Chapter 5
From Data Templates to Material Passports and Digital Product Passports

Meliha Honic, Pedro Meda Magalhães, and Pablo Van den Bosch

Abstract Lack of data and difficulty in tracking materials and elements are two major obstacles in the construction industry that hinder the realisation of a circular economy. Data templates, material passports (MPs), and digital product passports (DPPs) are passport instruments that provide valuable information about buildings. Data templates deliver digital standardised data structures for MPs (digital data sets describing building characteristics of, e.g. elements) and DPPs (cross-sectoral passports developed by the European Union to collect product data for sustainability).

MPs, which are associated with the built environment, help urban miners and building owners assess the value and reuse potential of building materials and elements. Several initiatives, such as Madaster, Concular, and Platform CB'23, have produced data templates and MPs for new and existing buildings. Challenges to their use include the lack of standardisation of data templates and MPs and difficulties in collecting and tracing data needed to create and maintain MPs through a building's life cycle. Standardisation would foster the implementation of passports, but aligning existing concepts and identifying overlaps remains a present challenge. Future research and practice suggest that using geographic information systems, laser scanning, and computer vision will help deploy MPs more effectively in practice.

Keywords Building passport · Circular building · Data traceability · Standardisation · Reuse

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5.1 Data Templates, Material Passports, and Digital Product Passports

The European Union Circular Economy Action Plan (EU 2020) identified the digitisation of material and product information as a key driver for enhancing the transition to a circular economy. Several existing concepts are gaining attention in the construction industry: data templates, material passports (MPs), digital product passports (DPPs), circularity passports, product circularity data sheets, building renovation passports, and digital building logbooks. This chapter provides an overview of existing passport approaches. It discusses their common and distinct aspects and demonstrates their application to real-world examples and their role as enablers of a circular economy. It further presents the business models of Madaster, Concular, and Platform CB'23.

5.1.1 Differences Between MPs and DPPs

MPs and DPPs are valuable concepts that can enable a circular economy. Both types of digital data sets contain valuable information such as material properties and potentials for reuse and disassembly: MPs about buildings (BAMB 2020) and DPPs about any product (European Commission 2022a). MPs and DPPs make it easier to assess the value of materials and elements incorporated in existing buildings or products and can prevent them from being demolished or disposed of and enable reuse. While MPs, circularity passports, and building passports are more common in the built environment, DPPs can be used in any industry (including the built environment) and have a focus on products. (In this chapter, MP is used to refer to passports in the built environment unless the term DPP is stated explicitly in literature or practice.)

Although the differences between MPs and DPPs are not clearly stated in the academic literature, MPs have mostly been applied in the built environment. Many MPs exist in academia and practice, yet no consensus on the content, the data formats, and the main requirements are given. DPPs are a cross-sectoral, relatively new concept by the EU (European Commission 2020a), and they pursue the same aim as MPs: a circular economy. MPs lack a regulative framework to standardise and align various MP approaches, while for DPPs the backbone (EU regulatory framework) is established.

MPs have been identified as the main enablers of a circular economy in the built environment next to, e.g. blockchain, artificial intelligence, and building information modelling (BIM) (Çetin et al. 2021). The EU Horizon 2020 project Buildings as Material Banks (BAMB) defines MPs as "digital sets of data describing defined characteristics of materials and components in products and systems that give them value for present use, recovery, and reuse" (Mulhall et al. 2017). BAMB describes how MPs can be used by various stakeholders across the value chain for different purposes (Luscuere and Mulhall 2018). They can also be generated at the material, element, or building scales. An MP can, e.g. indicate the type of timber (material scale), display the material composition of a slab (element scale), or show the amount of timber used in the entire building (building scale) (Honic et al. 2019b). The lack of information on the material composition of buildings is a major obstacle in the construction industry (Rose and Stegemann 2019), and implementing MPs would allow circular material flows in the built environment.

In the European strategy for data, DPPs are described as passports that "provide information on a product's origin, durability, composition, reuse, repair and dismantling possibilities, and end-of-life handling" (European Commission 2020a). According to the same European strategy, DPPs are "a structured collection of product-related data with a predefined scope and agreed data ownership and access rights conveyed through a unique identifier", set on a "decentralised system with a central registry" with "information related to sustainability, circularity, value retention for reuse/remanufacturing/recycling". One practical example is circularise (Circularise 2023), which ensures supply chain tracking through DPPs. Even though the EU regulative framework for DPPs exists, the specific content, data formats, and data structures of DPPs are not defined. To enable an implementation of both, MPs and DPPs, in the daily practice of companies, their standardisation is needed, wherefore data templates can play a crucial role.

5.1.2 Data Templates for MPs and DPPs

Data templates are digital data structures used to generate MPs, DPPs, or any other digital passport. To establish standardised and structured MPs and DPPs, data templates are of utmost importance. Data templates provide data structures or "skeletons" that can support all types of characteristics from material to building scale of such passports and can be used to generate structured and standardised MPs and DPPs. The International Organization for Standardization (ISO) provides data templates for the built environment, but they are also used in other sectors, albeit often with different terminology. Data templates can also be referred to as "metadata structures" or "digital templates" and apply to all industries and areas of activity where digitalisation is a trend. The ISO 23387 standard established the information and digital requirements for data templates to become digital, traceable, and interoperable (ISO 2020). Data templates enable construction project stakeholders to exchange information about construction objects through an asset life cycle, using the same data structure, terminology, and globally unique identifiers to ensure machine-readability. Data templates set the framework for MPs by providing common data structures and are key to evaluating the value of materials and products over time (Mêda et al. 2020). In this respect, they constitute a key background to enable the realisation of a digital twin (see Chap. 1 by Koutamanis on BIM to digital twins) at the building scale (Mêda et al. 2021).

5.1.3 The Development of Passport Instruments

The automotive industry was one of the first sectors to adopt passport instruments. The International Material Data System, which was introduced in the early 2000s (Frühbuss et al. 2000), is used to collect and transfer information about all materials in a product across the whole supply chain, thereby supporting the requirements of the European End-of-Life Vehicles Directive 2000/53/EC (EU 2000). This EU legal document states that a reuse and recovery rate of a minimum of 95% by an average weight per vehicle and year should be achieved (Walden et al. 2021). As part of the clean energy transition, the electrification of vehicles and, accordingly, batteries plays a crucial role.

A battery passport was introduced in 2019 by the World Economic Forum and the Global Battery Alliance, aiming for a sustainable battery value chain by 2030 (World Economic Forum 2019). In 2020, the EU mandated battery passports for new industrial and electric-vehicle batteries by 2026. Each passport should have a unique identifier, be linked to the information about the basic characteristics, be accessible online, and be allowed access to information (European Commission 2020b).

Similar to the battery passport, the EU proposed a regulation in which DPPs would be used in "a framework for setting eco-design requirements for sustainable products" in March 2022 (European Commission 2022b), which applies to all sectors except food, animal fodder, and medicinal products (European Commission 2022b). The regulation builds on the European Green Deal, the Circular Economy Action Plan, and the Ecodesign Directive. Under this regulation, DPPs should ensure access to product information, improve the traceability of products along the value chain, foster the verification of product compliance, and include relevant data attributes to enable tracking substances. The DPP should provide information on materials' origin and composition, on opportunities for repair and disassembly, and on possibilities for recycling and disposal at the end of life (Götz et al. 2022) This regulation shall apply to any physical good which is placed on the market or put into service. It includes components (a product intended to be incorporated into another product) and intermediate products (a product which requires further manufacturing or transformation such as mixing, coating, or assembling to make it suitable for end-users).

Other industries that used passports in a very early stage include the shipping industry, which introduced a "resource passport" in 2007 (de Brito et al. 2017), a "Cradle to Cradle Passport" in 2011 (Maersk 2011), and a "Circularity Passport" (EPEA Netherlands 2023). The electrical and electronic equipment industry introduced a "recycling passport" in 2000 (Hesselbach et al. 2001).

5.2 Passport Instruments in the Built Environment

MPs are not new to the built environment. A passport for buildings was first introduced by Eichstädt in 1982 and was foreseen as a document that records changes and enables a qualitative evaluation of factories (Eichstädt 1982). In the report of the United Nations Environment Programme, the MP "guides materials through industrial cycles, routing them from production through reuse, defining optimum uses and intelligent practices" (McDonough & Braungart, 2003, p. 15). The Horizon 2020 project BAMB has extensively explored MPs and their use in the built environment.

5.2.1 MPs and Life Cycles

MPs play a crucial role across the entire life cycle of buildings and materials. A building's life cycle includes every phase from the conceptualisation until the end of life. A material's life cycle starts with the extraction of the raw materials and proceeds with the manufacturing process, the use phase, and the end-of-life stage. Similar to a material's life cycle, a construction element's or product's life cycle begins outside a project context. Most elements and products are produced without knowing exactly where or for what they will be used. During their life cycle, elements or products might have the same lifetime as the built object for which they are used. They might be replaced or even last beyond the life of that specific built object. The reuse, recyclability, and disposal of all of those materials, elements, and products should be considered in the life cycles.

Using MPs throughout the life cycle of buildings would facilitate the planning of renovations and retrofit (Çetin et al. 2022), thus slowing the resource loops (Bocken et al. 2016). MPs could also enable managing sustainable end-of-life material flows, such as reusing and recycling materials and elements (Çetin et al. 2022), thereby closing the resource loops (Bocken et al. 2016). Environmental impact of all life cycle stages can be recorded in the MP to assess the impacts of the entire building (Honic et al. 2019b, further described in Sect. 5.4).

5.2.2 MPs and Digital Platforms

MPs can be generated to provide information that spans different life cycles and scales – from construction materials to elements, buildings, and cities – though a standard structure and scale for MPs do not exist. At a city scale (see Chap. 2 by Tsui et al. on geographic information systems), using MPs for the building stock and embedding them in digital platforms could provide several benefits for municipal authorities, urban miners, architects, and waste auditors. Municipalities could, for example, plan retrofits and renovations, predict upcoming waste streams, and implement sustainable end-of-life streams (e.g. reuse and recycling) in their existing building stock. Urban miners would be able to detect where valuable elements and materials are located within a city and be informed about when these will be available. Architects could design new buildings with materials and elements provided in the platform, thus facilitating reuse, and waste auditors would have an easier job while investigating existing buildings since most of the information needed for a waste audit would be available in the platform. Such a digital platform could also be used as an ecosystem for trading materials and elements, where MPs constitute the backend information provider.

To capture the value of materials, elements, and buildings, digital platforms will play an increasingly important role in the future (Chan et al. 2020). One example of a digital platform has been developed by Honic et al. (2023), who established a framework for a digital urban mining platform for the city of Vienna. BIM (see Chap. 1 by Koutamanis on BIM and digital twins), laser scanning, ground-penetrating radar, and GIS technologies were used to compile MPs and assess material intensities (tonnes/m^3 gross volume of a building) of single buildings. These material intensities were extrapolated to calculate the material composition of similar building types, which enabled a prediction of a large number of buildings in the city. The predicted material compositions were integrated into MPs, which were made available in the digital urban mining platform (Honic et al. 2023).

5.3 Passport Instruments for a Circular Economy

Considering "buildings as a material depot" (Rau and Oberhuber 2022) helps view the building stock as a potential provider of materials for new buildings. Reusing materials and elements from existing buildings, thereby avoiding extraction of raw materials and associated carbon emissions, serves the circular economy principle of "closing the loop" (Bocken et al. 2016). In existing buildings, valuable materials can only be reused for new construction if the necessary information on the materials, such as their quality, remaining lifetime, allocation within the building, accessibility, disassembly potential, etc., is available. However, the scarcity of information on materials and elements embedded in existing buildings (Arora et al. 2019) is a major obstacle in reaching high reuse rates.

5.3.1 MP-Related Concepts

To support and provide guidance on best practices for performing the assessment of demolition waste streams prior to demolition, the EU Commission developed the "Guidelines for the Waste Audits before Demolition and Renovation Works of Buildings" (European Commission 2018), which specify information to be collected during audits on existing buildings, such as the type of materials embedded in buildings and if they consist of harmful substances. However, the audits are conducted mainly to assess the amount of waste materials and plan how much of what type of material will be incinerated or disposed of at which landfill type (e.g. specific landfills for harmful substances). The waste audit documents are structured by waste categories (e.g. metallic, plastic, wood) established by the EU.

As the name implies, waste audits are made to assess the amount of waste and not to assess its potential reuse or provide information on disassembly. This is where MPs come into play. MPs provide more information than a waste audit: they store information about the disassembly, reuse, and recycling potential, as well as the allocation and amount of materials and elements (CB'23 2023; Madaster 2023). If generated in the design stage of a building and updated during its life span, at the end-of-life stage of a building, an MP can prevent building materials from being demolished, incinerated, or disposed of since information on the incorporated materials and elements exists which can be used to design a new building with the existing stock.

5.3.2 *MPs for New and Existing Buildings*

The use of MPs can be beneficial for both new and existing buildings. For new buildings, MPs could help implement all principles of a circular economy, from narrowing to slowing and closing the loop as well as regenerating nature. In the conceptualisation and design stage of buildings, an MP could serve as an optimisation tool to assess and reduce the amount of materials used for the building (thus narrowing the loop) and to choose materials with a long life span (slowing the loop), elements and products with a high reuse potential (closing the loop), and bio-based materials (regenerating nature). Creating an MP for new buildings is feasible due to existing 2D plans, 3D models, BIM models, environmental product declarations, declarations of performance, life cycle assessments, and energy certificates, all of which provide important information that could be stored in MPs.

Compiling MPs for existing buildings is a challenging task due to the lack of information about the existing building stock (Rose and Stegemann 2019). Several digital technologies can be applied to gather information on existing buildings at the city, building, and element scales. At the city scale, these are computer vision (see Chap. 4 by Armeni et al. on AI) and geographic information systems (see Chap. 2 by Tsui et al. on GIS). Laser scanning can be applied at the city and building scales (see Chap. 3 by Gordon et al. on Reality Capture). At the element scale, ground-penetrating radar is a useful technology. Some examples of these technologies are described in the next paragraph. More examples can be found in the associated chapters.

To acquire information at city, building, and element scale, several approaches have been developed. Raghu and De Wolf (2022) applied computer vision technology to detect facade materials and elements such as windows and doors and developed machine learning algorithms to detect cracks and evaluate the quality of materials and elements in the city of Zurich. Wu et al. (2022) explored the prediction of asbestos-containing materials in residential buildings in Gothenburg and Stockholm through artificial neural networks. Similar work using computer vision has been conducted by Koch et al. (2018), Mahami et al. (2020), and Nordmark and Ayenew (2021). Geographic information system models are provided from various

European cities which can be applied to assess material stocks and to investigate where specific materials are allocated (Bradshaw et al. 2020). Laser scanning can be used to gather geometrical information, e.g. the height of a building, and to generate a BIM model of a building (Mill et al. 2013). To acquire information on the materials, Honic et al. (2021a, b) used a ground-penetrating radar at element scale. They automatically identified building elements' material compositions through machine learning algorithms.

Combining the information gathered at city, building, and element scales can help generate new MPs for existing buildings or, if available, feed existing MPs with further information. The availability of MPs at city scale could enable the assessment of expected waste, planning of sustainable end-of-life streams, and generation of a digital platform for cities, as described in Sect. 5.2.2. Some examples of MPs for new and existing buildings are presented in Sect. 5.4.

5.4 Examples from Research and Practice

In the last decade, several MPs and data templates were developed in research and practice. Some of these examples are presented in this section: first, three academic examples, followed by one practical example and the initiatives CB'23 (CB'23 2023) from the Netherlands, Product Circularity Data Sheet from Luxembourg (PCDS 2023), and GrowingCircle project from Portugal (GrowingCircle 2023).

5.4.1 Examples from Research

Within the EU Horizon 2020 project BAMB (BAMB 2020), 300 MPs for various products, components, and materials, as well as an MP platform, were created. The platform was developed to facilitate the appropriate accessibility of information for different stakeholders at specific stages in the process (Fig. 5.1). The aim of the MP in BAMB was to keep or increase the value of materials, products, and components across their life cycles; to support developers, managers, and renovators in their selection of circular materials; to create incentives for suppliers to produce healthy and sustainable materials; and to facilitate the return of products, materials, and components. BAMB provided an MP platform in which various characteristics of elements and products could be uploaded by manufacturers or others. These elements and products were given an identification number, which helped identify them in a BIM model. However, changes in the BIM model could not be automatically integrated in the platform (BAMB 2020).

An automated process to generate MPs was developed by Honic et al. (2019a). BIM was used to compile an MP that optimises the design with regard to the reduction of waste and environmental impacts. This automated process has the advantage that different design variants can be compared with each other.

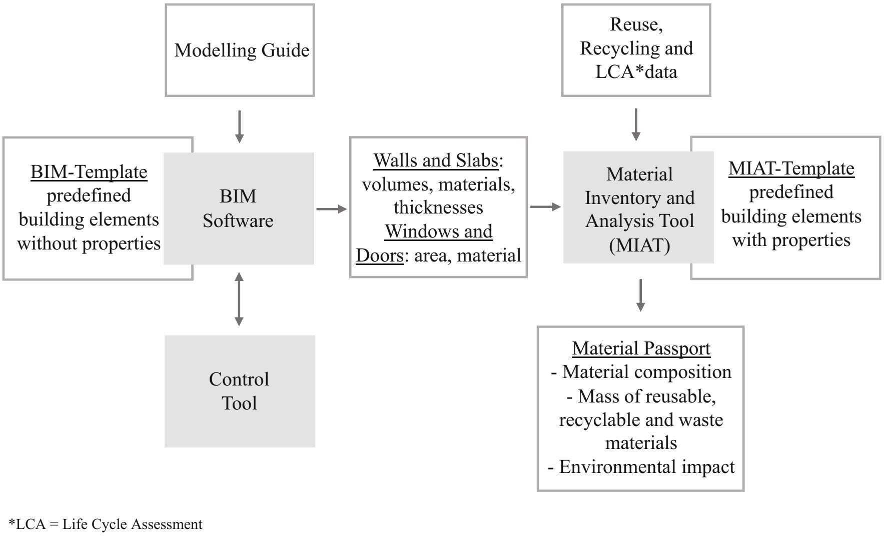

Fig. 5.1 BIM-based workflow for the generation of an MP. (Adapted from Honic et al. 2019a)

Automating the generation of the MP requires proper modelling in BIM (the use of proper BIM objects, geometry and materials, etc.). The researchers provide the framework, templates, and a modelling guideline to help users apply the MP method (Fig. 5.1). Since the basis for an MP and an environmental impact assessment is the same, namely, a bill of quantities on the element scale, the environmental impact assessment was also integrated into the MP. Three indicators were used for the environmental impact assessment: the global warming potential (CO_2 emissions), acidification potential (SO_2 emissions), and primary energy intensity. Insights and optimisations can be conducted on the material, element, and component (the aggregation of elements of the same type) to the building scale.

The researchers also explored MPs for existing buildings (Honic et al. 2021b). Digital technologies such as laser scanning and ground-penetrating radar were used to acquire the geometry and materials of existing buildings. The results showed that a compilation of MPs for existing buildings is possible and delivers valuable information on incorporated materials and elements. However, the cost and time needed to apply the digital technologies and process the data were very high, and optimisation is needed in terms of user-friendliness to be applicable in practice (Honic et al. 2021a).

5.4.2 *Examples from Practice*

An MP example from practice is provided by Concular, a digital platform that collects information on new and existing buildings. Concular aims to facilitate a circular and resource-efficient built environment. Concular uses BIM models and CSV files to generate MPs in the form of data sheets. The MPs enable the tracing of materials and elements throughout the whole life cycle. Next to MPs, CO_2 emissions and circularity assessments can be conducted for new and existing buildings. For existing buildings, Concular uses 3D scans and computer vision algorithms to detect objects (Concular 2023).

An example for data templates and MPs is CB'23, a platform developed by the joint efforts of professionals (market parties, policymakers, and scientists) from the Dutch construction sector. The platform offers guides for measuring circularity in and creating passports for the construction sector as well as a web tool for creating MPs for the whole life cycle of buildings. CB'23 provides a data template in form of a spreadsheet, which contains many parameters and characteristics needed for the MP. (To mention a few, these parameters include general information such as the object number, length, width, and origin of the data and technical information such as adaptability, existing certificates, and units in which this information should be provided.) The template is also aligned with the life cycle stages of buildings, thus giving information on which data is required at a certain stage.

Another example for data templates, namely, the Product Circularity Data Sheet, is provided by the Circularity Dataset Initiative. The initiative aims to provide an industry standard for product circular data using the Product Circularity Data Sheet (Mulhall et al. 2022). The data sheet works at the product level and consists of specific sections devoted to product identification, product composition, designs for better use, disassembly, and reuse.

A case study using data templates and MPs was conducted by the GrowingCircle project (GrowingCircle 2023), which was funded by the EEA grants (2014–2021). GrowingCircle focuses on the awareness and provides a proof of concept of how circular data is key to enabling circular economy processes. One of their case studies is a residential building renovation process where the digitalisation of meaningful elements was realised to generate an element catalogue (Mêda et al. 2022) that could feed a 3D model of the building with data. Using a data template framework, the element data from the renovation design, which was delivered by manufacturers, was integrated in MPs next to other performance-related data. Further, the data from the MP was attached to the 3D model to enable several analyses and deliverables associated with sustainability.

The examples from research and practice show the variety of existing MP and DPP concepts. Several approaches exist for generating MPs. Although not yet standardised, BIM is often used for generating MP. Some solutions offer the upload of a BIM model to create insights in terms of circularity or environmental impact assessment. One of these solutions is Madaster, which is further presented in the next section. The use of data templates is becoming more common and is expected gain importance in the future in order to create a common basis for MPs.

5.5 Business Models for Passport Instruments in a Circular Built Environment

A digital service for registering, storing, and exchanging data – in this case, in the form of MPs – is like a utility service, for which the user wants to be sure that the service is trustworthy, efficient, and effective. The business model of the service provider is based on providing the service, not on the value or relevance of the content of the service – similar to the business model of transportation companies where the price is based on transport, not on the content of the goods transported.

Madaster (Madaster, 2023), which started in 2017, is an example of an independent, international digital service provider that provides MPs. Technically Madaster works by using a BIM environment as a data source for the generation of MPs (Fig. 5.2). The interoperable exchange format within BIM – the industry foundation class (IFC) – and an XLS file can also be uploaded on the Madaster platform. As output, the platform delivers an MP next to the Madaster Circularity Index and embodied carbon and costs assessments.

The Madaster business model is based on the delivery of data registration, storage, exchange, processing, reporting, and analysis services, where the MP delivery is one of the offerings provided. Its business model consists of the following components:

- Initiation and market rollout: The Madaster platform development is funded by private investors (50%), grants and subsidies (25%), and early adopters (25%).
- Service provision and functional development: Usage of the Madaster platform requires a yearly subscription, where pricing depends on the country and type of

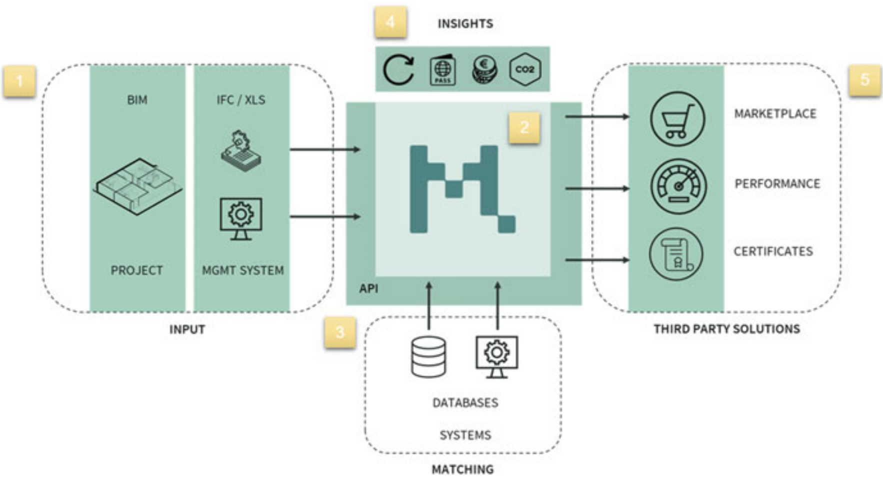

Fig. 5.2 Framework of the Madaster platform showing data inputs, outputs, and insights on MPs, cost, circularity, and CO_2 assessments (Madaster, 2023)

client. The subscription includes MPs, embodied carbon calculations, environmental and circularity assessments, and residual value reporting.
- Supervision and R&D: Madaster is supervised by the independent, not-for-profit Madaster Foundation. This foundation owns the brand IP and assures the availability of the (meta) data for public usage. A partnership agreement between Madaster Foundation and the service company describes the supervisory activities, including the possibility to select an alternative service company in case of noncompliance with the supervision criteria.

5.6 Discussion

A circular economy relies on digital data that can be tracked throughout the entire life cycle of buildings. Data templates, MPs, and DPPs all rely on digital data and aim to enable a circular economy. MPs, which rely on data templates and differ from DPPs only in terms of the industries and scales they are applied, can be generated for new and existing buildings whereby digital technologies are used to feed them with relevant information. The academic and practical examples in this chapter showed different approaches to generating an MP (e.g. BIM-based or with data templates from CB'23) and that the insights created from MPs can vary from circularity assessments including the reuse potential of buildings to environmental impact assessments.

Finding common technical language and standardising key data have been major challenges in construction since the publication of the first Directive on Construction Products in the late 1980s (Council of the European communities 1988). Presently, there is still no consensus on the data requirements, structures, and formats of MPs or DPPs. The initiatives associated with data templates, MPs, and DPPs mentioned in this chapter consider the need for the digital representation of the built environment. The integration of product data into an MP remains an obstacle if the data formats of the DPP and the MP are not aligned. Present efforts in aligning the concepts are being made by the Ecosystem Digital Product Passport Initiative, which aims to present an unambiguous cross-sectoral definition and description of a DPP and define a cross-sectoral product data model for it (CIRPASS 2023). In the initiative, MPs are presently not considered. However, the developments will influence how knowledge, standards, and orientations are implemented in the built environment.

A further challenge to increasing the use of digital passports lies in how the required data can be gathered, tracked, and made available throughout the life cycle of buildings. To overcome these obstacles, digital technologies can play a crucial role. Computer vision, geographic information systems, laser scanning, and ground-penetrating radar show potential for gathering data on existing buildings for MPs. For new buildings, BIM plays a crucial role, since, if modelled properly, models contain detailed information on each material and element used in a building. Blockchain technology (see Chap. 13 by Shojaei et al. on blockchain technology) promises greater transparency, improved traceability, and increased efficiency (IBM

2018). The integration of blockchain technology and the internet of things could enable tracking of the present state of materials and elements throughout their life cycle, thereby keeping information up-to-date and enabling predictions for reuse of materials and elements used in the built environment (Esmaeilian et al. 2020). The integration of the information delivered by different technologies into an MP needs further manual steps since the data formats and structures can vary significantly. Thus, aligning data formats and structures for data templates will be an important step in enabling the compilation of standardised MPs.

5.7 Key Takeaways

- Material passports (MPs) are a main enabler of a circular economy in the built environment, because they consist of relevant information that facilitates maintenance, repair, reuse, etc.
- MPs give building materials and elements value for present use, recovery, and reuse.
- Several passport instruments exist in academia and practice.
- Format, structure, and terminology for MPs are not standardised.
- Several digital technologies can support the gathering, storing, and maintaining information of new and existing buildings.

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