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Assessment methods and digital tools to support circular building strategies

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Assessment methods and digital tools to support circular building strategies

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Abstract. The aim of the paper is to highlight how digital technology can be a vector for maintaining information of buildings products, promoting supply chain transparency and traceability of materials and environmental data, contributing to activate a sustainable circular economy. Indeed, the current lack of knowledge of product characteristics often hinders the activation of reverse logistic and the assessment of the environmental benefits of circular material flows. This means, on one hand, the need to trace and collect product characteristics and product environmental information throughout the entire life cycle, and, on the other hand, the to identify ways of communicating and sharing information. This paper outlines current digital tools to support transparency and traceability of materials. Next, the paper verticalises the method and indicators used to declare the circular and sustainable profile of products, emphasising the importance of applying Life Cycle Assessment (LCA). Finally, the prefiguration of a possible integration between traceability tools and the LCA methodology is discussed, identifying possible drivers (e.g. legislative, trainings) and possible key-operators for the widespread of the "LCA-integrated traceability tools".

Keywords: circular economy, traceability, indicators, methods, Life Cycle Assessment, digital technology.

1. Introduction

The transition towards circular economy represents an opportunity for construction sector to rethink the management of materials flows, with the aim of extending the life cycle of products (e.g. though reuse and recycling).

In order to facilitate investment, the European Union [1], has introduced three basic elements to establish a sustainable financial framework. This framework provides for: I) a classification system or «Taxonomy» of sustainable activities, allowing for a common definition of sustainability to be shared, avoiding the practice of greenwashing; II) a disclosure framework for financial and non-financial companies, defining the information that companies must disclose about their environmental performance; and III) investment tools that provide operators with greater transparency, including benchmark indices and labels.

In this context, circular economy plays a key role, as it is included among the six climate and environmental objectives (specifically they are: I. climate change mitigation; II. climate change adaptation; III. Sustainable use and protection of water or marine resources; IV. transition to a circular economy; V. pollution prevention and control; VI. protection and restoration of biodiversity and ecosystems) of the Taxonomy classification system, to define whether an economic activity falls within the scope of environmental and climate sustainability.

Under this framework, every economic activity (including, therefore, construction and renovation activities) is required to provide documentation declaring that the activity contributes to one or more climate objectives and does not harm them (Do No Significant Harm, DNSH).

Within Taxonomy (Annex C, 3851) the substantial contributions to the transition to a circular economy of new construction, building renovation or demolition activities are related to:

- the reuse and recycling of construction and demolition waste generated on the construction site must be at least 90% (for new building and demolition) by mass in kilogrammes (excluding backfilling), going forwards the Waste Framework Directive 2008/98/CE (even if, for renovation activity, 70% is still required), assessing the materials flow with pre-demolition audit and waste management plans;
- the life-cycle Global Warming Potential (GWP) of the building resulting from the construction has been calculated for each stage in the life cycle;
- construction designs and techniques support circularity via the incorporation of concepts for design for adaptability and deconstruction;
- the use of primary raw material in the construction of the building is minimized, through the use of secondary raw materials, setting the percentage of secondary raw material from the total amount of each material category used in the works measured by mass in kilogrammes.

In this context, transparency of the supply chain, traceability of materials and environmental information, contribute to a sustainable circular economy. Indeed, it is necessary to trace and collect product characteristics and environmental information throughout the entire life cycle. However, the current lack of knowledge of product characteristics often hampers the possibility to assess the circular materials flows.

Furthermore, the assessment of building traceability and the communication of the circular indicator are two relevant issue to be clarified. Both practitioners (who have to trace and demostrate the circularity of products) and users (who have to understand and choose circular products) need clear supporting tools, methods and indicators.

Digital technologies are seen as means to achieve the required transparency, increasing traceability and efficiency and providing real-time information about a product at all stages of its life cycle and to all stakeholders. With supporting digital tools, it is seen as possible not only to support the transition to a circular economy, but also to enable the scalability of impacts and information [2].

This paper outlines the current state of digital tools considered to support the collection and storage of product and building information, highlighting the different information gathered, as well as the methods and indicators used to assess and communicate the level of circular economy of products/buildings, highlighting the different parameters and their readability and comprehensibility depending on the type of user (expert or not).

2. Method

This paper explores emerging digital technologies and evaluation methods related to the circular economy. Based on a desk research of EU policies and current scientific literature (through keyword searches in google scholar databases), this paper sets out an overview of the main digital tools and methods and indicators, as described below.

From the side of "digital technologies", there are the recently discussed Digital Product Passports, which mainly refer to cross-sectoral products (much discussed at policy level), Material Passports, which mainly refer to construction products, and Digital Building Logbooks, which refer to the building level [3]. They mainly concern the activities of manufacturers, designers and builders.

From the other side of "methods and indicators", there are several methods and indicators proposed by organizations and universities to measure circularity of products adapted to products/buildings such as: the Ellen MacArthur Foundation's Material Circularity Indicator, the guidelines established by

ISO/DIS 59020 standard “Circular economy. Measuring and assessing circularity”, the LCA indicators used to assess the environmental sustainability of circularity. They are primarily aimed at end-users or decision-makers of various circular choices (e.g. planners, policy-makers, customers).

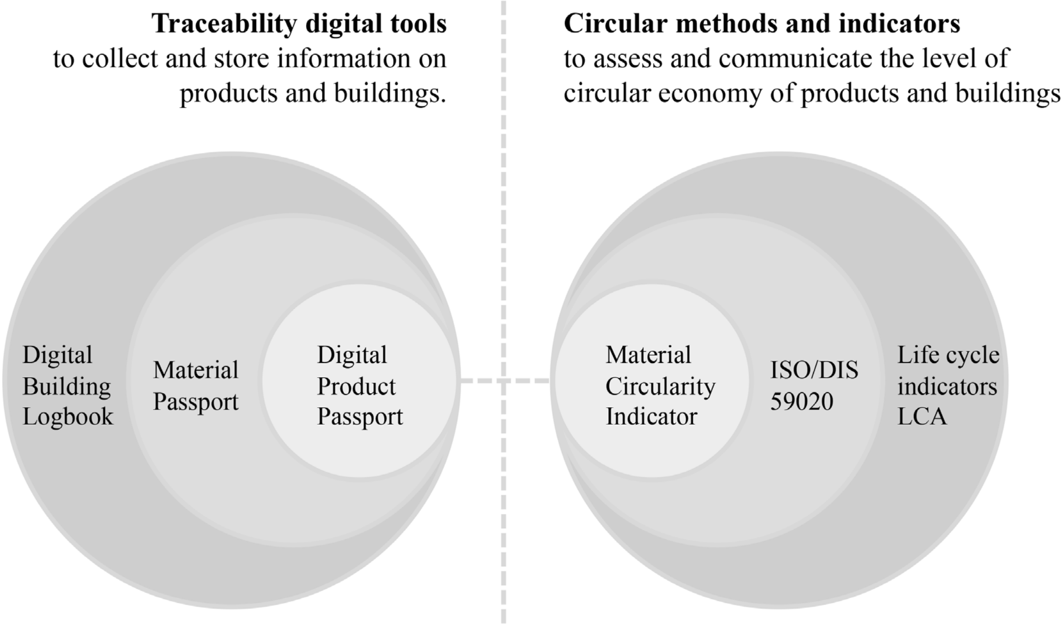

Fig. 1. Existing digital tools and assessment method to support circularity

Based on this framework, the paper compares traceability and evaluation tools/methods in a structured way, highlighting the following key-features:

Area of applicability	**Level of applicability**	**Type of support driver**	**Readability – end-users**	**Information content**
Cross-sectoral	Product	Top-down	Expert	List information for product traceability
Building sector	Building	Bottom-up	Non-expert	List of circular indicators and assumption

The key-features analysis is conducted in order to highlight the specific current barriers and challenges of digital traceability technologies and circular economy method and indicator in the construction sector, both at product level and building level. The paper (in the discussion session) also illustrates the level of diffusion of digital traceability tools and circular economy indicators (including LCA) in practice, in the construction sector. This results from a series of stakeholder engagements conducted by the author in various research activities and stakeholder working groups.

Finally, the paper prefigures the possible integration of traceability tools and circular indicators linked to the Life Cycle Assessment method (“LCA-integrated traceability tools”), to activate sustainable circular practices at the level of building design and end-of-life management.

However, there is still no real application of “LCA-integrated traceability tools” in practice. Therefore, it is not possible to assess the limits and obstacles of application.

3. Digital tools to trace traceability and transparency of products/buildings

In order to increase circular economy strategies as well as the durability, reusability, upgradability, and reparability of products, the European Commission, as part of its Circular Economy Action Plan

[4], highlights as a legislative initiative the "potential of digitalisation of product information", including solutions such as Digital Passports.

The idea of the Digital Passport finds a context of feasibility thanks to the development of "digital twin" enabled by software capable of designing and storing product information, such as Building Information Modeling (BIM), and the field of product certification based on the analysis of input and output flow, such as Environmental Product Declaration (EPD).

In addition, the Digital Passport in the construction sector can be linked to the Materials Passport, already discussed in scientific research and applied in practice by private entities, such as the Madaster Foundation.

In the particular case of the construction sector, the European Commission, also within its Circular Economy Action Plan [4], declares its willingness to promote a Digital Buildings Logbooks, as dynamic tool enabling a common repository for all relevant building data, including building owners, tenants, investors, financial institutions and public administrations.

The main differences between the three digital tools concern the scale of applicability (e.g. Product; Buildings), the sector of application (cross-sector or building sector) [3] and the supporting drivers, whether "top-down" (established by the will of European Commission) or "bottom-up" (established by private initiative and voulontary adopted by companies). In the next paragraph, all digital tools are described in detail.

Table 1. Main differences between the three digital tools

Traceability Digital Tool	**Area of applicability**	**Level of applicability**	**Support drivers**
Digital Passport	Cross-sector	Product	Top-dow
Materials Passport	Building sector	Product/Building	Bottom-up
Digital Logbooks	Building sector	Building	Top-dow

3.1. Digital Product Passports: information content

The digital product passports initiative is part of the proposal of Ecodesign for Sustainable Products Regulation (ESPR), published on 30 March 2022, which set that the Digital Product Passport «include attributes such as the durability and reparability, recycled content or availability of spare parts of a product. It should help consumers and businesses make informed choices when purchasing products, facilitate repairs and recycling and improve transparency about products' life cycle impacts on the environment. The product passport should also help public authorities to better perform checks and controls» [5].

The Digital Product Passport is seen as an emerging opportunity to achieve traceability of product life cycle information to enhance circular economy. The data contained in the Digital Product Passport can be used to optimize design, production, use, and end-of-life and to fill the gap between the circular economy concept and its practical implementation [2].

Furthermore, the Digital Product Passport can be related to Blockchain[1] technology to secure better data, transparency and traceability of products [6], which is also useful to scale the impact of the circular economy.

[1] Blockchain is a new application mode of information technology that enables its participants (es. key users/actors in building/product management) to directly exchange effective and truthful information by transferring Internet (IoT) resources without centralised third parties [8, 9]. For example, to enable circular process, blockchain technology exchange direct communication of prescriptions (e.g. modularity, connessions, decisions made in the design phase) or assembly, use, maintenance, disassembly directions to other actors in the supply chain. In this way, the information goes beyond the memory of the individual operator and is passed on over time, even through the various cycles of use. The sharing of information allows a continuous updating of

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The Digital Product Passport combined with Blockchain technology can be an enabler for upscaling the circular economy, going beyond local and artisanal circular dynamics. This, consequently, promotes the "Circular Industial economy", as called by W. Stahel [7], supported by the diffusion of independent and large companies that have developed technologies, tools and methods to improve the maintenance, repair and remanufacturing of their products, encouraging the «performance economy», which considers a change in business models by placing the «sale of goods […] with the provide a service» [7].

In order to understand what information is included in the Digital Product Passport, the European Commission , as part of its proposal for a Ecodesign for Sustainable Products Regulation, establishes a framework that includes:

- product durability and reliability;
- product reusability;
- product upgradability, reparability, maintenance and refurbishment;
- presence of substances of concern in products;
- energy and resource efficiency of products;
- recycled content in products;
- possibilities for product remanufacturing and recycling;
- carbon and environmental footprints of products;
- expected generation of waste materials.

The construction sector is one of the fields of application of the Digital Product Passport, along with textiles, electric vehicle batteries, packaging, and food.

The Construction Product Regulation (CPR), the specific regulatory framework for the construction sector concerning the provision of product performance and ensuring in the European market, has included the requirement of the Digital Product Passports to deliver all information on construction products, in order to facilitate the management and distribution of manufacturers' information throughout the value chain, establishing a reliable and harmonised system fully integrated in Building Information [10]. In this context product information includes: safety information, instructions of use, performance and conformity declarations and the integration of environmental product information, already established by the CPR within the Environmental Product Declarations (EPDs) based on the EN 15804 methodology.

Recently there are private companies selling the service of creating digital product passport, ensuring compliance with EU regulations on product lifecycle sustainabilty and providing QR-code access to product data stored on public blockchains. In this case, the example of information collected concerns:

- company details (name, address, contact info);
- raw materials materials/ingredients origin (sourcing information);
- raw materials use of recycled materials/ingredients;
- details on manufacturing process;
- manufacturing certifications;
- environmental impact declaration;
- carbon footprint disclosure and verification;
- expected construction materials durability;
- recyclability of construction materials;
- recyclability of packaging of the product;
- waste materials, in order to mitigate waste generation;
- waste materials diverted from landfill;
- disposal instructions;

knowledge and the possibility of becoming aware of the actions carried out throughout the product/building life cycle, in a process of continuous improvement.

- waste materials diverted for recycling;
- material recovery or remanufacturing possibility;
- material recycling.

Currently the Digital Product Passport is not mandatory for the company. The technology already exists to implement an effective digital product passport, but enterprises will remain sceptical until the feasibility is proven at scale. The electric car battery sector is the test case (with the development of the "Battery Passport"), but probably the Digital Product Passport obligation will become more widespread when more legislation on supply chain traceability, which will include more product categories, comes into force [11].

3.2. Material Passport: information content

In the construction secto, one of the first experiments of the Digital Product Passport can be related to the Material Passport..

The Material Passport is an instrument that provides digitised qualitative and quantitative life cycle information on the characteristics of a building product to enable circular strategy. Material Passports can be up on the scale of a product, building system or building, storing information along the entire life cycle, in order to facilitate access to this information for the different actors in the value chain and support strategic decisions towards reusability and recyclability [12;13].

Although they play a crucial role in the transition from a linear to a circular construction industry, there is no regulatory framework for buildings that allows standardisation and establishes common bases [3].

The BAMB (Building As Material Banks) project introduced the Material Passports prototype that tracks the residual value of building products along the supply chain [14]. Whithin the BAMB project, around 70 products were linked to data carriers (QR codes) to demonstrate the application of Material Passports. A current example is the GTB Lab, where all building elements are equipped with a QR code, which contain a lot of product information [15].

Knowing the location, quantity and characteristics of the materials stored in a building makes it possible to know the consistency of materials that become available after the first cycle of use, for possible reuse, rework or recycling. Material passports are designed to activate the chain use of other technologies: starting from the information recorded through the BIM environment, GIS (Geo- graphic Information System) data can be updated and implemented, which in turn can feed CIM (City Information Modeling) data. This makes it possible to visualise and monitor the resources stored within the built environment, providing a knowledge base to be able to analyse and manage resource flows into (new materials) and out of (reusable products or recyclable waste) the built heritage with greater awareness.

The application of Material Passports is still scarce and in an early stage [16], but an example of a private initiative is the Madaster Foundation, in the Netherlands, which introduce an innovative Material Passport at the building level [17]. The initiative has developed an interactive platform with BIM source files for storing and exchanging data on materials, components and products stored in buildings. The main users are designers, building owners and facility managers who, thanks to the platform, can generate passports (information booklets) of a building.

The Madaster platform returns various information about both the building and the materials stored in it, processing the source Building Modeling file, and integrating the information with data from the platform's internal databases. If the input data are more granular, the Material Passport generated by the Madaster platform will be more detailed. Therefore, the accuracy of the information is primarily based on the completeness of the information imputed or stored in the digital twins of the BIM source file.

The Material Passport generated by Madaster shows information about the material stored in the building, including:

- the type of material (e.g. concrete, brick, steel, etc.);
- the relative total quantity;

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- the position within the different parts of the building (e.g. load-bearing structure; envelope, etc.);
- the composition of the materials;
- the total number of similar products (e.g. total number of steel beams);
- the residual economic value of the materials;
- information on circularity (reuse, recycling; reusability and recyclability);
- the disassemblability of materials.

With this information, the Madaster Material Passport returns the "'Economic Material Valuation" to determine the future value of materials and end-of-life management costs, and the "Madaster Circularity Indicator" which provides information on the degree of circularity of the building. This value is expressed in percentage terms, ranging from 0% (non-circular) to 100% (fully circular).

3.3. Digital Building Logbooks: information content

As part of the Circular Economy Action Plan, the European Commision [4], in order to promote measures to improve the durability and adaptability of the building stock in line with the principles of circular economy for buildings design, established the definition of Digital Building Logbooks.

Digital Building Logbooks are defined as «a common repository for all relevant building data; it facilitates transparency, trust, informed decision making and information sharing within the construction sector, among building owners and occupants, financial institutions and public authorities» [18].

The Digital Building Logbook aims at fostering circularity in the built environment by supporting the collection and transparent storage of information on building and construction materials (type, quantity/amount, origin, recycled content, end-of-life dismantling, reuse and recycling possibilities) facilitates source separation and increasing the quantity/quality of recycling, preventing waste and closing loops.

The collection, data, information and documents to be recorded on major events and changes during the life cycle of a building, such as change of ownership, tenure or use, maintenance, refurbishment and other interventions. It includes [18]:

The collection, data, information and documents to be recorded on major events and changes during the life cycle of a building, such as change of ownership or use, maintenance, renovation and other interventions. Includes

- administrative documents;
- plans;
- description of the land, building and its surrounding;
- technical systems;
- traceability and characteristics of building materials;
- performance data such as operational energy consumption;
- indoor environmental quality;
- smart building potential and life cycle emissions;
- links to all building ratings and certificates.

Again, building information modelling (BIM) and digital twin are considered the best opportunity to gather data on the building's physical characteristics, including information on the materials in the building and and their location.

Information on the operation, use and performance of the building (maintenance, transfer of ownership, change of use etc.). can be retrieved during the sales/leasing, operation and management phases of the property.

All known building data can support end-of-life decision-making, allowing the building to be renovated instead of demolished or materials to be reused/recycled rather instead of disposed.

4. Methods and indicators to communicate circular economy information of products/buildings

Following the collection of life cycle information, the need to define a way to communicate the level of circularity of products and buildings (also to facilitate the comparisons of different products or construction choices) becomes increasingly crucial.

In recent years, several indicators have been proposed by organizations and academia to measure the circularity of products or buildings. Starting from the Material Circularity Indicator, developed by the Ellen MacArthur Foundation and taken up by various companies and tools, such as the Madaster Materials Passport, the European Commission responded to the need to create a common framework with the definition of the ISO/DIS 59020 standard "Circular economy. Measuring and assessing circularity". In addition to these, the LCA methodology, provided by ISO 14040 - ISO 14044 and ISO 15978, is useful for assessing and declaring not only the "circular" information but also the "sustainability" profile of circular dynamics.

All methods can have a cross-sector application; the main differences between the three analysed methods concern the details of indicators, and the readability of the indicators based on end-users. In the next paragraph all methods and indicators are described in detail.

Table 2. Main differences between the circular assessment method

Methods and indicators	**Area of applicability**	**Scale of applicability**	**Numeber of indicators**	**Readability – end-users**
Material Circularity Indicator	Cross-sector	Product / Building (if within Madaster)	1 indicator	Non-expert
ISO/DIS 59020	Cross-sector	Product	5 chategories of indicator (a total of 14 indicators)	Non-expert
Life Cycle Assessment	Cross-sector	Product / Building	12 (environmental) indicators	Expert

4.1. Material Circularity Indicator

The Material Circularity Indicator (MCI), developed in 2015 by the Ellen MacArthur Foundation, is one of the most well-known circularity indicators [19].

The MCI is based on four principles [20]: i) using feedstock from re-used or recycled sources; ii) reuse components or recycle materials after product use; iii) keep products in use longer (e.g. through re-use/redistribution); iv) make more intensive use of products (e.g. through service or performance models). The MCI is constructed from a combination of three product characteristics: the mass of a virgin raw material used in manufacture, the mass of non-recoverable waste attributed to the product, and a utility factor that takes into account the duration and intensity of the product's use.

Madaster's material passports adopted the Circularity Indicator method, which provides information on the degree of circularity of the building. The Madaster Material Circularity Indicator measures the level of circularity of buildings during 3 different phases:

- construction phase, in which the ratio between the volume of "virgin" materials and the volume of "recycled, reused or renewable" materials used is calculated;
- use phase, in which the expected functional life cycle of the products used is compared with the average functional life cycle of similar products;
- end-of-life phase, in which the ratio between the volume of "waste" and the volume of "reusable and/or recyclable" materials and products is calculated from the total amount of materials from demolition processes.

The indication of the level of circularity is intended to trigger a bottom-up leverage for stakeholders (investors, owners, etc.) wishing to equip themselves with material passports, in order to achieve 100% non-virgin materials in the construction phase, maximum product life extension in the use phase and 100% reuse/recycling of materials/waste in the end-of-life phase

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4.2. ISO /DIS 59020 "Circular economy. Measuring and assessing circularity"

The ISO/DIS 59020 standard provides a structured approach for measuring and evaluating circularity performance and sustainability impacts.

This standard aims to provide a clear and structured methodology for measuring and evaluating circularity performance standardizing the process by which organizations collect and calculate data using mandatory and optional circularity indicators, ensuring consistent and verifiable results. It provides a structured framework for defining system boundaries, selecting appropriate indicators, and interpreting data to assess circularity performance at multiple levels, from regional and inter-organizational to organizational and product-specific [21].

According to the standard, circularity indicators are organized into categories in terms of material, water, and energy and economy. The indicator categories are:

- Resource Inflows:
  - Average percent reused content of an inflow;
  - Average percent recycled content of an inflow;
  - Average percent renewable content of an inflow;
- Resource outflows:
  - Average lifetime of product or material relative to industry average
  - Percent actual reused content derived from outflow
  - Actual % recycling rate of outflow
  - Percent actual recirculation of outflow in the biological cycle
- Energy:
  - Average percent of energy consumed that is renewable energy
- Water:
  - Percent water withdrawal from circular sources
  - Percent water discharged in accordance with quality requirements
  - Ratio (onsite or internal) water reuse or recirculation
- Economic:
  - Revenue share of circular resources (or products) (Percent of total revenue generated per year by use of circular (and/or) non-circular resources)
  - Material productivity (Ratio of revenue generated by total mass of all linear resource inflows)
  - Resource intensity index (Quantitative measure of economic growth versus total resource use)

ISO/DIS 59020 states that in addition to circularity performance, a broad sustainability perspective must be considered to maximize the contribution to sustainable development.

To this end, ISO/DIS 59020 suggests to apply existing methods, approaches, guidelines, or standards to measure additional circularity aspects, as well as Life Cycle Assessment (ISO14040/14044) and Material Flow Analysis (ISO 14053) to consider environamental aspects and materials flows; and Social Responsibility standards (ISO 26000), and Life Cycle Costing methods (ISO 15686-5) to consider economic and social aspects. The list of these "complementary methods" is included in the Annex C of ISO/DIS 59020.

4.3. LCA methodology to measure circularity

As part of the transition to circular economy in the building sector, some Member States have promoted the widespread application of Life Cycle Assessment at the legislative level, providing methodological frameworks and tools to be used during the design phase.

These LCA tools aim to support planners, investors and policy-makers in comparing traditional and "circular" solutions, e.g. comparing the use of new materials with reused/recycled ones, assessing the environmental impact on the basis of a scientifically neutral method (LCA method). These life-cycle sustainability assessment tools, already on the market or in the process of being disseminated, are generally intended for the designer, who plays a key role in the choices, and are useful in the design decision phase to compare and quantify the economic and environmental sustainability of different design alternatives and different circularity strategies, such as the re-use of components.

These tools simplify the process of evaluating and analysing results thanks to an internal database, pre-established methodological aspects, such as allocation, normalisation and calculation methods for environmental indicators, and pre-established assumtions (e.g. maintence cycles and expeted life of products).

One example is the tool, developed in Belgium with government support to comply with the MMG (Milieugerelateerde Materiaalprestatie Gebouwelementen) policy and made available to practitioners free of charge. This tool is called TOTEM, which stands for Tool to Optimise the Total Environmental impact of Materials, based on the LCA methodology [22]. Within the TOTEM database, for example, parameters are already set that consider the recycled content and end-of-life scenarios of different types of materials, taking into account the percentage of recyclability or reusability to also assess different end-of-life scenarios for buildings. In addition, TOTEM outlines a common method to define scenarios for the number of replacements and maintenance of building products during the use stage (e.g. establishing the impact for cleaning with water or soap for different type of façades, external wall, internal walls, etc.). The number of replacements of a component during the service life of the building is defined: it is obtained by dividing the service life of the building by the service life of the component and reducing this result by 1 (the initial installation).

In the case of the application of LCA, the indicators for measuring circularity are in line with the environmental indicators established by the European LCA standards, presented by CEN/ TC 350, for environmental indicators and impact assessment defined by EN 15804:2012+A2:2019.

Therefore, for example, TOTEM currently includes 19 impact indicators which can be grouped into 12 main impact categories. The 12 main environmental impact categories listed below are included:

- Climate change
- Ozone depletion
- Acidification
- Eutrophication
- Photochemical ozone creation
- Depletion of abiotic resources
- Water use
- Particulate matter emissions
- Ionising radiation
- Eco-toxicity
- Human toxicity
- Land use

At the end of assessment, in accordance with EN 15804:2012+A2:2019, the impact can be aggregated into a single score. This means that, the characterised values of each individual environmental indicator are first normalised by dividing them with their respective normalisation factors. This allow all results to be expressed in one dimensionless unit. In a second step, the normalised results are weighted by multiplying them with the respective weighting factors. After weighting, the results of the different environmental indictors can be summed up to obtain a single overall score (expressed in milli-points in TOTEM).

As the indicators are difficult to read for non-experts, TOTEM (in compliance with the MMG policy) also offers the possibility to transform the indicators into more readable indicators, using monetization approach [23]. The impacts are monetised and calculated by multiplying the individual indicators by a monetisation factor.

5. Discussion on the relation between traceability tools and indicators for circular economy

The relationship between traceability tools and circularity indicator assessment methods is still unclear, both at the legislative and instrumental level. Moreover, some tools are defined to be applied in more than one sector, but it is necessary to take into account the specificities of the construction sector in their application, which is characterised by long process times (compared to industrial processes) and fragmented and discontinuous relationships between operators that do not facilitate the management and storage of information.

The context of Digital Product/Material Passports and Building Logbook is still heterogeneous and there is confusion between new information traceability tools and existing tools declaring product performance (e.g. EPDs). Current approaches lack a unifying scheme and vary in terminology, content, level of aggregation, use of technology and level of maturity [24].

In this scenario, the lack of understanding of the tools that should enable the dissemination of circular economy strategies by potential users may instead become a significant obstacle to their adoption. There is a need to harmonise tools to avoid market distortions and outdated results. In this context is necessary to development of a standardised approach for data collection, management and interoperability and the related legal framework.

In addition, companies that sell the product passport "study and editing service" without a clear quality certification of the data creation and collection procedure are spreading. This is still undefined and very risky because it could lead to the dissemination of environmental and circular information that fuels greenwashing, thus going against the original principles of taxonomy.

It is necessary to define dedicated bodies that can collect and store information with a certified level of quality, and that are responsible for managing access to and updating of information, developing guidelines for linking existing databases.

It follows that the legislative framework needs to be updated and clarified, but through a governance process that can accommodate all the current doubts and needs of the stakeholders who will have to generate and use such tools for traceability and transpartence of product information.

With regard to circularity indicators, there is still a lot of uncertainty and confusion, particularly with regard to the completeness of the information provided, and to whom this information is addressed, i.e. what level of expertise that the person reading the indicator must have.

On the one hand, simplified indicators have been developed that are easy to understand even for non-expert end-users, such as the MCI, which indicates a circularity value in percentage terms (0 to 100 per cent circularity). However, these indicators are somewhat reductive. They only consider the circularity of the material flow in terms of material reuse, recycling content, reusability, recyclability, neglecting the complexity of resource input/output flows that circular strategies trigger along the life cycle. Moreover, these simplified indicators do not clarify the true environmental profile of products, risking promoting circularity strategies that are not truly environmentally sustainable.

The indicators of ISO/DIS 59020, go into more detail in assessing the circularity of material flows and also consider flows of energy, water and even economic benefit. However, again, there is no clear restitution of the environmental impact that some certain circular products may generate. In addition, according to Patil et al. [25] there are still some important limitations in the assessment of ISO/DIS 59020 circularity, namely: the circularity performance of two systemic components cannot be compared if they are assessed using different indicator systems (depending on the objective and scope of each); the limited availability of data introduces uncertainty into the measurement and assessment process; economic impacts reflecting market changes may dynamically influence the assessment results.

In order to achieve greater control of the sustainability of products/buildings adopting circularity strategies, it is therefore essential to promote the use of Life Cycle assessment tools that comprehensively and comparably highlight the environmental loads and benefits (LCA) achievable through circularity strategies. This is essential to choose truly effective strategies in a life cycle assessment. LCA, in fact, allows to control the criticalities that an excessive push towards circularity can cause, by evaluating all life cycle phases and different impact indicators. For example, the promotion of reuse is not considered sustainable regardless of transport impacts; recycling is not considered sustainable by assessing only one environmental indicator without evaluating others (e.g. benefit of reduced CO_2 emissions but increased eutrophication impacts).

On the other hand, the application of the LCA method for the promotion of circularity is still little addressed. LCA indicators are complex and do not facilitate knowledge and awareness of the environmental benefits/costs of circular products. LCA indicators still remain cryptic and little used by end-users, remaining in the “B2B” sphere, as is the case of EPD environmental certifications.

Communicating the circularity of a product to the end-users is instead crucial to trigger a conscious process towards sustainable circular strategies. The role of consumers and their awareness is indeed crucial to influence a change in the economic system as a whole.

The solution found by tools such as TOTEM, which tried to define more comprehensible final circular indicator (e.g. expressed in money), is interesting. However, several problems persist in this field as well, mainly related to the definition of the monetisation factors to be assumed.

In order to integrate the emerging traceability tools with Life Cycle assessment methods, promotion initiatives are needed at the legislative level upstream to boost their use.

Before that, however, work is needed to spread awareness and knowledge of LCA methodologies and the ability to interpret the results against which optimisation and sustainability strategies can be defined. It is necessary to define indicators suitable for the user, i.e. indicators for experts, who must identify sustainable solutions to increase the circularity of products, and for non-experts, who must choose circular and sustainable products on the market.

Trying to identify which key actors of the building sector could be among the first to be involved in the testing of traceability tools integrated with LCA, one can mention manufacturers, who already have experience in collecting product information for existing certification, and the end-users, i.e. investors/users of building assets. Asset management companies play a special role here, as they are involved in all phases of the life cycle of their buildings, from the design phase, through the use/maintenance phase to decommissioning, collaborating closely with other actors in the building sector such as architects, construction companies and material suppliers. They hold a powerful position in the market and can influence the circular practices of the sector [3].

6. Conclusion

The paper highlights the need to foresee a possible integration between traceability tools and circular methods and indicators.

Several traceability tools are currently emerging, both cross-sectoral (Digital Product Passport) and construction-specific (Material Passport; Building Logbook). However, there are differences in terms of incentives, which can be supported by public (Digital Product Passport and Building Logbook) or private factors (Material Passport). In this context, a harmonisation of instruments is necessary, also in terms of the circular information collected. In addition, access to information and methods of updating data need to be clarified.

At the same time, various indicators and methods for evaluating circularity were discussed to meet the emerging need to communicate the circular economy level of products/buildings. However, different indicators have been developed and their readability and comprehensibility depending on the type of user (expert or not) is different. Furthermore, their readability is linked to the completeness of the assessment. Life cycle assessment methods (LCA, LCC, SLCA) are considered the most comprehensive and standardised, capable of assessing the real sustainability of circularity. However, it is still difficult to find indicators that are easy to read, but at the same time manage to consider all the complexities of the environmental and economic assessment of circularity.

Future areas of research will be to update the legislative framework through a governance process that can accommodate all the concerns and needs of stakeholders; to define the quality and responsibility of information management and updating, linking information from existing databases to new ones. Finally, it is necessary to define a training framework for: i) those who have to collect and manage the circular information (producers; building operators); those who have to use circular assessment methods (e.g. LCA experts) and interpret the results; and those who have to read and understand the circular indicators (end-users).

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