself and guidance on ways to maximize the sustainability performance, with durability and a long lifetime of products being of fundamental importance.

Products, in many ways, are at the core of circular economy developments. The regulation of products and their life cycle environmental impacts, not least in the European Union (EU), have been expanding in the last 30 years [7–9]. Various policies have been adopted, including producer responsibility rules to promote the collection and recycling of used

products, restrictions of hazardous substances in products, mandatory energy efficiency requirements for products set through the EU Ecodesign Directive, and mandatory energy labeling of products through the EU Energy Regulation [10]. In the last couple of years, we have seen more policies that aim to increase product lifetime and repairability [11]. The mandatory policies have been complemented with voluntary policies, such as public procurement and ecolabels, in order to provide further incentives for ecodesign and increase consumer awareness. Currently, the drivers for companies to improve product circularity include ecodesign regulations, right-to-repair (R2R) policies and laws, improved resilience, and customer expectations [11,12]. Other examples include several jurisdictions around the world that are proposing new R2R policies [13]. New national policies in Europe—such as the French repairability index and local repair vouchers in Austrian cities—are also strong drivers for change [14,15]. Therefore, broad legislative work is under way in the EU in the whole area. Stricter product requirements will go hand in hand with stricter rules on verifiability of environmental claims and labels. The EU Directive on empowering consumers in the green transition aims to contribute to a circular, clean, and green economy in the EU by empowering consumers to make informed purchasing decisions, thereby contributing to more sustainable consumption. The proposal contains new verifiability requirements for environmental claims in marketing. It also introduces requirements to provide certain information on commercial guarantees, the repairability of goods, the accessibility of spare parts, and the availability of updates to digital content. The opportunities provided by digitalization may serve to boost the acceleration toward sustainability leadership and transition toward a more circular economy for both responsible producers and consumers. The consumer wants to know that the purchased product fulfills high sustainability requirements and that it will last as long as promised by the producer. The producer wants to be trusted on the claims made. If this match between credibility and trust is achieved, a potential market will be accelerated toward a shift from fast linear consumption to sustainably driven circular consumption. However, currently, there is no impartial, credible, and universal market platform in which competition favors product and material data exchange and traceability. Therefore, this paper addresses the question of how to utilize digital tools to meet the challenges at the interface between the producer and the consumer. And how to effectively align the needs of consumers and producers to accelerate market-driven resource efficiency through an effective application of digitalization. To achieve this, the research acknowledges the requests from governmental and regulatory bodies, as well as from the industry and consumers, to solve a key challenge of joint interest and with a large potential to increase resource efficiency, namely, how to combine commercial relevance with trust and credibility regarding claims about an individual product's circularity, durability, and sustainability. The working idea throughout the project is for the producer to provide such information to the consumer via a certified label. This is expected to have a large potential to drive change in consumer behavior into favoring products that comply with the principles of the circular economy while at the same time better defining the market requirements for producers' products and business model development. The research responds to the EU Action plan on Circular economy [5], the Swedish Handlingsplan för cirkulär ekonomi (in English: the Swedish action plan for circular economy) [16], the final report Delegationen för Cirkulär ekonomis expertgrupp Förstärkt spårbarhet (in English: the Swedish Government's Delegation for Circular economy's expert group on Enhanced traceability) [17], and, not least, the Swedish, Nordic, and European industry's demand for a clear plan to act upon regarding product and material data exchange and traceability. If the information on the lifespan and durability of products becomes more common, we can expect consumers to increasingly take these product characteristics into account when purchasing in the future ("spill-over effects") [11,18].

The creation of a visible label, which verifies that the durability and long lifetime of products is certified by an independent third party, has a large potential to change consumer behavior into favoring the circular economy principles and increased resource efficiency [11,18–20]. The project aims to deliver a blueprint for an innovative IT system

necessary to establish traceability for the verification of claims. The information shall be available throughout a product's expected lifetime to guide use, refurbishment, remanufacturing, dismantling, recycling, etc. This certification system is called Certified to LAST, in which the letters L.A.S.T. comprise the four criteria of the certification system. The first criterion "lifetime" specifies the aspects of the product's durability. Lifetime is realized by the second criterion "accessibility", since the accessibility of information, service, and spare parts enables a longer lifetime of products. The third criterion "sustainability" assesses the environmental performance of the product and shows the environmental aspects of the model to describe the product's lifetime. The fourth criterion "transparency" specifies the digital twin that stores and makes available the information for users and stakeholders to know how to maintain, use, service, refurbish, dismantle, and recycle the product in a sustainable way. The Certified to LAST system is intended to establish a certified market competition platform for durable and sustainable products where producers can be trusted on a long-term after-market commitment to their customers. By providing such information, the research project aims to facilitate resource-efficient and circular product design, production, marketing, procurement, maintenance, and consumption and to contribute to transparency and traceability systems by showing how to merge the digital information of a product to provide credibility to consumers about the relevant sustainability aspects to support the purchasing decision. The system is being developed within the governmentally owned research institute RISE—Research Institutes of Sweden, together with six large companies in different sectors. It is worth noting that there is a strong interest from the industry, consumers, and government in this certification system. The full system is planned to be launched in early 2023.

The rest of the paper is structured as follows. The Background and Context section provides an overview of the notion of traceability and the concept of a certified market competition platform. Section 3 presents the methodology used in the analysis. Section 4 provides a comprehensive analysis of the system architecture of the Certified to LAST information system service and its information content with a real case example. The final section provides concluding remarks.

2. Background and Context

2.1. The Notion of Traceability

According to the international standard ISO 22005:2007, a traceability system can be seen as a "technical tool to assist an organization to conform with its defined objectives and is applicable when necessary to determine the history, or location of a product or its relevant components" ([21], p. 1). In the design of a traceability system, the following shall be included: (a) objectives; (b) regulatory and policy requirements relevant to traceability; (c) products and/or ingredients; (d) position in the feed and food chain; (e) flow of materials; (f) information requirements; (g) procedures; (h) documentation; (i) feed and food chain coordination [21]. In each step of the material flow of products (i.e., extraction of virgin materials, production of raw material, manufacturing of products, buying and using products, reusing, selling to the second-hand market, or sending for recycling, sorting, etc.), one needs to have the ability to identify, track, and trace the elements of a product as it moves along the supply chain from raw goods to finished products, since it is important to spread the information about material content, how to dismantle/recycle the material, to know the origins of materials, where the material comes from, etc. In general, material components and parts are individually branded in many different industries, such as the steel and foundry industry, plastics, paper, composites, and textiles. The purposes can be different, for example, securing ethical mining or a specific brand, tracking quality, controlling automation, or offering services linked to the label. This tracking is enabled by various more or less standardized tags, such as data matrix and QR codes, barcodes, RFID tags, etc. (see Table 1), linked to vendor-specific systems that store data and enable tracking within specific computer systems. Developing such traceability means using various technical solutions that meet the following needs:

- A practical way to tag individual material items, components, or products, so that the tagging stays readable over the product's life cycle. This can vary for different materials and applications. Tagging that can be read anywhere along the life cycle where it is relevant (check for counterfeit, warranty claim, service, access to manuals, service history, etc.).
- Globally agreed identity series and management to ensure that different individuals do not acquire the same identity.
- Agreements on how data should be structured and secured, so that data created by one organization with an IT system can be read or stored by another organization with other IT systems.
- IT management and correct transaction updates when changing ownership over the material life cycle.
- Data security solutions that make it possible to control the protection or sharing of data as the data owner wishes.

Table 1. Examples of tracking methods.

Method	Definition/Feature	Reference
Laser		
Laser that marks different covers with a variety of surfacing techniques, such as laser engraving, laser bonding, laser ablation (abrasion), foaming, hot-branding, annealing, and color changes.		
Direct marking, produce miniature data matrix codes	Using laser to produce miniature data matrix codes (DM), size: 2 * 2 mm ² . The problem is edge over-burn; this is a bigger problem with a small size, and it uses a higher energy laser beam.	[22]
Machining the surface		
Gentelligent micro pattern on the surface	Theory: mechanical data storage on surfaces is applied for audio and video signals. Method: during the turning process, a surface microstructure is generated. A piezo-electric-driven tool makes an additional motion perpendicular to the surface (a fast tool servo system). Later, the technology is transferred to face milling.	[23–25]
Radio frequency (RFID)		
The transponder can be placed into the drill hole within the metallic components or during the casting process. The light will be guided to the photodiode array through the polymer optical fiber. The photodiode array is used to produce power. It can reach a communication speed of 100 kb/s.		
Sand molds		
Pin-type tooling	An inserted tool, which changes shape between each molding, is part of the pattern plate and used for sand casting.	[26]
Stencils (perma-code)	A commercially available method of producing cast data matrix symbols, which applies ceramic stencils to create the symbol geometry. Stencils are made using a water jet cutting method to shape the ceramic material.	[27]
Laser cutting	Using data matrix symbols applying an yttrium aluminum garnet (YAG) laser in order to cut a symbol directly into a sand mold, which will be cast in metal.	

Using international standards, which either exist already or will need to be internationally developed, ID-tagged materials and tangible products, components, and parts are, in principle, globally traceable over time and geography and across sectoral and organizational boundaries. In addition, because these standards are designed for voluntary use, most standards also support both structured transparency and structured security. When the development of traceability technology takes place locally, without coordination via standards, the costs of data transfer between the different systems will grow exponentially for every new data exchange interface between the technology or application domain, organizations, or sectors. Instead, building on the existing sector-independent standards

and ongoing standard development early on reduces the risk of incompatible systems and such transaction and system costs. Therefore, the information system design/blueprint is based on ISO standards, which are specified in Table A1 of Appendix A, to provide the open transparency needed to verify and realize claims across national and organizational boundaries and business transactions over a long period. The system is designed to give the information needed to realize a resource-optimizing value chain from design to recycling in circular material loops. It is understood that full implementation of such singular lies far into the future. By establishing the design on existing standards, there is a clear current way to start, as well as a stable and maintained practical value along the way toward scalability, in all dimensions.

To create a reliable traceability and verification system, there is a need for frictionless tracking and making available the data on material products, components, and parts from the original material production, product design, component manufacturing, etc., to service, scrapping, reuse, remanufacturing, secondary life cycle, and material recycling. The Certified to LAST information system is intended to be based on inactive, optically readable QR codes, which, when scanned, enable the retrieval of any type of stored data regarding the individual tagged, as described above. The proposed traceability and verification system aims to provide a solution that can support the credibility and transparency of market claims between the producers and the consumers. To establish a reliable platform between the producers and consumers, it is important that the producer can be recognized and relevantly contacted throughout the life cycle use of a product. Likewise, it is important that the producer can relevantly distinguish their products from counterfeits and other similar products when questioned about, for example, ethics, quality, environmental impacts, chemical risks, service, or recycling.

2.2. The Concept of a Certified Market Competition Platform

The project idea is to establish a collaboration between companies and experts in a true spirit of co-creation to establish the fundamental content and structure of an information system needed to verify the promises and claims about individual product's circularity, durability, and sustainability. This refers to claims about the product's durability lifetime, accessibility to affordable service and spare parts, resource efficiency, and other sustainability claims about the materials and resources. These claims are classified into four groups, Long lifetime, Accessible service and spare parts, Sustainable materials and life cycle, and Transparent information, abbreviated into L, A, S, and T, and integrated into a certified market competition platform called Certified to LAST (see Figure 1).

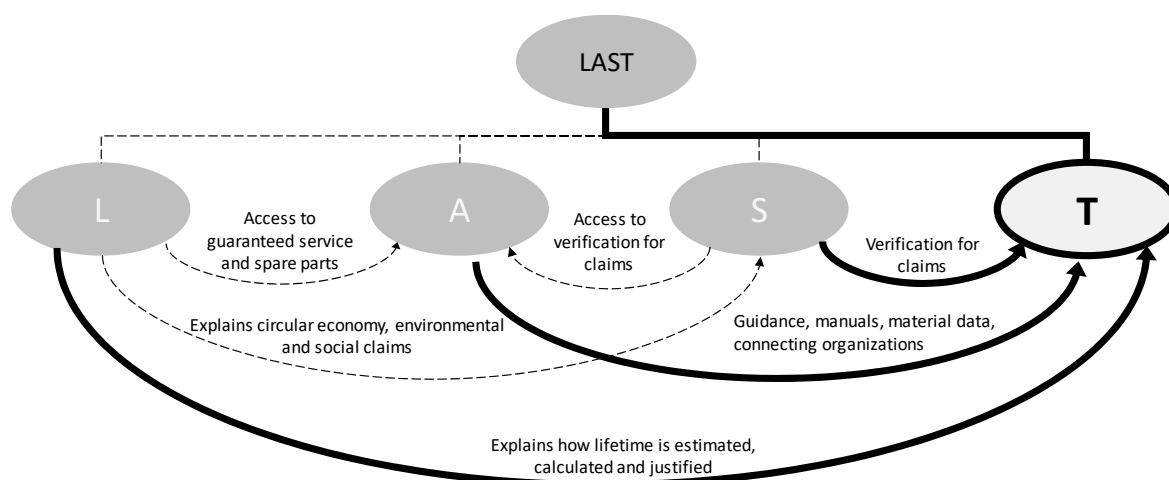


Figure 1. The role of (T)ransparency in a verified circularity product declaration based on (L)ong lifetime, (A)ccessible service and spare parts, and (S)ustainable materials and life cycle.

The thick black arrows in Figure 1 show how the different claims, statements, and data references made concerning Lifetime, Accessibility, and Sustainability are all represented and realized through an IT system named T (traceability):

- L: Long lifetime is verified by T—how the lifetime is estimated, calculated, and justified; by A—how access to guaranteed service and spare parts is ensured; and by S—what explanations of economic, social, and other sustainability claims exist about the product.
- A: Accessible service and spare parts are verified by T—access to guidance, manuals, material data, connecting organizations, and other data that verify and enable maintenance to achieve the claimed and promised lifetime and durability.
- S: Sustainable materials and life cycle are verified by T—access to relevant information trails, digital product passport, LCA studies, ecolabel certificates, and other information that can verify statements about the economic, social, and sustainability factors of products and how they are sustainably used, maintained, scrapped, made circular, etc.
- T: Transparent information holds the verifications in the form of contents (or verifiably secured access to the contents), verifiability requirements of the structure of the content, and the actual verification process(es) needed to ensure the credibility of the claims and promises.

Since the project is running in parallel with the European implementation of the Circular Economy Action Plan [5] and the Proposal for Ecodesign for Sustainable Products Regulation [28], it is therefore expected that much of what may be considered too demanding and difficult to establish with regard to Certified to LAST will soon be part of European legislation. This concerns data sharing, the verifiability of claims, and commonplace customer awareness of circular economy, repairability, and durability of products.

3. Methodology

The concept of Certified to LAST was developed together with the International Institute for Industrial Environmental Economics (IIIEE) at Lund University and six companies with global brands in different product segments. Companies have actively shown interest in circular issues and contribute knowledge about their products and their value chains. The project started in March 2021. During this time, different kinds of qualitative and quantitative data were collected, including a systematic literature review and secondary data sources review, in-depth interviews, and focus group discussions with representatives from the industry and businesses, as well as participant observations, canvas-based questionnaires, documentary and internet research, and document analysis. The practical prototype implementation process is described in Table 2. Therefore, our methodology can be seen as action research [29–31], since it implies “learning-by-doing”—a process of learning from practical experience [32]. It is worth noting that the project runs in parallel with strong participation in ISO standardization in this field, as well as in parallel with several independently related strategic investments within RISE.

Table 2. The research process of creating the Certified to LAST concept.

		Months	1	2	3	4	5	6	7	8	9	10	11	12
WP1	Operational specification													
WP2	Test and develop canvas system													
	RISE Research Institutes of Sweden													
	Company 1													
	Company 2													
	Company 3													
WP3	Establish criteria indicators													
	RISE Research Institutes of Sweden													
	Company 1													
	Company 2													
	Company 3													
WP4	Set criteria indicator thresholds													
	RISE Research Institutes of Sweden													
	Company 1													
	Company 2													
	Company 3													
WP5	Version beta of LAST label													
	RISE Research Institutes of Sweden													
	Company 1													
	Company 2													
	Company 3													
WP6	IT system specification													
WP7	Benchmark outside project													
	RISE Research Institutes of Sweden													
	Academic partners													
	Company 1 + service company													
	Company 2 + service company													
	Company 3 + service company													
WP8	Project management													
	RISE													
	Company 1													
	Company 2													
	Company 3													

The grey areas represent active phases of each activity, showing progress from conceptual test of canvases to beta labelling system.

4. Results and Discussion

4.1. The System Architecture of the Certified to LAST Information System Service

Figure 2 describes the general architecture of the information system, which provides the transparency and traceability functionality of the Certified to LAST service. The red arrow labeled “Request for accessible data” shows how the user acquires access to all the transparent and traceable data provided by the system. The QR code is placed directly on the product itself, for example, at the bottom of a coffee brewer, in the corner of a room with a flooring material, or on the textile label of apparel.

The user accesses the information by using a smartphone or another QR code reader on the information represented by the box labeled “Digital twin of product”. Whether this digital twin represents an individual product with an individual identity or with an article number is up to the provider of the product and the information provider. If the information is provided by the article number, the information can give much technical support about the product in general, but if the information is provided at the level of an individual product, it can also give information about, for example, the history of ownership, service, quality, and upgrades, as well as individual traceability. The blue arrow labeled “Request for certified data” points from the box labeled “Digital twin of product” to the box “Certified to LAST transparent data”, and the oppositely directed blue arrow labeled “Provision of certified data” represents how the information is requested and provided via the digital twin of the product from the data storage of the “Certified to LAST transparent data” of the information system to the digital twin. Although this data storage is represented as a box, it is implemented as a distributed system, where the producers, service providers, and other information suppliers are managing and maintaining their

individual parts of the information. Hence, the box “Certified to LAST transparent data” may be seen as the central switchgear of certified and reliable data rather than a database.

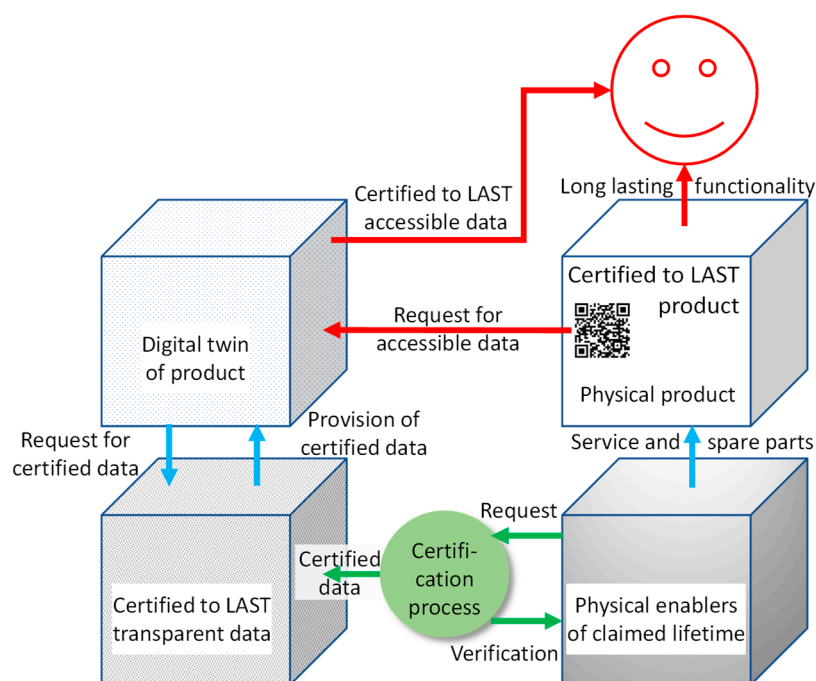


Figure 2. The architecture of the Certified to LAST information system service, which verifies and enables long-lasting functionality.

At the core of the functionality of the information system is the certification process, represented by the green circular “Certification process”, which is initiated by a request for verification from a product producer. This request is represented as an arrow labeled “Request” from the box “Physical enablers of claimed lifetime”, meaning that the producer wants the Certified to LAST certification body to verify that the physical design of the product, together with all its accessibility to spare parts and service and all the available information, verifies and validates that the product is living up to the claim of its long lifetime. If this statement can be verified, the “Certification process” can provide a “Verification” to the producer regarding the “Physical enablers of claimed lifetime”. When the result of the verification and validation conforms with the requirements of the Certified to LAST criteria for its product category, the product can be supplied with “Certified data”.

The two red arrows pointing to the schematic face at the top of the figure represent the two ways in which the information system supplies services to the user. The red arrow labeled “Certified to LAST accessible data” demonstrates the provision of manuals for handling, care, upgrading, service, recycling, and other information, which, for example, a seller, user, service technician, or recycler needs to realize the full long life of the product and its functionality, as well as the circular lifetime of its components and materials. The red arrow labeled “Long lasting functionality” pointing from the box “Certified to LAST product—Physical product” represents the functional ability of a Certified to LAST certified product to maintain a long product lifetime, mainly through access to upgrades, spare parts, second-hand markets, and addresses to service stations. Since a Certified to LAST product is also designed for sustainability and a circular life cycle, the information regarding the “Physical enablers of claimed lifetime” is also verified with regard to the claimed choice of materials, the potential for recycling, environmental and social life cycle impact.

4.2. The Information Content of the Certified to LAST System

To verify how a producer achieved the physical enablers of a claimed lifetime, the Certified to LAST system includes a number of canvases that are used to map the lifetime

and sustainability weaknesses of the product as well as how these weaknesses are handled with regard to accessibility to all the relevant and claimed information, such as, for example, the product lifetime risks canvas, which is presented in Figure 3. In this canvas, weaknesses with regard to the product's ability are mapped through a combination of assessing the failure statistics, how old products turn up at service stations, the reasons for guarantee claims, and interviews with users, as well as the different sorts of failure mode risk assessments, etc. The canvas presented in Figure 3 contains different categories for product lifetime weaknesses, which are defined in Table 3.

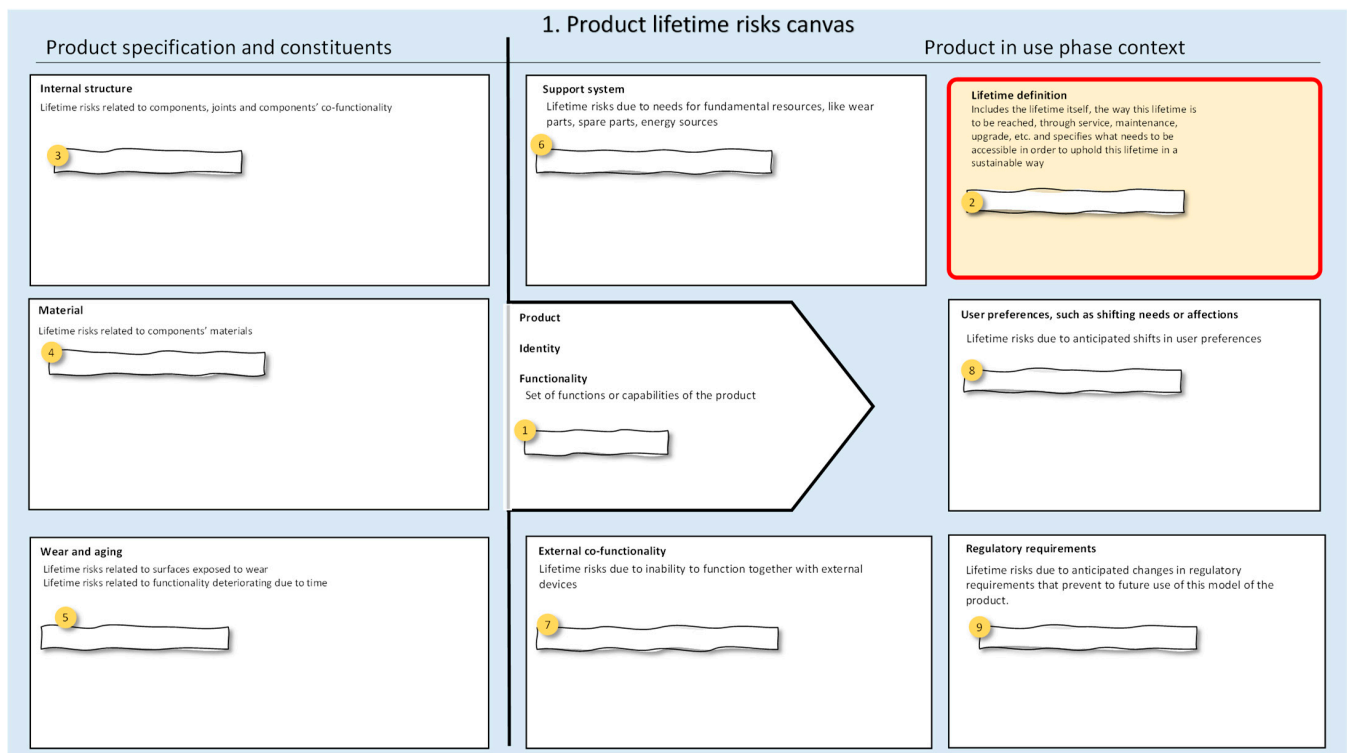


Figure 3. Canvas used to map the lifetime weaknesses of a product.

Table 3. Categories for product lifetime risk canvas.

Category	Definition
Product	analyzed object itself
Lifetime definition	includes the lifetime itself and the way this lifetime is to be reached, through service, maintenance, upgrade, etc.
Internal structure	relates to components (items considered part of the product), joints (the connection between components in the whole product) and components' co-functionality (set of co-functions or capabilities of the product)
Material	a type of material used in the production of one unit of a product
Wear and aging	how the material is worn until its functionality is lost
Support system	access to fundamental resources, such as spare parts, and energy
External co-functionality	a state in which the product and other objects can exist or occur together without problems or conflict
User preference	requirements that add value to a product for a user
Regulatory requirements	change in legal/regulatory/technical requirements that prevents use of this model

To achieve a certificate based on verification, all lifetime weaknesses need to be tackled, either by changing the design of the product in ways that guide the user to use or service

the product, or by providing access to affordable spare parts. Affordability of spare parts is key to the Certified to LAST concept, since many companies already provide spare parts today at a pricing level close to the price of a fully new product. How a specific company chooses to tackle each of the lifetime weaknesses is up to them, but the fact that their approach can indeed overcome the lifetime weakness needs to be verifiable.

A similar canvas is also developed for sustainability weaknesses, including material properties, circular material and product properties, manufacturing and dismantling, as well as the sustainability aspects of the support system, second product life, etc. The ways in which companies take responsibility for tackling product weaknesses and risks, facilitate the exploitation of the potential, and meet the requirements are mapped using an accessibility canvas, which describes what information to provide and to whom in order to realize the claimed product lifetime and sustainability performance. The fact that the lifetime promise, the sustainability claims, and the accessibility of information are realized is verified by the information contained in the box “Physical content of claimed lifetime” presented in Figure 2.

The certification process and the whole system design, as well as the process for defining the product category rules and criteria for specific product categories, are led by the RISE Research Institutes of Sweden. However, the setting of the indicators for criteria is performed as an open consultation process, and the actual verification of claims is carried out by verifiably impartial bodies based on the principles and requirements of ISO/IEC 17029:2019(en)—Conformity assessment—General principles and requirements for validation and verification bodies.

4.3. The Case Example of Information Content of the Product Lifetime Risk Canvas in the Certified to LAST System

All six participating companies were given the opportunity to test the product risks canvases of the Certified to LAST system. Figure 4 presents the product lifetime risk canvas with a real case example of a professional steam iron in which different parameters of the product in terms of its lifetime are defined and checked.

The left part of the canvas pertains to the product itself, its parts, mechanism, and material. First, the company looked at the production part and specified all the components that the steam iron contains. Afterward, any weak parts in the components and materials that the product consisted of, product functionality, and joints were checked. It was found that the internal structure of the product contains different possible risks, e.g., a switch part may break after long-term use, steam leakage may occur in the O-ring part of the product, some lacquer instructions may disappear, and the product’s details may be worn and malfunction after long-term use. In terms of product materials, potential risks were also found, which could reduce the durability of the product, for example, hard plastic that may break and internal copper, cork handle, or textile covered with steam tube and electric cable, lacquer, and rubber. The “Wear and aging” part evaluates the risks related to surfaces exposed to wear and functionality deterioration over time, which were found in cork handle that may harden and be worn down, as well as in steam tube and cable that may break if not protected properly.

In the middle part of the canvas, the product’s risk aspects that can limit the function and lifespan in the use phase context are described. The company evaluated any weaknesses in the product and use part, looking at whether there was any available support system (fundamental resources, such as spare parts and available repair service) and risks associated with external co-functionality that showed the inability of the product to function together with any external devices, for example, risks related to the level of pureness of water used for the iron or the available electric effect.

The right part of the canvas assesses user preferences and needs, i.e., the requirements that add value to a product for a user. For the steam iron, they could include changes in the fashion needs and new updated ironing technologies that could leave customers reluctant to continue using the steam iron model and buy the new, more modern one. Newly

established legal, regulatory, or technical requirements that prevent the use of this model also need to be taken into account when analyzing the lifetime of the product. According to the analysis provided, the company also needed to formulate the lifetime definition based on the analyzed product. The lifetime definition includes the lifetime itself, the ways in which this lifetime is to be reached through service, maintenance, upgrade, etc., and specifies what needs to be accessible in order to uphold this lifetime in a sustainable way.

Based on the risk canvas provided, the reviewer can evaluate whether the company fulfills the requirements to be certified according to the Certified to LAST system and also provide recommendations to the company to improve the product lifetime in terms of its design and functionality.

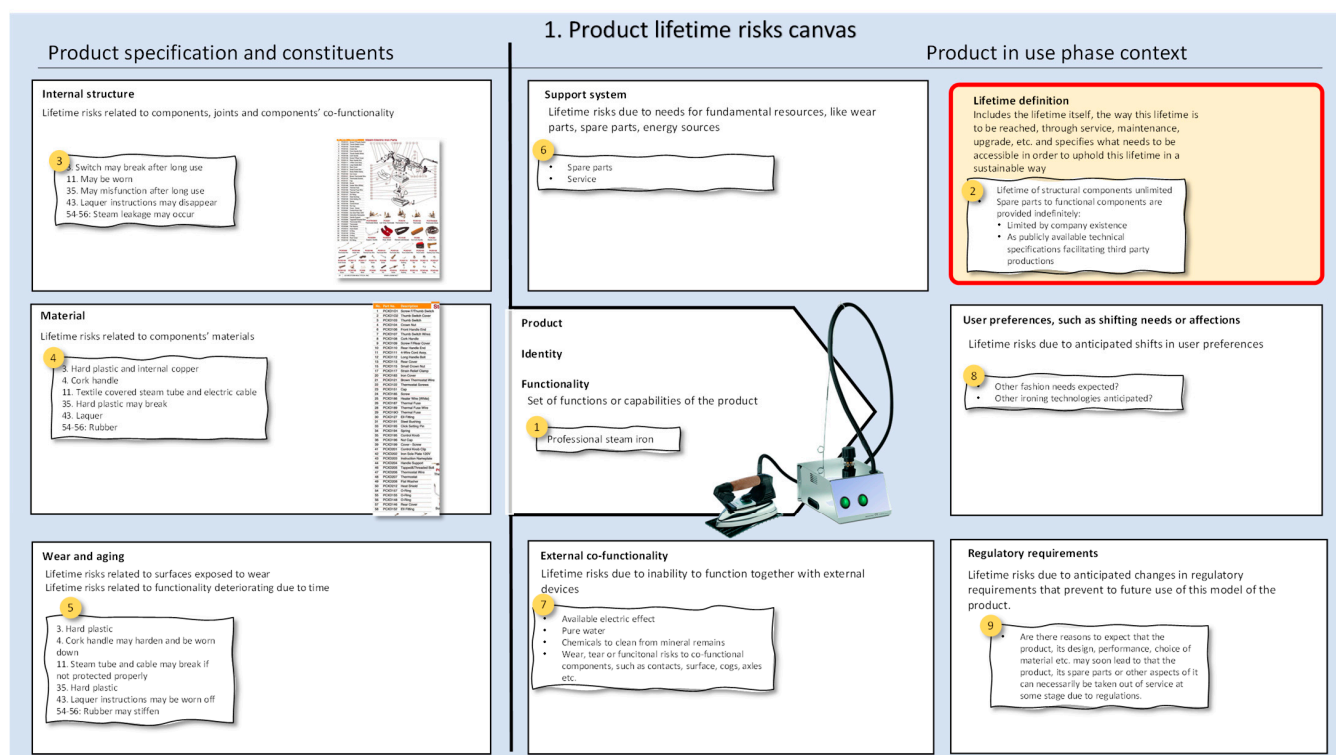


Figure 4. Canvas used to map the lifetime weaknesses of a professional steam iron product.

5. Conclusions

The project provides materially relevant practical transparency in order to make an impact on all stakeholders along the product value chain. The research shows how to merge the digital information of a product to provide credibility to consumers regarding the relevant sustainability aspects to support the purchasing decision. The sustainability information was connected to the physical product by attaching a digitally readable QR code linked to a universal digital twin that enables tracking, tracing, providing, and updating the information about the product [33]. The sustainability information is backed up by a full certification scheme “Certified to LAST”, which is based on (1) the claimed lifetime of the product, (2) the sustainability requirements met, (3) how the consumer will access service and spare parts, as well as the design of a universal digital twin.

Overall, this research contributes to the transparency and traceability systems by showing how organizations can work and cooperate to create verifiable information and establish claims that support resource efficiency decisions. It demonstrates how a traceability system can facilitate the efficient use of materials and energy resources by making verified and reliable claims about the product durability lifetime, accessibility to affordable service and spare parts, resource efficiency, and other sustainability claims about materials

and resources. This, in turn, contributes to the following comprehensive areas of concern being able to be mediated to the point of a purchase decision:

- (1) Traceability and transparency of information, which is important to implement throughout the supply and value chains to facilitate the transition to a circular economy and sustainability, as demanded by stakeholders across consumer and producer sectors.
- (2) Circular resource management and efficiency by achieving a system perspective of circular flows to maximize the reuse of material values and resources (regardless of whether the materials themselves are valuable or not) and the productivity of products in their first lifetime, as well as ensuring the transparency of greenhouse gas emissions and their progressive reduction.
- (3) Safety guarantees addressing the safety issues of a product along the entire chain, from material extraction to the manufacture of products, reuse, submission, and recycling. This, in turn, enables a safe second-life use and facilitates the circular recovery of the product's materials.
- (4) Social aspects, since the traceability and transparency of a product's life cycle along the value chain support responsible trade and anti-corruption practices, local value creation, and economic diversification, foster public health protection, minimizing the impact of pollution in the value chain, as well as eliminate child and forced labor, respecting the human rights of employees throughout the value chain.
- (5) Standardization development work. Since the project is running in parallel with strong participation in both ISO and European Committee for Standardization (CEN) standardization in this field, as well as in parallel with the EU development of product digital passports, the project is both shaped by and contributes to international standardization regarding data transparency and implementation of the circular.
- (6) Product on the consumer market. The real-life cases of companies that participate in the project are a good indication of that.

In summary, the system described in this article is well placed, since it does not rely on any specific levels of legal requirements but is intended to establish a platform where those companies that excel and provide even verifiably better products than what is required by law will be able to compete and stand out.

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Appendix A

Table A1. The main ISO standards used for the information system design.

Field	ISO Standard
Organization	ISO 8440-COR1:2000 Location of codes in trade document
	ISO 16609:2012 Financial services—Requirements for message authentication using symmetric techniques
	ISO/IEC 15944-4:2015(E) Information technology—Business operational view—Part 4: Business transaction scenarios—Accounting and economic ontology
	ISO/IEC 27014:2020 Information security, cybersecurity and privacy protection—Governance of information security
A. Labeling of material, products, and goods; B. Automatic identification and data capture techniques	ISO/IEC TR 24030:2021 Information technology—Artificial intelligence (AI)—Use cases
	ISO 1073-1:1976 Alphanumeric character sets for optical recognition—Part 1: Character set OCR-A—Shapes and dimensions of the printed image
	ISO 1073-2:1976 Alphanumeric character sets for optical recognition—Part 2: Character set OCR-B—Shapes and dimensions of the printed image
	ISO 1831:1980 Printing specifications for optical character recognition
	ISO/IEC 5218:2004 Information technology—Codes for the representation of human sexes
	ISO/IEC 5218 Information technology—Codes for the representation of human sexes
	ISO/IEC 6523-1:1998 Information technology—Structure for the identification of organizations and organization parts—Part 1: Identification of organization identification schemes
	ISO/IEC 6523-2:1998 Information technology—Structure for the identification of organizations and organization parts—Part 2: Registration of organization identification schemes
	ISO/IEC TR 9789:1994 Information technology—Guidelines for the organization and representation of data elements for data interchange—Coding methods and principles
	ISO/IEC 11179-1:2015 Information technology—Metadata registries (MDR)—Part 1: Framework
	ISO/IEC DIS 11179-1 Information technology—Metadata registries (MDR)—Part 1: Framework
	ISO/IEC TR 11179-2:2019 Information technology—Metadata registries (MDR)—Part 2: Classification
	ISO/IEC 11179-3:2013 Information technology—Metadata registries (MDR)—Part 3: Registry metamodel and basic attributes
	ISO/IEC 11179-3:2013/AMD 1:2020 Information technology—Metadata registries (MDR)—Part 3: Registry metamodel and basic attributes—Amendment 1
	ISO/IEC DIS 11179-3 Information technology—Metadata registries (MDR)—Part 3: Metamodel for registry common facilities
	ISO/IEC 11179-4:2004 Information technology—Metadata registries (MDR)—Part 4: Formulation of data definitions

Table A1. Cont.

Field	ISO Standard
	ISO/IEC 11179-5:2015 Information technology—Metadata registries (MDR)—Part 5: Naming principles
	ISO/IEC 11179-6:2015 Information technology—Metadata registries (MDR)—Part 6: Registration
	ISO/IEC DIS 11179-6 Information technology—Metadata registries (MDR)—Part 6: Registration
	ISO/IEC 11179-7:2019 Information technology—Metadata registries (MDR)—Part 7: Metamodel for data set registration
	ISO/IEC DIS 11179-30 Information technology—Metadata registries (MDR)—Part 30: Basic attributes of metadata
	ISO/IEC TS 11179-30:2019 Information technology—Metadata registries (MDR)—Part 30: Basic attributes of metadata
	ISO/IEC DIS 11179-31 Information technology—Metadata registries (MDR)—Part 31: Metamodel for data specification registration
	ISO/IEC DIS 11179-32 Information technology—Metadata registries (MDR)—Part 32: Metamodel for concept system registration
	ISO/IEC DIS 11179-33 Information technology—Metadata registries (MDR)—Part 33: Metamodel for data set registration
	ISO/IEC DIS 11179-35 Information technology—Metadata registries (MDR)—Part 35: Metamodel for model registration
	ISO/IEC 14957:2010 Information technology—Representation of data element values—Notation of the format
	ISO 15000-1:2021 Electronic business eXtensible Markup Language (ebXML)—Part 1: Messaging service core specification
	ISO 15000-2:2021 Electronic business eXtensible Markup Language (ebXML)—Part 2: Applicability Statement (AS) profile of ebXML messaging service
	ISO/DIS 15000-3 Electronic business eXtensible Markup Language (ebXML)—Part 3: Registry and repository
	ISO 15000-5:2014 Electronic Business Extensible Markup Language (ebXML)—Part 5: Core Components Specification (CCS)
	ISO/IEC 15200:1996 Information technology—Adaptive Lossless Data Compression algorithm (ALDC)
	ISO 15394:2017 Packaging—Bar code and two-dimensional symbols for shipping, transport and receiving labels
	ISO/IEC 15415:2011 Information technology—Automatic identification and data capture techniques—Bar code symbol print quality test specification—Two-dimensional symbols
	ISO/IEC CD 15415 Information technology—Automatic identification and data capture techniques—Bar code symbol print quality test specification—Two-dimensional symbols
	ISO/IEC 15416:2016 Automatic identification and data capture techniques—Bar code print quality test specification—Linear symbols

Table A1. Cont.

Field	ISO Standard
	ISO/IEC 15417:2007 Information technology—Automatic identification and data capture techniques—Code 128 bar code symbology specification
	ISO/IEC 15418:2016 Information technology—Automatic identification and data capture techniques—GS1 Application Identifiers and ASC MH10 Data Identifiers and maintenance
	ISO/IEC 15419:2009 Information technology—Automatic identification and data capture techniques—Bar code digital imaging and printing performance testing
	ISO/IEC 15420:2009 Information technology—Automatic identification and data capture techniques—EAN/UPC bar code symbology specification
	ISO/IEC 15421:2010 Information technology—Automatic identification and data capture techniques—Bar code master test specifications
	ISO/IEC 15423:2009 Information technology—Automatic identification and data capture techniques—Bar code scanner and decoder performance testing
	ISO/IEC 15424:2008 Information technology—Automatic identification and data capture techniques—Data Carrier Identifiers (including Symbology Identifiers)
	ISO/IEC 15426-1:2006 Information technology—Automatic identification and data capture techniques—Bar code verifier conformance specification—Part 1: Linear symbols
	ISO/IEC 15426-2:2015 Information technology—Automatic identification and data capture techniques—Bar code verifier conformance specification—Part 2: Two-dimensional symbols
	ISO/IEC CD 15426-2 Information technology—Automatic identification and data capture techniques—Bar code verifier conformance specification—Part 2: Two-dimensional symbols
	ISO/IEC 15434:2019 Information technology—Automatic identification and data capture techniques—Syntax for high-capacity ADC media
	ISO/IEC 15438:2015 Information technology—Automatic identification and data capture techniques—PDF417 bar code symbology specification
	ISO/IEC 15459-1:2014 Information technology—Automatic identification and data capture techniques—Unique identification—Part 1: Individual transport units
	ISO/IEC 15459-2:2015 Information technology—Automatic identification and data capture techniques—Unique identification—Part 2: Registration procedures
	ISO/IEC 15459-3:2014 Information technology—Automatic identification and data capture techniques—Unique identification—Part 3: Common rules
	ISO/IEC 15459-4:2014 Information technology—Automatic identification and data capture techniques—Unique identification—Part 4: Individual products and product packages
	ISO/IEC 15459-5:2014 Information technology—Automatic identification and data capture techniques—Unique identification—Part 5: Individual returnable transport items (RTIs)

Table A1. Cont.

Field	ISO Standard
	ISO/IEC 15459-6:2014 Information technology—Automatic identification and data capture techniques—Unique identification—Part 6: Groupings
	ISO/IEC 15961-1:2021 Information technology—Data protocol for radio frequency identification (RFID) for item management—Part 1: Application interface
	ISO/IEC 15961-2:2019 Information technology—Data protocol for radio frequency identification (RFID) for item management—Part 2: Registration of RFID data constructs
	ISO/IEC 15961-3:2019 Information technology—Data protocol for radio frequency identification (RFID) for item management—Part 3: RFID data constructs
	ISO/IEC 15961-4:2016 Information technology—Radio frequency identification (RFID) for item management: Data protocol—Part 4: Application interface commands for battery assist and sensor functionality
	ISO/IEC 15962:2022 Information technology—Radio frequency identification (RFID) for item management—Data protocol: data encoding rules and logical memory functions
	ISO/IEC 15963-1:2020 Information technology—Radio frequency identification for item management—Part 1: Unique identification for RF tags numbering systems
	ISO/IEC 15963-2:2020 Information technology—Radio frequency identification for item management—Part 2: Unique identification for RF tags registration procedures
	ISO/IEC 16022:2006 Information technology—Automatic identification and data capture techniques—Data Matrix bar code symbology specification
	ISO/IEC 16022:2006/COR 1:2008 Information technology—Automatic identification and data capture techniques—Data Matrix bar code symbology specification—Technical Corrigendum 1
	ISO/IEC 16022:2006/COR 2:2011 Information technology—Automatic identification and data capture techniques—Data Matrix bar code symbology specification—Technical Corrigendum 2
	ISO/IEC CD 16022.2 Information technology—Automatic identification and data capture techniques—Data Matrix bar code symbology specification
	ISO/IEC 16023:2000 Information technology—International symbology specification—MaxiCode
	ISO/IEC 16388:2007 Information technology—Automatic identification and data capture techniques—Code 39 bar code symbology specification
	ISO/IEC DIS 16388 Information technology—Automatic identification and data capture techniques—Code 39 bar code symbology specification
	ISO/IEC 16390:2007 Information technology—Automatic identification and data capture techniques—Interleaved 2 of 5 bar code symbology specification
	ISO/IEC 16480:2015 Information technology—Automatic identification and data capture techniques—Reading and display of ORM by mobile devices

Table A1. Cont.

Field	ISO Standard
	ISO/IEC DIS 17360 Automatic identification and data capture techniques—Supply chain applications of RFID—Product tagging, product packaging, transport units, returnable transport units (RTIs) and returnable packaging items (RPIs)
	ISO/IEC 18000-2:2009 Information technology—Radio frequency identification for item management—Part 2: Parameters for air interface communications below 135 kHz
	ISO/IEC 18000-3:2010 Information technology—Radio frequency identification for item management—Part 3: Parameters for air interface communications at 13,56 MHz
	ISO/IEC 18000-4:2018 Information technology—Radio frequency identification for item management—Part 4: Parameters for air interface communications at 2,45 GHz
	ISO/IEC 18000-6:2013 Information technology—Radio frequency identification for item management—Part 6: Parameters for air interface communications at 860 MHz to 960 MHz General
	ISO/IEC 18000-7:2014 Information technology—Radio frequency identification for item management—Part 7: Parameters for active air interface communications at 433 MHz
	ISO/IEC 18000-61:2012 Information technology—Radio frequency identification for item management—Part 61: Parameters for air interface communications at 860 MHz to 960 MHz Type A
	ISO/IEC 18000-62:2012 Information technology—Radio frequency identification for item management—Part 62: Parameters for air interface communications at 860 MHz to 960 MHz Type B
	ISO/IEC 18000-63:2021 Information technology—Radio frequency identification for item management—Part 63: Parameters for air interface communications at 860 MHz to 960 MHz Type C
	ISO/IEC 18000-64:2012 Information technology—Radio frequency identification for item management—Part 64: Parameters for air interface communications at 860 MHz to 960 MHz Type D
	ISO/IEC TR 18001:2004 Information technology—Radio frequency identification for item management—Application requirements profiles
	ISO/IEC 18004:2015 Information technology—Automatic identification and data capture techniques—QR Code bar code symbology specification
	ISO/IEC CD 18004 Information technology—Automatic identification and data capture techniques—QR Code bar code symbology specification
	ISO/IEC 18046-1:2011 Information technology—Radio frequency identification device performance test methods—Part 1: Test methods for system performance
	ISO/IEC 18046-2:2020 Information technology—Radio frequency identification device performance test methods—Part 2: Test methods for interrogator performance
	ISO/IEC 18046-3:2020 Information technology—Radio frequency identification device performance test methods—Part 3: Test methods for tag performance
	ISO/IEC 18046-4:2015 Information technology—Radio frequency identification device performance test methods—Part 4: Test methods for performance of RFID gates in libraries

Table A1. Cont.

Field	ISO Standard
	ISO/IEC 18047-2:2012 Information technology—Radio frequency identification device conformance test methods—Part 2: Test methods for air interface communications below 135 kHz
	ISO/IEC 18047-3:2022 Information technology—Radio frequency identification device conformance test methods—Part 3: Test methods for air interface communications at 13,56 MHz
	ISO/IEC TR 18047-4:2004 Information technology—Radio frequency identification device conformance test methods—Part 4: Test methods for air interface communications at 2,45 GHz
	ISO/IEC 18047-6:2017 Information technology—Radio frequency identification device conformance test methods—Part 6: Test methods for air interface communications at 860 MHz to 960 MHz
	ISO/IEC TR 18047-7:2010 Information technology—Radio frequency identification device conformance test methods—Part 7: Test methods for active air interface communications at 433 MHz
	ISO/IEC DIS 18047-63 Information technology—Radio frequency identification device conformance test methods—Part 63: Test methods for air interface communications at 860 MHz to 960 MHz
	ISO/IEC 18050:2006 Information technology—Office equipment—Print quality attributes for machine readable Digital Postage Marks
	ISO/IEC 18180:2013 Information technology—Specification for the Extensible Configuration Checklist Description Format (XCCDF) Version 1.2
	ISO/IEC 18305:2016 Information technology—Real time locating systems—Test and evaluation of localization and tracking systems
	ISO/IEC 19502:2005 Information technology—Meta Object Facility (MOF)
	ISO/IEC 19503:2005 Information technology—XML Metadata Interchange (XMI)
	ISO/IEC 19508:2014 Information technology—Object Management Group Meta Object Facility (MOF) Core
	ISO/IEC 19509:2014 Information technology—Object Management Group XML Metadata Interchange (XMI)
	ISO/IEC TR 19583-1:2019 Information technology—Concepts and usage of metadata—Part 1: Metadata concepts
	ISO/IEC DTR 19583-21.2 Information technology—Concepts and usage of metadata—Part 21: 11179-3 Data model in SQL
	ISO/IEC TR 19583-22:2018 Information technology—Concepts and usage of metadata—Part 22: Registering and mapping development processes using ISO/IEC 19763
	ISO/IEC TR 19583-23:2020 Information technology—Concepts and usage of metadata—Part 23: Data element exchange (DEX) for a subset of ISO/IEC 11179-3
	ISO/IEC DTR 19583-24 Information technology—Concepts and usage of metadata—Part 24: 11179-3:2013 Metamodel in RDF
	ISO/IEC 19762:2016 Information technology—Automatic identification and data capture (AIDC) techniques—Harmonized vocabulary

Table A1. Cont.

Field	ISO Standard
	ISO/IEC 19763-1:2015 Information technology—Metamodel framework for interoperability (MFI)—Part 1: Framework
	ISO/IEC CD 19763-1 Information technology—Metamodel framework for interoperability (MFI)—Part 1: Framework
	ISO/IEC 19763-3:2020 Information technology—Metamodel framework for interoperability (MFI)—Part 3: Metamodel for ontology registration
	ISO/IEC 19763-5:2015 Information technology—Metamodel framework for interoperability (MFI)—Part 5: Metamodel for process model registration
	ISO/IEC 19763-6:2015 Information technology—Metamodel framework for interoperability (MFI)—Part 6: Registry Summary
	ISO/IEC 19763-7:2015 Information technology—Metamodel framework for interoperability (MFI)—Part 7: Metamodel for service model registration
	ISO/IEC 19763-8:2015 Information technology—Metamodel framework for interoperability (MFI)—Part 8: Metamodel for role and goal model registration
	ISO/IEC TR 19763-9:2015 Information technology—Metamodel framework for interoperability (MFI)—Part 9: On demand model selection
	ISO/IEC 19763-10:2014 Information technology—Metamodel framework for interoperability (MFI)—Part 10: Core model and basic mapping
	ISO/IEC CD 19763-10 Information technology—Metamodel framework for interoperability (MFI)—Part 10: Core model and basic mapping
	ISO/IEC 19763-12:2015 Information technology—Metamodel framework for interoperability (MFI)—Part 12: Metamodel for information model registration
	ISO/IEC TS 19763-13:2016 Information technology—Metamodel framework for interoperability (MFI)—Part 13: Metamodel for form design registration
	ISO/IEC 19763-16:2021 Information technology—Metamodel framework for interoperability (MFI)—Part 16: Metamodel for document model registration
	ISO/IEC 19773:2011 Information technology—Metadata Registries (MDR) modules
	ISO/IEC TR 19782:2006 Information technology—Automatic identification and data capture techniques—Effects of gloss and low substrate opacity on reading of bar code symbols
	ISO/IEC TR 20017:2011 Information technology—Radio frequency identification for item management—Electromagnetic interference impact of ISO/IEC 18000 interrogator emitters on implantable pacemakers and implantable cardioverter defibrillators
	ISO/IEC 20248:2018 Information technology—Automatic identification and data capture techniques—Data structures—Digital signature meta structure
	ISO/IEC 20248 Information technology—Automatic identification and data capture techniques—Digital signature data structure schema

Table A1. Cont.

Field	ISO Standard
	ISO/IEC 20830:2021 Information technology—Automatic identification and data capture techniques—Han Xin Code bar code symbology specification
	ISO 20909:2019 Radio frequency identification (RFID) tyre tags
	ISO 20910:2019 Coding for radio frequency identification (RFID) tyre tags
	ISO/IEC TR 20943-1:2003 Information technology—Procedures for achieving metadata registry content consistency—Part 1: Data elements
	ISO/IEC TR 20943-3:2004 Information technology—Procedures for achieving metadata registry content consistency—Part 3: Value domains
	ISO/IEC TR 20943-5:2013 Information technology—Procedures for achieving metadata registry content consistency—Part 5: Metadata mapping procedure
	ISO/IEC TR 20943-6:2013 Information technology—Procedures for achieving metadata registry content consistency—Part 6: Framework for generating ontologies
	ISO/IEC 20944-1:2013 Information technology—Metadata Registries Interoperability and Bindings (MDR-IB)—Part 1: Framework, common vocabulary, and common provisions for conformance
	ISO/IEC 20944-2:2013 Information technology—Metadata Registries Interoperability and Bindings (MDR-IB)—Part 2: Coding bindings
	ISO/IEC 20944-3:2013 Information technology—Metadata Registries Interoperability and Bindings (MDR-IB)—Part 3: API bindings
	ISO/IEC 20944-4:2013 Information technology—Metadata Registries Interoperability and Bindings (MDR-IB)—Part 4: Protocol bindings
	ISO/IEC 20944-5:2013 Information technology—Metadata Registries Interoperability and Bindings (MDR-IB)—Part 5: Profiles
	ISO/IEC 21277:2018 Information technology—Radio frequency identification device performance test methods—Crypto suite
	ISO/IEC/IEEE 21450:2010 Information technology—Smart transducer interface for sensors and actuators—Common functions, communication protocols, and Transducer Electronic Data Sheet (TEDS) formats
	ISO/IEC/IEEE 21451-1:2010 Information technology—Smart transducer interface for sensors and actuators—Part 1: Network Capable Application Processor (NCAP) information model
	ISO/IEC/IEEE 21451-2:2010 Information technology—Smart transducer interface for sensors and actuators—Part 2: Transducer to microprocessor communication protocols and Transducer Electronic Data Sheet (TEDS) formats
	ISO/IEC/IEEE 21451-4:2010 Information technology—Smart transducer interface for sensors and actuators—Part 4: Mixed-mode communication protocols and Transducer Electronic Data Sheet (TEDS) formats

Table A1. Cont.

Field	ISO Standard
	ISO/IEC/IEEE 21451-7:2011 Information technology—Smart transducer interface for sensors and actuators—Part 7: Transducer to radio frequency identification (RFID) systems communication protocols and Transducer Electronic Data Sheet (TEDS) formats
	ISO/IEC 21471:2020 Information technology—Automatic identification and data capture techniques—Extended rectangular data matrix (DMRE) bar code symbology specification
	ISO/IEC 22243:2019 Information technology—Radio frequency identification for item management—Methods for localization of RFID tags
	ISO/PRF TR 22251-1 Application Guideline for use of RFID on Returnable Transport Items—Part 1: For metal returnable transport items
	ISO/DTR 22251-2 Application Guideline for use of RFID on Returnable Transport Items—Part 2: For Plastic RTIs
	ISO/IEC 22603-1:2021 Information technology—Digital representation of product information—Part 1: General requirements
	ISO/IEC DIS 22603-2 Information technology—Digital representation of product information—Part 2: Requirements for electronic devices with integral display
	ISO/IEC 23200-1:2021 Information technology—Radio frequency identification for item management—Part 1: Interference rejection performance test method between a tag as defined in ISO/IEC 18000-63 and a heterogeneous wireless system
	ISO/IEC DIS 23200-2 Information technology—Radio frequency identification for item management—Part 2: Interference rejection performance test method between an Interrogator as defined in ISO/IEC 18000-63 and a heterogeneous wireless system
	ISO/IEC 23634:2022 Information technology—Automatic identification and data capture techniques—JAB Code polychrome bar code symbology specification
	ISO/IEC 23941:2022 Information technology—Automatic identification and data capture techniques—Rectangular Micro QR Code (rMQR) bar code symbology specification
	ISO/IEC TR 24244:2022 Automatic identification and data capture techniques—Bar code print quality test specification—Evolution of the grading and measurement of linear symbols in ISO/IEC 15416
	ISO/IEC 24458:2022 Information technology—Automatic identification and data capture techniques—Bar code printer and bar code reader performance testing specification
	ISO/IEC TR 24720:2008 Information technology—Automatic identification and data capture techniques—Guidelines for direct part marking (DPM)
	ISO/IEC 24723:2010 Information technology—Automatic identification and data capture techniques—GS1 Composite bar code symbology specification
	ISO/IEC 24724:2011 Information technology—Automatic identification and data capture techniques—GS1 DataBar bar code symbology specification
	ISO/IEC 24728:2006 Information technology—Automatic identification and data capture techniques—MicroPDF417 bar code symbology specification

Table A1. Cont.

Field	ISO Standard
	ISO/IEC TR 24729-1:2008 Information technology—Radio frequency identification for item management—Implementation guidelines—Part 1: RFID-enabled labels and packaging supporting ISO/IEC 18000-6C
	ISO/IEC TR 24729-2:2008 Information technology—Radio frequency identification for item management—Implementation guidelines—Part 2: Recycling and RFID tags
	ISO/IEC TR 24729-3:2009 Information technology—Radio frequency identification for item management—Implementation guidelines—Part 3: Implementation and operation of UHF RFID Interrogator systems in logistics applications
	ISO/IEC TR 24729-4:2009 Information technology—Radio frequency identification for item management—Implementation guidelines—Part 4: Tag data security
	ISO/IEC 24730-1:2014 Information technology—Real-time locating systems (RTLS)—Part 1: Application programming interface (API)
	ISO/IEC 24730-2:2012 Information technology—Real time locating systems (RTLS)—Part 2: Direct Sequence Spread Spectrum (DSSS) 2,4 GHz air interface protocol
	ISO/IEC 24730-5:2010 Information technology—Real-time locating systems (RTLS)—Part 5: Chirp spread spectrum (CSS) at 2,4 GHz air interface
	ISO/IEC 24730-21:2012 Information technology—Real time locating systems (RTLS)—Part 21: Direct Sequence Spread Spectrum (DSSS) 2,4 GHz air interface protocol: Transmitters operating with a single spread code and employing a DBPSK data encoding and BPSK spreading scheme
	ISO/IEC 24730-22:2012 Information technology—Real time locating systems (RTLS)—Part 22: Direct Sequence Spread Spectrum (DSSS) 2,4 GHz air interface protocol: Transmitters operating with multiple spread codes and employing a QPSK data encoding and Walsh offset QPSK (WOQPSK) spreading scheme
	ISO/IEC 24730-61:2013 Information technology—Real time locating systems (RTLS)—Part 61: Low rate pulse repetition frequency Ultra Wide Band (UWB) air interface
	ISO/IEC 24730-62:2013 Information technology—Real time locating systems (RTLS)—Part 62: High rate pulse repetition frequency Ultra Wide Band (UWB) air interface
	ISO/IEC 24753:2011 Information technology—Radio frequency identification (RFID) for item management—Application protocol: encoding and processing rules for sensors and batteries
	ISO/IEC 24769-2:2013 Information technology—Real-time locating systems (RTLS) device conformance test methods—Part 2: Test methods for air interface communication at 2,4 GHz
	ISO/IEC 24769-5:2012 Information technology—Automatic identification and data capture techniques—Real time locating systems (RTLS) device conformance test methods—Part 5: Test methods for chirp spread spectrum (CSS) at 2.4 GHz air interface
	ISO/IEC 24769-61:2015 Information Technology—Real Time Locating System (RTLS) Device Conformance Test Methods—Part 61: Low rate pulse repetition frequency Ultra Wide Band (UWB) air interface
	ISO/IEC 24769-62:2015 Information Technology—Real Time Locating System (RTLS) Device Conformance Test Methods—Part 62: High rate pulse repetition frequency Ultra Wide Band (UWB) air interface

Table A1. Cont.

Field	ISO Standard
	ISO/IEC 24770-5:2019 Information technology—Real-time locating system (RTLS) device performance test methods—Part 5: Test methods for chirp spread spectrum (CSS) air interface
	ISO/IEC 24770-61:2015 Information technology—Real Time Locating System (RTLS) device performance test methods—Part 61: Low rate pulse repetition frequency Ultra Wide Band (UWB) air interface
	ISO/IEC 24770-62:2015 Information technology—Real-time locating system (RTLS) device performance test methods—Part 62: High rate pulse repetition frequency Ultra Wide Band (UWB) air interface
	ISO/IEC 24770:2012 Information technology—Real-time locating system (RTLS) device performance test methods—Test methods for air interface communication at 2,4 GHz
	ISO/IEC 24778:2008 Information technology—Automatic identification and data capture techniques—Aztec Code bar code symbology specification
	ISO/IEC CD 24778 Information technology—Automatic identification and data capture techniques—Aztec Code bar code symbology specification
	ISO/IEC 24791-1:2010 Information technology—Radio frequency identification (RFID) for item management—Software system infrastructure—Part 1: Architecture
	ISO/IEC 24791-2:2011 Information technology—Radio frequency identification (RFID) for item management—Software system infrastructure—Part 2: Data management
	ISO/IEC 24791-3:2014 Information technology—Radio frequency identification (RFID) for item management—Software system infrastructure—Part 3: Device management
	ISO/IEC DIS 24791-3 Information technology—Radio frequency identification (RFID) for item management—Software system infrastructure—Part 3: Device management
	ISO/IEC 24791-5:2012 Information technology—Radio frequency identification (RFID) for item management—Software system infrastructure—Part 5: Device interface
	ISO 28219:2017 Packaging—Labelling and direct product marking with linear bar code and two-dimensional symbols
	ISO 28560-1:2014 Information and documentation—RFID in libraries—Part 1: Data elements and general guidelines for implementation
	ISO 28560-2:2018 Information and documentation—RFID in libraries—Part 2: Encoding of RFID data elements based on rules from ISO/IEC 15962
	ISO 28560-3:2014 Information and documentation—RFID in libraries—Part 3: Fixed length encoding
	ISO/TS 28560-4:2014 Information and documentation—RFID in libraries—Part 4: Encoding of data elements based on rules from ISO/IEC 15962 in an RFID tag with partitioned memory
	ISO/IEC 29133:2010 Information technology—Automatic identification and data capture techniques—Quality test specification for rewritable hybrid media data carriers
	ISO/IEC 29143:2011 Information technology—Automatic identification and data capture techniques—Air interface specification for Mobile RFID interrogators

Table A1. Cont.

Field	ISO Standard
	ISO/IEC 29158:2020 Information technology—Automatic identification and data capture techniques—Direct Part Mark (DPM) Quality Guideline
	ISO/IEC 29160:2020 Information technology—Radio frequency identification for item management—RFID Emblem
	ISO/IEC 29161:2016 Information technology—Data structure—Unique identification for the Internet of Things
	ISO/IEC TR 29162:2012 Information technology—Guidelines for using data structures in AIDC media
	ISO/IEC 29167-1:2014 Information technology—Automatic identification and data capture techniques—Part 1: Security services for RFID air interfaces
	ISO/IEC 29167-10:2017 Information technology—Automatic identification and data capture techniques—Part 10: Crypto suite AES-128 security services for air interface communications
	ISO/IEC 29167-11:2014 Information technology—Automatic identification and data capture techniques—Part 11: Crypto suite PRESENT-80 security services for air interface communications
	ISO/IEC DIS 29167-11 Information technology—Automatic identification and data capture techniques—Part 11: Crypto suite PRESENT-80 security services for air interface communications
	ISO/IEC 29167-12:2015 Information technology—Automatic identification and data capture techniques—Part 12: Crypto suite ECC-DH security services for air interface communications
	ISO/IEC 29167-13:2015 Information technology—Automatic identification and data capture techniques—Part 13: Crypto suite Grain-128A security services for air interface communications
	ISO/IEC 29167-14:2015 Information technology—Automatic identification and data capture techniques—Part 14: Crypto suite AES OFB security services for air interface communications
	ISO/IEC TS 29167-15:2017 Information technology—Automatic identification and data capture techniques—Part 15: Crypto suite XOR security services for air interface communications
	ISO/IEC 29167-16:2015 Information technology—Automatic identification and data capture techniques—Part 16: Crypto suite ECDSA-ECDH security services for air interface communications
	ISO/IEC DIS 29167-16 Information technology—Automatic identification and data capture techniques—Part 16: Crypto suite ECDSA-ECDH security services for air interface communications
	ISO/IEC 29167-17:2015 Information technology—Automatic identification and data capture techniques—Part 17: Crypto suite crypto GPS security services for air interface communications
	ISO/IEC 29167-19:2019 Information technology—Automatic identification and data capture techniques—Part 19: Crypto suite RAMON security services for air interface communications
	ISO/IEC 29167-21:2018 Information technology—Automatic identification and data capture techniques—Part 21: Crypto suite SIMON security services for air interface communications
	ISO/IEC 29167-22:2018 Information technology—Automatic identification and data capture techniques—Part 22: Crypto suite SPECK security services for air interface communications

Table A1. Cont.

Field	ISO Standard
Material, product, and goods data	ISO 37180:2021 Smart community infrastructures—Guidance on smart transportation with QR code identification and authentication in transportation and its related or additional services
	ISO/IEC 30116:2016 Information technology—Automatic identification and data capture techniques—Optical Character Recognition (OCR) quality testing
	ISO 8887-1:2017 Technical product documentation—Design for manufacturing, assembling, disassembling and end-of-life processing—Part 1: General concepts and requirements
	ISO/TR 23087:2018 Automation systems and integration—The Big Picture of standards

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