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Accordingly, with the Articles 25.2.j) and 29.4 of the 'Applicants Guide for Financing of Projects Supported by Environment, Climate Change and Low Carbon Economy Programme'.

https://www.eeagrants.gov.pt/media/2994/applicants-guide-for-financing-eea-grants_environment-projects_28112019.pdf

Index

i. Introduction

The Construction Industry (CI) is the economic activity responsible for materialising and transforming the built environment. Just as construction products are essential for the materialisation of a building or infrastructure, their characteristics and properties are the keys to the practice of more circular and efficient processes. The Construction Sector is a fundamental economic activity because it represents about 9% of the European Gross Domestic Product and directly employs more than 18 million people. The magnitude of its impacts on natural resources, energy consumption, and CO^2 production means an imperative need to improve performance, new technologies and innovative practices. The digitisation and circularity of processes are assumed to achieve efficiency, sustainability, and competitiveness. Communication failures and information losses during construction processes are responsible for more than 50% of the inefficiencies related to the repetition of work. And many of these have their origins in construction products.

People spend about 90% of their time indoors, such as housing, offices, or factories, and about 5% on the move. More than 95% of the time is spent in the built environment, buildings, or transport infrastructure. In these buildings and infrastructures that we use and especially in our homes, obtaining data on their characteristics is a challenge.

The absence of a thread of data on buildings inhibits the implementation of more circular practices and impacts the efficiency and sustainability of the sector. All agents that participate in the construction processes experience productivity losses due to inefficiencies that result from information management. Digitisation opens the door to many possibilities, but the existence of incomplete and paper-based elements is a problem due to the manual work that data entry entails and the mistakes that can be made. Data Templates are standardised, interoperable metadata structures used to describe the characteristics of construction objects [1]. A survey carried out in the beginning of the project observed the knowledge regarding this definition among agents in the Portuguese construction sector. The results evidence that 78% of respondents are unaware of Data Templates (Figure 1).

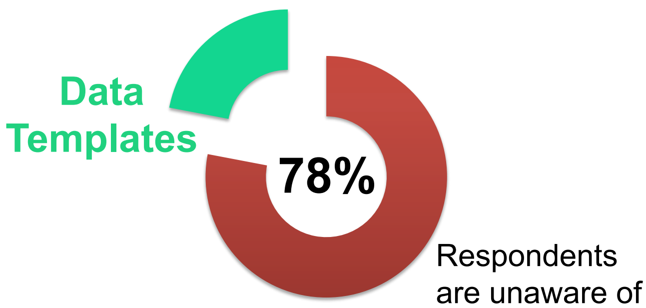

Figure 1. Data Templates Awareness

In order to enhance the digitalisation trends in the construction industry, it is necessary to ensure mechanisms that make it possible to systematise, aggregate, manage, track and maintain information about the built objects and the construction products that compose them. Data Templates are the key element to ensure data traceability and to digital integrate the assessment of buildings' whole life cycle.

ii. Scope

This document provides the state-of-the-art of Data Templates based on standards developed by ISO/IEC, CEN/CENELEC, Governmental and Private initiatives/reports, scientific publications (e.g., papers and books), or other sources describing information needs. Also, a survey was conducted to assess the awareness of stakeholders from the Portuguese Construction Industry.

The target audience of this document is AECOO (Architecture, Engineering, Construction, Owner Operator) and construction products supply-chain (e.g., Manufacturing, Retail).

It is not in the scope of this document to neither provide the content of any Data Templates nor conceptualise any solution/platform to exchange data/information.

iii. Data Templates Definition

Data template (DT) "*is a common data structure describing the characteristics (called 'properties') of a construction object, and its physical qualities, according to a credible source of information – be it a standard or regulation.*" [2].

"*The international Standardisation bodies CEN and ISO are developing a series of standards to cover the methodology for creating data templates. These standards are developed as part of the CEN technical committee 442 works:*

EN ISO 23386 *Building information modelling and other digital processes used in Construction – Methodology to describe, author and maintain properties in interconnected dictionaries;*

EN ISO 23387 *Building Information Modelling (BIM) – Data templates for construction objects used in the life cycle of any built asset – Concepts and principles.*" [2].

According to ISO 23387 (p. 5): "***Data template****s will 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 enable machine-readability.*

Data templates *should be standardized and made available across the built environment sector through data dictionaries based on ISO 12006-3:2007.*

Data templates *should be used in conjunction with Industry Foundation Classes (IFC) in ISO 16739-1 to enable and support open BIM processes.*" [1].

"*For its user, a* ***data template (DT)*** *is a common data structure describing the characteristics (called 'properties') of a construction object, and its physical qualities, according to a credible source of information – be it a standard or regulation. On the other hand, for any software, the* ***data template*** *structure is a set of concepts that are connected to each other with different relationships. By establishing the connectedness between concepts through unique pieces of code, a specific logic for machines is set. This allows, as example, to Cobuilder to create a common technological language, which helps any software convey meaning consistently regardless of the language used in a particular* country." [2].

Often Data Templates are misunderstood and are confused with Product Technical Sheets, this is, pdf documents where construction products or construction systems properties are disclosed by a manufacturer. In fact a Data Sheet produced from a Data Template can become a pdf document, but when this happens it is a result from a back office data organization based on interoperability and standardization assumptions and these are the ones that lay behind the true definition of Data Templates in accordance with ISO 23387 standard. Yet, to promote improved understanding and to reinforce the digital essence of the Data Templates, during the project and in awareness actions Digital Data Template (DDT) will be the terminology to use, mainly to back away any bias or ideas related to Technical Data from products and systems in pdf formats.

iv. Terms and Definitions

"**Building Information Modelling, BIM,** *use of a shared digital representation of an asset to facilitate design, construction and operation processes to form a reliable basis for decisions [SOURCE: ISO 19650-1:2018, 3.3.14, modified — The wording "a built asset" has been changed to "an asset"; Note 1 to entry has been removed.]*" [3].

"buildingSMART *is the worldwide industry body driving the digital transformation of the built asset industry. buildingSMART is committed to delivering improvement by the creation and adoption of open, international standards and solutions for infrastructure and buildings. buildingSMART is the community for visionaries working to transform the design, construction, operation and maintenance of built assets. buildingSMART is an open, neutral and international not-for-profit organization."* [4].

"Circular economy *is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended. In practice, it implies reducing waste to a minimum. When a product reaches the end of its life, its materials are kept within the economy wherever possible. These can be productively used again and again, thereby creating further value. This is a departure from the traditional, linear economic model, which is based on a take-make-consume-throw away pattern. This model relies on large quantities of cheap, easily accessible materials and energy. Also part of this model is planned obsolescence, when a product has been designed to have a limited lifespan to encourage consumers to buy it again. The European Parliament has called for measures to tackle this practice."* [5].

"COBie *standard achieved in several "firsts" in the use of open standard building information. COBie was the first standard to define objectively testable quality control standards that allow automated format verification by software companies and content validation by project teams. COBie was the first standard to address specific requirements for non-geometric building information. COBie was the first standard to document and model each lifecycle process where building equipment information is created, updated, and applied to predict of potential reduction in direct and overhead costs resulting from its adoption on projects and portfolios. COBie has been the only IFC-based non-geometric standard that conformed to International Alliance for Interoperability and buildingSMART alliance technical standards for Information Delivery Manuals and Model View Definitions. Aside from geometric coordination, which has now been largely integrated directly into design software, COBie is the most widely used open standard for the delivery of building information in use today."* [6].

"Cobuilder *is a privately-owned international business with more than 120 employees distributed at HQ in Oslo and wholly-owned subsidiaries in England, France and Bulgaria. The company is a major driver for the digitization in Construction and is a strategic contributor to ISO, buildingSMART, CEN and CENELEC and winners of several innovation awards internationally. Cobuilder offers an IT platform that employs all relevant international standards for data management to help construction industry actors exploit the potential of product data. Fit-for-purpose and accurate product data improves quality of service, time to market and reduces time, cost and environmental footprint.*" [7].

"**Component,** *named and individually scheduled physical item and feature that might require management, such as inspection, maintenance, servicing or replacement, during the in-use phase. Note 1 to entry: Components can serve as interacting objects in a system. [SOURCE: ISO 6707-1:2017, 3.4.1.4, modified — Note 1 to entry has been added.]*" [1].

"**Construction object,** *object of interest in the context of a construction process. EXAMPLE 1 The construction object "wall" is a type of system. EXAMPLE 2 The construction object "calcium silicate masonry unit" is a type of product. [SOURCE: ISO 12006-2:2015, 3.1.2, modified — EXAMPLEs 1 and 2 have been added.]*" [1].

"Construction product, *means any product or kit which is produced and placed on the market for incorporation in a permanent manner in construction works or parts thereof and the performance of which has an effect on the performance of the construction works with respect to the basic requirements for construction works"* [8].

"**Data dictionary,** *centralized repository of information about data such as meaning, relationships to other data, origin, usage and format. Note 1 to entry: The definition is from the Dictionary of IBM & Computing Terminology*" [1].

"Digital twin, *a digital twin allows bi-directional data interaction between the physical built and a digital/responsive twin* [9]. *Digital Twins concept integrates many technologies/methodologies, as BIM (Building Information Modelling)* [10]. *Digital Twin is a platform to connect through sensors the physical assets to cyberspace that allows collection, processing, analysis of data to simulate and controlling the assets* [11–13]."

"Digital building logbook, *is 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. A digital building logbook is a dynamic tool that allows a variety of data, information and documents to be recorded, accessed, enriched and organised under specific categories. It represents a record of major events and changes over a building's lifecycle, such as change of ownership, tenure or use, maintenance, refurbishment and other interventions. As such, it can include administrative documents, plans, description of the land, the building and its surrounding, technical systems, traceability and characteristics of construction materials, performance data such as operational energy use, indoor environmental quality, smart building potential and lifecycle emissions, as well as links to building ratings and certificates. As a result, it also enables circularity in the* *built environment. Some types of data stored in the logbook have a more static nature while others, such as data coming from smart meters and intelligent devices, are dynamic and need to be automatically and regularly updated. A digital building logbook is a safe instrument giving control to users of their data and the access of third parties, respecting the fundamental right to protection of personal data. Data may be stored within the logbook and/or hosted in a different location to which the logbook acts as a gateway."* [14].

"DigiPLACE *is a framework allowing the development of future digital platforms as common ecosystems of digital services that will support innovation, commerce, etc. It will define a Reference Architecture Framework for digital construction platform based on an EU-wide consensus involving a large community of stakeholders, resulting in a strategic roadmap for successful implementation of this architecture. DigiPLACE will rely on a relevant set of partners, linked third parties and an Advisory Board. The consortium, composed of an unprecedented collaboration between EU construction industry representatives, a strong academic partnership and the support of 3 countries' public authorities will work together during 18 months. From September 2019, the project partners are collaborating to create the framework for the digital platform. The 19 partners from 11 countries led by Politecnico di Milano will pave the way for future projects in the field of digital construction. This project is the first ever proposal targeting the digital transformation of the construction industry to receive EU funding from Directorate-General for Communications Networks, Content and Technology (DG CONNECT)."* [15].

"Group of properties, *collection enabling the properties to be prearranged or organized. Note 1 to entry: In this document, "group of properties" is used for organizing properties through the use of xtdCollection. [SOURCE: ISO 23386:2020, 3.14, modified — Notes 1 to 4 to entry have been removed; new Note 1 to entry has been added.]*" [1].

"**Industry Foundation Classes IFC,** *conceptual data schema and exchange file format for building information modelling (BIM) data. Note 1 to entry: See ISO 16739-1.* " [1].

"**Product construction,** *product item manufactured or processed for incorporation in construction works [SOURCE: ISO 6707-1:2017, 3.4.1.3, modified — Note 1 to entry has been removed.]*" [1].

"**Property,** *inherent or acquired feature of an item. Note 1 to entry: When a property is named together with reference to a technical specification, where the instructions to assess the performance are available (usually standards), it is to be regarded as a specific property. The relationship between the property and the specific property is modelled as a parent child relationship. EXAMPLE 1 Length, sound reduction index (properties). EXAMPLE 2 Length according to EN 12058, sound reduction index according to ISO 10140-4 (specific properties). [SOURCE: ISO 6707-1:2017, 3.7.1.3, modified — Note 1 to entry and EXAMPLEs 1 and 2 have been added.].*" [1].

"**Quantity**, *property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed by means of a number and a reference Note 1 to entry: Quantities can appear as base quantities or derived quantities. EXAMPLE 1 Length, mass, electric current (ISQ base quantities). EXAMPLE 2 Plane angle, force, power* *(derived quantities). [SOURCE: ISO 80000-1:2009, 3.1, modified — Notes 1 to 6 to entry have been removed; new Note 1 to entry and EXAMPLEs 1 and 2 have been added.]*" [1].

"**System**, *interacting objects organized to achieve one or more stated purpose [SOURCE: ISO/IEC/IEEE 15288:2015, 4.1.46, modified — The words "combination of" at the beginning have been removed; "elements" has been replaced by "objects"; Notes 1 to 3 to entry have been removed.]*" [1].

"**UML Unified Modelling Language**, *language to provide system architects, software engineers, and software developers with tools for analysis, design, and implementation of software-based systems as well as for modeling business and similar processes Note 1 to entry: See ISO/IEC 19505-1.*" [1].

v. Data Templates (state-of-the-art)

Data Templates are data structures used to describe the characteristics of construction objects [1]. They are also information exchange enablers across the construction life cycle. The standard is aligned with the digital processes and assumptions. Yet, this is still not the understanding among the majority of the stakeholders across the sector. Many don't know the term and others point to information structures that despite their value do not highlight the real value of the Data Templates. As mentioned, to contribute to the full realization of the potential role of these structures and despite the standard, it worth's highlighting that we are addressing data templates as Digital Data Templates (DDT).

Focusing on construction products, understood as manufactured products (tiles as an example) and raw materials (sand), and on systems (wall composed by several products) it becomes more clear the role that these structures can have in each stage, both for the compliance of more "traditional" requirements, as well as requirements related with sustainability. DDT has their properties defined following products types, applicable standards and requirements.

The Manufacturing phase is where a specific product, understood as a brand with an associated model, specific designation and performance values bourns. This means the specific values for the properties are addressed to the DDT, transforming this structure into the Digital Data Sheet (DDS) of that specific product. Depending on the type of product and manufacturer characterization process, the DDS might have more or fewer properties with filled values.

The DDS are used during the design and become part of the specifications. They are a substantial part of the AIM alphanumerical information, supporting also some geometrical information. During construction, the DDS's gain more values, namely the ones that depend on the construction process, as asset code, date of placement, warranty start date and so forth [16].

During construction, changes might occur in construction products, either by changing the product type maintaining the manufacturer, changing the manufacturer or even changing the design specified solution. All these changes need to be safeguarded to assure data traceability. Given this, it can be easily understood the relevance and the role of these structures for the digitalization strategies of Manufacturing 4.0, Construction Process 4.0 and Site 4.0 [17].

Gigante-Barrera et al., (2017) highlighted that was particularly challenging for manufacturers defining PDTs (Product Data Templates) data, as there was a scarcity of content knowledge which includes BIM uses (i.e. electrical design) and processes (i.e. cable tray sizing) that support client's lifecycle processes [18]. They found that: "*UK manufacturers are gradually embracing the adoption of Level 2 Building Information Modelling (BIM) standards (3D models and embedded data) within their product model elements. However, these are not always well defined due to inaccuracies related to the scope and the content of the model attributes.*" [18].

Lucky et al., (2019) pointed that in the construction industry several research and development projects demonstrated the need of coherent product libraries to ease information sharing among involved stakeholders [19]. Also, "*designers are often the main actors addressed in the creation and fruition of such product libraries*" [19]. To achieve coherent product libraries, there was issues such as standardisation of PDT, the great amount and heterogeneity of products categories, interoperability in sharing data and scarce thrust of manufacturers in developing extensive libraries [19].

In addition, "*considering the European directives and regulations, manufacturers are required to provide detailed and structured information about their products, e.g. in the form of CE marks and/or Declaration of Performance (DOP). Hence, developing data structures that are already compliant with CE marks and DOPs information requirements improves manufacturers' capability of promoting their products. Moreover, this makes clients and users aware of provided information, giving them the possibility of comparing performances of different products and consequently choosing only those products that fit better their needs.*" [19]. Further, "*manufacturers use EPD (Environmental product declaration), which is regulated by the European Standard EN 15804: 2014 and at the same time by the International ISO 21930: 2017, as an environmental certification and communication tool by which they can declare the environmental performance of their products through the use of specific indicators*" [20]. Spagnolo et al. (2020) Development of a BIM library for products data sharing based on UNI/TS 11337-3:2015.

Many stakeholders interaction is needed to establish a full use of the data templates, as example:

- Product Life-cycle Manager (Manufacturing);
- Supplier Manager;
- Designers, BIM Manager;
- Asset Manager;
- Owner, Client, User;
- Building Manager, Facility Manager.

Thereby, it is also possible to envision new functions for those who must coordinate the actions related to product data. The responsible in a specific company, as a manufacturer, or contractor, by the management of Data Template or Data Sheets related information could be called the **Data Template Manager.** When addressing to the construction process, the responsible for the identification of the required data, data reliability analysis and evaluation of its source of through or consistency in a certain phase or across the construction process phases, could be defined as the **Information Consistency Manager.**

The supply chain process of the construction products could be established in four ways:

- **Engineered-to-order (ETO)** "*products are specially made based on either fully designs or only details received from an engineering company (e.g., power distribution equipment, preassembled rebar components). They are defined by parameters such as manufacturer, model, raw materials, and drawings"* [21];
- **Made-to-order (MTO)** "*products are usually products manufactured once customer orders have been placed (e.g., cast-in-place concrete, prefabricated panels). Usually, MTO products are characterized by manufacturer, model, and raw materials parameters*" [21];
- **Assembled-to-order (ATO)** "*products are also assembled (manufactured) after customer orders, however these products are usually standard or made of standard components (e.g., doors, windows). In BIM module, manufacturer and model parameters have been used for ATO products*" [21];
- **Made-to-stock (MTS)** *"products are commodities (e.g. consumables such as bolts) characterized by short lead times. Even though manufacturer is the only parameter that used for MTS products, they should be defined as a resource for the corresponding activities in the schedule in order to address how often they are ordered and in what batch size"* [21].

It is undeniable that it is not possible in this stage to have Data Templates for all products and solutions and, therefore, there are always some aspects that prioritize the use or adoption of these structures. There is always one aspect that is essential to all economic activities that is the cost. Given this, products with higher relevance in terms of cost in a specific project are those that should be assumed as the more relevant to disclosure or to be set on a construction project using Data Templates. Following the construction trends, products that contribute to the built environment efficiency at energy, CO2 or waste levels are also found to be in the forefront. Given the broad scope of products that exists and from the perspective of manufacturers, the most standard solutions, either in terms of characteristics or sales volume are found to be the ones with the highest added-value. The development of Data Templates is also aligned with the existence of reliable sources of information to appoint or characterize the properties of products, systems or objects. These rely on standards, namely harmonized standards, regulations, environmental declarations, facility management properties, interoperability tools such as IFC or bsDD properties.

A concept of PLM (product life-cycle management) [22,23,32–41,24–31] is broadly connected to product data management. The PLM *"is defined as an approach for the integrated management of all product related information and processes through the* *entire lifecycle, from the initial idea to end-of-life (Apud. Saaksvuori 2004 and Arnold et al. 2005). Most authors currently agree that PLM does not only refer to individual computer software, but, moreover, it is related to a broad management concept, which depends on the integration of multiple software components (Apud. Saaksvuori 2004; Arnold et al. 2005; Abramovici et al. 2005; Scheer et al. 2006). Based on this conceptual foundation, in this research PLM is defined as a business approach for the integrated management of business process and information related to products through the entire lifecycle. This approach requires integrated information systems to support collaboration over the extend enterprise throughout the product lifecycle (Apud. Zancul 2009)."* p. 244 [33].

According to Stark (2020) p.160-161 (adapted), "*product data is a main component on the PLM 'spectrum'. In many ways, product data is the product. Product data is the definition of a product. It's all the knowledge and know-how about the product. In addition, it's all the knowledge and know-how about the way the product is designed, manufactured, supported, used and recycled*." [31].

According to Alemanni et al. (2011) p. 1 (adapted), a "*Model-based definition (MBD) is a strategy of product lifecycle management (PLM) based on computer-aided design (CAD) models transition from simple gatherers of geometrical data to comprehensive sources of information for the overall product lifecycle*." [39]. A process-oriented MBD scenario is able to root specific data, as:

- Identification data
  - Part number
  - Nomenclature
  - Revision
- Lifecycle management data
  - Dataset UID
  - Dataset version
  - Approval status/status
- Material and technology
  - Material description
  - Material heat treatment
  - Material standard manual
  - Material X\density
  - Technology
- FT&A
  - Annotation set X\views\…
  - Annotation set X\datums\…
  - Annotation set X\geom tolerances\…
  - Annotation set X\dimensions\…
- Notes
  - Standard notes\…
  - Part notes\…
- Relations
  - Relations\formula XX\…
  - Relations\formula YY\…
- Engineering geometry

- Engineering geometry\stock size\…
- Engineering geometry\datums\…

As stated, product life cycle management (PLM) relies on data and on the ability to use it and trace it through the life cycle. MBD is a way to structure visions of the data to make it more comprehensive and useful for different stakeholders across the life cycle. These terms overlap with many others and this topic itself could constitute the overall report. Without neglecting the relevance for a streamlined awareness of these concepts it is important to realize that, to work better, these concepts require standardized data, because if this is not the case, different concepts expressing the same properties will be managed differently and will be missing or will have to be interpreted alongside that construction life cycle. Simple example is the use of different terminology to express the insulation level of two different products, one used for the roof and other for the exterior wall. The development of thermal analysis will have to rely on the ability to identify those nomenclatures and link them to the verification being made. In addition to errors this translates into re-work, interpretation and manual work developed by one or more stakeholders. DDT are structured and meant to overcome these potential problems, by setting universal or machine-readable properties to be used from the manufacturing process to the end of construction life cycle and with the ability to be used and managed on a project context by different stakeholders. At this point it is important to highlight that the design and construction phases play an essential role in the construction process, but their reason is to materialize a built object that is going to be used. This means that through design and construction different products are brought together to accomplish several goals in terms of performance and to produce a compliant built object that will be used during a period of time fulfilling one or more roles. The use time is the longest and where several components are intervened/maintained, replaced, upgraded, among other interventions. In order to perform these activities specific needs of data are required. As mentioned, Data Templates are structured based on Facility Management properties. These are the ones that are important for the use phase and COBie is designed to systematize and capture in use phase relevant data.

The Construction Operation Building Information Exchange (COBie) standard defines asset data of a subset of building information models (BIM) focused on delivering asset data rather than geometric information [42,43,52–61,44,62–64,45–51]. Kumar and Teo (2020) identified key benefits of COBie:

“Vendor-neutral to solve interoperability, *COBie is vendor-neutral and, therefore, can solve interoperability issues associated with the handover of information in proprietary formats*” [44].

“Structure facilities handover information, *COBie has helped in structuring facilities handover information for AEC professionals for better information capturing at design and construction stages”* [44].

“Potential to integrate with CMMS (Computerized maintenance management system) and other FM (Facility Management) platforms, *COBie being vendor-neutral* *and using ifcXML and ifcSTEP formats have the potential to integrate and map effectively with existing FM systems”* [44].

“Requires less IT knowledge for the generation, *Since it can be generated in a spread sheet format, it has given the flexibility to users to concentrate more on information capturing than learning new technology”* [44].

“Reduce ambiguity on what and when to collect data, *COBie provides detailed guides on what information to be collected at what stages of the project through various guides such as COBie Guide”* [44].

“Reduce ambiguity on who provide information at what stage, *COBie provides a detailed matrix of who provides information to different data requirements at various stages of the project through the COBie responsibility matrix”* [44].

“Cost-saving in FM, *COBie can help in delivering the required information to the FM stage, reducing the efforts to recreate them from paper handover documents resulting in cost saving”* [44].

“Time-saving in FM, *COBie can help in saving time by reducing the efforts to recreate the data again inside custom FM systems”* [44].

“Easy sharing of information among stakeholders, *The spread sheet format of the COBie sheet was designed for easy sharing and visualization of information among stakeholders”* [44].

Structuring information based on COBie increase data availability for facility maintenance, operations, helping the asset managers to more quickly operate their facilities at a lower life-cycle cost [46]. Products data is essential to the development of Facility Management (FM) [42,43,58–60,63,65–70,45,71–80,46,81–90,52,91–94,53–57]. Dixit et al. (2019) investigated BIM-FM issues into different categories as BIM execution and information management, Technological, Cost-based, Legal and contractual [71], being it mostly connected to data/information issues:

- Unclear BIM workflow;
- Improper information capture;
- Failure to update BIM information;
- Lack of client demand to use BIM for FM;
- Incompatible file exchange formats;
- Availability of multiple software platforms;
- Interoperability between BIM-FM technologies;
- Large file size;
- Software issues;
- Long adaptation time towards using new technology;
- Cost associated with training BIM personnel;
- Cost associated with information management;
- Unperceived cost benefits of using BIM;

- Ownership and responsibility of BIM data;
- Contractual and compliance;
- Cyber security and privacy.

Just as it is relevant to standardize product information to be applied to new buildings, it is also necessary to have the digital data of existing products in existing buildings, especially historical ones. Barontini et al. (2021) aiming at a standardisation of the heritage information content, a template for the different classes of damage was created, inspired by the concept of Product Data Templates for new manufacturer's products [95]. Heesom et al. (2020) highlighted that: "*Very often, HBIM (Heritage Building Information Modelling) will be required on projects where renovation works are due to take place. In these cases, the value of the intangible data can be significant to both the design, construction and facilities management teams. For the design teams, it can give insight into the historic design philosophy of the building, and as such, provide guidance to future interventions. For the construction and asset management teams, any intangible data can identify historic significance of elements of the building, which can influence construction methods and future maintenance schedules.*" [96].

The mandatory need to assess the performance of a building throughout its life cycle, integrating all its phases to achieve better levels of effectiveness in several dimensions such as cost, emissions, comfort, makes vital implement asset management. Consequently, asset management is progressively gaining considerable academic and practitioner interest [46,49,80,82,84,85,87,93,97–100,53,101–110,58,111–120,60,121,122,63,64,68,76,78]. According to Silva and Couto (2021), "*Asset Management (AM) is a challenging and increasingly important area in modern society, as efficient management, maintenance and operation of assets can bring numerous benefits. The actual global developments as well as the economic growth have increased the need to know well organization's assets. In response to requests related to the asset operation phase, emerges the Facility Management (FM), as the integration of processes to maintain and develop the agreed services that support and improve the effectiveness of each organization's primary activities has been used to improve the management of the activities that support the main activity.*" [63].

Farghaly et al. (2018) "*proposed taxonomy of the required data for successful implementation of BIM in AM. The taxonomy adopts a two-level tree structure with a top-down development process. The top level is classified into six main branches/classes: location/space, classifications, specifications, warranty, assets capex, and maintenance. At the second level, 60 sub- classes represent the required BIM data/parameters for AM at the handover stage. These parameters can be collected in any of the following stages: planning and design; construction; commissioning; handover and closeout; and finally, O&M. The classification category includes the following parameters: Revit classification, ACE-IM classification, Uniclass2, NRM3, SFG20 "Standard Maintenance Specification for Building & Engineering Services", Revit ID, type name, asset type, and control panel Revit ID.*" [76]. Being the parameter for each category:

Space/location

- Facility type;
- Building name;
- Building number;
- Level name;
- Zone name;
- Department number;
- Room name;
- Room number;
- Room classification;
- Room ID.

Classification

- Revit category;
- ACE-IM classification;
- Uniclass2;
- NRM3;
- SFG20;
- Revit ID;
- Type name;
- Unique Type ID;
- Asset type;
- Control panel Revit ID.

Assets capex

- Asset ID;
- Barcode ID;
- Control panel ID;
- Cost;
- Purchase order number;
- Purchase documents.

Specification

- Manufacturer;
- Supplier;
- Model name;
- Serial number;
- Colour;
- Insulation class;
- Voltage;
- Phase;
- Power (kW);
- Current (amperes);

- Water;
- Gas;
- Heat generated;
- Specifications;
- Documentations;
- Code compliance;
- Spare parts information.

Warranty

- Installation date;
- Installation guide;
- Test reports;
- Certificates;
- Certificates description;
- Life-cycle phase;
- Warranty start date;
- Warranty duration;
- Warranty description.

Maintenance

- Documents;
- Scope;
- Frequency;
- Annual cost;
- Instructions;
- Status;
- History;
- Accessibility.

Until this point, Data Templates in accordance with IS0 23387 are presented as the interoperable and standardized structures with the ability to cluster all construction products, systems and objects relevant data. What makes these different from spreadsheets with groups of properties and properties? The answer relies on IFC and on BuildingSmart Data Dictionary.

The buildingSMART Data Dictionary (bSDD) is an online services that hosts classifications and their properties, allowed values, units and translations. The bSDD allows linking between all the content inside the database. It provides a standardized workflow to guarantee data quality and information consistency.

The key for Data Templates relies on the ability to use these properties from the very beginning or set the link between properties that are the same but used different concepts. It becomes easy to understand that the ability to use the original source brings significant gains in terms of work, but mainly in terms of long-term understanding of the meanings and terms within the industry.

Building sustainability assessment methods (BSAM) frameworks the concepts of sustainability in buildings, e.g. LEED (2019), DGNB (2019), BREEAM (2019), (*apud* Markelj et al., 2014) [123]. Life Cycle Assessment (LCA) methodology intent to evaluate the buildings environmental impacts taking an advance on the information on the Environmental Product Declarations (EPDs) [90,91,131,123–130]. The BSAM "*vary in their assessment attributes, assessment models and weighting schemes according to ISO 21929e1, these methods adapt the general sustainability principles to the specifics of buildings and address the economic, social and environmental impacts. Due to the profound impact of the building sector on the environment, the environmental aspect of sustainability is becoming increasingly important and should become part of the building design.*" [123]. European Commission concluded that LCA provides the best currently available framework for assessing the potential environmental impacts of construction products (Communication on Integrated Product Policy, COM/2003/ 0302, 2003) [123].

According to Durão et al. (2020) "*In parallel with the development and implementation of LCA standards, the communication of environmental assessment results has also been the object of standardisation, the ISO developed standards referring to several types of environmental declarations*" [125]:

- ISO 14020 - Environmental labels and declarations. General Principles [125];
- ISO 14021 - Environmental labels and declarations - Self-declared environmental claims (Type II environmental labelling). It standardises environmental declarations for which products do not need to comply with previously defined criteria. These Type II declarations are developed by the production company and are not verified by an independent third party [125];
- ISO 14024 - Environmental labels and declarations. Environmental Labelling Type I. Principles and procedures. Standardises declarations that qualify the declared product, as they ensure that it com- plies with a pre-established minimum reference level of environ- mental performance (defined by the labelling programme), and consists of an instrument aimed at communicating with the final consumer [125];
- ISO 14025 - Environmental labels and declarations - Type III environmental declarations - Principles and procedures (ISO, 2006c). Standardises EPDs, which do not qualify the product as they do not ensure a given level of performance. Rather, they objectively communicate the results of an LCA study developed according to standardised methods and are usually subject to third party verification [125].

Nevertheless, Durão et al. (2020) pointed that "*ISO 14040, ISO 14044 and ISO 14025 leave space for important methodological choices during the LCA study and the development of an EPD. Therefore, even ISO 14025 compliant EPDs may be not comparable, as shown by several studies (apud. Gelowitz and McArthur, 2017; Subramanian et al., 2012). Thus, besides these ISO standards, standardisation activities were developed specifically for construction products both by ISO and by the European*

Committee for standardisation (CEN), Technical Commission 350 (CEN/TC 350, 2001), on Sustainability of construction works, to better specify the requirements of EPDs for construction products, namely, in the business-to-business format" [125]:

- ISO 21930 - Sustainability in building construction - Core rules for environmental declarations of construction products and services (ISO/TC 59, 2007);
- EN 15804 - Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products (CEN/TC 350, 2019);
- EN 15942:2011 - Sustainability of construction works - Environmental product declarations - Communication format business-to-business (CEN/TC 350, 2001).

Also, "*ISO 21930 was initially meant to provide the principles and requirements for type III environmental declarations EPD of building products. It provided a framework and the basic requirements for PCR (ISO/TC 59, 2007) but was not a PCR for this product category. It contained specifications and requirements for the EPD of building products, complementing ISO 14025.*" [125]. Yet, an upcoming ISO 22057 will update the standardisation of the Environmental Product Declarations (EPDs).

According to Azuma et al. (2014), "*information on the compositions of construction products is useful to construction designers, builders and occupants to help establish good indoor air quality and building environment. Existing measures to deliver this information, such as labelling or material safety data sheets, have not been adequate for construction products.*" [132]. Adding to this, Díaz-Soler et al. (2019) highlighted that "*the use of engineered nanomaterial's (ENMs) in the construction sector is a newly emerging risk as there is limited knowledge about this topic*" [133]. Still, a detailed composition of the construction products is necessary to evaluate the risks both on-site and handover. On the other hand, it is challenging to have this data over manufacturers' concerns on knowledge and patents. Finally, "*the consequences of not providing adequate information are that workers may be exposed to ENMs that are known to have the potential for causing adverse effects on human health. Similarly, this situation hampers the se- lection of proper risk management measures, including engineer- ing controls and personal protective equipment. Regarding the definition of the potential of exposure to ENMs for the representative uses identified in the construction site, it is concluded that a major exposure potential is expected in those activities dealing with nano-enabled construction products in powder form or applied as sprays. The inhalation and dermal routes are critical in both types of activities.*" [133].

The BAMB (Buildings As Material Banks) EU2020 project aimed to promote materials information to achieve an effective recovery and reuse of components, products or materials in buildings [134]. "*The electronic Materials Passports developed in BAMB aim to be a one stop shop for material information. Materials Passports developed in BAMB are sets of data describing defined characteristics of materials in products that give them value for recovery and reuse.*" [134]. According to Luscuere (2017) That BAMB [135] through the material passports [136–138] can integrated into BIM aspects related to LCA and EPD, "*tools to inventory composition such as bill of materials or bill of substances and tools to detail technical properties such as technical data sheets (TDS) or material safety* *data sheets (MSDS)*" [138]. A BOM (Bill of Materials) [139,140] "*is one of the principal elements of any materials management system. In general, The BOM is a technical document that clarifies the composition of a module (or a facility)*" [140]. Finally, a QTO (Quantity take-off) [73,141] is "*a detailed measurement of materials and labor needed to complete a construction project (apud. Holm et al., 2005). It serves as the foundation for other tasks in construction management such as cost estimation and schedule planning, and its accuracy can directly affect downstream analyses and decision making. The QTO process is an information extraction process during which quantities of building elements or features are measured based on the design drawings or the 3D model.*" [73].

Digital solutions are spread across the Construction Industry and focus on automating processes across the built whole lifecycle. Digital Twins concept integrates many technologies/methodologies, as BIM (Building Information Modelling). BIM is a digital platform that composes the built elements targeting the assets visualisation, information, and operations [10]. Several systems assist the building processes, from the design (e.g., software for structural calculations), through the execution (e.g., systems for development/monitoring schedules), to information repositories (e.g., computer databases) that are later used in the operation phase (Facility Management). Digital Twin is a platform to connect through sensors the physical assets to cyberspace that allows collection, processing, analysis of data to simulate and controlling the assets [11–13].

The concept of Digital Twin [77,100,110,122,142,143] must be broad, and its materialization starts at the conception of the enterprise. It takes shape throughout the execution of the project, intercommunicating data at all times, and thus the DTC (Digital Twin Construction) [144] terminology is more appropriate/specific for CI. "*Digital twin construction (DTC) is a new mode for managing production in construction that leverages the data streaming from a variety of site monitoring technologies and artificially intelligent functions to provide accurate status information and to proactively analyze and optimize ongoing design, planning, and production. DTC applies Building Information Modeling technology and processes, lean construction thinking, the Digital Twin Concept, and AI to formulate a data-centric mode of construction management.*" [144]. To allow that construction management on-site it is needed a sensored construction site to continued monitoring workers, products and equipment/machines [145]. Also, a Smart Building is a Digital Twin powered by IoT in the operation/use phase. It is throughout this 'Smart-Digital-Building-Twin' (i.e., Digital Twin) that the built systems are controlled/operated (e.g., energy management, facility management, indoor comfort, safety&security) [146]. However, there is no Digital Twin without Digital Data.

In 2012, the publication of the European Union (EU) "Strategy for the Sustainable Competitiveness of the Construction Sector and its Enterprises" set the global challenges for the industry (even surpassing the EU boundaries) and opened the way for the development of strategies to raise the industry bar. Due to the AECOO vast scope and number of challenges, different headings were assumed by leading organizations, namely EU DG's - Directorate-General. During this time, many strategic documents, research projects and guidelines were developed. Table 1 presents a collection of initiatives that target sustainable goals into a digital era. Many of them, due to the nature of the organizations have focused on specific issues, topics and priorities to be solved. Given this and looking from a broad perspective, their approaches followed different assumptions and became “fuzzy” when there is the need to perform a combination or harmonization between them.

Following the strategic approaches and placing them as a layer framed with the construction life cycle, Digital Transformation tends to look forward to the construction value-chain and its processes, to the implementation of Industry 4.0 technologies, raising the sector to an analogue 4.0 paradigms. The Sustainability and Waste look behind, to the already existing Built Environment and to the industry installed capacity (understood as production capacity and potential of the built stock), seeking ways to become more eco-efficient both through the production of more environmentally friendly products, waste reduction and re-use and recycling of products/elements.

The AECOO is identified as a priority domain on the action plan for Circular Economy in Europe because, in volume terms, is among the biggest sources of waste [147]. The promotion of the efficient use of resources to reduce overall environmental impacts throughout the full life cycle is a major goal. To accomplish it, reliable indicators must be developed seeking to evaluate total energy use, including operational energy, material use, carbon footprint, the durability of construction products, recyclability and reusability as well as recycled content used in construction products [148]. These indicators rely on comparable and affordable data, methods and tools on which the operators in the supply chain can analyse and benchmark the environmental performance of different solutions. Yet this is still lacking [148]. The ability to perform improved assessments and quality reliable data is essential to develop the environmental analysis and achieve the abovementioned indicators [149]. As well, despite some quick wins on the recycling and re-use of products, there are still several data challenges at this level.

Table 1. The content of the selected Initiatives and Standards publications, in terms of Digital solution implemented (DDT = Digital Data Templates, DBL = Digital Building Logbook, DTC = Digital Twin Construction), the Spectrum (World, EU, Country, Sector, Sub-sector), the Strength (Law, Standard, Guideline, Strategy) and, the research main aim identified.

Publication	Digital Solution	Spectrum	Strength	Main aim identified
[150] HM Government. (2015). Digital Built Britain Level 3 Building Information Modelling - Strategic Plan. UK Government.	DTC	Country [UK]	Strategic Plan	Definition of strategic headings at country level for the development of a more digital sector

[151] Fabbri, M., et al. (2016). Building Renovation Passports: Customised roadmaps towards deep renovation and better homes. Buildings Performance Institute Europe.	DBL	EU	Guideline	Overview of existing initiatives, contextualization and Conclusions/Recommendations for future developments. Building Renovation Passports can be framed as the infancy of DBL
[152] Thompson, S. (2016). Product Data Definition: A technical specification for defining and sharing structured digital construction product information.	DDT	Country [UK]	Guideline	Support DDT awareness and contextualization with BIM standards
[153] Product Data Working Group. (2018). A Fresh Way Forward For Product Data. UK BIM Alliance.	DDT	Country [UK]	Guide/ Strategy	Realization of the role of Data in the construction process and guidance towards structuring data
[147] European Commission. (2018). A monitoring framework for the circular economy COM(2018) 29 final.	—	EU	Strategy	When addressing resources efficiency data structures and traceability is present, meaning that DDT and DBL are implicit in the document
[154] European Commission. (2018). Guidelines for the waste audits before demolition and renovation works of buildings. UE Construction and Demolition Waste Management.	—	EU	Guideline	The document presents and defines the processes that need to take place prior to refurbishment actions; the waste audits. This relies on data stored and identified leading to material inventories. From an indirect view point DDT and DBL are related with this topic
[155] BS EN ISO 19650-1:2018. (2018). Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling.	—	World	Standard	Regulation of processes / Promotion of common understandings The focus of the standard is BIM methodology. DDT are BIM enablers and DBL and DTC benefit from BIM. The concepts are explored from an indirect point of view by the document

[156] BS EN ISO 19650-2:2018. (2018). Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling.	—	World	Standard	Regulation of processes / Promotion of common understandings The focus of the standard is BIM methodology. DDT are BIM enablers and DBL and DTC benefit from BIM. The concepts are explored from an indirect point of view by the document
[157] Brilakis, I., et al. (2019). Built Environment Digital Twinning.	DTC	Country [Germany]	Guide/ Strategy	Industry awareness and disclosure of company level visions (Siemens)
[158] Andy Neely, et al. (2019). Developing the capabilities for a digital built Britain.	DTC	Country [UK]	Guide/ Strategy	Capabilities awareness and strategic roadmap. Centres on DTC but DDT and DBL are part of it
[159] Daskalova, M., et al. (2019). Digital Supply Chains: Data Driven Collaboration.	DDT	World	Guide/ Strategy	Realization of the role of Data in the construction process and how collaboration plays an essential role towards improvement
[160] Mario, G., et al. (2019). The data-driven innovation strategy for the development of a trusted and sustainable economy in Luxembourg.	—	Country [Lux]	Strategic Plan	Broad strategic document ranging several areas. From an indirect point of view it approaches DTC and DDT
[161] European Commission. (2019). The European Green Deal.	—	EU	Strategy	Actions at EU level to achieve climate neutrality by 2050. Among these actions DDT, DBL and DTC are broadly mentioned. However, this document frames all the others from the European Commission that are mentioned here
[162] European Union. (2020). A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives.	—	EU	Strategy	Among the actions for the Renovation Wave are the DBL and the ability to have more data related with construction products, i.e. DDT

[163] BS EN 17412-1:2020. (2020). BSI Standards Publication Building Information Modelling — Level of Information Need.	DDT	EU	Standard	BIM related standard that details processes from ISO 19650 and focus on data for purposes; Level of Information Need
[3] ISO/FDIS 23386:2019(E). (2020). Building information modelling and other digital processes used in construction — Methodology to describe, author and maintain properties in interconnected data dictionaries.	DDT	World	Standard	Concepts and principles awareness and developments towards joint understanding of the topic
[1] ISO/FDIS 23387:2020(E). (2020). Building information modelling (BIM) — Data templates for construction objects used in the life cycle of any built asset — Concepts and principles.	DDT	World	Standard	Concepts and principles awareness and developments towards joint understanding of the topic
[164] PAS 14191:2020. (2020). Built environment – Management and operation of interconnected construction data dictionaries – Specification.	——	Country [UK]	Standard	Standard document to foster interoperability requirements. Touches from indirect point of view in DDT and DTC
[165] Gilbert, T., et al. (2020). Built environment data standards and their integration: an analysis of IFC, CityGML and LandInfra.	——	World	Guideline	This awareness document explores interoperability issues and from an indirect point of view deals with the 3 aspects in research
[166] Allison, N., & Hartley, G. (2020). Digital Product Data for Lifting Productivity.	DDT / DTC	Country [NZ]	Overview/Strategy	Overview of existing initiatives, contextualization and Conclusions/Roadmap
[9] buildingSMART. (2020). Enabling an Ecosystem of Digital Twins.	DTC	World	Guide/	Industry awareness and disclosure of entity vision

			Strategy	
[14] European Commission. (2020). Study on the Development of a European Union Framework for Digital Building Logbooks (Final Report).	DBL	EU	Overview/Strategy	Overview of existing initiatives, contextualization and Conclusions/Recommendations for future developments on DBL
[167] buildingSMART. (2020). Facilities Management Handover – COBie 2.5.	DBL	World	Guide/ Strategy	COBie is a way to transfer BIM data into FM systems. This relates with the three topics as DDT enables a streamlined COBie and this can provide structured data to DBL therefore supporting DTC
[168] Verbeke, S., et al. (2020). Final report on the technical support to the development of a smart readiness indicator for buildings. European Commission.	DTC	EU	Overview/Strategy	Roadmap to implement a Smart Readiness Indicator for Building. This topic is related with DTC ecosystems and namely in Buildings
[10] European Construction Sector Observatory. (2021). Digitalisation in the construction industry.	DTC	EU	Overview/Strategy	Overview of existing initiatives, contextualization and potential future headings

The strategic level documents explored in the previous Table 1 globally define some of the ACEOO main challenges, focusing both on global and specific aspects. Yet and despite some converging endeavours, the underlying message still lacks common approaches and terminology, causing confusion and inaction at sector, companies and personal levels. As evidenced, BIM methodology and circular economy in construction based on sustainability and waste efficiency arise as main topics. Ganiyu et al. (2020) developed a study ranging the two dimensions seeking to identify the required competencies to deliver projects fulfilling both types of requirements. One of the aspects that are highlighted in the introduction is that "*BIM usage for delivering waste-efficient projects is not commonplace*" [169], meaning that there is still a lot to explore.

In accordance with ISO 19650 series, the Asset Information Model (AIM) is composed of Documentation, Alphanumerical information and Geometrical information [155]. This must be a fundamental understanding around all BIM uses becoming increasingly indispensable when dealing with life cycle approaches. At this level, all the added value is on the data and its interpretation, compilation and organization into useful information. From the literature review, it highlights that Data is a common point between both challenges and strategies meaning that it constitutes a connection point to start bridging the existing gap.

A waste audit is a specific action before the demolition (C1 with other terminology) or renovation (B5, likewise) of buildings and infrastructures that must be foreseen within a project planning in order to understand and quantify the types and amounts of elements and materials that will be deconstructed and/or demolished, and to issue recommendations on their future handling [154]. A specific document with guidelines on this task was produced by the EU and despite all processes and benefits it confirms, as mentioned, a “siloed” approach to the construction challenges as there is no single reference to “digitalisation” nor “BIM”. Despite that, there are some key aspects (that may, however, go unnoticed) that on one hand confirm the existing gap, namely in terms of communication, and on the other hand, are used as starting point to bridge that gap (in terms of processes). Both support the need and contributions of this research. These aspects are the “Data to achieve the materials inventory” and the “Data Traceability concerns”.

In terms of “Data Traceability,” it is stated that “*Waste audits should be considered as living documents that are revised periodically*” [154]. In this, there are considered 3 stages that run from a situation prior to the deconstruction/refurbishment until the end of the process (disposal or reuse). This is found to be a short-term traceability requirement but one that is not so different and can glue to wider traceability requirements running through different construction process phases as evidenced. Regarding the “Data in Materials Inventory”, it is stated that “*The inventory of waste fractions and elements is the core part of the waste audit report*” [154] “*The assessment of materials aims to present reliable data about the type and amount of the demolition waste*” [154]. The material inventory must include the materials quantification in relevant units of measurement and type of material under several classifications as the European Waste Catalog (EWC), EURAL waste list and data related to hazard ability, recycling and re-use. None of this required data has an origin in this process. It is data that comes from prior stages but is identified and organized in this action for a specific/different purpose.

The study action for the development of an EU framework for digital building logbooks has recently published a report where through this tool, the building logbook, aims to bridge the gap between construction digitalization and environment initiatives [14]. In accordance with it: “*A digital building logbook is a common repository for all relevant building data”.”... is a dynamic tool that allows a variety of data...*”. “*As such, it can include administrative documents, … technical systems, traceability and characteristics of construction materials, performance data such as operational energy use, indoor environmental quality, smart building potential and lifecycle emissions.*” [14]. Given this, and for the purpose of the present research, the Building Logbook is found to be the “place” where all the Data Sheets of a specific build object are stored and updated, mainly from handover until refurbishment/deconstruction. As so, this closes the data and information cycle required to implement a circular economy in construction. The EU Renovation Wave strategic document to foster refurbishment actions across the European Building stock highlights that all these processes should seek for the [162]:

- Use of Building Logbooks;
- Development of waste audits;
- Implementation of BIM.

From this results that the Digital Transformation and Environment and Sustainability challenges identify Data within their concerns to provide common or specific information and that there are common data structures with the ability to support both requirements, from the processes perspective. Therefore, the information communication strategies to the AECOO and their stakeholders addressing both dimensions should use data and digital data structures to bridge the gap and foster a more favourable environment to promote a circular economy. The Digital Data are used to bridge the gaps at process and communication levels and set a movement to promote the digital circular construction based on information. Figure 2(a) presents the existing gap between strategies, and Figure 2(b) sets the Circular Economy built on Digital Transformation and Environment and Sustainability goals.

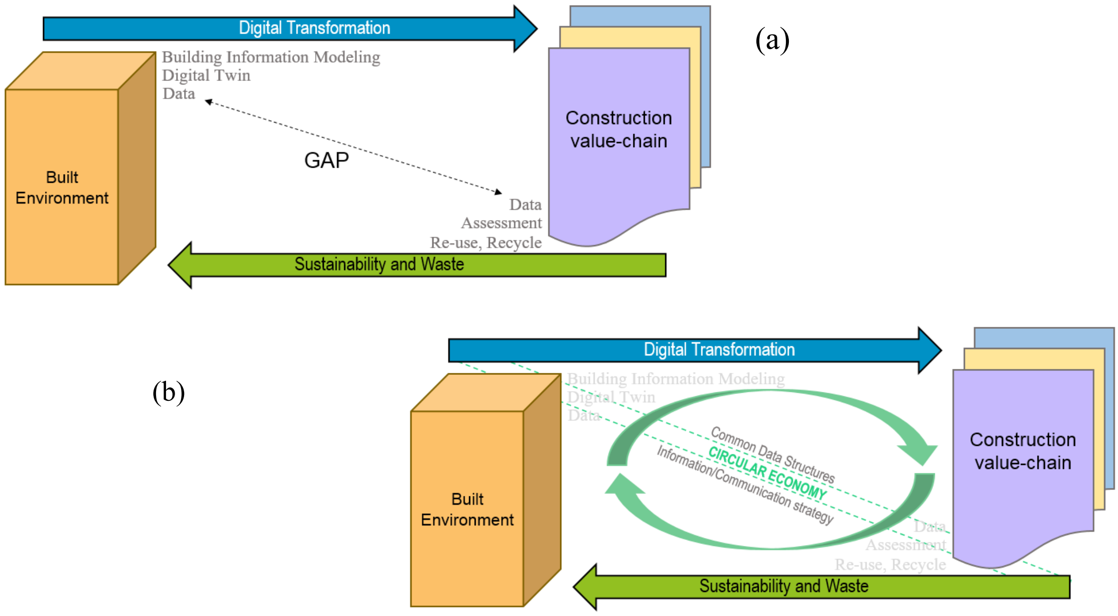

Figure 2. Digital bridge to Sustainable goals

Given the elements and concepts above reviewed the conceptualisation of their potential uses and relationships to make a proof of concept on how both challenges can work combined through the use of Digital Data Templates. The first conceptualisation is focused on the combination of the waste audit action and the DDT, Digital Data Templates, use for the situation of two different Built Environment scenarios. The Digital Building Logbook concept is used as the "information vault" through the construction life cycle and is used here to introduce an overall conceptual framework.

Considering a new project/construction process, the DDT's are called to support specific construction products/elements data becoming Digital Data Sheet and following a part of the AIM alphanumerical information. During the handover phase, the Logbook assumes the role of information vault/container with several layers supporting all kinds of information. On the edge, it can become part of the Digital Twin system or eco-system with traceability and update routines, contributing to the update of the Material Inventory that will, in a certain moment of the life cycle, be called either in the case of a refurbishment or for the deconstruction process. A similar situation, and the one that is expected to happen the most, is the case of an "old"/existing built object facing a refurbishment or a deconstruction process.

The digital data relating to these cases is often none and most times the paper/other formats available information is not sufficient. Facing a waste audit, the material inventory will be developed from scratch. In these cases, if the waste audit guideline could point to the use of DDT, even without all the values, these structures would suit for the purpose of the waste audit itself and also for the case of products/elements to be re-used or recycled. At this point, it is important to distinguish also if the built object is going to be deconstructed or refurbished. If it is the second case, the use of DDT will support the development of the Building Logbook. Figure 3 provides a conceptualization of how the processes can run for both types of situations; new projects and existing built objects.

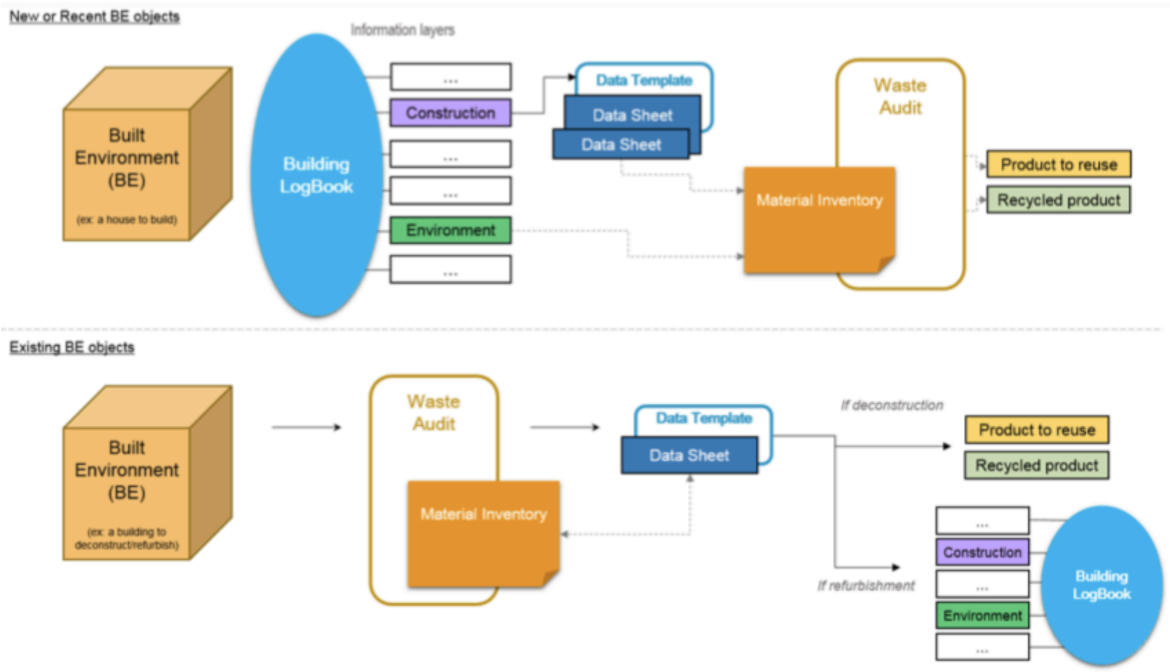

Figure 3. Data Templates enabling CI digital information

It is also important to highlight that the adoption of Digital Data Templates can introduce benefits in many other processes besides waste audits. Through the organization of the data in a standardised way, it is possible to streamline other processes in other phases as sustainability assessments during design, simulations, and so forth. Following a data-centric perspective applied to a circular construction life cycle, it becomes clear the essential role that DDT must play. The conceptual framework presented in Figure 4 evolves from all the elements and concepts reviewed. The Environmental Product Data (EPD) and the CE mark values constitute layers or groups of properties of the Data Templates, as well as some of the waste audit information requirements. LEVEL(s) is a sustainability assessment as LEED or BREEAM that uses products/elements values, meaning values from different DDS under DDT's.

From a whole life cycle perspective, a built object at the end of its life will be refurbished or deconstructed and its systems and elements will become waste, recyclable products, or products with the ability to be re-used [154]. This identification should be made prior to each one of those actions through a waste audit. As a product can be suited for re-use, so its information must be. Therefore, the waste audit was selected to conceptualize a proposal aimed to close the information circle through the construction life cycle and to be used as an example to bridge essential aspects between the digital transformation strategies and the sustainability and waste goals applied to construction. EN 15978:2011 [170] is used to support the construction life cycle stages, from A1 (Raw material supply) to D (Recovery/Reuse/Recycling-potential), and system boundary covering to cradle to grave. The new standards ISO 19650-1:2018 [155] and ISO 23387:2020 [1] should be regarded as strategic facilitators for the accomplishment of the challenges.

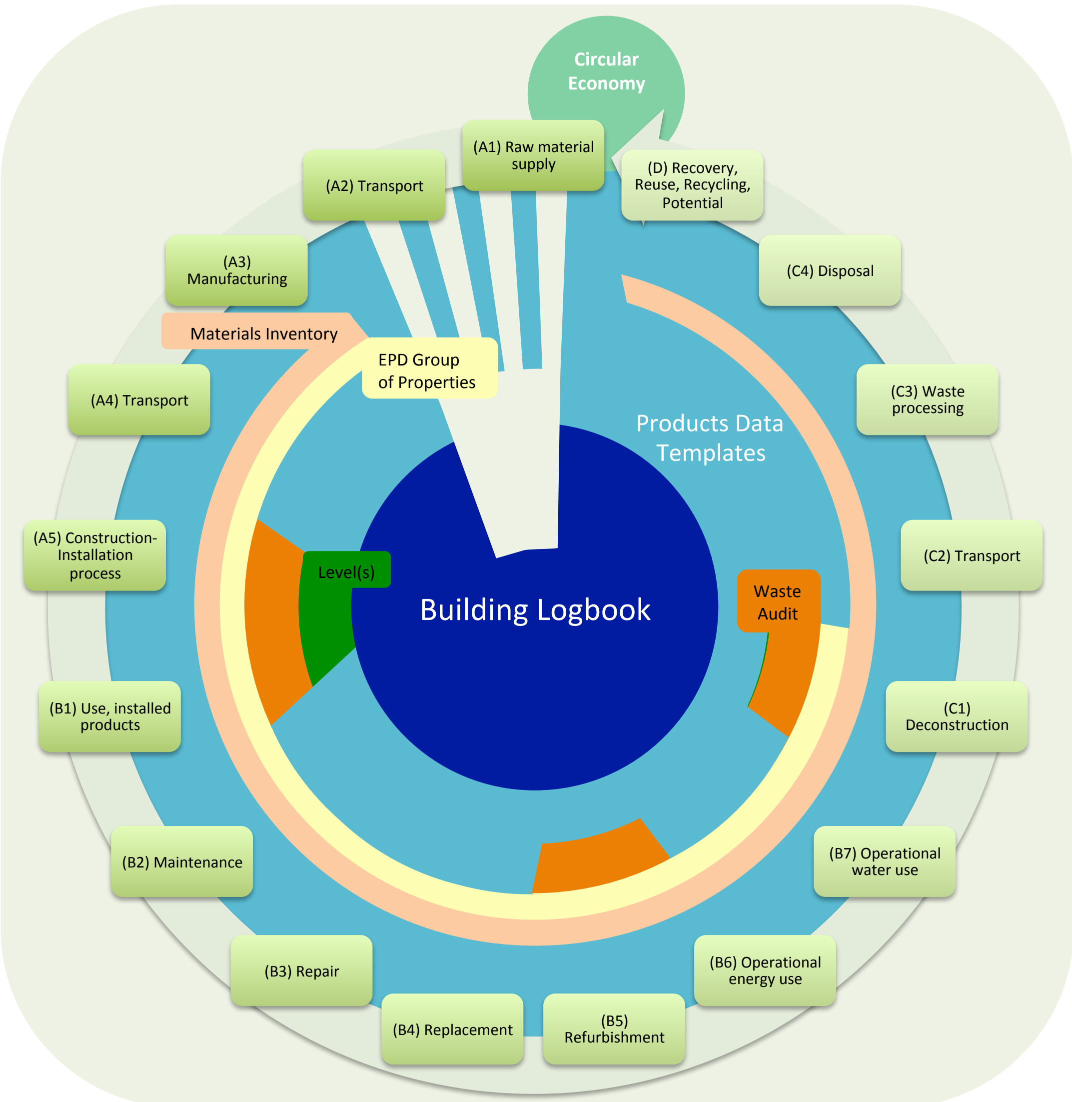

Figure 4. Data Templates enabling a Circular Building life cycle

The AECOO is being called to build smarter and more efficient built objects. Underlying, there are challenging requirements to be accomplished as the Digital Transformation of the construction value-chain and Sustainability and Waste goals, both for new or existing built objects construction processes to achieve a circular construction. As evidence, it is important to align the communication to highlight how digitalisation and environment strategies can work, evolve together and support each other, promoting more circular and efficient practices. The waste audit action was used as example to deliver a conceptual approach of a relevant improvement that can be achieved if both challenges are approached from a combined point of view. The novelty was to perform this kind of approach using the Digital Data Templates across the value-chain and the Digital Twin Construction and Digital Building Logbooks concepts to assure the production, storage and traceability of the construction-related information to be available at the moment of deconstruction or refurbishment, feeding and fulfilling most of the waste audit requirements, as they are now established in the guidelines.

Considering the outcome, a similar approach was introduced for the situation of existing built objects where before refurbishment/deconstruction and through the use of DDT's the data that is possible to collect will be ready and in the right format to support the characterization of a product/element/systems that will be reused, recycled or disposed in the landfill. In addition, a conceptual framework based on the construction life cycle was developed evidencing the different phases, the processes, groups of properties and strategic actions such as LEVEL(s). These frameworks constitute the basis for future studies to prove how several elements working together can provide interesting outcomes, both in recent or future construction processes as well as on processes working with existing built objects. Specific case studies involving data sheets exploring further the data flows and the information exchanges through the life cycle are a goal. In regards to building logbooks, the research will address the requirements to foster and streamline the relationship between these tools and the Data Templates.

vi. Data Templates (awareness)

Following the webinar promoted by APCMC (Portuguese Association of Building Materials Traders), "Digitisation of Companies in B2B Business", which took place on the 5th of November 2020, the first GrowingCircle survey was presented and sent to its associates. This survey aimed to understand agents' views regarding the Digitalisation processes and, specifically, concerning Data Templates. Respondents from more than 30 different institutions applied the survey. As presented before, 78% of respondents are unaware of Data Templates. As presented in Figure 5, ten innovative solutions awareness were tested (including Data Templates). It is seen in the graphical representation that the closer the lines get to the centre of the figure, the greater is the maturity. The results are indicative in that, the great part of technologies/methodologies lacks research and development for application in CI. However, the results presented guide the future development and application of these technologies/methodologies in the CI market.

It can be observed that the maturity of the technologies/methodologies is mainly related to two factors, the time (degree of penetration) of application and the level of complexity of the same. In this context, Mobile devices (smartphone, tablet, others), Information digitalisation and metadata, Cloud computing, Connectivity (Bluetooth, wi-fi), Systems integration/interoperability stand out. On the other hand, more recent solutions as Automatization and Robotization, Sensoring and Wearables, Data Templates, Augmented Reality, 3D printing, have reached a lower maturity. The results are presented below in order from the greatest diagnosed knowledge to the lowest level of awareness:

1. Mobile devices (smartphone, tablet, others);
2. Information digitalisation and metadata;
3. Cloud computing;
4. Connectivity (Bluetooth, wi-fi);
5. Systems integration/interoperability;
6. Automatization and Robotization;
7. Sensoring and Wearables;
8. Data Templates;
9. Augmented Reality;
10. 3D printing.

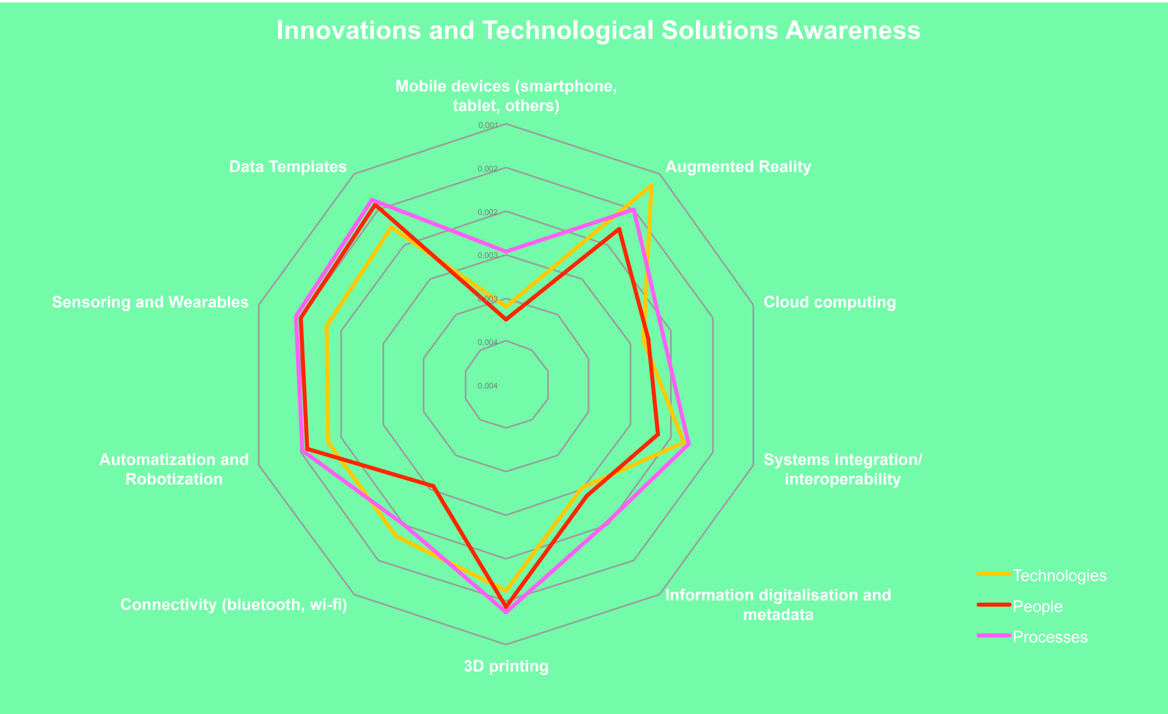

Figure 5. Innovative solutions Awareness

We sought to identify the level of engagement of the various AECOO stakeholders for actions to digitise the sector (Figure 6). Where, in the respondents' perception, design companies have a broader knowledge of digitisation. With owners, contractors, and

Construction Products Traders, diagnosed as less knowledgeable about digitisation processes. As in order from the most to least engaged is presented below:

1. Design Companies (Architecture);
2. Design Companies (Engineering);
3. Real Estate;
4. Facility Management;
5. Construction Products Manufacturers;
6. Construction Surveyors;
7. Private Owners;
8. Contractors;
9. Public Owners;
10. Construction Products Traders.

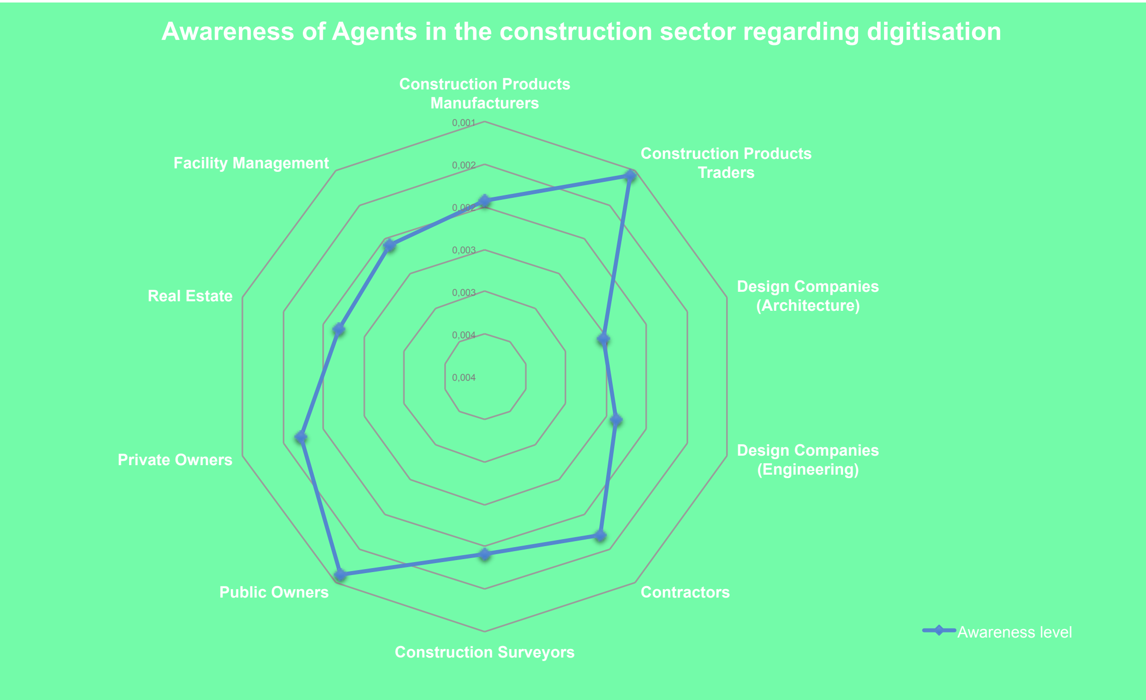

Figure 6. Sector Stakeholders Awareness

Concerning Data Templates, it is clear that lack of awareness in the three PPT dimensions, with a slightly greater awareness of the Technological dimension over People and Process (Figure 7). In order to increase Data Templates awareness, it is vital to introduce the technology showing how people can take advantage of this to improve the current processes.

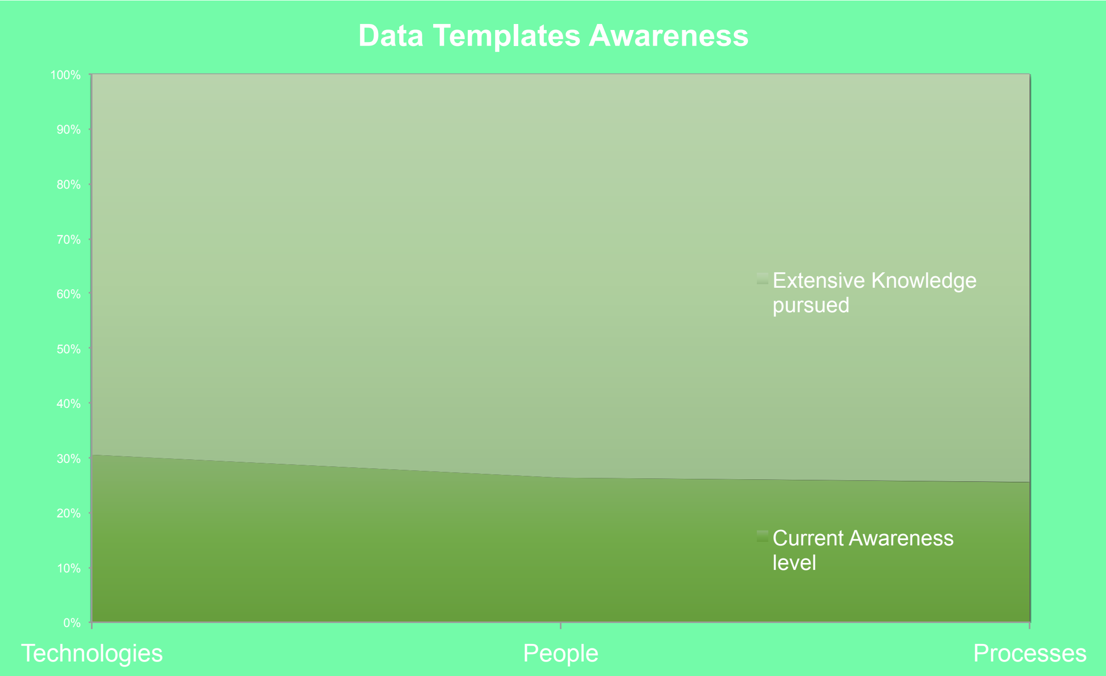

Figure 7. Data Templates Awareness

Finally, Figure 8 presents crosswords regarding the open questions concerning Enhances/Hinder to the sector' digitisation and about the Data Templates' added value brings to the industry.

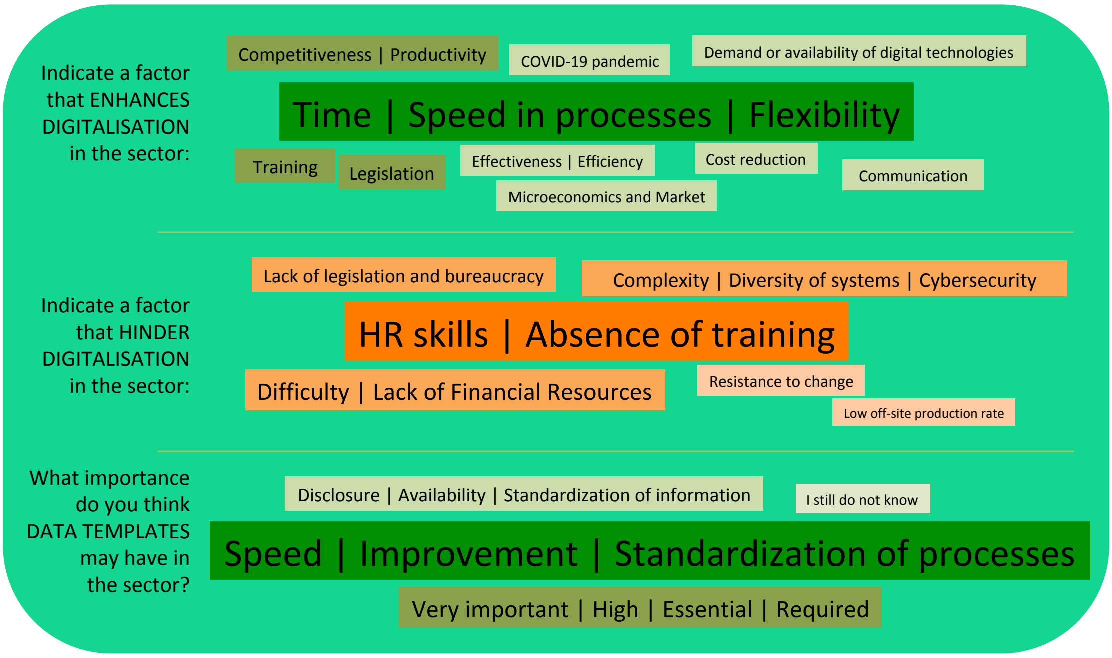

Figure 8. What People say about it

The survey results are in line with the overall perception that motivates the development of the GrowingCircle project. Yet, and despite some scepticism when we start developing the questions, these results are impressive given the higher level in terms of lack of knowledge, constituting therefore an even more challenging task to accomplish.

On the other hand and given this absence of knowledge there are interesting impressions that the respondents provide and these express their real “feelings” on the situation. As an example, they envisage time savings and flexibility as main enablers for digitalisation and on the same time the absence of skills as the main barrier followed at distance by regulations misalignment and financial resources. This means that the industry is eager for awareness and training in digitalisation and that it is key to push on the ability of the technology to save time and introduce flexibility. Data Templates accomplish both situations and therefore the results present interesting headings for future actions.

Cut crossing the reading of these results with the results on the importance of Data Templates, we find similar feelings and what we can present as a very broad term “Standardization of Processes” that is important to frame in different dimensions and work these in higher detail.

vii. Bibliography

[1] ISO/FDIS 23387:2020(E), Building information modelling (BIM) — Data templates for construction objects used in the life cycle of any built asset — Concepts and principles, 2020.

[2] Cobuilder, What is A Data Template (DT) in the construction industry?, (2021). https://cobuilder.com/en/what-is-a-data-template/ (accessed May 24, 2021).

[3] ISO/FDIS 23386:2019(E), Building information modelling and other digital processes used in construction — Methodology to describe, author and maintain properties in interconnected data dictionaries, 2019 (2019).

[4] buildingSMART, buildingSMART - The International Home of BIM, (n.d.). https://www.buildingsmart.org/ (accessed May 25, 2021).

[5] European Parliament, Circular economy: definition, importance and benefits | News | European Parliament, (n.d.). https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits (accessed June 4, 2021).

[6] buildingSMART, Reading List - buildingSMART COBie, (n.d.). https://cobie.buildingsmart.org/reading-list/ (accessed June 4, 2021).

[7] Cobuilder, Cobuilder web page, (n.d.). https://cobuilder.com/en/ (accessed May 25, 2021).

[8] EU (European Union), The Construction Products Regulation EU 305/2011, Off. J.

Eur. Communities. (2011).

[9] buildingSMART, Enabling an Ecosystem of Digital Twins, 2020. https://www.buildingsmart.org/buildingsmart-positioning-paper-enabling-an-ecosystem-of-digital-twins/.

[10] European Construction Sector Observatory, Digitalisation in the construction industry, 2021.

[11] Y. Tchana, G. Ducellier, S. Remy, Designing a unique Digital Twin for linear infrastructures lifecycle management, Procedia CIRP. 84 (2019) 545–549. https://doi.org/10.1016/j.procir.2019.04.176.

[12] C. Boje, A. Guerriero, S. Kubicki, Y. Rezgui, Towards a semantic Construction Digital Twin: Directions for future research, Autom. Constr. 114 (2020) 103179. https://doi.org/10.1016/j.autcon.2020.103179.

[13] T.M.B. Fjeld, Digital Twin - Towards a joint understanding within the AEC/FM sector, Norwegian University of Science and Technology, 2020.

[14] European Commission, Study on the Development of a European Union Framework for Digital Building Logbooks (Final Report), European Commission, 2020. https://op.europa.eu/en/publication-detail/-/publication/cacf9ee6-06ba-11eb-a511-01aa75ed71a1/language-en/format-PDF/source-search.

[15] DigiPLACE, DigiPLACE web page, (n.d.). https://digiplaceproject.eu/ (accessed May 25, 2021).

[16] P. Mêda, H. Sousa, E. Hjelseth, Data Templates—Product Information Management Across Project Life-Cycle, in: Sustain. Mater. Build. Constr. Build. Pathol. Rehabil. 11, Springer International Publishing, 2020: pp. 117–133. https://doi.org/10.1007/978-3-030-46800-2_5.

[17] H.J.C. de Sousa, P.N.M. Magalhães, Estratégias para a fileira da construção nacional – síntese de visões e resultados de implementação, in: Int. Congr. Eng., 2017.

[18] Á. Gigante-Barrera, D. Ruikar, M. Crunden, K. Ruikar, Lod object content specification for manufacturers within the UK using the idm standard, J. Inf. Technol. Constr. 22 (2017) 80–103. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85024106928&partnerID=40&md5=1633af754a4460ae53fd5cda0431f12f.

[19] M.N. Lucky, D. Pasini, S.L. Spagnolo, Product Data Management for Sustainability: An Interoperable Approach for Sharing Product Data in a BIM Environment, in: IOP Conf. Ser. Earth Environ. Sci., 2019. https://doi.org/10.1088/1755-1315/296/1/012053.

[20] M. Signorini, S. Frigeni, S.L. Spagnolo, Integrating environmental sustainability indicators in BIM-based product datasheets, in: IOP Conf. Ser. Earth Environ. Sci., 2019. https://doi.org/10.1088/1755-1315/296/1/012028.

[21] J. Irizarry, E.P. Karan, F. Jalaei, Integrating BIM and GIS to improve the visual monitoring of construction supply chain management, Autom. Constr. 31 (2013) 241–254. https://doi.org/10.1016/j.autcon.2012.12.005.

[22] J. Stark, Product Data in the PLM Environment, in: Prod. Lifecycle Manag. (Volume 1), Decis. Eng., 2015: pp. 131–171. https://doi.org/10.1007/978-3-319-17440-2_4.

[23] J. Stark, PLM and the PLM Initiative, in: Prod. Lifecycle Manag. (Volume 1), Decis. Eng., 2020: pp. 489–539. https://doi.org/10.1007/978-3-030-28864-8_14.

[24] J. Stark, PLM Applications, 2011. https://doi.org/10.1007/978-0-85729-546-0.

[25] J. Stark, PLM in Industry, in: Prod. Lifecycle Manag. (Volume 1), Decis. Eng., 2020: pp. 541–569. https://doi.org/10.1007/978-3-030-28864-8_15.

[26] J. Stark, Information Systems in the PLM Environment, in: Prod. Lifecycle Manag. (Volume 1), Decis. Eng., 2015: pp. 173–233. https://doi.org/10.1007/978-3-319-17440-2_5.

[27] J. Stark, PLM and Business Processes, in: Prod. Lifecycle Manag. (Volume 1), Decis. Eng., 2020: pp. 99–158. https://doi.org/10.1007/978-3-030-28864-8_4.

[28] J. Stark, PLM and PDM, in: Prod. Lifecycle Manag. (Volume 1), Decis. Eng., 2020: pp. 221–242. https://doi.org/10.1007/978-3-030-28864-8_6.

[29] J. Stark, PLM Applications, in: Prod. Lifecycle Manag. (Volume 1), Decis. Eng., 2016: pp. 199–231. https://doi.org/10.1007/978-3-319-24436-5_10.

[30] J. Stark, PLM and Product-Related Applications, in: Prod. Lifecycle Manag. (Volume 1), Decis. Eng., 2020: pp. 243–307. https://doi.org/10.1007/978-3-030-28864-8_7.

[31] J. Stark, PLM and Product Data, in: Prod. Lifecycle Manag. (Volume 1), Decis. Eng., 2020: pp. 159–219. https://doi.org/10.1007/978-3-030-28864-8_5.

[32] J. Stark, Example of a PLM Vision, in: Prod. Lifecycle Manag. (Volume 2), Decis. Eng., 2016: pp. 485–508. https://doi.org/10.1007/978-3-319-24436-5_25.

[33] E. Zancul, L. Piccini, S. Berglehner, L. Lachenmaier, Product Lifecycle Management Functional Reference Model for Software Support, in: Smart Prod. Eng., 2013: pp. 243–251. https://doi.org/10.1007/978-3-642-30817-8_24.

[34] T. Buchert, A. Pförtner, R. Stark, Target-Driven Sustainable Product Development, in: Sustain. Manuf. Sustain. Prod. Life Cycle Eng. Manag., 2017: pp. 129–146. https://doi.org/10.1007/978-3-319-48514-0_9.

[35] L. Lämmer, M. Theiss, Product Lifecycle Management, in: Concurr. Eng. 21st Century Found. Dev. Challenges, 2015: pp. 1–839. https://doi.org/10.1007/978-3-319-13776-6.

[36] J.R. Jupp, Incomplete BIM implementation: Exploring challenges and the role of

product lifecycle management functions, IFIP Adv. Inf. Commun. Technol. 409 (2013) 630–640. https://doi.org/10.1007/978-3-642-41501-2_62.

[37] Y. Qie, L. Qiao, J. Zhang, P. Rao, A Framework for Agile Configuration of Product Structure Data, Proc. - 2017 5th Int. Conf. Enterp. Syst. Ind. Digit. by Enterp. Syst. ES 2017. (2017) 119–124. https://doi.org/10.1109/ES.2017.26.

[38] J. Li, F. Tao, Y. Cheng, L. Zhao, Big Data in product lifecycle management, Int. J. Adv. Manuf. Technol. 81 (2015) 667–684. https://doi.org/10.1007/s00170-015-7151-x.

[39] M. Alemanni, F. Destefanis, E. Vezzetti, Model-based definition design in the product lifecycle management scenario, Int. J. Adv. Manuf. Technol. 52 (2011) 1–14. https://doi.org/10.1007/s00170-010-2699-y.

[40] O. Eck, D. Schaefer, A semantic file system for integrated product data management, Adv. Eng. Informatics. 25 (2011) 177–184. https://doi.org/10.1016/j.aei.2010.08.005.

[41] Q.Y. AlKhazraji, C. Saldana, S. Kumara, Material information model across product lifecycle for sustainability assessment, Re-Engineering Manuf. Sustain. - Proc. 20th CIRP Int. Conf. Life Cycle Eng. (2013) 511–514. https://doi.org/10.1007/978-981-4451-48-2_83.

[42] A. Alnaggar, M. Pitt, Towards a conceptual framework to manage BIM/COBie asset data using a standard project management methodology, J. Facil. Manag. 17 (2019) 175–187. https://doi.org/10.1108/JFM-03-2018-0015.

[43] S. Lavy, N. Saxena, M. Dixit, Effects of BIM and COBie Database Facility Management on Work Order Processing Times: Case Study, J. Perform. Constr. Facil. 33 (2019) 04019069. https://doi.org/10.1061/(asce)cf.1943-5509.0001333.

[44] V. Kumar, E.A.L. Teo, Perceived benefits and issues associated with COBie datasheet handling in the construction industry, Facilities. (2020). https://doi.org/10.1108/F-09-2019-0100.

[45] P. Mêda, J. Moreira, H. Sousa, Delivering COBie with ProNIC — compliance and implementation, in: EWork Ebus. Archit. Eng. Constr. – Karlshøj Scherer, 2018: pp. 215–222.

[46] D. Bose, E.W. East, R.R.A. Issa, Impact of COBie on Design Activities, Lect. Notes Civ. Eng. 98 (2021) 672–682. https://doi.org/10.1007/978-3-030-51295-8_47.

[47] V. Kumar, E.T.A. Lin, Conceptualizing “COBieEvaluator”: A rule based system for tracking asset changes using COBie datasheets, Eng. Constr. Archit. Manag. 27 (2020) 1093–1118. https://doi.org/10.1108/ECAM-04-2019-0216.

[48] M. Yalcinkaya, V. Singh, Exploring the use of Gestalt’s principles in improving the visualization, user experience and comprehension of COBie data extension, Eng. Constr. Archit. Manag. 26 (2019) 1024–1046. https://doi.org/10.1108/ECAM-10-2017-0226.

[49] R. Perumpilly, R. Kenley, T. Harfield, CONie is not COBie: Information exchange differences between network and building handover to asset management, IOP Conf. Ser. Mater. Sci. Eng. 512 (2019). https://doi.org/10.1088/1757-899X/512/1/012041.

[50] H. Abdirad, C.S. Dossick, Normative and descriptive models for COBie implementation: discrepancies and limitations, Eng. Constr. Archit. Manag. 26 (2019) 1820–1836. https://doi.org/10.1108/ECAM-10-2018-0443.

[51] M. Yalcinkaya, V. Singh, VisualCOBie for facilities management: A BIM integrated, visual search and information management platform for COBie extension, Facilities. 37 (2019) 502–524. https://doi.org/10.1108/F-01-2018-0011.

[52] M. Sadeghi, J.W. Elliott, N. Porro, K. Strong, Developing building information models (BIM) for building handover, operation and maintenance, J. Facil. Manag. 17 (2019) 301–316. https://doi.org/10.1108/JFM-04-2018-0029.

[53] A. Alnaggar, M. Pitt, Lifecycle Exchange for Asset Data (LEAD): A proposed process model for managing asset dataflow between building stakeholders using BIM open standards, J. Facil. Manag. 17 (2019) 385–411. https://doi.org/10.1108/JFM-06-2019-0030.

[54] W. Chen, K. Chen, J.C.P. Cheng, Towards an ontology-based approach for information interoperability between BIM and facility management, Springer International Publishing, 2018. https://doi.org/10.1007/978-3-319-91638-5_25.

[55] W.L. Kuo, H.X. Lee, S.H. Hsieh, Designing a Database Schema for Supporting Visual Management of Variable Parameters in BIM Models, Comput. Civ. Eng. 2019 Vis. Inf. Model. Simul. - Sel. Pap. from ASCE Int. Conf. Comput. Civ. Eng. 2019. (2019) 425–431. https://doi.org/10.1061/9780784482421.054.

[56] B. Gu, S. Ergan, B. Akinci, Generating as-is building information models for facility management by leveraging heterogeneous existing information sources: A case study, Constr. Res. Congr. 2014 Constr. a Glob. Netw. - Proc. 2014 Constr. Res. Congr. (2014) 1911–1920. https://doi.org/10.1061/9780784413517.0195.

[57] H. Abdirad, K.-Y. Lin, Advancing in Object-Based Landscape Information Modeling: Challenges and Future Needs, Comput. Civ. Eng. 2015. (2015) 548–555. http://ascelibrary.org/doi/10.1061/9780784479247.083.

[58] Z. Alwan, B.J. Gledson, Towards green building performance evaluation using asset information modelling, Built Environ. Proj. Asset Manag. 5 (2015) 290–303. https://doi.org/10.1108/BEPAM-03-2014-0020.

[59] P. J, D. N, V. V, K. M, BIM for facilities management: evaluating BIM standards in asset register creation and service life, ITcon Vol. 20, Pg. 313-331, Http//Www.Itcon.Org/2015/20. 20 (2015) 313–331.

[60] J. Patacas, N. Dawood, D. Greenwood, M. Kassem, Supporting building owners and facility managers in the validation and visualisation of asset information models (aim) through open standards and open technologies, J. Inf. Technol. Constr. 21

(2016) 434–455.

[61] W.E. East, N. Nisbet, Analysis of life-cycle information exchange, Proc. Int. Conf. Comput. Civ. Build. Eng. (2010).

[62] C. Benghi, Automated verification for collaborative workflows in a Digital Plan of Work, Autom. Constr. 107 (2019). https://doi.org/10.1016/j.autcon.2019.102926.

[63] M.J. Falcão Silva, P. Couto, Facility and Asset Management on BIM Methodology, Adv. Sci. Technol. Innov. (2021) 75–79. https://doi.org/10.1007/978-3-030-35533-3_11.

[64] M.G. Niestroj, D.A. McMeekin, P. Helmholz, Overview of standards towards road asset information exchange, Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. - ISPRS Arch. 42 (2018) 523–527. https://doi.org/10.5194/isprs-archives-XLII-4-443-2018.

[65] C. Talamo, M. Bonanomi, Knowledge management and information tools for building maintenance and facility management, Knowl. Manag. Inf. Tools Build. Maint. Facil. Manag. (2015) 1–211. https://doi.org/10.1007/978-3-319-23959-0.

[66] W.L. Lee, M.H. Tsai, C.H. Yang, J.R. Juang, J.Y. Su, V3DM+: BIM interactive collaboration system for facility management, Vis. Eng. 4 (2016). https://doi.org/10.1186/s40327-016-0035-9.

[67] T. Hartmann, R. Amor, E.W. East, Information Model Purposes in Building and Facility Design, J. Comput. Civ. Eng. 31 (2017) 04017054. https://doi.org/10.1061/(asce)cp.1943-5487.0000706.

[68] G.M. Di Giuda, P.E. Giana, M. Schievano, F. Paleari, Guidelines to Integrate BIM for Asset and Facility Management of a Public University, in: Digit. Transform. Des. Constr. Manag. Process. Built Environ. Res. Dev., Springer International Publishing, 2020: pp. 309–318. https://doi.org/10.1007/978-3-030-33570-0.

[69] S. Ashworth, M. Tucker, C.K. Druhmann, Critical success factors for facility management employer's information requirements (EIR) for BIM, Facilities. 37 (2019) 103–118. https://doi.org/10.1108/F-02-2018-0027.

[70] J. Lucas, W. Thabet, Using a case-study approach to explore methods for transferring bim-based asset data to facility management systems, Constr. Res. Congr. 2018 Constr. Inf. Technol. - Sel. Pap. from Constr. Res. Congr. 2018. 2018-April (2018) 439–448. https://doi.org/10.1061/9780784481264.043.

[71] M.K. Dixit, V. Venkatraj, M. Ostadalimakhmalbaf, F. Pariafsai, S. Lavy, Integration of facility management and building information modeling (BIM): A review of key issues and challenges, Facilities. 37 (2019) 455–483. https://doi.org/10.1108/F-03-2018-0043.

[72] A.H. Abd Jamil, M.S. Fathi, Enhancing BIM-Based Information Interoperability: Dispute Resolution from Legal and Contractual Perspectives, J. Constr. Eng. Manag. 146 (2020) 05020007. https://doi.org/10.1061/(asce)co.1943-

7862.0001868.

[73] H. Liu, M. Lu, M. Al-Hussein, Ontology-based semantic approach for construction-oriented quantity take-off from BIM models in the light-frame building industry, Adv. Eng. Informatics. 30 (2016) 190–207. https://doi.org/10.1016/j.aei.2016.03.001.

[74] S. Lupica Spagnolo, G. Amosso, A. Pavan, B. Daniotti, BIMReL: The interoperable bim library for construction products data sharing, Springer International Publishing, 2020. https://doi.org/10.1007/978-3-030-33570-0_4.

[75] Y.C. Lee, C.M. Eastman, W. Solihin, Logic for ensuring the data exchange integrity of building information models, Autom. Constr. 85 (2018) 249–262. https://doi.org/10.1016/j.autcon.2017.08.010.

[76] K. Farghaly, F.H. Abanda, C. Vidalakis, G. Wood, Taxonomy for BIM and Asset Management Semantic Interoperability, J. Manag. Eng. 34 (2018) 04018012. https://doi.org/10.1061/(asce)me.1943-5479.0000610.

[77] Q. Lu, X. Xie, A.K. Parlikad, J.M. Schooling, Digital twin-enabled anomaly detection for built asset monitoring in operation and maintenance, Autom. Constr. 118 (2020) 103277. https://doi.org/10.1016/j.autcon.2020.103277.

[78] H.B. Cavka, S. Staub-French, E.A. Poirier, Developing owner information requirements for BIM-enabled project delivery and asset management, Autom. Constr. 83 (2017) 169–183. https://doi.org/10.1016/j.autcon.2017.08.006.

[79] G. Mayo, R.R.A. Issa, Nongeometric Building Information Needs Assessment for Facilities Management, J. Manag. Eng. 32 (2016) 04015054. https://doi.org/10.1061/(asce)me.1943-5479.0000414.

[80] W. Thabet, J. Lucas, Asset Data Handover for a Large Educational Institution: Case-Study Approach, J. Constr. Eng. Manag. 143 (2017) 05017017. https://doi.org/10.1061/(asce)co.1943-7862.0001389.

[81] G. Gudnason, Katranuschkov, Balaras, R.J. Scherer, Framework for Interoperability of Information Resources in the Building Energy Simulation Domain, Comput. Civ. Build. Eng. (2014) 617–624.

[82] H. Abdirad, C.S. Dossick, Rebaselining Asset Data for Existing Facilities and Infrastructure, J. Comput. Civ. Eng. 34 (2020) 05019004. https://doi.org/10.1061/(asce)cp.1943-5487.0000868.

[83] A. Borhani, H.W. Lee, C.S. Dossick, L. Osburn, M. Kinsman, BIM to facilities management: Presenting a proven workflow for information exchange, Congr. Comput. Civ. Eng. Proc. 0 (2017) 51–58. https://doi.org/10.1061/9780784480823.007.

[84] E. Suprun, R.A. Stewart, S. Mostafa, O. Sahin, E. Bertone, Integrating Lifecycle Thinking in Asset Management Through BIM: Opportunities for the Water Sector, in: 10th Int. Conf. Eng. Proj. Prod. Manag. Lect. Notes Mech. Eng., Springer Singapore, 2020: pp. 81–88. https://doi.org/10.1007/978-981-15-1910-9_7.

[85] B. Daniotti, S.L. Spagnolo, An Interoperable ICT Tool for Asset and Maintenance Management, Sustain. Constr. Build. Pathol. Rehabil. 8. (2016) 147–161. https://doi.org/10.1007/978-981-10-0651-7_7.

[86] P. Meadati, J. Irizarry, BIM and QR code for operation and maintenance, Congr. Comput. Civ. Eng. Proc. 2015-Janua (2015) 556–563. https://doi.org/10.1061/9780784479247.069.

[87] F. Re Cecconi, S. Maltese, M.C. Dejaco, Leveraging BIM for digital built environment asset management, Innov. Infrastruct. Solut. 2 (2017) 1–16. https://doi.org/10.1007/s41062-017-0061-z.

[88] P.E.D. Love, J. Zhou, J. Matthews, C.P. Sing, B. Carey, A systems information model for managing electrical, control, and instrumentation assets, Built Environ. Proj. Asset Manag. 5 (2015) 278–289. https://doi.org/10.1108/BEPAM-03-2014-0019.

[89] M.S. Mehany, Mohammed, K. Strong, Integrating Building Information Models and Building Operation Information Exchange Systems in a Decision Support Framework for Facilities Management, Constr. Res. Congr. 2018. (2018) 770–779.

[90] T.P. Lützkendorf, Product data and building assessment - Flow of information, IOP Conf. Ser. Earth Environ. Sci. 225 (2019). https://doi.org/10.1088/1755-1315/225/1/012038.

[91] M. Signorini, S. Frigeni, S.L. Spagnolo, Integrating environmental sustainability indicators in BIM-based product datasheets, IOP Conf. Ser. Earth Environ. Sci. 296 (2019). https://doi.org/10.1088/1755-1315/296/1/012028.

[92] C. Wijekoon, A. Manewa, A.D. Ross, Enhancing the value of facilities information management (FIM) through BIM integration, Eng. Constr. Archit. Manag. 27 (2018) 809–824. https://doi.org/10.1108/ECAM-02-2016-0041.

[93] K.K.W. Wong, M. Kumaraswamy, G. Mahesh, F.Y.Y. Ling, Building integrated project and asset management teams for sustainable built infrastructure development, J. Facil. Manag. 12 (2014) 187–210. https://doi.org/10.1108/JFM-05-2013-0025.

[94] A.Z.T. Tan, A. Zaman, M. Sutrisna, Enabling an effective knowledge and information flow between the phases of building construction and facilities management, Facilities. 36 (2018) 151–170. https://doi.org/10.1108/F-03-2016-0028.

[95] A. Barontini, C. Alarcon, H.S. Sousa, D. V Oliveira, M.G. Masciotta, M. Azenha, Development and Demonstration of an HBIM Framework for the Preventive Conservation of Cultural Heritage, Int. J. Archit. Herit. (2021). https://doi.org/10.1080/15583058.2021.1894502.

[96] D. Heesom, P. Boden, A. Hatfield, S. Rooble, K. Andrews, H. Berwari, Developing a collaborative HBIM to integrate tangible and intangible cultural heritage, Int. J. Build. Pathol. Adapt. (2020). https://doi.org/10.1108/IJBPA-04-2019-0036.

[97] J. Heaton, A.K. Parlikad, J. Schooling, A Building Information Modelling approach to the alignment of organisational objectives to Asset Information Requirements, Autom. Constr. 104 (2019) 14–26. https://doi.org/10.1016/j.autcon.2019.03.022.

[98] C.J. Roberts, E.A. Pärn, D.J. Edwards, C. Aigbavboa, Digitalising asset management: concomitant benefits and persistent challenges, Int. J. Build. Pathol. Adapt. 36 (2018) 152–173. https://doi.org/10.1108/IJBPA-09-2017-0036.

[99] J. Backman, H. Helaakoski, Evaluation of internet-of-things platforms for asset management, Lect. Notes Mech. Eng. PartF4 (2016) 97–104. https://doi.org/10.1007/978-3-319-27064-7_9.

[100] C.S. Götz, P. Karlsson, I. Yitmen, Exploring applicability, interoperability and integrability of Blockchain-based digital twins for asset life cycle management, Smart Sustain. Built Environ. (2020). https://doi.org/10.1108/SASBE-08-2020-0115.

[101] M. Munir, A. Kiviniemi, S. Jones, S. Finnegan, BIM-based operational information requirements for asset owners, Archit. Eng. Des. Manag. 16 (2020) 100–114. https://doi.org/10.1080/17452007.2019.1706439.

[102] M. Griffin, S. Patro, Railway bridge assessment for effective asset management, Proc. Inst. Civ. Eng. Bridg. Eng. 171 (2018) 303–312. https://doi.org/10.1680/jbren.15.00032.

[103] F. Re Cecconi, M.C. Dejaco, N. Moretti, A. Mannino, J.D. Blanco Cadena, Digital asset management, Springer International Publishing, 2020. https://doi.org/10.1007/978-3-030-33570-0_22.

[104] J. Zeb, T. Froese, Tangible capital asset ontology in infrastructure management, Infrastruct. Asset Manag. 1 (2014) 81–92. https://doi.org/10.1680/iasma.14.00012.

[105] T. Le, H. David Jeong, Interlinking life-cycle data spaces to support decision making in highway asset management, Autom. Constr. 64 (2016) 54–64. https://doi.org/10.1016/j.autcon.2015.12.016.

[106] V. Edmondson, M. Cerny, M. Lim, B. Gledson, S. Lockley, J. Woodward, A smart sewer asset information model to enable an 'Internet of Things' for operational wastewater management, Autom. Constr. 91 (2018) 193–205. https://doi.org/10.1016/j.autcon.2018.03.003.

[107] N.S. Grigg, J. Butler, Distribution Systems: Has Asset Management Made a Difference?, J. Pipeline Syst. Eng. Pract. 10 (2019) 04019010. https://doi.org/10.1061/(asce)ps.1949-1204.0000379.

[108] P.E.D. Love, J. Matthews, I. Simpson, A. Hill, O.A. Olatunji, A benefits realization management building information modeling framework for asset owners, Autom. Constr. 37 (2014) 1–10. https://doi.org/10.1016/j.autcon.2013.09.007.

[109] J.M. Davila Delgado, L.O. Oyedele, BIM data model requirements for asset monitoring and the circular economy, J. Eng. Des. Technol. 18 (2020) 1269–1285. https://doi.org/10.1108/JEDT-10-2019-0284.

[110] Q. Lu, X. Xie, J. Heaton, A.K. Parlikad, J. Schooling, From BIM towards digital twin: Strategy and future development for smart asset management, Springer International Publishing, 2020. https://doi.org/10.1007/978-3-030-27477-1_30.

[111] P.E.D. Love, J. Zhou, J. Matthews, H. Luo, Systems information modelling: Enabling digital asset management, Adv. Eng. Softw. 102 (2016) 155–165. https://doi.org/10.1016/j.advengsoft.2016.10.007.

[112] M. Munir, A. Kiviniemi, S.W. Jones, S. Finnegan, The business value of BIM for asset owners: a cross-case analysis, J. Facil. Manag. 18 (2020) 469–486. https://doi.org/10.1108/JFM-06-2020-0037.

[113] R. Jang, W. Collinge, Improving BIM asset and facilities management processes: A Mechanical and Electrical (M&E) contractor perspective, J. Build. Eng. 32 (2020) 101540. https://doi.org/10.1016/j.jobe.2020.101540.

[114] M. Munir, A. Kiviniemi, S. Finnegan, S.W. Jones, BIM business value for asset owners through effective asset information management, Facilities. 38 (2019) 181–200. https://doi.org/10.1108/F-03-2019-0036.

[115] T. Le, C. Le, H. David Jeong, Lifecycle Data Modeling to Support Transferring Project-Oriented Data to Asset-Oriented Systems in Transportation Projects, J. Manag. Eng. 34 (2018) 04018024. https://doi.org/10.1061/(asce)me.1943-5479.0000620.

[116] J. Hull, I.J. Ewart, Conservation data parameters for BIM-enabled heritage asset management, Autom. Constr. 119 (2020) 103333. https://doi.org/10.1016/j.autcon.2020.103333.

[117] M. Brunet, A. Motamedi, L.M. Guénette, D. Forgues, Analysis of BIM use for asset management in three public organizations in Québec, Canada, Built Environ. Proj. Asset Manag. 9 (2019) 153–167. https://doi.org/10.1108/BEPAM-02-2018-0046.

[118] K. Farghaly, F.H. Abanda, C. Vidalakis, G. Wood, BIM-linked data integration for asset management, Built Environ. Proj. Asset Manag. 9 (2019) 489–502. https://doi.org/10.1108/BEPAM-11-2018-0136.

[119] M. Munir, A. Kiviniemi, S.W. Jones, Business value of integrated BIM-based asset management, Eng. Constr. Archit. Manag. 26 (2019) 1171–1191. https://doi.org/10.1108/ECAM-03-2018-0105.

[120] M. Al-Kasasbeh, O. Abudayyeh, H. Liu, A unified work breakdown structure-based framework for building asset management, J. Facil. Manag. 18 (2020) 437–450. https://doi.org/10.1108/JFM-06-2020-0035.

[121] A. Bosch, L. Volker, A. Koutamanis, BIM in the operations stage: Bottlenecks and implications for owners, Built Environ. Proj. Asset Manag. 5 (2015) 331–343. https://doi.org/10.1108/BEPAM-03-2014-0017.

[122] Q. Lu, X. Xie, A.K. Parlikad, J.M. Schooling, E. Konstantinou, Moving from Building Information Models to Digital Twins for Operation and Maintenance, Proc. Inst. Civ.

Eng. - Smart Infrastruct. Constr. (2020) 1–9. https://doi.org/10.1680/jsmic.19.00011.

[123] D. Božiček, R. Kunič, M. Košir, Interpreting environmental impacts in building design: Application of a comparative assertion method in the context of the EPD scheme for building products, J. Clean. Prod. 279 (2021). https://doi.org/10.1016/j.jclepro.2020.123399.

[124] M. Rangelov, H. Dylla, A. Mukherjee, N. Sivaneswaran, Use of environmental product declarations (EPDs) of pavement materials in the United States of America (U.S.A.) to ensure environmental impact reductions, J. Clean. Prod. 283 (2021) 124619. https://doi.org/10.1016/j.jclepro.2020.124619.

[125] V. Durão, J.D. Silvestre, R. Mateus, J. de Brito, Assessment and communication of the environmental performance of construction products in Europe: Comparison between PEF and EN 15804 compliant EPD schemes, Resour. Conserv. Recycl. 156 (2020) 104703. https://doi.org/10.1016/j.resconrec.2020.104703.

[126] L. Sariola, A. Ilomaki, RTS EPD's - Different Methods of Producing Reliable Environmental Information of Building Products in Finland, IOP Conf. Ser. Earth Environ. Sci. 297 (2019). https://doi.org/10.1088/1755-1315/297/1/012029.

[127] W.K. Biswas, Y. Alhorr, K.K. Lawania, P.K. Sarker, E. Elsarrag, Life cycle assessment for environmental product declaration of concrete in the Gulf States, Sustain. Cities Soc. 35 (2017) 36–46. https://doi.org/10.1016/j.scs.2017.07.011.

[128] M. Rochikashvili, J.C. Bongaerts, How eco-labelling influences environmentally conscious consumption of construction products, Sustain. 10 (2018). https://doi.org/10.3390/su10020351.

[129] M.D.C. Gelowitz, J.J. McArthur, Comparison of type III environmental product declarations for construction products: Material sourcing and harmonization evaluation, J. Clean. Prod. 157 (2017) 125–133. https://doi.org/10.1016/j.jclepro.2017.04.133.

[130] S. Lasvaux, N. Schiopu, G. Habert, J. Chevalier, B. Peuportier, Influence of simplification of life cycle inventories on the accuracy of impact assessment: Application to construction products, J. Clean. Prod. 79 (2014) 142–151. https://doi.org/10.1016/j.jclepro.2014.06.003.

[131] S. Lasvaux, G. Habert, B. Peuportier, J. Chevalier, Comparison of generic and product-specific Life Cycle Assessment databases: application to construction materials used in building LCA studies, Int. J. Life Cycle Assess. 20 (2015) 1473–1490. https://doi.org/10.1007/s11367-015-0938-z.

[132] K. Azuma, R. Funaki, A. Hasegawa, N. Shinohara, M. Yamaguchi, K.O. Fujita, Y. Kikuchi, S.I. Tanabe, Integrating requirements for the delivery of information relating to construction-product compositions, Indoor Built Environ. 23 (2014) 653–664. https://doi.org/10.1177/1420326X12462912.

[133] B.M. Díaz-Soler, M.D. Martínez-Aires, M. López-Alonso, Potential risks posed by the use of nano-enabled construction products: A perspective from coordinators for

safety and health matters, J. Clean. Prod. 220 (2019) 33–44. https://doi.org/10.1016/j.jclepro.2019.02.056.

[134] BAMB, BAMB - Buildings As Material Banks (BAMB2020) - BAMB, (2016). https://www.bamb2020.eu/ (accessed June 4, 2021).

[135] C.M. Rose, J.A. Stegemann, Characterising existing buildings as material banks (E-BAMB) to enable component reuse, Proc. Inst. Civ. Eng. Eng. Sustain. 172 (2018) 129–140. https://doi.org/10.1680/jensu.17.00074.

[136] I. Kovacic, M. Honic, H. Rechberger, Proof of Concept for a BIM-Based Material Passport, Springer International Publishing, 2019. https://doi.org/10.1007/978-3-030-00220-6.

[137] C.A. Wandiga, Methodological review: Socio-cultural analysis criteria for BIM modeling and material passport tracking of agriwaste as a building construction raw material, MRS Energy Sustain. 7 (2020) 1–14. https://doi.org/10.1557/mre.2020.29.

[138] L.M. Luscuere, Materials Passports: Optimising value recovery from materials, Proc. Inst. Civ. Eng. Waste Resour. Manag. 170 (2017) 25–28. https://doi.org/10.1680/jwarm.16.00016.

[139] H. Tang, S. Guo, L. Huang, L. Li, Y. Li, Research and development on key models and technology of PDM system, Int. J. Adv. Manuf. Technol. 78 (2015) 1865–1878. https://doi.org/10.1007/s00170-014-6765-8.

[140] M. Safa, A. Shahi, C.T. Haas, K.W. Hipel, Supplier selection process in an integrated construction materials management model, Autom. Constr. 48 (2014) 64–73. https://doi.org/10.1016/j.autcon.2014.08.008.

[141] T. Akanbi, J. Zhang, Y.-C. Lee, Data-Driven Reverse Engineering Algorithm Development Method for Developing Interoperable Quantity Takeoff Algorithms Using IFC-Based BIM, J. Comput. Civ. Eng. 34 (2020) 04020036. https://doi.org/10.1061/(asce)cp.1943-5487.0000909.

[142] Q. Lu, A.K. Parlikad, P. Woodall, G. Don Ranasinghe, X. Xie, Z. Liang, E. Konstantinou, J. Heaton, J. Schooling, Developing a Digital Twin at Building and City Levels: Case Study of West Cambridge Campus, J. Manag. Eng. 36 (2020) 05020004. https://doi.org/10.1061/(asce)me.1943-5479.0000763.

[143] Y. Al-Saeed, D.J. Edwards, S. Scaysbrook, Automating construction manufacturing procedures using BIM digital objects (BDOs): Case study of knowledge transfer partnership project in UK, Constr. Innov. 20 (2020) 345–377. https://doi.org/10.1108/CI-12-2019-0141.

[144] R. Sacks, I. Brilakis, E. Pikas, H.S. Xie, M. Girolami, Construction with digital twin information systems, Data-Centric Eng. 1 (2020). https://doi.org/10.1017/dce.2020.16.

[145] D. Calvetti, P. Mêda, M.C. Gonçalves, H. Sousa, Worker 4.0: the Future of Sensored Construction Sites, Buildings. 10 (2020) 1–23.

https://doi.org/10.3390/buildings10100169.

[146] M. Jia, A. Komeily, Y. Wang, R.S. Srinivasan, Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications, Autom. Constr. 101 (2019) 111–126. https://doi.org/10.1016/j.autcon.2019.01.023.

[147] European Commission, A monitoring framework for the circular economy COM(2018) 29 final, COM/2018/29 Final. 29 (2018) 1–11. http://ec.europa.eu/environment/circular-economy/index_en.htm.

[148] Mariela Daskalova, A major step forward for BIM Standardisation - EN ISO 23386 published, (2020). https://cobuilder.com/en/a-major-step-forward-for-bim-standardisation-en-iso-23386-published/ (accessed May 24, 2021).

[149] European Comission, EU construction sector: in transition towards a circular economy, (2019).

[150] HM Government, Digital Built Britain Level 3 Building Information Modelling - Strategic Plan, 2015.

[151] M. Fabbri, M. De Groote, O. Rapf, Building Renovation Passports: Customised roadmaps towards deep renovation and better homes, 2016.

[152] S. Thompson, Product Data Definition: A technical specification for defining and sharing structured digital construction product information, 2016.

[153] Product Data Working Group, A Fresh Way Forward For Product Data, 2018. https://www.ukbimalliance.org/project/a-fresh-way-forward/.

[154] European Commission, Guidelines for the waste audits before demolition and renovation works of buildings. UE Construction and Demolition Waste Management, Ref. Ares(2018)4724185 - 14/09/2018. (2018) 37. https://ec.europa.eu/docsroom/documents/31521.

[155] BS EN ISO 19650-1:2018, Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling, 2018.

[156] BS EN ISO 19650-2:2018, Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling, 2018.

[157] I. Brilakis, Y. Pan, A. Borrmann, H.-G. Mayer, F. Rhein, C. Vos, E. Pettinato, S. Wagner, Built Environment Digital Twinning, 2019.

[158] Andy Neely, J. Schooling, C. Boulton, K. Lamb, Developing the capabilities for a digital built Britain, 2019. https://doi.org/https://doi.org/10.17863/CAM.41751 The.

[159] M. Daskalova, S. Dermenjiev, E. Blonk, A. Mercer, E. Schulze, P. Surin, Digital Supply Chains: Data Driven Collaboration, 2019.

[160] G. Mario, G. Crean, E. Boever, The data-driven innovation strategy for the development of a trusted and sustainable economy in Luxembourg, 2019.

[161] European Commission, The European Green Deal, Eur. Comm. 53 (2019) 24. https://doi.org/10.1017/CBO9781107415324.004.

[162] European Union, A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives, COM(2020) (2020) 1–26. https://ec.europa.eu/transparency/regdoc/rep/1/2020/EN/COM-2020-662-F1-EN-MAIN-PART-1.PDF.

[163] BS EN 17412-1:2020, BSI Standards Publication Building Information Modelling — Level of Information Need, 2020.

[164] PAS 14191:2020, Built environment – Management and operation of interconnected construction data dictionaries – Specification, (2020) 1–19.

[165] T. Gilbert, H.-C. Gruler, T.H. Kolbe, A. Mercer, N. Nisbet, J. Plume, C. Rönsdorf, S. Simmons, L. van Berlo, Built environment data standards and their integration: an analysis of IFC, CityGML and LandInfra, 2020. https://www.buildingsmart.org/buildingsmart-international-bsi-and-open-geospatial-consortium-ogc-release-bim-and-gis-integration-paper/.

[166] N. Allison, G. Hartley, Digital Product Data for Lifting Productivity, 2020.

[167] buildingSMART, Facilities Management Handover – COBie 2.5, 2020.

[168] S. Verbeke, D. Aerts, G. Reynders, Y. Ma, P. Waide, Final report on the technical support to the development of a smart readiness indicator for buildings, European Commission, 2020.

[169] S.A. Ganiyu, L.O. Oyedele, O. Akinade, H. Owolabi, L. Akanbi, A. Gbadamosi, BIM competencies for delivering waste-efficient building projects in a circular economy, Dev. Built Environ. 4 (2020) 100036. https://doi.org/10.1016/j.dibe.2020.100036.

[170] EN15978:2011, Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method, (2011) 64.

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ANNEXES

N/A