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Interoperability opportunities for managing as-built CO2-emissions in construction projects

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beyond the obvious

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Summary

The report explores how interoperability in data systems can support the management of as-built CO_2 emissions in construction projects. It emphasizes the growing importance of embodied emissions—those generated during the production and construction phases (EN 15978 modules A1–A5)—as operational emissions decline due to improved energy efficiency. The construction supply chain is fragmented and complex, involving multiple product types (Engineer-to-Order, Make-to-Order, Assemble-to-Order, Make-to-Stock), each with distinct data availability and emissions profiles.

The report reviews regulatory frameworks (e.g., EU's CSRD, EPBD, CPR) and voluntary sustainability standards (e.g., GHG Protocol, Level(s)) that increasingly demand emissions transparency. It also details relevant standards for life cycle assessment (LCA) and environmental product declarations (EPDs), including ISO 14040, EN 15804, ISO 22057, and ILCD+EPD formats.

A key finding is that while standards and data sources exist, they are not yet fully interoperable or machine-readable, limiting their utility for automated emissions tracking. The European Construction Products Regulation (CPR) revision and Digital Product Passports (DPPs) offer promise but are years from full implementation.

The report concludes that no single data format currently supports comprehensive emissions tracking across all product types and lifecycle stages. However, combining future-ready standards like eFTI and Peppol with enhanced emissions data from EPDs, national databases and in the future the DPPs, could provide a viable interim solution. Further research is recommended to develop frameworks for linking diverse data sources and improving emissions visibility, especially for site operations.

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Preface

Report introduces partial results of a Finnish Co-Innovation project AIXCon (Rakennusalan transformaatio dataan perustuvilla älykkäillä prosesseilla) which was funded by Business Finland and VTT. The results are part of broader research and development project that was coordinated by Aalto University and other involved partners in the project were Trimble Solutions Oy, Sitedrive Oy (initially Fira Group Oy) and Celsa Steel Service Oy.

This report examines literature, interview results, and data-driven methods to manage as-built CO2e emissions in construction projects. The goal was to identify data formats and sources to estimate emissions from materials (A1-3), transportation (A4), and site operations (A5) to set a target for construction implementation, and to track actual emissions with the most current data available.

Acknowledgments

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Terms and abbreviations

ATO	Assemble-to-Order
c-PCR	Complementary Product Category Rules
CPR	Construction Products Regulation
DoP	Declaration of Performance
DoPC	Declaration of Performance and Conformity
EF	Environmental Footprint (see also PEF and OEF)
EPLCA	European Platform on Life Cycle Assessment
EPD	Environmental Product Declaration
ETO	Engineer-to-Order
ILCD	International (Reference) Life Cycle Data System
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory Analysis
LCIA	Life Cycle Impact Assessment
LCDN	Life Cycle Data Network
MTS	Make-to-Stock
MTO	Make-to-Order
OEF	Organisation Environmental Footprint
PEF	Product Environmental Footprint
PCR	Product Category Rules

Contents

1. Introduction

The environmental targets for construction have been introduced and applied for a long time, even throughout the last few decades. However, awareness of those has raised significantly in last years in the construction domain as well as in society in general. The construction of buildings and their operation consume around 36% of global energy and produces around 40% of global energy-related carbon dioxide emissions making them a significant contributor to climate change (International Energy Agency IEA, 2019).

Given the considerable emissions originating from the industry, it is not surprising that construction stakeholders in the EU are confronted with increasingly tightening regulation and the adoption of voluntary sustainability frameworks by states, clients, or their own organizations, all aiming to reduce carbon emissions. Besides regulation supporting these targets, pioneering companies have been developing products and services following clients' and public expectations for environmental friendliness. For example, the environmental certificate for buildings is a value-adding feature for building owners offering premises in the market.

While current regulatory efforts and business opportunities have mainly sprung from the management of operational emissions, new efforts and opportunities are expected to come from the management of embodied emissions in construction. Since, as a result of successfully decreasing operational emissions, the relative emissions from embodied emissions will grow in the future (Kanafani et al., 2023; Röck et al., 2022). Embodied emissions in this report are those emissions that can be attributed to modules A1-A5 according to EN 15978 (i.e., from product phase up and until the construction phase). Currently the declaration of emissions from modules A1-A5 is already mandatory in Norway and Sweden, while the declaration of emission from A1-A3 is currently obligatory in Denmark. All Nordic countries and Estonia are however currently preparing legislation requiring the declaration of all emissions originating from modules A1-A5 (Lavikka et al., 2023).

Managing embodied emissions will present different challenges than managing operational emissions. Where operational emissions can be managed on a building and systems level, embodied emissions will need to be managed on a construction product level. As a single building incorporates thousands of products, the challenge here will be how to efficiently handle the vast amounts of information associated with embodied emissions. Linking digital construction product data with sustainability data could provide an answer to this challenge but requires the integration of different data elements (or information) from different domains (industries) on different abstraction levels (see Figure 1).

In order to get an overview of the possibilities for linking digital construction product data to facilitate embodied emissions management, this report will outline the current status and key developments in this area. This report will begin with an investigation of the main contributors to embodied carbon emissions (chapter 2), followed by an overview of relevant regulation and policy initiatives (chapter 3). After that life-cycle analysis (LCA), and construction data management standards will be introduced (chapter 4), followed by related data types and data sources (chapter 5). With that overview, this report will present the options of construction product data to facilitate the management of embodied emissions of the main emitters (chapter 6), followed by concluding remarks and recommendations (chapter 7).

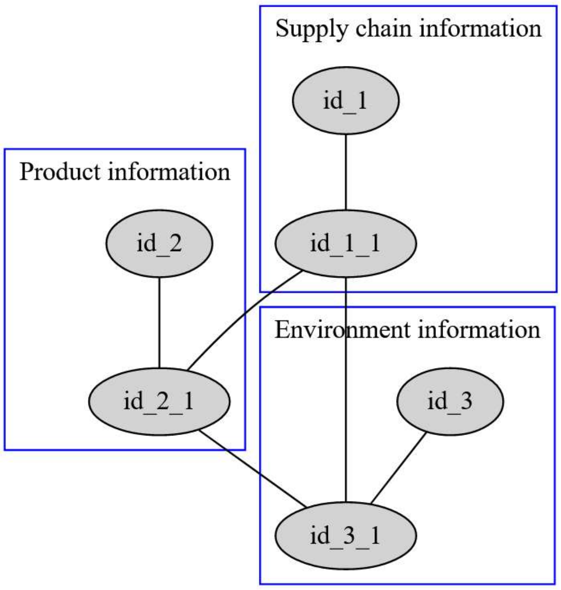

Figure 1: Linking digital construction product data with sustainability data requires the integration of data types from different domains

2. Main contributors to carbon emissions in the construction supply-chain

The construction supply-chain is complex and to determine where the main impact can be made regarding carbon emissions, the following section will present an impact-based analysis of the supply-chain. Earlier impact assessments have been mostly focused on the phases in the construction process that have the highest emissions mitigating impact. Those analyses show that the biggest impact can be made in the design-phase by opting for low-carbon products (Ahmed et al., 2020). However, the topic of this report is the possibility of linking construction data to enable emissions tracking. Therefore, it is more important to focus on the impact made by the tracked products, instead of the phases. This does however not mean that it is no longer important to make conscious carbon-saving decisions throughout the building lifecycle.

2.1 Description of the construction supply-chain

The construction supply-chain can be typified as being fragmented, producing unique, one-off products (i.e., buildings, infrastructure, etc.) in geographically different locations (O'Brien et al., 2008). Furthermore, the construction supply-chain can be characterized as one consisting of multiple supply-chains, that all come together at the construction site (see Figure 2). This is relevant with regard to carbon emissions tracking, as the carbon emissions that are eventually embodied in buildings and building products, are the combined outcome of the activities taking place in those different supply-chains, as well as site-specific activities not linked to particular products and their supply-chains.

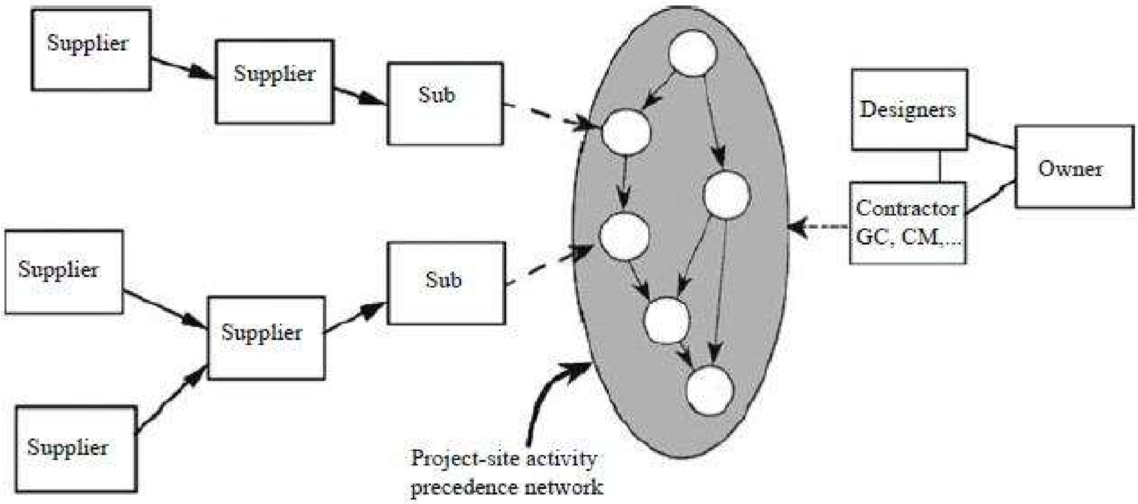

Figure 2: Conceptual view of a construction project supply-chain (source: O'Brien et al., 2002)

The various 'upstream' supply-chains delivering products and components to the construction project, have different compositions and characteristics depending on the type of product or component. One way of characterizing these different supply-chain compositions is through the so-called decoupling point of supply-chains (also referred to as the moment of client engagement in the supply-chain). Based on the decoupling point, we can identify four different main product types: Engineer-to-Order (ETO), Make-to-Order (MTO), Assemble-to-Order (ATO), and Make-to-Stock (MTS). Table 1 shows the characteristics for each type, as well as some examples for each product type in the construction industry.

Table 1: Characteristics and examples of different product types (adapted from: 'O Brien et al., 2008)

	Make-to-Stock (MTS)	**Assemble-to-Order (ATO)**	**Make-to-Order (MTO)**	**Engineer-to-Order (ETO)**
Characteristics	Products that are commodities (stock is held)	Products that are manufactured after customer orders. Products are usually standard or consist of standard components (some stock is held)	Products that are manufactured once customer orders have been placed (usually no stock is held)	Specials made for the customer following detailed specifications
Examples	Bricks, Nuts, Bolts, etc. Trade-sized rebar components Residential air ducts Cable ladders and trays	Doors Windows Non-residential air ducts	Fire- and safety doors and windows Prefabricated panels	Hollow-core slabs Preassembled rebar components HVAC-equipment Power distribution equipment

Naim et al. (1999) were the first to translate the decoupling point to construction supply-chains, but the original concept stems from postponement theory, which has been researched in a manufacturing context for a significantly longer time (Alderson, 1957). In a manufacturing context the use of decoupling points and postponement theory has evolved as a supply-chain strategy tool (Lampel & Mintzberg, 1996; Yang et al., 2004), and is primarily applied in strategic decision-making. In the construction industry however, such strategic decision-making related to supply-chain design is often absent (O'Brien et al., 2008), limiting the use of decoupling points here to supply-chain descriptions. The implication of using decoupling points as mere supply-chain descriptors is that, in the absence of a deliberate strategy, the placement of examples of ETO, MTO, ATO, or MTS products in Table 1, is arbitrary to a certain degree and may vary slightly between different projects, where it is thinkable that a certain product could be considered as an MTO-product in one project, and as an ETO-product in another project depending on the specifics. On a higher level, however, it is clear that an MTS-product cannot be considered as an ETO-product or vice versa, even in absence of a strategic decision-making context. Since the construction supply chain is made up of multiple supply chains, it might also occur that ETO-products will be manufactured from MTS-products. E.g., in Table 1 ETO pre-assembled rebar products will probably be manufactured from MTS trade-sized rebar components.

2.2 Product types and embodied carbon

Although buildings and their construction have been the subject of numerous sustainability assessments (often through LCA-analyses), the output of these studies has mostly concentrated on the share of impact caused by certain materials (e.g., concrete, steel, etc.), and not necessarily on the components or products of which those materials are a part (Malabi Eberhardt et al., 2021). The robustness of conclusions derived from these studies is therefore not too high, and it has to be kept in mind that the studies referred to here have taken place in different international contexts, with different LCA-approaches and boundaries, and that a high-level comparison always entails a degree of simplification.

Nevertheless, Malabi Eberhardt et al. (2021) in a Danish context, Viola (2012) in a Swiss context, as well as De Wolf et al. (2014) in an American context, all find that the biggest impact when it comes to embodied emissions can be found in the following parts of the building: (1) external walls, (2) floors and ceilings, and (3) roofs. In all these studies these parts of the case-study buildings account for at least half of the embodied emissions, often even a bigger amount. Malabi Eberhardt et al. (2021) and Viola (2012) also find that after those three building parts; windows are probably the next biggest component category in terms of embodied emissions. Research by Säynäjoki et al. (2017) for one Finnish case-study indicates that also in the Finnish context, the category 'structural frame and roof' has by far the largest impact (51-52%) on embodied emissions in buildings.

For building services (HVAC & electrical) the numbers are a bit more ambiguous. While De Wolf et al. (2014) did not take into account building services in their study, Malabi Eberhardt et al. (2021) and Viola (2012) did and linked only a small amount of embodied emissions to them. Other studies, however, point to a much larger share of embodied emissions attributable to building services, only slightly ranking behind a building's structural components (Kiamili et al., 2020; Rinne et al., 2022). The largest impacts in this category seem to originate from their distribution components i.e., air ducts, piping, and their accessories. Also here, there is a lack of in-depth studies, but considering their potentially large impact, building services may not be ignored here.

Any attempt at carbon emissions tracking in the construction industry should therefore take all product types into account, with a slightly bigger focus on MTO and ETO products as most of the products discussed in this paragraph belong to that category. However, this does not mean that MTS and ATO products can be excluded in further analyses, mainly due to the potential importance of emissions of building services. Apart from that, we need to take into account that MTO and ETO products might be partially dependent upon the other product types as sub-components.

2.3 Emissions originating from transportation and construction sites

Specific site activities that are not directly related to a certain product type (e.g., energy-, and water-use on site, vertical transport enablers (e.g., tower cranes, lifting devices, site elevators, etc.), are the final category of embodied building emissions being considered here. These depend on environmental conditions, like construction in winter vs. summer, or location of the site affecting transportation distances and methods.

Just like with LCA-studies focusing on products, components and building layers, there are relatively few studies focusing on emissions caused by the construction process (Kanafani et al., 2023). Interestingly, the same knowledge gap was already identified more than 20 years ago by Hendrickson and Horvath (2000). The impact of these processes has been deemed as small compared to whole life building carbon emissions and have therefore not been taken into account to a similar degree as emissions from other life cycle stages (Bilec et al., 2006; Fenner et al., 2018). Relative emissions in construction processes, and therefore their importance, are however expected to rise in the future as the absolute emissions in other life cycle stages (operational phases in particular) are decreasing (Kanafani et al., 2023; Röck et al., 2022).

There are not many recent studies focusing on site emissions in a European context, however Kanafani et al. (2023) are an exception. In their research, which covered around 60 case buildings in Denmark, they found that the emissions of modules A4 (transportation) + A5 (site operations) amount to 14% of total building emissions over a 50-year reference period, where each module accounts for 3% and 11% of total emissions respectively. Even if emissions from module A4 are generally considered low, some studies which tracked real-life transport for construction projects may report numbers of up to 10% of total building emissions (Sezer and Fredriksson, 2021). Also, emissions in A5 may be underreported, as communicated numbers in other studies are frequently based on assumptions made in the design phase. For example, a Norwegian study that undertook a detailed study of truly emitted emissions on a construction site, reported significantly higher emissions than they modelled for the same site in the design phase (Fufa et al., 2019).

Based on this limited sample, a definitive conclusion about the size of emissions originating from construction sites and transportation cannot therefore be drawn. What can be stated is that previous research points to construction site and transportation emissions equaling 3-21% of total building emissions, where the exact number will be likely in the second half (12-21%) of the range.

3. Regulation and policy initiatives

Several regulatory initiatives to address carbon emissions in the construction sector are in preparation or have recently been adopted (see Figure 3). These initiatives can be divided into policies and regulation on an industry level (not specifically targeting the construction industry, but industries in general), on a building level, and on a construction product level. Also, several voluntary sustainability frameworks that have been adopted in the construction industry can be identified.

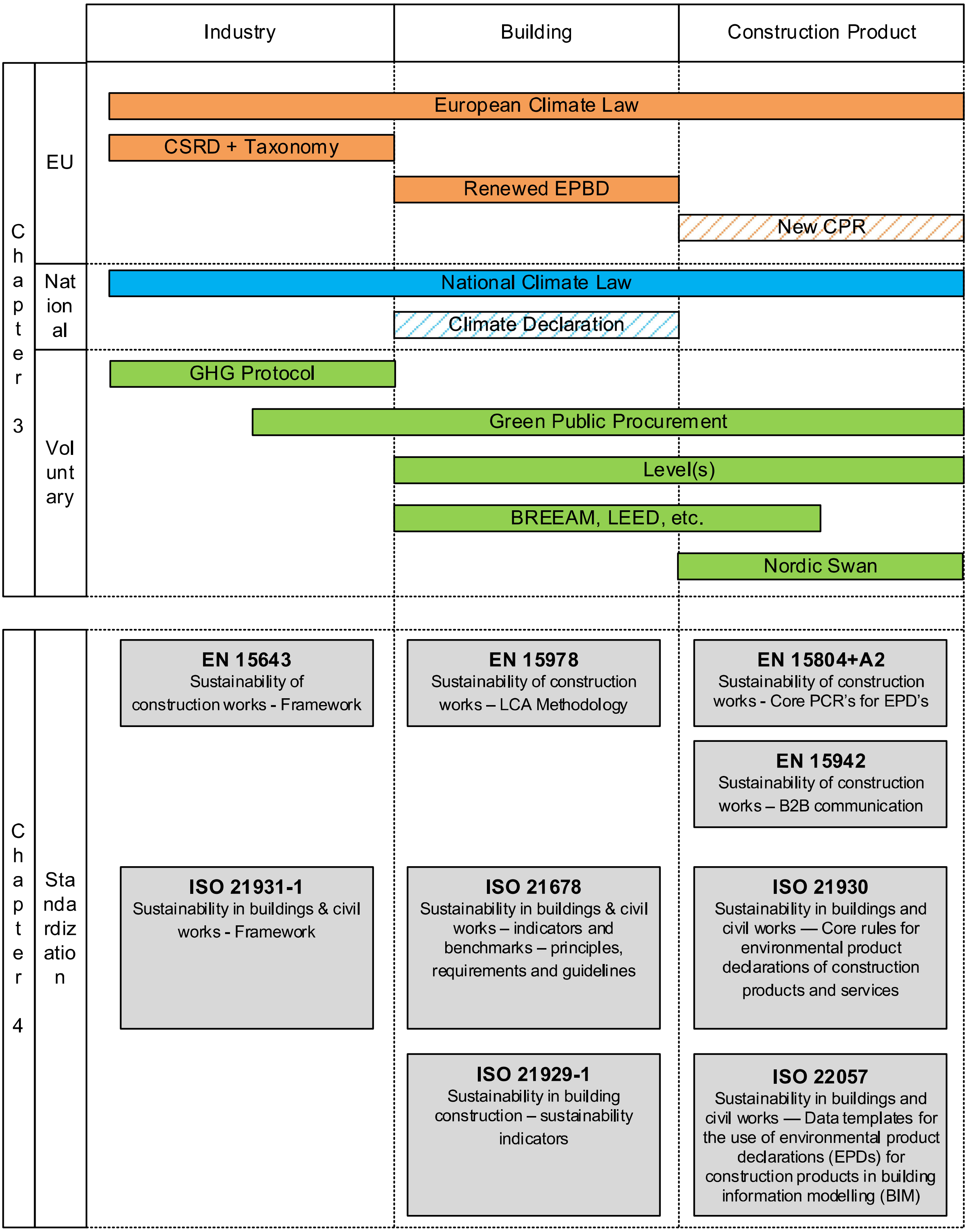

Figure 3: Relevant regulation, voluntary actions, and standards across different categories. Shaded regulation is momentarily in preparation. Chapter column on the left indicates in which chapter of the report these items are elaborated upon (own image).

3.1 Industry level regulation and policy initiatives

With regards to emissions regulation on an industry level, the EU objective to be climate neutral in 2050 (European Climate Law, 2021) sets the goal of reducing Greenhouse Gases (GHG) by 55% by 2030 compared to the levels of 1990. Inspired by this, many countries have set ambitious targets for climate neutrality. E.g., Finland took a new Climate Law into action in 2022 that incorporates national emission reduction targets for the years 2030 (60% less) and 2040 (80% less), compared to 1990 levels (10.6.2022/423 Ilmastolaki, 2022). On an organizational level, the EU Corporate Social Responsibility Directive (CSRD) (EUR-Lex-32022L2464) requires emissions disclosure for all larger EU-companies from 2024 onwards. For the construction industry, the CSRD-directive can be expected to have limited impact as only large companies will be obligated to report their emissions. The presence of such companies in the construction industry is lower than 20%, leaving reporting voluntary for more than 80% of the industry (Eurostat, 2023). With the great variety of stakeholders involved throughout the construction life-cycle stages, this will likely mean that information about certain stages will be missing as not all stakeholders will be participating in reporting. Those companies under the scope of the CSRD are also required to disclose the sustainability of their operations according to the EU Taxonomy. The taxonomy facilitates informed sustainable investment decision-making for investors through a tool and classification system (European Commission, 2020a).

3.2 Building regulation and policy initiatives

On a building level, the recently adopted revision of the Energy Performance of Building Directive (EPBD) necessitates the calculation of all new buildings' greenhouse gas emissions (global warming potential GWP) from 2030 onwards, along with the creation of digital building renovation passports for existing buildings to map the needed actions to reduce GHG-emissions, and a digital building logbook that includes all relevant information concerning carbon emissions (European Commission, 2023). Across several countries, climate declarations for buildings, necessitating buildings' Life-Cycle Assessments (LCAs), are also being implemented. In Nordic countries, Sweden has already been demanding climate declarations since 2022 (von Malmborg et al., 2023) and Denmark has set carbon emissions limit values for buildings (Malabi Eberhardt et al., 2023).

In Finland the new building act will require LCA calculation for selected building types in new construction at start of 2026. This Climate declaration shall be presented to authorities in handover phase, and it shall go below required limit values. The Climate declaration cover all life cycle phases of a new building, including carbon handprint. The emission data in Climate declaration shall be based on verified EPD data or on national conservative public carbon emission database (Kuittinen & Häkkinen, 2020). The required limit values for GHG-emission are under evaluation and values will be given in regulation before 2026. Energy Performance of Building Directive (EPBD) has entered into force on 28.5.2024 and there is 2 years period for implement regulation on national level. In government presentation for building act revision (https://valtioneuvosto.fi/delegate/file/142721) is expected that detailed regulation for building act needs to be adjusted in the future as EPBD sets time limits to widen the scope of emission calculation to all buildings.

3.3 Construction product regulation and policy initiatives

On a construction product level, the revision of the Construction Products Regulation (CPR) will require manufacturers to produce a harmonized Environmental Product Declaration (EPD) to go along with product conformity regulation (i.e. CE-marking). This initiative comes with a digital construction products database and a digital product passport (European Commission, 2022). Implementation of the new CPR is however a long-term effort. It is foreseen that the full legislation comes into effect in 2040. However, there are indications that the old and new standard might co-exist for a while, therefore adoption for certain product category types might already start 10-15 years earlier. The EU is also developing green public procurement rules for construction products, to be implemented in 2026. These rules will set mandatory minimum environmental sustainability requirements for publicly procured construction products. As a runup to the procurement rules, Green Public Procurement (GPP) criteria for public construction acquisition processes have already been published (European Commission, 2016).

3.4 Voluntary sustainability frameworks

Voluntary sustainability frameworks being used in the construction industry consist of various assessment methods, certificates, and labels, such as BREEAM, LEED, and the Nordic Swan (in the Nordics). In attempting to provide a common language for assessing and reporting buildings' sustainability The EU has created Level(s). This is a wider framework for sustainable buildings that addresses buildings' life-cycle GHG emissions through macro-objectives that consider embodied energy and energy consumption during the use phase (European Commission, 2020b). Even if Level(s)' adoption is voluntary, the definitions and terms used are part of the EU Taxonomy (see 3.1).

Another significant voluntary sustainability framework is the GHG-protocol. The GHG-protocol is a framework focused on organizations and their carbon emissions. The framework distinguishes between emissions originating from scope 1 (direct emissions), scope 2 (indirect emissions from purchased energy), and scope 3 (indirect emissions within the value chain) (GHG Protocol, 2024). Even if the GHG-protocol is voluntary, the CSRD-directive (see 3.2) follows a similar system to account for carbon emissions. Compliance with CSRD will also mean compliance with the GHG-protocol (Momblanco et al., 2024). However, GHG Protocol reporting is usually done on the participating companies' overall fiscal level (as it is principally a corporate accounting method), not on specific product levels, diminishing the probability of obtaining product specific data. Any emissions data obtained attributed to specific products will therefore likely be a translation of company or overall site emissions to specific products.

4. Standardization for construction sustainability data management

4.1 LCA methods and related standards

Life Cycle Assessment (LCA) is a structured, comprehensive and internationally standardised method. It quantifies all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues that are associated with the entire life cycle of any goods or services.

4.1.1 Standardization for LCA

The ISO 14040 and 14044 standards provide an important framework for LCA but these standards leave the individual practitioner with a range of choices, which can affect the legitimacy of the results of an LCA study. To counteract this in the construction domain, there are domain specific LCA standards (see Figure 4). The first one defines the LCA calculation method for buildings and the other one declares environmental indicators for products;

- EN 15978:2011 Sustainability of construction works. Assessment of environmental performance of buildings (calculation method). The standard is evolving, and a new version is expected to be published 2024 or 2025.

- EN 15804:2012 + A2:2019 Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products

For building products, LCA analyses consider various life-cycle stages. The different stages are defined according to EN 15978 (see Figure 4). These stages are used to assess the emissions realized in various stages of a product's life-cycle. It shall be noted that the regulation based normative LCA in different countries may have varying requirements about the included life-cycle phases or even included building components and systems (see e.g., Lavikka et al. (2023) for the situation in the Nordics and Estonia).

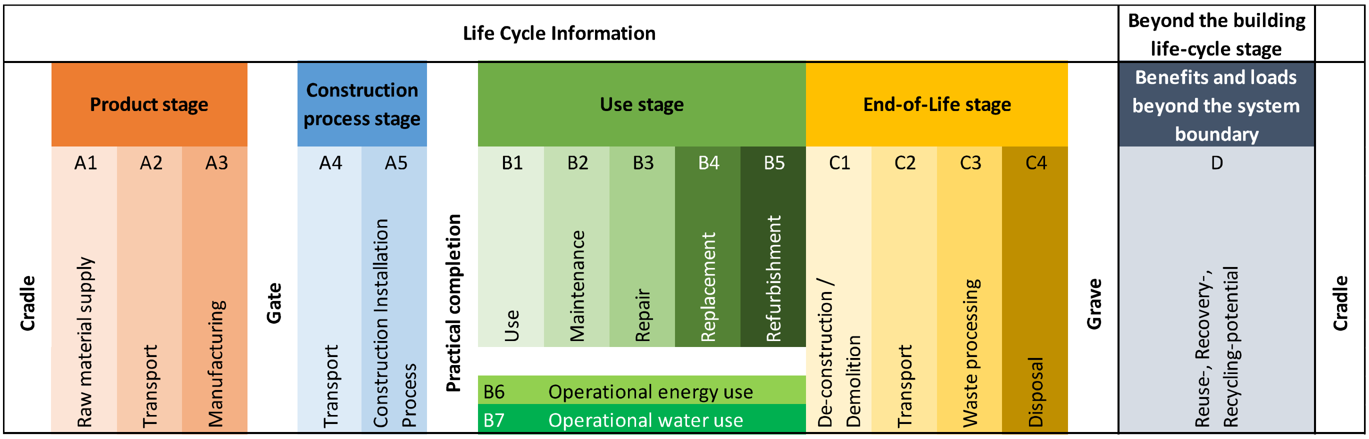

Figure 4: Life-cycle stages according to EN 15978 (own image)

The remaining range of options for the practitioner mentioned in the previous paragraph mainly concern the B-,C- and D-modules according to EN 15978, where scenarios form the basis for the reported emissions. However, for the A-modules, which are under investigation in this report, the emissions reported through LCAs are based on actual manufacturing processes, diminishing possible legitimacy concerns. These concerns are diminished further as the International Reference Life Cycle Data System (ILCD) provides a consistent, robust, and quality-assured basis for life cycle data and studies (EUR 24708).

4.1.2 EU level: PEF and OEF alignment with European standards (e.g. EN 15804)

Next to standards EN 15978 and EN 15804+A2 introduced in the previous section, in the EU context there is also the option to declare emissions through the Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF) frameworks. This report will however focus on the EN standards and not on the PEF and OEF frameworks for several reasons. First, while also based on ISO 14040, the PEF framework conflicts with EN 15804+A2 which is widely adopted in the construction industry, making their results incomparable (Durão et al., 2020). Second, the OEF framework presents a similar scope as the CSRD framework, but the latter is obligatory to adopt while the former is not (Damiani et al., 2022; EUR-Lex-32022L2464).

4.2 EPD and data dictionary standards

Environmental Product Declarations (EPDs) dealt with in this report are Type III environmental declarations which report the environmental performance of specific products over their defined parts or entire life cycle. EPD is standardized in ISO 14025 (EUR 24710 EN) and SFS-EN 15804+A2. EPDs quantify environmental information using predetermined parameters based on ISO 14040, ISO 14044 and other relevant environmental information. The data content of the EPD consist of producer specific data of production methods and resource consumption, and emission data of public data bases. EPSs are verified by an external reviewer. EPD data is used to specify, compare and select products or set out the basis for benchmarks and predict a performance. For this reason, a reliable and sustainable information exchange in machine-interpretability way is also a key characteristic for exchanging EPD information.

A data dictionary is a database that contains meta data (information, requirements, and attributes) for data about construction work and objects. Data dictionary model is a base for a data templates (ISO/DIS 23387, 2024). The data templates provide a standardized data structure for the characteristics of objects (e.g. EPDs) and enables seamless and machine-interpretable way to exchange data in business processes. A data dictionary's language-independent information model is specified in ISO 12006-3 (2022) standard by EXPRESS data definition language. The model conforms to ISO 23386 and ISO 23387 standards, and it is applied while specifying an extensible taxonomy or ontology for construction objects. The standard enables also co-use and data exchange between separate data dictionaries via API and XML schema definitions. In addition, change requests are specified for maintaining, developing, and reviewing the contents of data dictionary.

Note: ISO 22057 (2022) has the unversioned reference to ISO 12006-3 and the versioned reference to ISO 23387 (2020). The later standard is changing, and the version ISO/DIS 23387 (2024) is applied in this report because it is much simpler and clearer than the earlier version. Similarly, the latest version of ISO 12006-3 (2022) is applied.

4.2.1 ISO 22057 - EPD data template

This section focuses on EPD standardization, the following sections declare background information models. SFS-EN ISO 22057 (2022) provides a standardized data model (data template) for EPDs. The standard structures requirements (product category rules, PCR) given in ISO 21930, EN 15804:2012+A1:2013 and EN 15804:2012+A2:2019. PCRs are needed to ensure that EPDs within the same sector or category of products are calculated and presented in the same way. The core rules for PCRs are laid out in EN 15804+A2. In addition, sub-category and complementary Product Category Rules (c-PCR) may state additional requirements. The application of product category rules enables comparability between different EPDs. The SFS-EN ISO 22057 follows the data dictionary model (ISO 12006-3) while structuring requirements as shown in Figure 5.

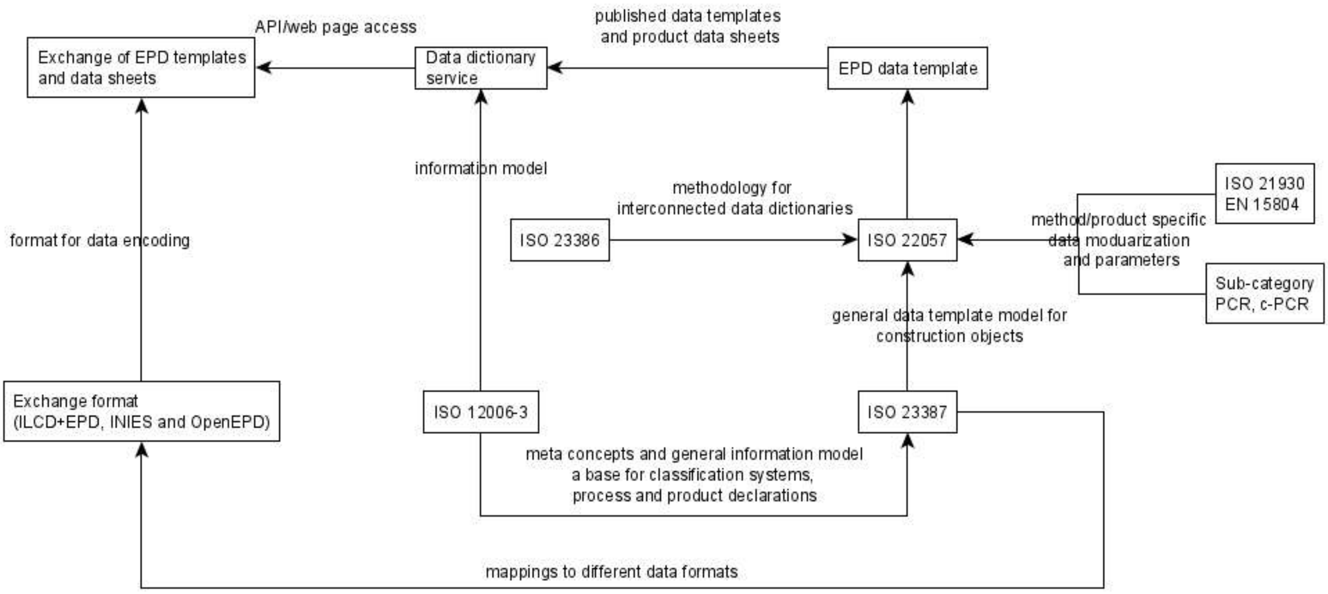

Figure 5. Relationship between standards (retold from SFS-EN ISO 22057*).*

Data templates for EPD information enable stakeholders to exchange machine-interpretable content using the same data structure, terminology, and globally unique identifiers. The data templates are made available through data dictionaries (Section 4.2.2).

Terminology used to specify EPD structures differs lightly from construction object data template terminology (Section 4.2.3). In EPD vocabulary:

- construction object is called to construction product, element or technical system;
- properties are indicators or scenario parameters;

- a group of properties is a set of indicators or parameters (such as product information group, technical data group, programme operator group, content declaration group or EPD type group), a reference unit group or a reference service life group (i.e. a function provided to application, performance characteristics or a period of time).

Typically, EPD data template is created in the following way:
1. Create and define a reference document (e.g. product category rules document, core or product-type-specific PCR, or other source)
2. Create and connect an EPD data template with the reference document
3. Find and connect construction product with the EPD data template
4. Specify indicators for the EPD data template and connect them with dependent indicators and parameters.
5. Specify groups of indicators and attach indicators to these groups. Connect a group to the EPD data template or a parent group of indicators.

Composite EPD data templates (for system with components) are created by links between construction products or data templates. Note, methodological differences between ISO 21930, EN 15804+A1 and EN 15804+A2 standards result to different EPD data templates. The data templates distinguish between groups of indicators and parameters. In other words, names of property groups and properties depend on used characterization method (e.g. TRACI 2.1 or ISO 21930:2017).

The EPD information module is a compilation of data that covers one or more-unit processes in a product life cycle. Information modules are described by one or more alternative scenarios (assumptions). Each scenario produces its own data sheet according to a data template because indicator values (also method and rules) are different in different scenario. So, an indicator may have multiple quantities declared for each information module. However, sub-scenarios are modelled as groups of properties to support better a reuse of templates.

EPD data calculation uses either functional units (applied in certain situations, uses and construction types) or declared units (independent from specific situations) as the reference by which resource, product and LCA results are normalized. EPDs based on declared units are more useful as their can be used for any appropriate situation. The reference quantity could be item, length, area, mass or volume but the mass conversion factor shall always be provided (for transport, end of life). In addition, a scaling factor can be given to convert results for other similar product (e.g. different thickness). Another way to provide information for similar products is to repeat the property ‘product name’ in ‘construction product information’ group to covering products with different packages. In addition, standard/non-standard technical committee (TC) can define additional properties.

SFS-EN ISO 22057(2022) supports to exchange EPD data in several data formats. The annex D of the standard guides how to deliver EPD information as a part of a declaration of performance (DoP) in XML format. In addition, the EPD data templates are aligned with existing data formats: ILCD+EPD (Section 4.2.5), INIES and OpenEPD. The annex B of the standard lists Property mappings between the standard terminology and other formats. The annex B is available at https://standards.iso.org/iso/22057/ed-1/en/.

4.2.2 ISO 12006-3 - Data dictionary model

SFS-EN ISO 12006 Part 3 (2022) specifies a language-independent information model which is used to define subjects with properties to classify entities and to define relationships between subjects (i.e. dictionaries about construction work). The model includes the root entity, the object entity with attributes to track changes and the concept entity for sub-entities: subject, units, dimensions, values, relationships to connect specialized or depend on properties and relationships to connect subjects.

The root entity provides the globally unique identifier. Multiple names (e.g. synonyms or multilanguage names), descriptions, version information and creation date can be assigned to the object entity. Relationships between subjects have the kind attribute to specify the indented use of the relationship. The kind attribute can have a value: schema or instance level. The schema level relationships cannot be instantiated. They are used such as the type-of relation (SFS-EN ISO 12006-2, 2020), to organize subjects in the data dictionary. Instance level relationships is used between entities (instances) such as part-of relation (SFS-EN ISO 12006-2, 2020) to associate a composite product to its constituent parts. Similarly, aggregate-of relationship with instance level kind can be defined to specify a set of related objects in a construction complex. Properties define a set of possible units which can be attached to a value and the unique dimension which is expressed as a decomposition of 7 base quantities. Also, datatype, format and possible values for a property can be specified.

4.2.3 ISO 23387 - Data templates

Data templates provide the concepts and relations needed to describe information about construction objects over the whole life cycle. ISO/DIS 23387 (2024) provides a standardized data structure to describe construction object's characteristics or a view for specific information exchange needs. Typically, data templates should also be made available across interested parties, sector or industry through data dictionaries (SFS-EN ISO 12006-3, 2022) to enable and support open and digital BIM processes.

For one construction object the multiple data templates can be defined. The base elements of a data template model are Objects, Data templates, Properties and Groups of properties. In addition, all elements of the model can be liked to several external documents (Reference documents) which define source documents, purpose, structure and meaning of the elements. A data template can compose of other data templates to reuse existing definitions. All specified properties are directly associated to a data template and also can be collected to groups of properties. The different data templates can have disjoint or same properties and groups of properties. It is recommended to relate data templates to objects for which they can be applied. The objects and groups of properties can also form compose of hierarchies. The draft standard provides some predefined (specialized) groups of properties for different needs such as Purpose, Indended use, User defined and Set of properties.

Data template elements (Object, Data template, Groups of properties) and user defined construction objects (typically products, family of products, generic products) are xtdSubject instances according to SFS-EN ISO 12006-3 (2022) terminology and they should be instantiated into a data dictionary. Similarly, data template Property elements are instances of xtdProperty.

Classification systems (such as SFS-EN ISO 12006-2) classify information based on different needs and perspectives. This draft standard recommends the xtdSubject entity to model all kinds of existing classification systems in a data dictionary. Then, to classify a Data template, a (construction) Object or a Property the "member of" (xtdRelationshipToSubject with instance level kind) relationship is used for categorization.

4.2.4 ILCD format

The European Commission's ILCD Format have only a limited capability to exchange EPD information. The following ILCD formats are available:
- ILCD base set
- extended-ILCD (eILCD, v2.1.1) which adds the life cycle model dataset-scheme to allow representing entire models consisting of ILCD process data sets

The main data sets in ILCD's base set and their relation to EPD information are specified as follows:
1. Process (contains time, location, and technological representativeness for EPD information)
2. Flow (an elementary, product, e.g. mineral wool, or waste flow, one is a reference flow)
3. Flow Property (a quantity with unit to quantify a flow)
4. Unit Group (dimension, a group of convertible units and conversion factors according to a reference unit)

5. LCIA Method (a method and its characterisation factors e.g. an impact category such as global warming potential (GWP) or ecotoxicity, has a reference to a Flow Property to quantify characterisation factors)
6. Source (an external source of information: literature, database or data format, can also refer to a contact information)
7. Contact (a person and an organisation hierarchy)

More information and format specifications about ILCD can be found at

- ILCD data format : https://eplca.jrc.ec.europa.eu/LCDN/developerILCDDataFormat.xhtml
- Developer pages: https://eplca.jrc.ec.europa.eu/LCDN/developer.xhtml
- ILCD International Life Cycle Data system: https://eplca.jrc.ec.europa.eu/ilcd.html

Below is presented a part of an example dataset to exchange total Global Warming Potential (GWP) as an ILCD ProcessDataSet/LCIAResults data set.

```
&lt;LCIAResults&gt;
  &lt;LCIAResult&gt;
    <referenceToLCIAMethodDataSet refObjectId="6a37f984-a4b3-458a-a20a-64418c145fa2" version="21.01.000" type="LCIA method data set"
uri="../lciamethods/6a37f984-a4b3-458a-a20a-64418c145fa2.xml">
      &lt;common:shortDescription xml:lang="en"&gt;Global Warming Potential - total (GWP-total)&lt;/common:shortDescription&gt;
      &lt;common:shortDescription xml:lang="de"&gt;Globales Erwärmungspotenzial - total (GWP-total)&lt;/common:shortDescription&gt;
    &lt;/referenceToLCIAMethodDataSet&gt;
    &lt;common:other&gt;
      &lt;epd:amount epd:module="A1-A3"&gt;1.63335111843996&lt;/epd:amount&gt;
      &lt;epd:amount epd:module="C2"&gt;0.0328302070351863&lt;/epd:amount&gt;
      &lt;epd:amount epd:module="C4"&gt;0.7525528406734&lt;/epd:amount&gt;
      <epd:referenceToUnitGroupDataSet refObjectId="1ebf3012-d0db-4de2-aefd-ef30cedb0be1" version="25.00.000" type="unit group data set"
uri="../unitgroups/1ebf3012-d0db-4de2-aefd-ef30cedb0be1.xml">
        &lt;common:shortDescription xml:lang="en"&gt;kg CO2 eq.&lt;/common:shortDescription&gt;
```

4.2.5 ILCD+EPD format

All EPD information cannot be modelled in the ILCD format as presented in the section 4.2.4. ILCD format has the Process dataset used for an EPD's information because it already holds the relevant metadata, inventory results and the impact assessment result for all lifecycle stages of the product. The inventory results are in the <exchanges> element and LCIA results are in the <LCIAResults> element. However, ILCD+EPD format extends the model as presented in Figure 6 to support EPD module, scenarios and material information.

Figure 6: Extending the ILCD data format (source: EPD Data Format – Developer Quick Start Guide)

An introduction on the ILCD+EPD format with annotations (ILCD+EPD Data format primer.pdf) is available at https://cloud.okworx.com/index.php/s/7wzdMndTosJDSkb.

The latest version (ILCD+EPD v1.2 MR5) of the full specification of the ILCD+EPD format can be obtained at https://www.indata.network/resources under the Technical Documents-section. It contains the specification, examples and XML Schemas.

4.3 Other Product data models

4.3.1 Domain specific product data standards

Product data standard term is used here for formal definition of product properties and other needed data types that are used in digital services enabling automated data exchange between stakeholders in construction and facility management processes. Fabricators' product data is needed in design and product selections, purchasing and logistics, correct and safe use in installations and maintenance as well as in compliance approvals. Product information includes, for example, product identifiers and classifications, specification of characteristics and information needed in supply chains. The product data standards cover normally only the Make-to-Stock (MTS) products. The features and properties of project specific products (ATO, ETO) are defined in project level design and specifications. Need for formal product data is universal but in different domains have been created definitions for their specific needs.

The data models for managing and exchanging digital product data have been created by different organizations and interest groups. Some are based in formal international standardization, like IEC 61360-2 (SFS-EN 61360-2, 2013). Standard data element types with associated classification scheme for electric components, but usually product data standards are defined by some industry or trade stakeholders.

Examples of industry led organisations developing product data standards are ETIM, the European Technical Information Model (https://www.etim-international.com/), and ECLASS, ECLASS e.V. (https://eclass.eu/). Those are funded by members and organizations are getting also licencing income to develop and promote product data standards with members' guidance. For construction domain ETIM is more widely used as ECLASS is used in several domains and have large German industry members.

Development of ETIM standard has started on electrical components domain and usage has widened for HVAC products, and to other product categories. The ETIM has national nodes that use system locally and participate in development and voting of new international developments. Important part of ETIM is product classification taxonomy to help managing and finding products by classes.

ETIM standard has been partially adopted in Finland in national product data model "Tuotetietostandardi" (https://www.sahkonumerot.fi/fi/tietoa-ja-ohjeet/tuotetiedot, In Finnish). The data model is used in national electrical, HVAC and construction product databases for providing wider options to product suppliers to present detailed technical characteristics. Same kind combination approach is used in Sweden in Vilma standard (https://www.byggmaterialhandlarna.se/vilmastandarden/) and product database Finfo (https://www2.finfo.se/).

Product data management have evolved over long time following needs in the markets and the product data standards have been updated regularly. During last years the embodied carbon emission data types have been included in the product data standards and actual data added in product data bases as fabricators have been publishing the data in EPDs. This parallel publishing has brought the environmental indicator data more close to other product data management and operative use cases in the supply chains.

4.3.2 Digital product passport (DPP)

The renewed European Construction Product Regulation (CPR) affects remarkably in the demand for environmental impact data of construction products in European markets. In the CPR (European Parliament and the Council, 2024) is defined the environmental indicators that fabricators must present in Declaration of Performance and Conformity to have CE marking to the product. The climate change indicators for lifecycle of the product, in practice GWP values, shall be available when regulation comes into force and other indicators 4 to 6 years later. The Declaration of Performance and Conformity shall be available in digital human and machine-readable format of free of charge. It shall be noted that more product categories will be regulated with CPR and those are listed in directive annex. The new regulation empowers Commission to organize needed activities to develop of the requirements for new product categories.

The new CPR introduces and sets requirements for digital product passport (DPP) of construction products. Digital product passport regulation has set in domain independent Ecodesign directive ((EU) 2024/1781) that has come into force 18.7.2024. The CPR is referring to Ecodesign directive with additions to construction specific topics, like DPP shall be compatible and interoperable with DPP characteristics defined in Ecodesign directive, but “without compromising interoperability with Building Information Modelling (BIM) , and taking into account the specific characteristics and requirements related to construction product” (European Parliament and the Council, 2024; Article 75 point 2.a).

In the CPR (European Parliament and the Council, 2024) there is not defined detailed data structures or formats to ensure the machine-readability or interoperability of construction product data. However, the Commission is obliged to create a Digital product passport system for construction products and give delegated acts and detailed rules to achieve the system. Moreover, Ecodesign directive requires the Commission to establish DPP register latest on 19.7.2026 with limited data content, and also the Commission shall set up a publicly accessible web portal allowing to search for and compare data included in digital product passports. However, implementation of digital product passport system in construction will be depended on the schedules of the needed delegated acts.

The harmonized European construction product standards define properties for product categories, and manufacturers or importers shall announce the corresponding values in declaration of performance and conformity DoPC (Declaration of Perforrnance DoP in previous CPR). These property definitions have not previously been identified formally to be used in data exchange, although those might be shared in current product data repositories where product data can be searched and shared to different use cases either with user interfaces or non-standardised APIs.

As the earlier discussed EPBD-directive includes the adoption of a renovation passport, and the new CPR-regulation includes the adoption of a product passport, we may expect this approach to change in the future to sustainability assessments that are viewed over the entire lifecycle of buildings and products. As DPP aims to track the history of a product in terms of origin, composition, repair and waste management at the end-of-life (Götz et al., 2022).

Ruismäki explored the benefits of DPP for construction (Ruismäki, 2023):
- tracing products allow designers to quickly access information, contractors to manage the duration of construction, or government agencies to improve policy processes
- DPP would especially foster circular practices that extend the lifespan of product and its parts
- tracing product’s history would allow potential customers to make more informed assessments of the condition and quality
- save time during construction and demolition
- save time in information retrieval due to the readily available information, eliminating issues of scattered or missing information
- new opportunities in organizing and planning the construction phase, for instance, by optimizing the transportation and positioning of products

Each supply chain actor will have access to relevant information on the product and may add data to the DPP during the products life cycle (Koppelaar et al., 2023). The form of these passports is not yet known, and in the absence of an ‘official’ passports, several actors have started to offer early commercial options, for the construction industry for instance by Circularise (https://www.circularise.com/) and Tracid (https://www.tracid.net/) or EU-projects like CIRPASS-2 funded by the European Commission’s Digital Europe Programme (https://cirpass2.eu/).

4.3.3 Product data template (PDT)

The product data template (PDT) is an approach to create machine interpretable data definitions for construction product categories based on EN ISO 23387 standard, see concept and details in section 4.2.3. As the standard EN ISO 23387 is created by CEN Technical Committee 442 “Building Information Modelling (BIM)”, the PDT method is targeted to be compatible with BIM modelling and related data management. Some pre-studies and PDT creation have been implemented at least in Sweden and Norway, see e.g. https://www.pdtnorge.no/. It can be expected that those efforts are targeting to propose PDT method in some extent for the digital representation of digital product passports in construction domain.

4.4 Supply chain data management standards

4.4.1 GS1 Standards

The following GS1 Stardards description is based on sources of:

- https://www.gs1.org/standards [Accessed 28 Dec 2022]
- https://www.gs1.org/standards/log
- https://www.gs1.org/glossary
- https://www.gs1.org/standards/gs1-system-architecture-document/current-standard#3-General-considerations+3-1-Standards,-guidelines,-data-services,-solutions

The GS1 system is a collection of standards, guidelines, solutions, and services. It is developed for open supply chains and value networks to facilitate interoperability (agreements on the structure, meaning and mechanism of data exchange). The interoperability is defined as a capability of different systems to exchange data based on a shared understanding of business processes (e.g. formats, protocols, interfaces between partners i.e. data carriers). In an open value network, a set of trading partners (e.g. manufacturers, distributors, retailers) is not known in advance or they change over time. The interface definitions and standards are negotiated and implemented outside the context of any trading relationship to ensure their broad adaptation. In addition, the GS1 system architecture promotes technology independence and a layered approach. The standards are either technical standards or application standards. The technical ones are for identification, automatic identification and data capture (AIDC) (e.g. barcodes and RFID tags), master data (e.g. product catalogue), information exchange (e.g. EDI) or visibility event data (e.g. EPCIS). The application ones determine a normative use of technical standards for a certain business use case.

GS1 System Architecture is a modular approach and has the following layers (according to roles supporting information needs, see figure 6):

1. Identification standards

   These standards are used to identify entities with GS1 identification keys (simple or compound) and to associate additional information about them. The entities may be physical (e.g. product, raw material, logistics unit, location, production equipment), digital (e.g. eBook, business transactions and documents) or conceptual (e.g. product category, a company as a legal entity)

2. Capture standards or Automatic Identification and Data Capture (AIDC) standards

These standards are aimed to automatically capture identifiers on physical entities. The AIDC data carriers (e.g. barcode and radio-frequency identification (RFID)) enable bridge between physical and digital worlds. The specifications for data carriers are contained in the capture standards which sit between the identification standards and the sharing standards. Note, not all identification is automated and not all data capture is identification. In some cases, certain business data (the weight of an item) can be provided directly in AIDC data carrier without use of sharing standards.

3. Share standards

These standards provide the foundation for electronic business transactions (e.g. purchase order, invoicing information), electronic visibility of the physical and digital world, and other applications. They are for information sharing (e.g. master data, business transaction data, visibility event data), communication, and resolver infrastructure. The sharing standards may use identification standards directly without any AIDC standards (data capture). For example, when a trade item related master data is shared between trading partners.

4. Use / Application standards

The use or application standards provide a normative selection of technology and data to meet business or regulatory requirements. The provide definitions, rules, and/or conformance specifications that shall be followed in special business cases.

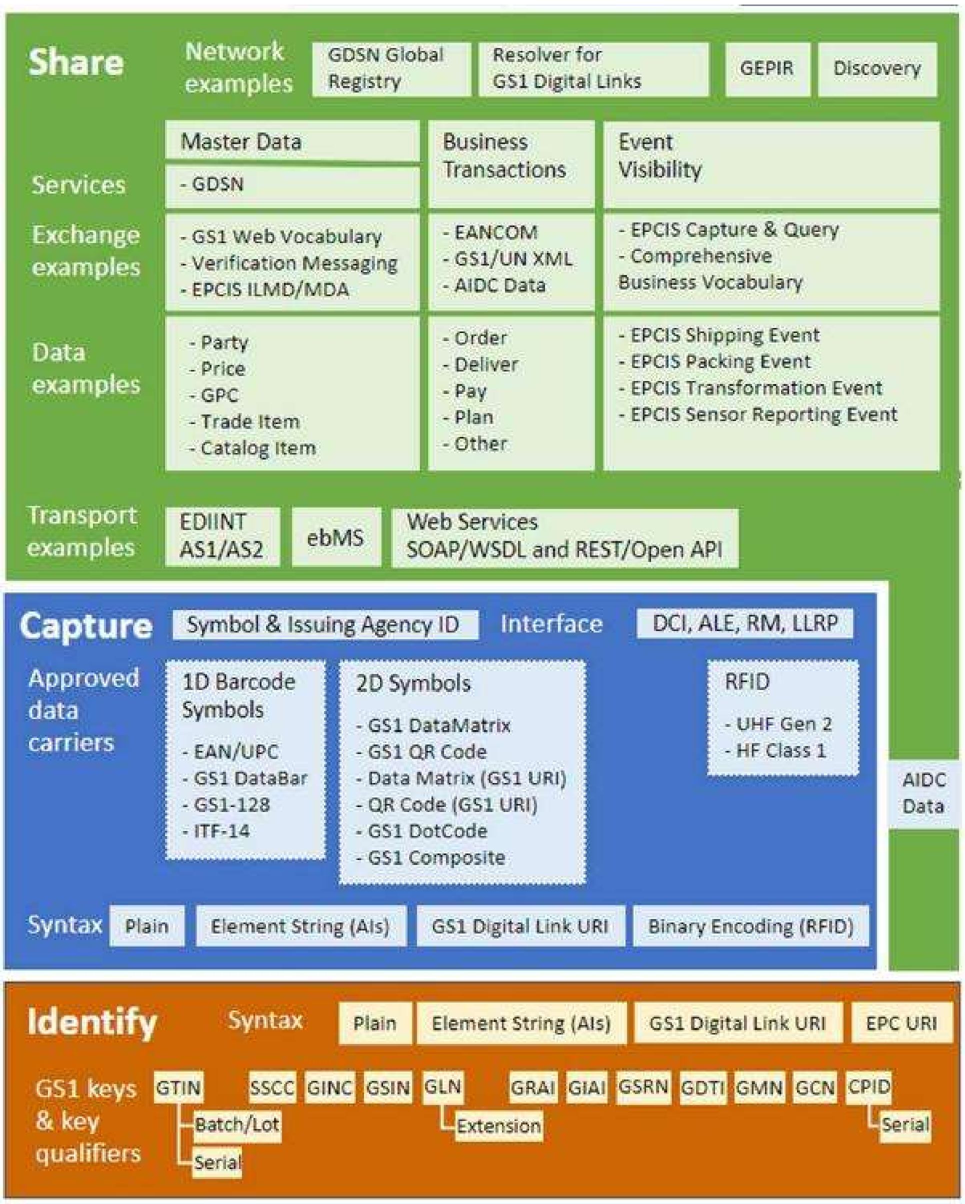

Figure 7. Visual representation of the Identification, Automatic Identification & Data Capture, and Data Exchange (source: GS1 System Architecture)

More information is available at https://www.gs1.org/standards/gs1-system-architecture-document/current-standard

The standardized **GS1 system element strings** are the basis for the unambiguous identification of items of every kind. The standard defines the GS1 system element string as a combination of a **GS1 Application Identifier** and a GS1 Application Identifier data field. The GS1 Application Identifier specifies syntactical rules for system element strings, and which kind of **GS1 identification key** is presented in the data field. GS1 system element strings can be carried by GS1-128, GS1 DataBar symbology, GS1 Composite, GS1 DataMatrix and GS1 QR Code symbol. GS1 Application Identifier is declared implicitly or explicitly by a data carrier or an electronic message. More information is available at https://www.gs1.org/docs/barcodes/GS1_General_Specifications.pdf

GS1 system standardizes many kinds of identification keys. Below, only the generally used identification keys are introduced.

Global Trade Item Number (GTIN) provides a global supply chain solution by identifying any physical (product) or non-physical (service) trade item. The trade item may be a single or an assortment (group) that may be priced, ordered or invoiced at any point in the supply chain. The GTIN is assigned to a product for maintaining operational efficiencies while exchanging pre-defined information, ensuring the smooth operations and ensuring the right products are available in the store. The GTIN may be an eight, twelve, thirteen or fourteen-digit string encoded in a data carrier. More information is available at https://www.gs1.org/sites/default/files/docs/barcodes/GS1_GTIN_Management_Standard.pdf

GS1 **Global Data Model (GDM)** simplifies and harmonises the exchange of foundational product information by defining a globally consistent set of product attributes (e.g. for contact information, weights, dimensions, packaging, or compliance). In addition, it defines a trade item hierarchy which consists of multiple linked GTINs to represent base units, inner packs, cases and pallet. Different kinds of hierarchies (simple, complex, variety and loose packed) are supported. More information is available at https://ref.gs1.org/guidelines/gdm-implementation/ and https://www.gs1.org/standards/gs1-global-data-model/2-4.

A logistic unit is an item of any composition established for transport and/or storage. To track and trace the units, they are identified with a GS1 identification number called the **SSCC (Serial Shipping Container Code)**. For each individual unit, a unique number is allocated. The number remains same for the whole life of the logistic unit and should not be assigned to another unit within one year of the shipment date. The combination of a GTIN and a serial number does not replace the SSCC as the identifier of a logistic unit.

In addition, GS1 system standardizes identification keys for logical groupings of products or logistic units. When referring to multiple logistic unit identification for trade, GS1 uses the term shipment (**GSIN**) and when referring to multiple logistic unit identification for transport, GS1 uses the term consignment (**GINC**).

The GS1 Digital Link standard, one of identification standards, defines a method, rules and a web URI syntax for GS1 identifier keys, key qualifiers and data attributes. GS1 Digital Link URIs are a subset of general web URIs. Multiple Digital Link URIs can identify the same real world or conceptual entity for which the online information is provided. The URI format is based on GS1 Application Identifiers and GS1 Application Identifier data fields. GS1 Application Identifiers define format and meaning for data fields. Class 1 and Class 2 GS1 identifier keys can be encoded into the data fields. Additionally, data carriers such as QR codes and NFC tags can encode complete GS1 Digital Link URIs.

4.4.2 Digital formats for supply-chain transactions

Electronic data interchange (EDI) methods have been used for decades in defining in machine-readable format of business documents and information models for supply chain, procurement, and transportation. Several standards have bee used, like UN/EDIFACT, and those are still widely used. More modern framefork is Universal Business Language (UBL) which is an open library of standard electronic business documents and information models designed to streamline supply chain operations and digital communication between stakeholders. Developed by the OASIS Technical Committee, UBL supports a wide range of business processes by providing standardized formats for documents such as purchase orders, invoices, and waybills.

Standards based digital messages can used in 1-to-1 business transactions, but greater value can be achieved in a network environment where communication can be conducted in the same way with multiple business partners. In Finland most widely used message-based information transfer method is Finvoice invoicing method that was created by banks, and it complies with the Finnish E-Invoicing Act 241/2019. Finvoice messages are transferred to sending organisation’s service provider, who then forwards them to client’s service provider for delivery to actual client.

This decentralised four-corner architecture is also applied in international OpenPeppol[1] framework that is utilizing UBL in formatting business documents. OpenPeppol interoperability network is a set of technical specifications and standards designed to facilitate the electronic exchange of business documents between organisations. It is connecting buyers and suppliers through Peppol-accredited Service Providers in a secured manner. Peppol is under implementation in Finland as the State Treasury promotes its adoption in public administration, but also in the private sector. The State Treasury is an official member of the OpenPeppol Association and operating as Peppol authority since 2022.

The OpenPeppol framework is currently being applied to the construction domain in Finland in an ongoing development project. In Sweden the definition of digital business documents for construction domain has been initiated already late 1980's and currently the developments are done by BEAst.se. BEAst is a non-profit association that develops common standards and working methods for digital communication in collaboration. BEAst is adjusting their standards to able to be used also in OpenPeppol network. Nordic Peppol authorities have organized in 2024 also the Nordic Peppol Construction Industry Forum for promoting and coordinating OpenPeppol related activities and, in general digitalization of construction supply chains.

5. Carbon footprint data

5.1 LCA data for products

Commonly used LCA databases may be divided into three categories; (1) generic databases containing typicals for products and their production processes, (2) national databases gathering relevant (average or typical) emission data related to construction products and processes within the national boundaries, and (3) EPD databases containing sustainability data for manufacturer specific products.

5.1.1.1 Generic databases

Examples of generic databases covering global products, and production processes (including the construction sector) are for instance Ecoinvent, and Sphera (formerly GaBi). In order to ensure a fit with EN 15804+A2, Econinvent offers a database which contains only those items that comply with the standard.

Data is offered for adoption into the Ecoinvent database by industry partners. Before data can be adopted in the Ecoinvent database, a third-party verification needs to take place, which is facilitated by the platform. For Sphera the process is more or less similar, with the exception that an internal review is necessary before adoption into databases is possible. Both Ecoinvent and Sphera databases support the ecoSpold2-format, allowing conversion of data into the xml-format.

5.1.1.2 National databases

National databases to aid in construction emissions data exist in several countries. In Finland for instance, there is the co2data.fi[2] database comprised of average emission values for typical construction activities and processes. In Sweden, Boverket offers a similar database[3], while e.g., Estonia currently has a draft version of a national database ready (Lavikka et al., 2023).

[1] https://peppol.org/
[2] https://co2data.fi/rakentaminen/
[3] https://www.boverket.se/en/start/building-in-sweden/developer/rfq-documentation/climate-declaration/climate-database/

The databases are created according to EN 15804+A2, but due to the national context, results may not be directly comparable amongst each other. Second, even though the data quality in the Finnish database is for instance in order, machine readability and data sharing has not been prioritized when creating the database, hampering the digital distribution of its contents.

5.1.1.3 EPD databases

There are several EPD databases offering formal EPD data prepared according to EN15804 containing CO2e-emission data as GWP-values. Different web-based databases are often originating from a specific geographic context. However, the databases can contain EPD's from wider geographic area as well. Examples of EPD databases are Rakennustieto EPD-ympäristöseloste (Finland), Environdec (Sweden) or EPD Norge. German Ökobaudat maintained by Federal Ministry for Housing, Urban Development and Building, is a national database containing generic dataset like average or representative EPDs, but it is implemented with the same data format ILCD+EPD as the commercial EPD platforms.

EPDs in all of these databases need to comply with EN 15804+A2, but there are existing EPDs following previous version of the standard. Third party verification is necessary for all of these databases, and most of them provide a list with acknowledged verification organizations or experts. All databases are capable of exporting data in an xml-file format (usually through the ILCD+EPD data format). When registering EPDs however, this is optional. In practice this means that some EPDs might be machine-readable, while others will not be.

5.1.2 EPD platform ecosystem

The most of EPD databases described in 5.1.1.3 are connected to The Environmental Product Declaration (EPD) platform ecosystem. It is a comprehensive framework designed to facilitate the exchange and management of environmental data for products, particularly in the construction sector. This ecosystem is built upon the collaboration between various platforms and initiatives, including the ECO Portal[4] and the InData network[5].

The ECO Portal serves as a central access point for users to obtain digital EPD data. It is developed by the ECO Platform, which aims to provide credible and scientifically accurate data to support sustainable development and decarbonization efforts in the construction industry. Users can access a wide range of digital EPD data through a single platform, simplifying the process of data retrieval and usage. The portal supports the ILCD+EPD data format, ensuring consistency and interoperability across different systems and applications. The ECO Portal provides APIs for direct access to digital EPD data, enabling seamless integration with various LCA (Life Cycle Assessment) tools and other digital applications.

The InData network complements the ECO Portal by providing a standardized framework for EPD data exchange. It focuses on harmonizing EPD databases and ensuring that data meets specific compliance rules. InData works towards aligning different EPD databases to ensure consistent data quality and format. The network provides tools to validate EPD datasets against the InData compliance rules, ensuring the technical validity of the data. InData and ECO Platform have engaged in a dialogue to facilitate closer cooperation, enhancing the overall functionality and reach of the EPD ecosystem.

The EPD platform ecosystem is further strengthened by a network of interconnected EPD platforms. This network allows for the seamless exchange of EPD data across different platforms and databases, promoting a more integrated and efficient approach to environmental data management.

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[4] https://www.eco-platform.org/eco-portal-access-point-to-digital-product-data.html
[5] https://www.indata.network/resources

In summary, the EPD platform ecosystem, built on the collaboration between the ECO Portal and the InData network, provides a robust and standardized framework for managing and exchanging environmental data. This ecosystem supports sustainable development by ensuring the availability of credible and scientifically accurate EPD data, facilitating its integration into various digital tools and applications.

5.1.2.1 soda4LCA application

Soda4LCA is an open-source service-oriented (web) database application which can be set up to share your own ILCD data sets directly or as a node of Life Cycle Data Network[6]. The data sets and referenced documents are stored into a MySQL relation database. The application has been primarily developed by the Institute for Applied Computer Science (IAI) in cooperation with the European Commission Joint Research Centre (JRC) and is now maintained by OkworX[7] and the JRC.

5.2 Transport to site

Data for transport to site (module A4 in EN 15804+A2) is currently mostly managed manually and on sites through waybills. The waybills are collected on site to allow for e.g., billing of orders. However, freight companies are usually able to follow all relevant logistics data online, and larger shipping companies might even offer this data and (services alongside) as commercial platform solutions (see e.g., Dachser8). The data generally does not include emissions data but does include all of the relevant data (e.g., trip lengths, vehicle type, fuel type, etc.) for the calculation of carbon emissions related to logistics. Smaller logistics companies and/or dedicated logistics solutions may not be in the possession of such a platform.

One initiative that may ease the availability of logistics data is Electronic freight transport information (eFTI). eFTI is an EU-wide initiative to set up a legal and standardized framework for the digital exchange of logistics information (eFTI, 2024). I.e. eFTI provides a machine-readable electronic waybill, in first instance for police and customs authorities. But data may also be provided to third parties if authorized by the data owner (EUR-Lex-32020R1056). If combined with standards like Peppol, it could be possible to obtain data from procurement of a product to its delivery. This is currently under development in Finland as part of the Real-time Economy initiative (Valtiokonttori, 2024). Also eFTI does not include emissions data but includes the relevant data to base the emissions calculations upon.

5.3 Site operations

Data for site operations (module A5 in EN 15804+A2) is currently mostly managed manually. General data (number of units, unit sizes, etc.) for construction equipment and temporary works (e.g., cranes, elevators, scaffolding, formwork) may be retrieved from the Building Information Model (BIM), provided that these are (1) modelled but, (2) not as solid objects. This data will most likely not contain direct emissions numbers.

Usage data for construction equipment (use-time, type of equipment, fuel consumption) may be retrieved through bills (either analogue or digital), or through supplier tracking systems. Certain parties are offering commercial services where carbon emissions from rented equipment are calculated and reported to the client. Energy and water use on site is currently also tracked manually through bills or pictures, with no direct emissions data provision.

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[6] https://eplca.jrc.ec.europa.eu/LCDN/howto.xhtml
[7] https://bitbucket.org/okusche/soda4lca
[8] Dachser eLogistics

Proxy emissions data for site operations may be able to be retrieved from national databases like https://co2data.fi, but these are more generic and might lack the depth to provide emissions for specific site activities, temporary works, equipment, and/or energy consumption.

6. Data options for as-built carbon footprint calculation

The following section describes the probability of availability of the earlier described data, data formats and services in chapters 4 and 5 in different life-cycle stages for each of the defined four product types (ETO, MTO, ATO, MTS), as well as specific construction site activities that are not covered by the product type descriptions.

The probability of availability of different data formats is described for each of the life-cycle stages provided by EN 15978, supplemented with several activities that are not part of the EN 15978 framework, but that can be specifically linked to the data formats presented earlier. The supplemented activities can be recognized in Figures 8-12 as being marked in white and not having an EN 15978 life-cycle stage code.

The data formats are divided into four different categories:

1. Building data; that covers the building information model (BIM) in all of its different sub formats and appearances.
2. Supply chain data; that covers different data formats currently in use, or that will be use in the future, to organize the supply chain (GS1, Peppol, EFTi).
3. Sustainability data; that covers the emissions and/or LCA data for different construction products (EPD's, national databases).
4. Regulatory data; that covers the current and future legally required information regarding construction products (new CPR).

Picturing the probability of availability of different data formats for different life-cycle stages principally does not say anything about emission data capturing (e.g., supply chain data formats in their current form do not contain any information about emissions data). However, their probability of availability does reveal which data formats would be interesting to study further regarding emission data capturing.

If e.g., a certain data format has a strong presence throughout different life-cycle stages, it might prove interesting to investigate its possibilities to carry or communicate emissions data. If those possibilities are mapped, it is then possible to describe the data requirements that still need to be developed for each product type.

6.1 Engineer-to-order

See Figure 8 for the total overview of possible availability of the different data formats for ETO-products.

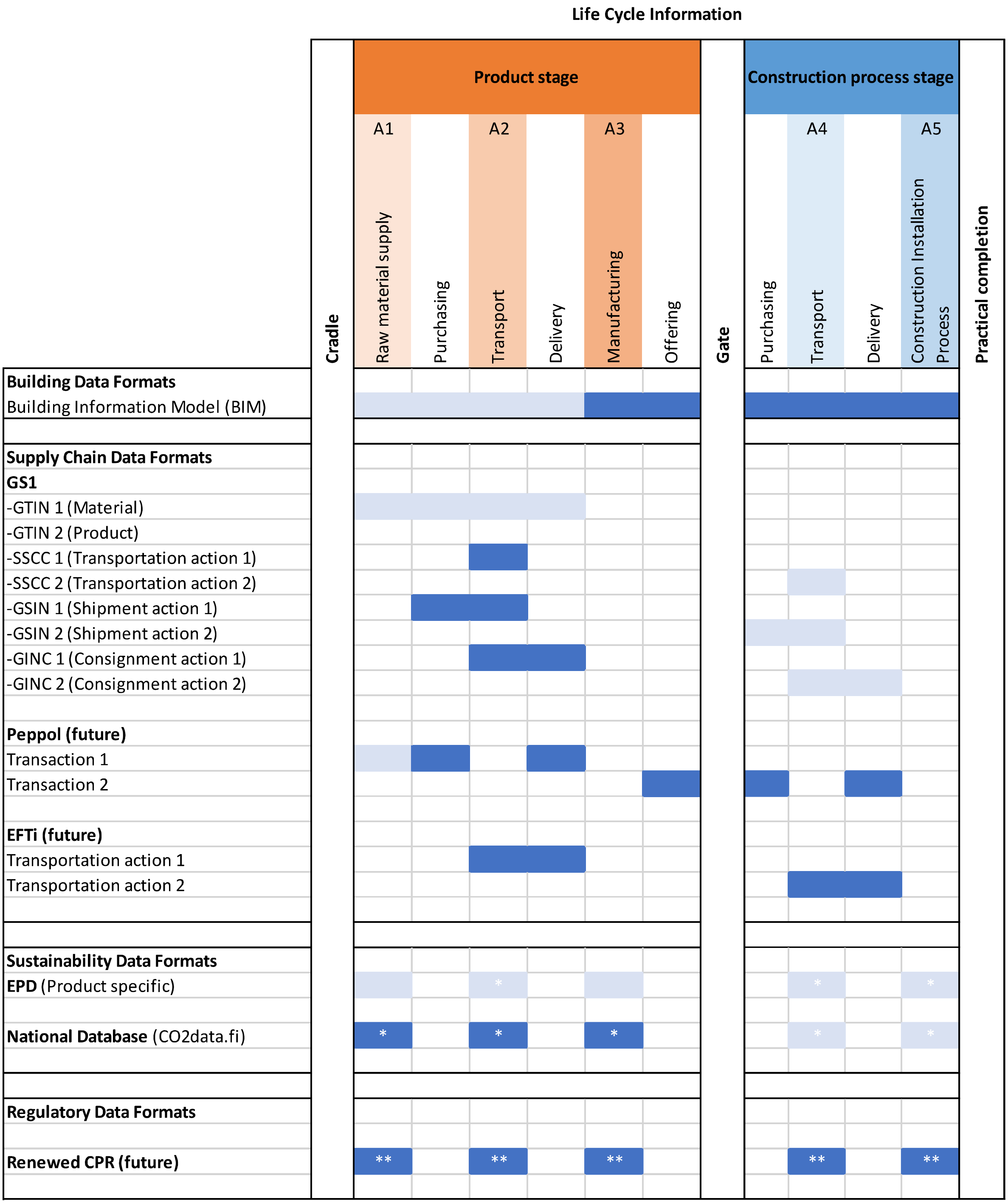

Figure 8: Data formats and their availability for ETO-products. A coloured block shows the probability that a particular data format is available for that certain life-cycle stage. A light-faded block signals decreased likeliness of availability for that particular data format in that particular life-cycle stage.

Building data formats
Since ETO-products are specials that are being made per customer order, it is likely that building data will be available in digital and/or BIM-formats for at least stages A3-A5, as these (can) act as preliminary blueprints for the production of the products in question. Depending upon the degree of specialty, data might also be available for modules A1-A2.

Supply Chain data formats

GS1 data formats will be less likely to be present with ETO-products. For sub-components that make up the total ETO-product (modules A1-A3), there might be transportation, shipment, and/or consignment data present. For later stages, this is less likely due to e.g., a subcontractor ordering specific transportation for the produced products to be delivered on site. Also the use of GTIN codes is not likely with these unique products.

Peppol might play a part in covering the purchasing to delivery process of the ETO-product as a whole, whereas EFTi might be able to cover the transportation actions. Combined coverage would likely be modules A1-A4.

Sustainability data formats
EPD-data is not likely to be available for ETO-products. If there is any available data, it is likely linked to (several) subcomponents of the ETO-product and/or consist of proxy data.

Through the Finnish national emissions database sustainability data will likely be available for products that are similar to the one under investigation, rendering it possible to at least extract proxy emissions data from this source for Cradle-to-gate.

Regulatory data formats
Based on the current CPR-draft, which includes sustainability data linked to construction products CE-marking, it may be expected that sustainability data will be available from modules A1-A5. It might however mean that data from (several) subcomponents would need to be combined in order to obtain a complete picture for modules A1-A5.

6.2 Make-to-order

See Figure 9 for the total overview of possible availability of the different data formats for MTO-products. For the specific data format categories, only the differences with the between MTO- and the earlier described ETO-products are described.

Building data formats
Compared to ETO-products, for MTO-products it is not likely that a BIM-model or equivalent will be available for modules A1-A2, as these will most likely concern more ‘standard’ sub-components that will be produced by manufacturers regardless of the particular construction project under investigation.

Supply Chain data formats
The (probability of) availability of supply chain data is similar as with ETO-products.

Sustainability data formats
Availability of sustainability data will be similar to that of ETO-products, with the exception of modules A1-A3, where due to the earlier described increased use of ‘standard’ sub-components, it is more likely that EPD (proxy) data can be obtained.

Regulatory data formats
The (probability of) availability of regulatory data is similar as with ETO-products.

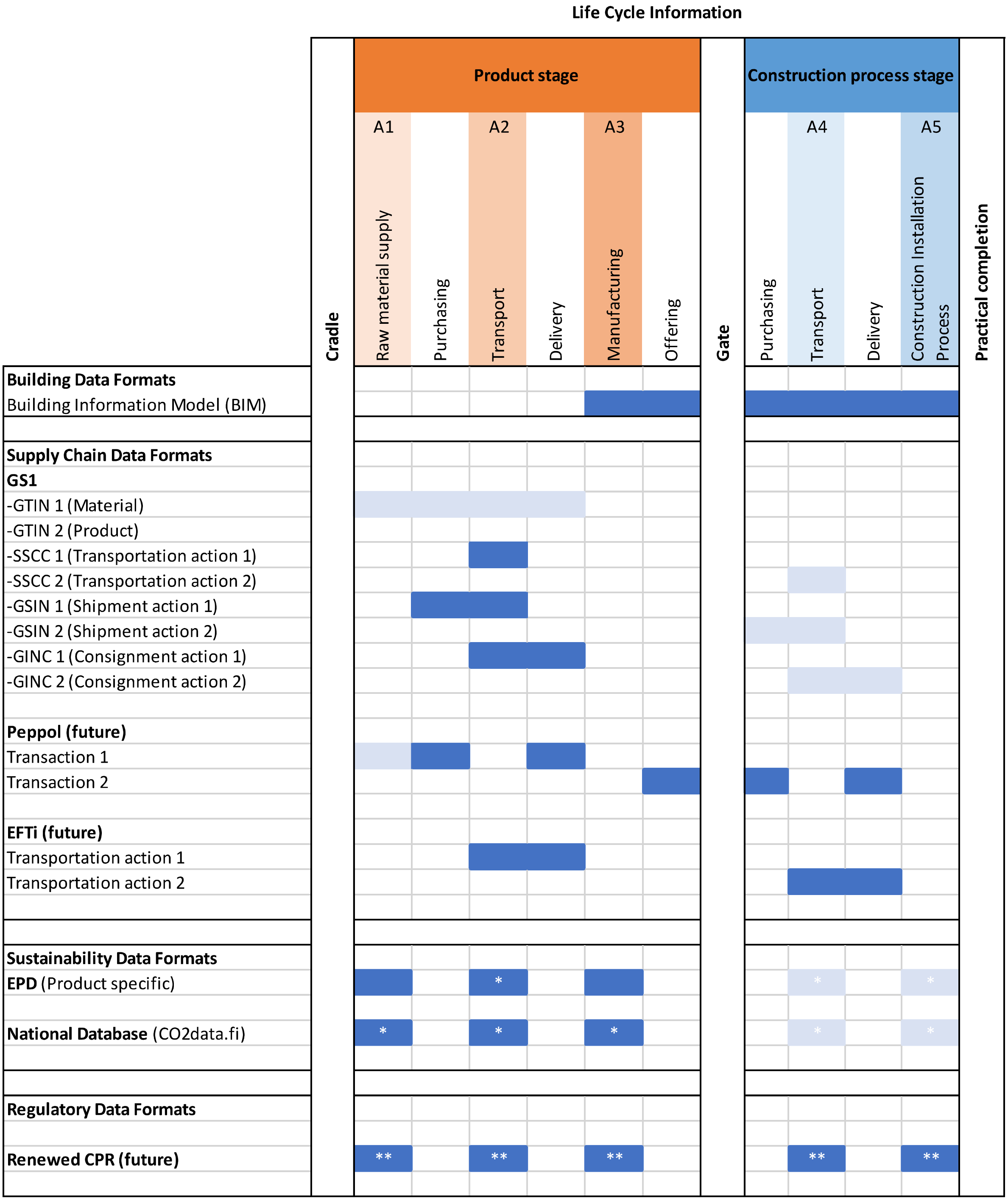

Figure 9: Data formats and their availability for MTO-products. A coloured block shows the probability that a particular data format is available for that certain life-cycle stage. A light-faded block signals decreased likeliness of availability for that particular data format in that particular life-cycle stage.

6.3 Assemble-to-order

See Figure 10 for the total overview of possible availability of the different data formats for ATO-products. For the specific data format categories, only the differences with the between ATO- and the earlier described MTO-products are described.

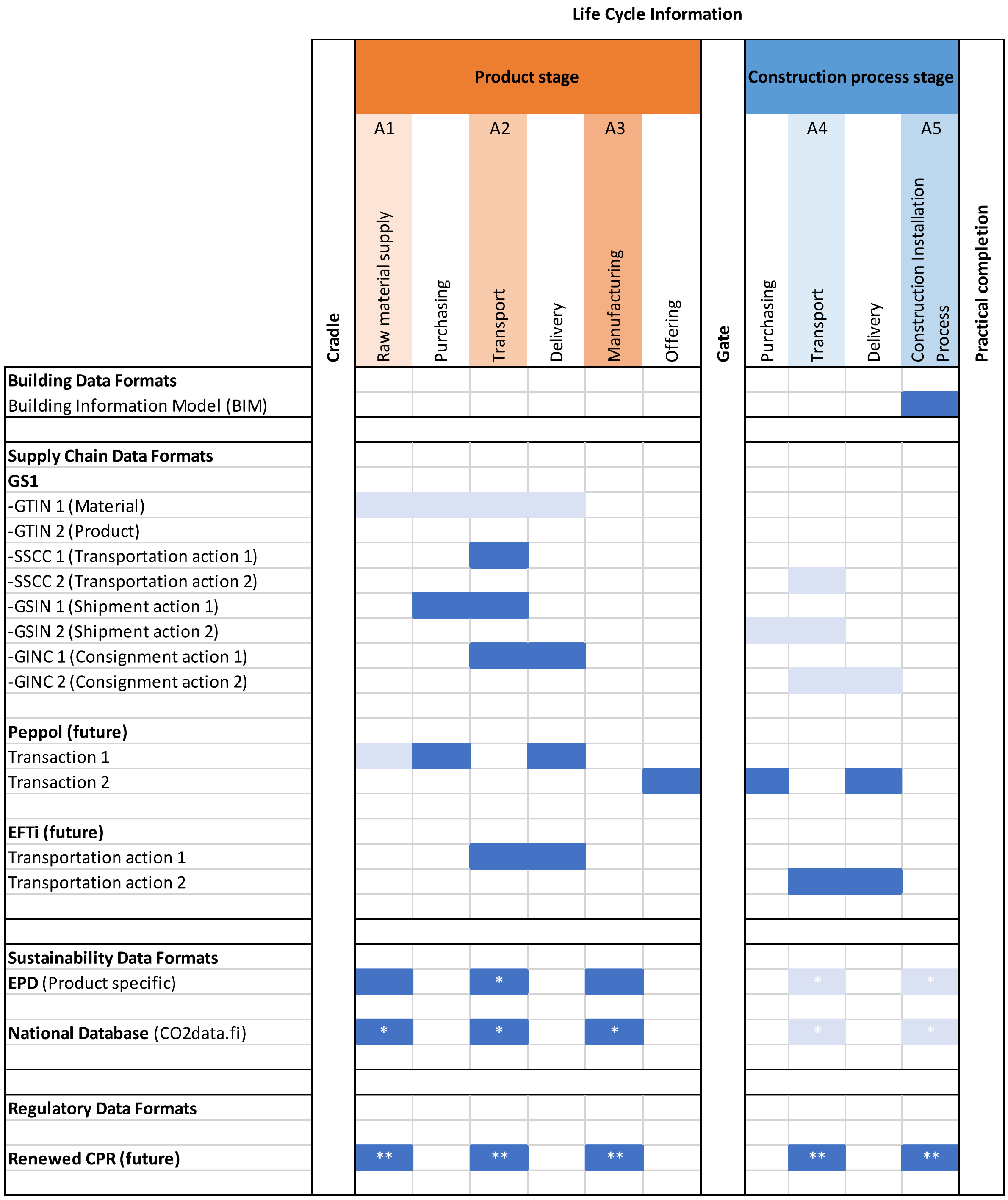

Figure 10: Data formats and their availability for ATO-products. A coloured block shows the probability that a particular data format is available for that certain life-cycle stage. A light-faded block signals decreased likeliness of availability for that particular data format in that particular life-cycle stage.

Building data formats

Compared to MTO-products, for ATO-products it is not likely that a BIM-model or equivalent will be available for modules A3-A4, as these will most likely concern more 'standard' sub-components that will be produced by manufacturers regardless of the particular construction project under investigation.

Supply Chain data formats

The (probability of) availability of supply chain data is similar as with MTO-products.

Sustainability data formats
Availability of sustainability data will be similar to that of MTO-products.

Regulatory data formats
The (probability of) availability of regulatory data is similar as with MTO-products.

6.4 Make-to-stock

See Figure 11 for the total overview of possible availability of the different data formats for MTS-products. For the specific data format categories, only the differences with the between MTS- and the earlier described ATO-products are described.

Building data formats
The (probability of) availability of supply chain data is similar as with ATO-products.

Supply Chain data formats
Compared to ATO-products, for MTS-products more data may be expected to be available in modules A4-A5. Specific GTIN codes for products are for instance likely to be available, as well as additional transportation, shipment, and consignment data. To get a complete picture throughout modules A1-A5, it might however be necessary to link different pieces of data together.

Sustainability data formats
Compared to ATO-products, for MTS-products it availability of EPD’s for modules A1-A5 is larger. The data may however be largely based upon proxy data.

Regulatory data formats
The (probability of) availability of regulatory data is similar as with ATO-products.

Figure 11: Data formats and their availability for MTS-products. A coloured block shows the probability that a particular data format is available for that certain life-cycle stage. A light-faded block signals decreased likeliness of availability for that particular data format in that particular life-cycle stage.

6.5 Site Operations

See Figure 12 for the total overview of possible availability of the different data formats for site operations.

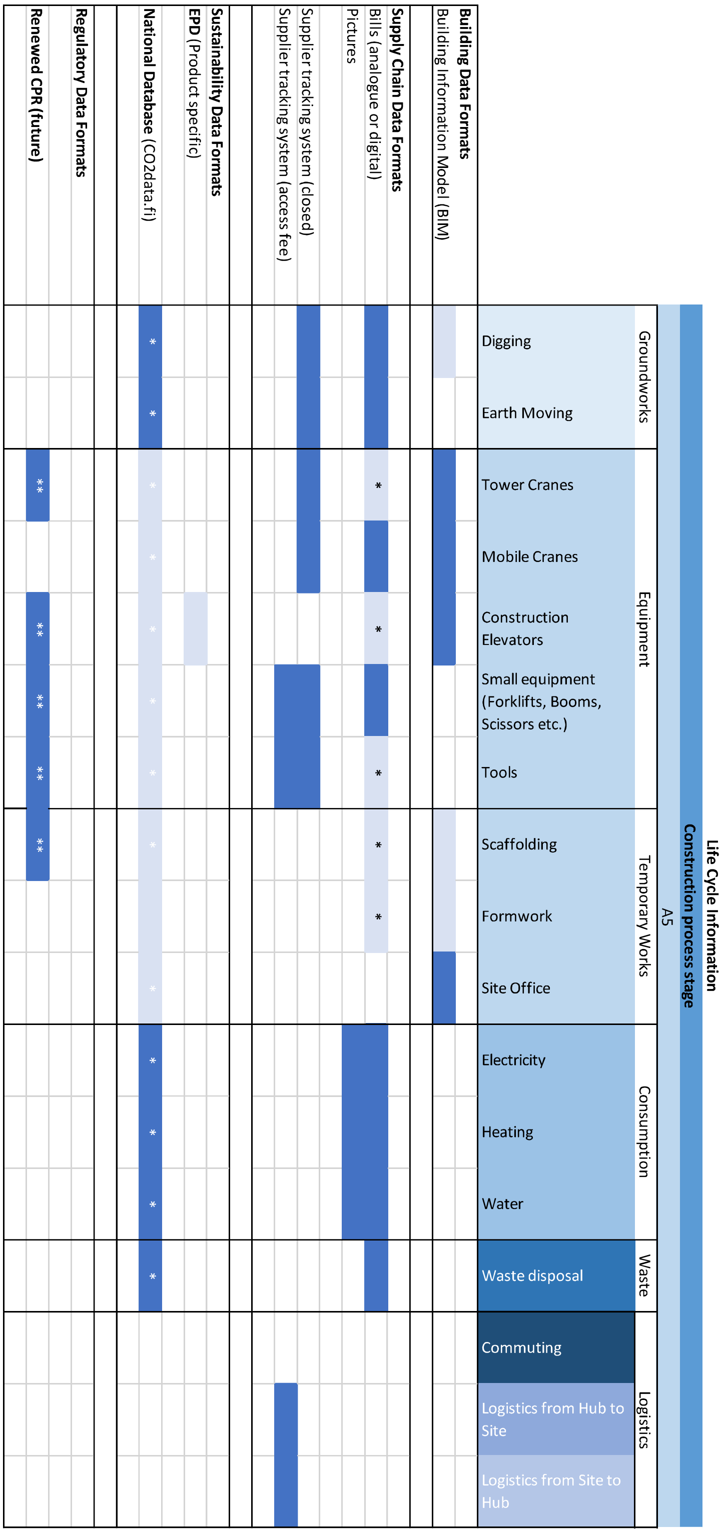

Figure 12: Data formats and their availability for site operations. A coloured block shows the probability that a particular data format is available for that operation. A light-faded block signals decreased likeliness of availability for that particular data format for that particular operation.

Building data formats

The (probability of) availability of building data varies for different site operations. For certain operation useful data may be available if these are not modelled as 'solids'. This could be the case for tower and mobile cranes, construction elevators, and the site office. For operations such as digging, scaffolding, and formwork, data may be available dependent on the level of detail of the model. For other operations it is not likely that data will currently be available.

Supply Chain data formats
Bills in either an analogue or digital (machine-readable) format may be available for groundworks, mobile cranes, and small equipment (if these are rented), as well as consumption data for electricity, heating, water use, and waste disposal, as all of these items are billed based on consumption. This may to a lesser extent also be true for tower cranes, construction elevators, (rented) tools, scaffolding and or formwork. But in the latter category data is most likely to be proxy data (i.e. denoted in another quantity unit that would be a useful unit for emissions calculations). All of the bills are not likely to include emissions data as-is. For the consumption of electricity, heating, and water also pictures might be available if the construction site does not have a separate connection for these services.

Diggers and earth moving equipment may be equipped with digital beacons, and tower- and mobile cranes, as well as small equipment and tools with sensors that send usage data to the supplier of the equipment. To the knowledge of the authors this data is closed off and not accessible for third parties, except for certain types of small rental equipment and tools where this data is commercially offered. The same holds true for certain software solutions connected to logistics hubs. In the last two cases, even emissions data may already be included. This is less likely for the closed supplier tracking systems mentioned earlier.

Sustainability data formats
EPDs are not likely to be available for site operations. Except perhaps for construction elevators in case these are based on the final to be delivered elevators. As there might be EPDs available for the finished elevators.

Proxy data from the national database may be found for the groundwork, consumption, and waste data. In terms of equipment and temporary work, it might be possible to find proxy data.

Regulatory data formats
Based on the draft of the new CPR, it may be expected that emissions data will be available for tower cranes, construction elevators, small equipment, tools and scaffolding, as these need to be CE-marked under the current CPR.

7. Conclusions

This report stated in the introduction that linking digital construction product data with sustainability data could provide an overview of as-built emissions data but requires the integration of different data types from different domains on different abstraction levels. After analyses of the data types, formats, sources and their applicability and availability in the construction domain, this hypothesis has been confirmed.

Although sustainability standards exist, key emission data sources and formats (such as EPDs and national databases) are likely to continue operating under parallel definitions and standards for several years. These include industry-level standards that are not fully international and national data definitions. The major advancement in managing sustainability data of construction products would be based on Digital Product Passports (DPP) required by the new CPR. However, CPR final implementation is foreseen in 2040, but the required standardized digital data definitions and data sharing methods of DPPs will be developed in the coming years.

The construction industry will need to find a temporary solution to track as-built emissions data. However, the availability of data types differs between product groups and there is not one clear data type which may be used across modules A1-A5 for all different construction product types. A combination of eFTI and Peppol may provide information for modules A1-A4 across product types, provided that related emissions data could be linked to these data formats. Please note however, that eFTi and Peppol are standards to be implemented. For site operations in module A5, it is more likely that a combination of different data types will be needed for a complete picture of as-built emissions.

Further research should therefore focus on identifying the technical capabilities of linking different kinds of data for site operations and develop a framework to retrieve relevant as-built emissions data for the four product types from EPDs, national databases, and supply-chain data formats.

References

10.6.2022/423 Ilmastolaki (2022). https://www.finlex.fi/fi/laki/ajantasa/2022/20220423

Ahmed, N., Abdel-Hamid, M., Abd El-Razik, M.M. & El-Dash, K.M. (2020). Impact of sustainable design in the construction sector on climate change. Ain Shams Engineering Journal, Faculty of Engineering, Ain Shams University, 12(2), 1375–1383. DOI: 10.1016/j.asej.2020.11.002.

Alderson, W. (1957). Marketing Efficiency and the Principle of Postponement. Marketing Behavior and Executive Action (1957), 423-427.

Bilec, M., Ries, R., Scott Matthews, H., & Sharrard, A.L. (2006). Example of a Hybrid Life-Cycle Assessment of Construction Processes. Journal of Infrastructure Systems 12(4). https://doi.org/10.1061/(ASCE)1076-0342(2006)12:4(207)

De Wolf, C., Iuorio, O., & Ochsendorf, J. (2014). Structural Material Quantities And Embodied Carbon Coefficients: Challenges And Opportunities. In: Griffin, C. & Mollner, J., (eds.). Proceedings of the 5th Annual School of Architecture Symposium - Sustainable Structures: The Intersections of Structural Systems and Green Buildings, 16-18 Apr 2014, Portland State University, Portland, OR, USA. School of Architecture, Portland State University, 309-328. ISBN 978-0-9718903-1-2.EUR 24708

Damiani, M., Ferrara, N., & Ardente, F. (2022). Understanding Product Environmental Footprint and Organisation Environmental Footprint methods. Luxembourg: Office of the European Union. doi:10.2760/11564, JRC129907.

Durão, V., Dinis Silvestre, J., Mateus, R., & De Brito, J. (2020). Assessment and communication of the environmental performance of construction products in Europe: Comparison between PEF and EN 15804 compliant EPD schemes. Resources, Conservation and Recycling, 156, 104703. DOI: https://doi.org/10.1016/j.resconrec.2020.104703.

eFTI (2024). About Electronic Freight Transport Information (eFTI). Retrieved 18.09.2024, through: https://efti.fi/en/about-electronic-freight-transport-information-efti.

EPD Data Format – Developer Quick Start Guide in Developer Documentation ILCD+EPD v1.2 MR5, https://www.indata.network/resources [Accessed 2 Jan 2023].

EPD - ENVIRONMENTAL PRODUCT DECLARATIONS [online]. The International EPD® System. Available from: https://www.datocms-assets.com/37502/1608730947-introducingepd2017englishweb-1.pdf [Accessed 29 Jun 2022].

EUR 28251 EN, Fazio, S., Kusche, O., Zampori, L., European Commission, and Joint Research Centre, 2016. Life Cycle Data Network — Handbook for data developers and providers [online]. Version 2.0. Publications Office of the European Union. Available from: https://eplca.jrc.ec.europa.eu/permalink/JRC104371_lb-na-28251-en-c.pdf [Accessed 1 Jun 2022].

EUR 24710 EN, European Commission, Joint Research Centre and Institute for Environment and Sustainability, 2010. International Reference Life Cycle Data System (ILCD) Handbook - Review schemes for Life Cycle Assessment (LCA) [online]. First edition. Luxembourg: Publications Office of the European Union. Available from: https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-Review-schemes-LCA-online-March2010-ISBN-fin-v1.0-EN.pdf [Accessed 2 Jun 2022].

EUR-Lex-32020R1056 (2020). Regulation (EU) 2020/1056 of the European Parliament and of the Council of 15 July 2020 on electronic freight transport information. Retrieved 18.09.2024, through: https://eur-lex.europa.eu/eli/reg/2020/1056/oj.

EUR-Lex-32022L2464 (2022). Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting. Retrieved 16.11.2023, from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32022L2464

European Commission, Joint Research Centre and Institute for Environment and Sustainability, 2010. International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance [online]. First edition. Luxembourg: Publications Office of the European Union. Available from: https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-General-guide-for-LCA-DETAILED-GUIDANCE-12March2010-ISBN-fin-v1.0-EN.pdf [Accessed 2 Jun 2022].

European Commission (2016). Green Public Procurement Criteria and Requirements. Https://Green-Business.Ec.Europa.Eu/Green-Public-Procurement/Gpp-Criteria-and-Requirements_en.

European Commission (2020a). Taxonomy Regulation - 2020/852/EU. EU Taxonomy for Sustainable Activities. https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en

European Commission (2020b). How does Level(s) work? Https://Environment.Ec.Europa.Eu/Topics/Circular-Economy/Levels/Lets-Meet-Levels/How-Does-Levels-Work_en.

European Commission. (2023). Revised Energy Performance of Buildings Directive. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en#revised-energy-performance-of-buildings-directive

European Parliament and the Council (2024). Regulation (EU) 2024/3110 of the European Parliament and of the Council of 27 November 2024 laying down harmonised rules for the marketing of construction products and repealing Regulation (EU) No 305/2011. http://data.europa.eu/eli/reg/2024/3110/oj

European Climate Law, Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law') (2021). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119

Eurostat (2023). Number of persons employed by enterprise size class, 2019. Retrieved 16.11.2023, from: https://ec.europa.eu/eurostat/cache/infographs/sbs_2022/?s=F.

Fenner, A.E., Kibert, C.J., Woo, J., Morque, S., Razkenari, M., Hakim, H., & Lu, X. (2018). The carbon footprint of buildings: A review of methodologies and applications. Renewable and Sustainable Energy Reviews, 94, 1142-1152. https://doi.org/10.1016/j.rser.2018.07.012

Fufa, S.M., Wiik, M.K., & Andressen, I. (2019). Estimated and Actual Construction Inventory Data in Embodied Greenhouse Gas Emission Calculations for a Norwegian Zero Emission Building (ZEB) Construction Site. In: Kaparaju, P., Howlett, R., Littlewood, J., Ekanyake, C., & Vlacic, L. (eds). Sustainability in Energy and Buildings 2018. KES-SEB 2018. Smart Innovation, Systems and Technologies, vol 131. Springer, Cham. https://doi.org/10.1007/978-3-030-04293-6_14

GHG Protocol, 2024. FAQ. Retrieved 18.09.2024, through: https://ghgprotocol.org/corporate-standard-frequently-asked-questions.

Hendrickson, C., & Horvath, A. (2000). Resource use and environmental emissions of U.S. construction sectors. Journal of Construction Engineering and Management, 126(1), 38-44. DOI: 10.1061/(ASCE)0733-9364(2000)126:1(38).

International Energy Agency IEA. (2019). 2019 Global Status Report for Buildings and Construction - Towards a zero-emissions, efficient and resilient buildings and construction sector. International Energy Agency.

Kanafani, K., Magnes, J., Munch Lindhard, S., & Balouktsi, M. (2023). Carbon Emissions during the Building Construction Phase: A Comprehensive Case Study of Construction Sites in Denmark. Sustainability, 15(14), 10992. https://doi.org/10.3390/su151410992

Kiamili, C., Hollberg, A., Habert, G. (2020). Detailed Assessment of Embodied Carbon of HVAC Systems for a New Office Building Based on BIM. Sustainability, 12, 3372. https://doi.org/10.3390/su12083372

Kuittinen, M., & Häkkinen, T. (2020). Reduced carbon footprints of buildings: new Finnish standards and assessments. Buildings and Cities, 1(1), 182-197.

Lampel, J., & Mintzberg, H. (1996). Customizing Customization. Sloan Management Review 38(1), 21-30.

Lavikka, R., Vainio-Kaila, T., Kiviniemi, M., Ala-Kotila, P., Kouhia, M., & Nyholm, C. (2023). The Operating Environment of Building LCA and BIM in the Nordics and Estonia. Nordic Innovation. http://dx.doi.org/10.6027/nord2023-463.

Malabi Eberhardt, L.C., Rønholt, J., Birkved, M., & Birgisdotter, H. (2021). Circular Economy potential within the building stock - Mapping the embodied greenhouse gas emissions of four Danish examples. Journal of Building Engineering 33, 101845. https://doi.org/10.1016/j.jobe.2020.101845

Malabi Eberhardt, L. C., Kuittinen, M., Häkkinen, T., Moinel, C., Nibel, S., & Birgisdottir, H. (2023). Carbon handprint – a review of potential climate benefits of buildings. Building Research & Information, 1–16. https://doi.org/10.1080/09613218.2023.2266020

Momblanco, H., Aiuto, K., & Huckins, S. (2024). Overview of GHG Protocol Integration in Regulatory Climate Disclosure Rules. Retrieved 18.09.2024, through: https://ghgprotocol.org/sites/default/files/2024-03/GHG-Protocol-Integration.pdf.

Naim, M., Naylor, J., & Barlow, J. (1999). Developing Lean and Agile Supply Chains in the UK Housebuilding Industry, 7th Annual Conference of the International Group for Lean Construction, 159-170.

O'Brien, W.J., London, K., & Vrijhoef, R. (2002). Construction Supply Chain Modeling - A Research Review and Interdisciplinary Research Agenda, 10th Annual Conference of the International Group for Lean Construction.

O'Brien, W.J., Formoso, C.T., Vrijhoef, R., & London, K. (Eds.) (2008). Construction Supply Chain Management Handbook. Boca Raton: Taylor & Francis Group. DOI: https://doi.org/10.1201/9781420047462

Rinne, R., Ilgın, H.E., and Karjalainen, M., 2022. Comparative Study on Life-Cycle Assessment and Carbon Footprint of Hybrid, Concrete and Timber Apartment Buildings in Finland. International Journal of Environmental Research and Public Health, 19 (2).

Röck, M., Allacker, K., Auinger, M., Balouktsi, M., Birgisdottir, H., Fields, M., Frischknecht, R., Habert, G., Hvid Horup Sørensen, L., Kuittinen, M., Le Den, X., Lynge, K., Muller, A., Nibel, S., Passer, A., Piton, F., Rasmussen, F.N., Ruschi Mendes Saade, M., Alaux, N., Satola, D., Sørensen, A., Spitsbaard, M., Tikka, S., Tozan, B., Truger, B., Van Leeuwen, M., Vesson, M., Viitala, A., Zonnevijlle, R., & Lützkendorf, T. (2022). Towards indicative baseline and decarbonization pathways for embodied life cycle GHG emissions of buildings across Europe. IOP Conf. Series: Earth and Environmental Science 1078, 012055. doi:10.1088/1755-1315/1078/1/012055.

Sezer, A.A. and Fredriksson, A., 2021. Environmental impact of construction transport and the effects of building certification schemes. Resources, Conservation and Recycling, 172.

SFS-EN ISO 12006-2, 2020. Building construction. Organization of information about construction works. Part 2: Framework for classification. Finnish Standards Association SFS.

SFS-EN ISO 12006-3, 2022. Building construction. Organization of information about construction works. Part 3: Framework for object- oriented information. Finnish Standards Association SFS.

SFS-EN 15804:2012 + A2:2019, 2019. Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products. 3rd ed. Finnish Standards Association SFS.

SFS-EN ISO 22057, 2022. Sustainability in buildings and civil engineering works. Data templates for the use of environmental product declarations (EPDs) for construction products in building information modelling (BIM). Finnish Standards Association SFS.

ISO/DIS 23387, 2024 (en). Building information modelling (BIM). Data templates for objects used in the life cycle of assets. Concepts and principles. The International Organization for Standardization.

SFS-EN 61360-2, 2013. STANDARD DATA ELEMENT TYPES WITH ASSOCIATED CLASSIFICATION SCHEME FOR ELECTRIC COMPONENTS - PART 2: EXPRESS DICTIONARY SCHEMA. Finnish Standards Association SFS.

Säynäjoki, A., Heinonen, J., Junnonen, J.M., & Junnila, S. (2017). Input–output and process LCAs in the building sector: are the results compatible with each other? Carbon Management, 8(2), 155-166. https://doi.org/10.1080/17583004.2017.1309200.

Valtiokonttori (2024). Real-time economy. Retrieved 18.09.2024, through: https://www.valtiokonttori.fi/en/services/services-for-the-economy-of-municipalities-and-well-being-areas/real-time-economy/#procurement-communication.

Viola, J. (2012). Derivation of reliable simplification strategies for the comparative LCA of individual and “typical” newly built Swiss apartment buildings. ETH Zurich: Diss. No. 20608.

Von Malmborg, F., Rohdin, P., & Wihlborg, E. (2023). Climate declarations for buildings as a new policy instrument in Sweden: a multiple streams perspective. Building Research and Information. https://doi.org/10.1080/09613218.2023.2222320

Yang, B., Burns, M.D., & Backhouse, C.J. (2004). Postponement: a review and an integrated framework. International Journal of Operations & Production Management 24(5), 468-487. DOI: 10.1108/01443570410532542.

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Tietueiden seuranta

Tila: Alkuperäinen 29 joulukuuta 2025 | 13:42	Haltija: Jessica Vepsäläinen Jessica.Vepsalainen@vtt.fi	Sijainti: DocuSign

Allekirjoittajan tapahtumat	Allekirjoitus	Aikaleima
Rita Lavikka rita.lavikka@vtt.fi Research Team Leader Suojaustaso: Sähköposti, Tilin todennus (ei mitään), Todennus **Todennustiedot** SMS-todennus: Tapahtuma: 6f5e7391-aa7e-44c5-a6ba-36b71bfd4207 Tulos: onnistui Myyjän tunnus: TeleSign Tyyppi: SMSAuth Suoritettu: 30 joulukuuta 2025 | 08:30 Puhelin: +358 50 3841662 **Sähköistä tietuetta ja allekirjoitusta koskeva ilmoitus:** Ei tarjottu Docusignin kautta		Lähetetty: 29 joulukuuta 2025 | 13:49 Tarkasteltu: 30 joulukuuta 2025 | 08:30

Henkilökohtaisen allekirjoittajan tapahtumat	Allekirjoitus	Aikaleima

Muokkaajan toimitustapahtumat	Tila	Aikaleima

Edustajan toimitustapahtumat	Tila	Aikaleima

Välittäjän toimitustapahtumat	Tila	Aikaleima

Sertifioidut toimitustapahtumat	Tila	Aikaleima

Kopiotapahtumat	Tila	Aikaleima

Todistustapahtumat	Allekirjoitus	Aikaleima

Notaaritapahtumat	Allekirjoitus	Aikaleima

Kirjekuoren yhteenvetotapahtumat	Tila	Aikaleimat
Kirjekuori lähetetty	Hajautettu/salattu	29 joulukuuta 2025 | 13:49
Sertifioitu toimitetuksi	Turvatarkastettu	30 joulukuuta 2025 | 08:30

Maksutapahtumat	Tila	Aikaleimat