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Digitalization and verifiability strategy for sustainability management of transports in the construction sector

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RISE rapport 2024:17

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RISE Research Institutes of Sweden AB

RISE rapport 2024:17
ISBN 978-91-89896-62-8

Content

Preface

This report is produced as part of the FEDeRATED project Living Lab 22: Electronic Business Standard of the Construction Industry – The Swedish Transport Administration's Energy Management System for Facilities (BEAst – ELSA). This report presents a digitalization and verifiability strategy for the sustainability management of transports in the construction sector, based on the pilots in Living Lab 22.

RISE's work in the project consists of analyzing how BEAST can be adapted to ISO 14033 information management structure, based on the data reporting and use of the BEAST system. The results of this will also be taken forward based on the conclusions:

If the adaptability between BEAST and ISO 14033 proves to be high enough, RISE will describe how BEAST can be used to produce verifiable data according to ISO 14033.

If the comparison shows significant deviations between BEAST and ISO 14033, RISE will focus on proposing adaptations of the BEST system or its application in order for it to be able to follow the process structure in accordance with ISO 14033.

The emphasis of Living Lab 22 is to establish a common future path for the applicable semantics and data exchange mechanism regarding environmental data for construction and maintenance works for road and rail infrastructure. Many initiatives exist which may create a rather fragmented situation. Conversely, an electronic message standard for construction, rental, and building business information exchange, BEAst, was identified as the most appropriate standard to be used for data exchange between various data platforms. BEAst is developed as part of the digital system ELSA, developed by the Swedish Transport Administration for internal use. ELSA is designed in parallel with BEAst, to monitor operational energy and materials flows, due to contract works, starting with greenhouse gas emissions from fuel combustions form transport excavated soil masses. ELSA intends to reduce environmental impact and optimize resource efficiency by utilizing the information quality available through the digital message standard. The standard also has a paramount potential for reducing administration costs and improving communication on project progress and the economy.

Summary

The construction sector is under a strong transformation, partly due to accelerating digitalization, and partly due to an increase in sustainability requirements. The drivers of digitalization are increased productivity, efficiency, and quality, whereas the requirements on sustainability performance are related to many external forces impacting the sector, such as stricter regulations on the verifiability of claims concerning resource efficiency, emissions, and waste management. In particular, the transport actors within the construction sector need a strategy to digitalize all their sustainability information. This report approaches this issue by integrating the BEAst (PEPPOL) standard for the construction sector's data exchange with the ISO standard ISO 14033 for controlling the verifiability of quantitative sustainability information. The report shows how standards-based requirements on data exchange to and from all construction transport actors and stakeholders enable digitalization and data flows in a cost-efficient way and with short lead time to reduce administration, facilitate follow-up, enable traceability and verifiability, efficiency, and goal fulfillment combining societal and environmental benefits.

1 Introduction

In transport, the traditional role of public authorities was to provide the development, building, and maintenance of the physical infrastructure and to foster the safety of traffic, which later was elaborated by various sustainability criteria. Due to the substantial increase in freight transport, which leads to significant congestion problems, and the emerging role of IT, public authorities have obtained responsibility for virtual infrastructure development.

Supply chain business interoperability increasingly depends on seamless data interconnectivity. This has caused new collaboration concepts, platform development, and different roles of traditional logistics operators, including public authorities. Digitized services are fostered to pursue smart mobility solutions leading toward the next level of customer integration into the supply chain (supply chain excellence). The effective exchange of data, including the proliferation of data requirements by various service providers, has become a major management concern and challenge for both the public and private domains. Digital infrastructure can solve current bottlenecks in the physical world. This paper presents a standards-based strategic digitalization process for the transport sustainability data of large-scale construction projects, which is intended for the different parts of strategic digitalization processes of the sustainability management of construction project transports, such as:

- when assessing the overall scope of a future or existing information system;
- when appraising the potential values of available or planned data sources;
- when analyzing existing information systems for potential or compatibility;
- when planning to procure new total information systems;
- to outline information system architectures;
- to reduce misunderstanding during designs of information system design;
- to assess complexity and costs during system constructions and extensions.

The process and methodology are designed to link all relevant sustainability-related, categorical, and measurable entities of construction project transports, such as types of vehicles and energy sources to individual loads of building materials, as well as any relevant geo-fencing data.

Essentially, the process is based on two standards, ISO 14033 Environmental management – Quantitative environmental information – Guidelines and examples (ISO 14033, 2019) and BEAst standard (BEAst, 2023). ISO 14033 includes two different graphical modeling languages to enable verifiable information. The first (Figure 3) describes how some measurable quantity via measurement and data management becomes meaningful information, or conversely, how to produce measurement data to obtain meaningful information. The second (Figure 4) describes how different levels of already meaningful information are combined into new meaningful information, or conversely, how to find which information needs to be combined to obtain some specific meaningful information. BEAst is of interest since it focuses on an open data exchange format, which is fully specified and machine-readable and, hence can be communicated effectively and efficiently between different actors in the construction sector in general. Consequently, it also facilitates data exchange between actors in a construction project.

It is worth noting that the paper does not provide technically detailed support for specifying, for example, the choice of quantities to measure, data formats, technical solutions, or the choice of supplier. Instead, the model language aims to facilitate a common overview of visions, plans, and proposals for information systems. The purpose of mapping the status, needs, opportunities, and risks of a producing organization's digitalization is to enable a relevant level of digitalization that is a vision, a distant and moving goal, which depends on a variety of factors, such as how many different parameters govern efficiency, quality, work environment and sustainability in production, technically and economically existing opportunities, legal requirements, customer requirements, competition, etc.

2 Background

2.1 Sustainable development of transport in the construction sector

Transport in the construction sector accounts for a significant part of the climate impact of the construction process (Fredriksson et al., (2022)). Thus, modern solutions for managing the sustainability performance of transports are needed. The sustainable development of transport in the construction sector can involve adopting practices and implementing strategies that minimize environmental impacts, promote efficiency, and enhance social and economic well-being. Here is the summary of some key methods that can help to achieve more sustainable development in transport within the construction sector:

1. ***Green Transport Modes:***

a. Electrification: transitioning to electric or hybrid vehicles within the construction fleet helps reduce greenhouse gas emissions and air pollution, especially when coupled with renewable energy sources for charging infrastructure.

There are three major concepts of Electric Road Systems (ERS): a) conductive overhead lines/catenary technology, b) conductive rails, and c) wireless induction technologies that are currently in different stages of demonstration in Sweden as well as abroad.

a) Conductive overhead lines/catenary technology builds on the same idea as the railway, with roadside support masts to hold contact cables about 5 meters above the road (f3 Innovation Cluster for Sustainable Biofuels, 2021). Trucks or buses with pantographs mounted on the roof will be able to connect to the overhead lines and charge conductively while driving. The difference from trolleybuses is that vehicles can connect to the lines while in motion and likewise disconnect if for instance having to change lanes. Overhead transmission is the most developed solution today and has no direct impact on road construction, which leads to easier maintenance of both transmission and road network. However, it requires extra infrastructure, i.e., the support masts that visually impact the landscape (Halldén, 2022). This solution is only suitable for heavy traffic and scheduled traffic but not for example for passenger vehicles.

b) Conductive rails are the technology solution that can be installed on the road surface, bolted upon the surface, or at the side of the road (f3 Innovation Cluster for Sustainable

Biofuels, 2021). This technology can be used for heavy-duty and distribution trucks as well as for passenger vehicles. In comparison with the catenary technology, conductive rails do not visually impact the landscape. However, maintenance of the line and road becomes more complicated, and the risk of injury to people and animals is greater with this type of line technology (Halldén, 2022).

c) Wireless induction is the most mobile solution since the vehicle and the road create contact via magnetic radiation instead of physical contact. Copper coils are installed underneath a surface layer of asphalt. Wireless induction technology is totally embedded within the road construction, with the visible impact being electrical distribution boxes/boards that are regularly placed along the roadside road (f3 Innovation Cluster for Sustainable Biofuels, 2021). There are many advantages of such technology, e.g., regular road maintenance and operations (e.g., snow ploughing, or preventive anti-icing) will not be affected by or harm the technology itself. However, there are concerns about risks for people around magnetic radiation (Kloo & Larsson, 2019).

b. Choice of fuel: increase the use of fossil-free fuel.

The report written by Kloo & Larsson (2019) presents the analysis of today's technologies/fuels (hydrogenated vegetable oil (HVO), hydrogen/ fuel cells and battery) and future goals for heavy goods transport. Nowadays, diesel fuel is used to the greatest extent in goods transport. Since the majority of all diesel vehicles can be fueled with biodiesel, existing vehicles and distribution can be used. Today's diesel is mixed with HVO in a concentration between 30 and 50%, but there is also pure HVO available (so-called HVO 100). For further development, more actors and research against other types of extraction materials are needed, including waste and other cellulose raw materials that are not based on crops (Kloo & Larsson, 2019).

Biogas in the gaseous form of compressed biogas (CGB) is not fully compatible with engines in heavier traffic, the efficiency of CBG is lower and today's engines have to be modified. Biogas can also be used in liquid form (i.e., liquefied biogas, LBG), which is compatible with diesel cars, but this technology requires more expensive and more advanced technology for storage and distribution (Kloo & Larsson, 2019). Both CGB and LGB can be used for scheduled traffic, transport and passenger traffic, biogas in gaseous form is not suitable for long-distance transport as the energy density is lower and affects the range.

Fuel cell-powered vehicles that run on hydrogen is still in the research stage. The research development is progressing rapidly, but it has not taken the same pace as the development of battery operation (Climate Policy Council, 2019). At the same time, hydrogen is seen as one of the fuels of the future. When using hydrogen, electricity, water vapor and heat are formed, which is classified as emission-free, however, the environmental classification depends on the production of hydrogen (Halldén, 2022). Nowadays, it is more common to be produce hydrogen via natural gas, which cannot be classified as emission-free (Kloo & Larsson, 2019).

With the transition to an electrified vehicle fleet, batteries are crucial in the deployment of zero-emission mobility and intermittent renewable energy storage, and in the EU's transition to a climate-neutral economy (European Commission, 2020; European Parliament and Council, 2006). The number of electric vehicles (EVs) is increasing every year in Sweden. In 2021, a total of 57,469 electric cars, 22,196 electric hybrids, and 77,847 plug-in hybrids were registered. By comparison, in 2016, 2,775 electric cars, 13,501 electric hybrids, and 9,816 plug-in hybrids were registered (Mobility Sweden, 2023). The technology for battery vehicles is the most environmentally smart choice as the vehicles are emission-free during the operating phase and create less noise compared to fossil-powered ones (Kloo & Larsson, 2019). However, as the battery capacity and charging options are not sufficiently developed, it makes longer transports more difficult (Halldén, 2022). Therefore, the possibility of hybrid solutions to create a cleaner urban environment via electricity and the possibility of using hydrogen, HVO, or other hybrid solutions for longer distances sound more relevant at the current stage (ibid).

2. *Efficient Logistics and Operations:*

a. Route Optimization: utilize digital tools like route planning software, GPS tracking, and real-time traffic information to optimize transportation routes, minimizing travel distance, fuel consumption, and associated emissions.

b. Consolidation and Collaboration: promote collaboration between construction companies to consolidate transport activities and share resources, reducing the number of trips, optimizing vehicle load capacity, and minimizing overall environmental impact.

c. Efficient Vehicle Use: maintain and upgrade construction vehicles and equipment to ensure optimal performance and fuel efficiency. Regular maintenance, eco-driving training for operators, and proper load management can contribute to reducing energy consumption and emissions.

For example, Bergman (2016) claims that with good construction logistics, the number of transports to and from a construction site can be reduced by 60 – 80% when building houses. Fredriksson et al., (2022) also describe that by coordinating transport between different construction sites and increasing the use of fossil-free fuel, the goal of net zero emissions can be approached. This can be done through coordinated orders and that the transport never leaves the construction site with an empty trailer. Colicchia et al., (2013) describe measures and logistics solutions such as planning programs, speed limits, and reduced idling.

There is a large variety of fossil-free machines on the market today, such as a hydrogen-powered excavator by JCB, Volvo battery-powered machines, including loaders and excavators, and a hydrogen-powered dump truck, the first of its kind in the world, etc. (Halldén, 2022). The European branch organization ACEA, together with Volvo, Scania, Daimler, Man, Daf, Iveco, and Ford, has taken a joint decision that commercial transport must be fossil-free by 2050 at the latest (ibid). Together, through the decision, they must find the best technology to reduce fossil use and develop the technology for fossil-free operation going forward (ACEA, 2020).

3. *Materials Management:*

a. Sustainable Material Selection: choose environmentally friendly and locally sourced construction materials to reduce the carbon footprint associated with transportation. Opt for materials with lower embodied energy and consider alternatives such as recycled or reclaimed materials.

b. Waste Reduction and Recycling: implement waste management strategies that prioritize waste reduction, reuse, and recycling on construction sites. This minimizes the need for waste transportation and disposal, conserves resources, and reduces environmental impact.

To reduce the volume of waste on the construction site and increase the amount of waste per transport from the work site, Colicchia et al., (2013) mention the use of compactors to compress the waste on site to reduce its volume. In this way waste transport can be minimized and the amount of waste per transport can increase (Halldén, 2022). With the help of a compactor, the volume of the waste can be reduced by approximately 70 to 90% (ibid).

4. *Stakeholder Collaboration:*

a. Engage Local Communities: involve local communities in the decision-making processes related to transport and construction projects. Address their concerns, provide alternative transportation solutions during construction, and strive for community benefits.

b. Collaboration with Authorities: collaborate with local authorities, transportation agencies, and regulatory bodies to ensure compliance with environmental regulations and foster sustainable transport practices. Participate in relevant initiatives and partnerships for knowledge sharing and coordinated efforts.

Construction sites can benefit from a third-party actor who manages the construction logistics. For example, a third-party logistician can take care of the construction site's machine and material planning, including, among other things, storage of materials and waste, in and deliveries from the construction site, machines, orders, and planning (Oskarsson et al., 2013; Halldén, 2022).

5. *Monitoring and Evaluation:*

a. Data Collection and Analysis: implement systems for collecting and analyzing transport-related data, such as fuel consumption, emissions, vehicle performance, and logistics operations. This data can help identify areas for improvement and measure progress towards sustainability goals.

b. Performance Indicators and Targets: establish key performance indicators (KPIs) and set targets for sustainable transport within construction projects. Regularly monitor and evaluate performance against these targets to track progress and identify areas for further improvement.

For example, Ciliberti et al., (2008) describe that ICT applications can analyze the choice of transport routes, optimal speeds depending on the vehicle and log idling runs. By adapting transport routes and speed according to road type, altitude levels and distances, speed can be optimized to reduce acceleration and braking. Through ICT, idling can also be registered and reduced for each vehicle (Halldén, 2022).

By adopting these methods, transport in the construction sector can contribute to sustainable development by reducing emissions, optimizing resource use, minimizing environmental impacts, and improving the overall efficiency and resilience of transportation systems.

2.2 Digitalisation in the construction sector

Digitalization plays an important role in promoting sustainable transport within the construction sector. By leveraging digital technologies, the sector can reduce its environmental footprint, enhance operational efficiency, and ensure compliance with sustainability goals. First digitalization strategies, which can help transportation achieve sustainable development in the construction sector, is *Artificial Intelligence* that is <system> capability to acquire, process, create and apply knowledge, held in the form of a model, to conduct one or more given tasks [ISO/IEC TR 24030:2021, 3.1]. AI can analyze traffic patterns, weather conditions, and other relevant data to optimize transportation routes, reducing fuel consumption and emissions. AI-powered predictive maintenance can monitor the condition of vehicles and construction machinery, enabling early detection of potential issues. This helps prevent breakdowns and reduces the need for frequent replacements, leading to lower resource consumption and waste. AI can also optimize the operations of construction equipment, such as cranes, excavators, and bulldozers, to minimize energy consumption while maintaining productivity. AI can analyze data on building materials and recommend sustainable alternatives with lower environmental impact. Additionally, AI can assist in optimizing material usage to minimize waste generation during construction. AI-powered sensors and monitoring systems can provide real-time data on construction sites, traffic conditions, and vehicle performance. However, it is essential to ensure that AI deployment is done ethically, responsibly, and with careful consideration of potential unintended consequences.

The next digitalization solution is *Building Information Modeling* (BIM), which is the use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions [ISO 19650-1:2018]. BIM can facilitate the optimization of transportation routes, materials management, and logistics, leading to reduced energy consumption and emissions. BIM also enables stakeholders to visualize and analyze various design options and scenarios for transportation infrastructure projects. This includes road layouts, bridges, tunnels, and other transportation elements. BIM allows for energy analysis and simulation, helping design teams optimize the energy performance of transportation-related structures. It can assess factors like lighting, HVAC systems, and material selection to create more energy-efficient buildings, transport hubs, and maintenance facilities. BIM can be integrated with IoT sensors and real-time monitoring systems to track the performance of transportation infrastructure. This data helps identify inefficiencies and areas for improvement, leading to better resource utilization and sustainability. By utilizing BIM in transportation-related construction projects, stakeholders can make informed decisions, optimize resources, and design infrastructure that aligns with sustainability goals.

Multi-Criteria Decision Making (MCDM) and *Geographical Information Systems* (GIS) are used to assist in urban road planning (Ouma et al., 2014). GIS is a computer system capable of assembling, storing (1) <placement>, manipulating, and displaying geographically referenced information, i.e., data identified according to their locations [ISO 23611-6:2012]. The *digital twin* (DT) concept can also provide a solution for road planning to digitalizing and interpreting the information in the physical world, including geometric and non-geometric information (Jiang et al., 2022). A digital twin is a digital replica of physical assets (physical twin), processes and systems that can be used for various purposes or a fit-for-purpose digital representation of something outside its own context with data connections that enable convergence between the physical and virtual states at an appropriate rate of synchronization [ISO 23704-1:2022]. Different sectors have applied digital twin to realize many applications e.g., manufacturing (Leng et al., 2021) and aerospace industry (Liu et al., 2021). Also, digital twin has been employed in the construction sector, specifically in the design, construction stage, and operation and maintenance stages (Jiang, et al., 2021), since it can assist in decision-making and designing (e.g., digital twin city) (Shahat et al., 2021) in complex and sustainable urban road planning considering various factors including sustainability development.

The Internet of Things (IoT) is an infrastructure of interconnected objects, people, systems, and information resources together with intelligent services to allow them to process information of the physical and the virtual world and to react [ISO/IEC 23093-1:2022]. IoT devices, such as sensors and telematics, can be deployed in vehicles, construction equipment, and infrastructure to collect real-time data on traffic flow, congestion, and vehicle movements. This data can be used to optimize transport routes, monitor fuel consumption, track vehicle maintenance, and promote efficient resource allocation. IoT-enabled devices can be installed in construction vehicles and transport fleets to monitor their performance, fuel efficiency, and maintenance needs. Fleet managers can use this data to optimize routes, reduce idle time, and schedule maintenance, leading to lower fuel consumption and emissions. IoT devices can be used to track the movement of construction materials from suppliers to the construction site. This helps optimize logistics, minimize material wastage, and improve the overall efficiency of the supply chain. IoT sensors can be employed in construction machinery and vehicles to monitor their health and detect potential maintenance issues in advance. By identifying and addressing problems early, the lifespan of equipment can be extended, reducing the need for replacements, and minimizing waste.

Universal traceability of material items needs to depend on less complex and much less costly solutions to even in principle aim to individualize every material item. Carlsson et al., (2017) describe the evolution of the *Internet of Materials* concept (IoM) following IoT. IoM is material items with digital identity and functionality, which utilizes computers and the internet for all computing, data storage, and sharing. A general structure of IoM includes the material item (e.g., metal component) with some individualized communication aspect (e.g., QR code etched into the metal, antenna with individual resonance frequency - RFID) that can be read by some aspect communicator, such as an optical reader that both captures the QR code and identifies the material item. A material item in the IoM concept only has its identity. It is linked with its digital twin through this identity. IoM has several benefits to IoT as the solution for universal traceability such as fewer costs, easier to implement, and more sustainable choice. Since IoM only requires identifiability by some data capturing technology, it is substantially cheaper to enable material items' identifiability during manufacture compared to using IoT. Often IoM requires no extra production cost for each material item. The efficiency of scale applies. The material items that make up the IoM do not require advanced technologies to be included with the material item. Compared with IoT which needs some energy source to operate, IoM-enabled material items only require energy when the item is created and when its data is requested, updated, or deleted. Such universal traceability and data sharing solutions can help to provide efficient and effective material logistics, effective remanufacturing, reuse, and recycling, connect different sustainable business models in a variety of industries, nationally and internationally, control of critical materials flows as well as quality control over the entire life cycle/several life cycles.

2.3 Regulations and legislation

The European Commission has developed a tool - *Level(s)* - to assess and report on sustainability aspects during the entire life of buildings. The aim is to provide a common language on sustainability and circularity in buildings aimed at the mainstream market. Level(s) is an easy entry point to sustainability assessment, especially for new build and renovation projects that currently consider such an assessment too complex and costly. It is essentially a step-by-step approach to LCA in buildings with a focus on enabling comparability, data availability and benchmarking. The Level(s) framework can assess buildings from the earliest stages of their conceptual design, all the way to their estimated service life. It is not a new stand-alone certification system for buildings, nor does it set performance benchmarks, but rather links the individual building's environmental impact to other priorities such as healthy and comfortable spaces, adaptation and resilience to climate change, and the whole life cycle cost and value of the building. Given the importance of and the long-term horizon for the EU's climate goals.

The European Commission has drawn up a policy roadmap to gradually mandate the use of Level(s) from a voluntary framework to, eventually, a standard requirement in buildings. Such a change, implemented by the EU Commission and its GD Environment, sees Life-Level(s) as the most important factor when it comes to promoting the values that Level(s) represent. Life-Level(s) was funded by the Life programme, and aims to adapt the most recognized European certification systems to the level criteria. In the coming period, the Life-Level(s) is also building on integrating national public procurement practices with Level(s) indicators.

Directive 2010/40/EU of the European Parliament and of the Council, adopted on 7th July 2010, is a legislative framework that aims to promote and facilitate the deployment of Intelligent Transport Systems (ITS) within the field of road transport and also aims to establish interfaces with other modes of transport. The Directive outlines measures to enhance transportation systems' efficiency, safety, and sustainability through the integration of advanced technologies and communication systems. It plays a significant role in shaping the future of transportation technology and infrastructure within the European Union.

The Directive seeks to ensure the interoperability and compatibility of ITS systems across EU Member States, allowing seamless communication and cooperation between different transportation modes and networks. It emphasizes the need for developing and adopting common technical standards for ITS to ensure consistent and efficient implementation throughout the European Union. The Directive encourages the sharing of relevant data among public and private stakeholders to improve transport services, traffic management, and safety. It addresses privacy concerns related to the collection and use of personal data in the context of ITS deployment, ensuring compliance with relevant data protection laws. The Directive identifies a set of priority services that should be deployed, including traffic and travel information, multimodal travel planning and ticketing, traffic management, and road safety-related services.

Regulation (EU) No 70/2012 of the European Parliament and of the Council, adopted on 18th January 2012, concerns statistical returns related to the carriage of goods by road within the European Union. The regulation establishes a framework to collect and compile statistical data on the movement of goods by road transport, aiming to facilitate the analysis and monitoring of road freight transport activities. It defines the scope of data to be collected, including information on goods transported, distance covered, type of vehicles used, and the countries of origin and destination. It sets out the frequency and format for data reporting. The regulation aims to harmonize data collection methodologies to ensure consistency and comparability of statistics across Member States. The statistical data collected under the regulation serves as a basis for the development and evaluation of policies related to road freight transport, such as infrastructure planning, environmental sustainability, and safety improvements.

Directive (EU) 2019/1161 of the European Parliament and of the Council, adopted on 20th June 2019, is an amendment to Directive 2009/33/EC with the aim of promoting the use of clean and energy-efficient road transport vehicles. The directive focuses on advancing the deployment of alternative fuel vehicles (AFVs) and encouraging the use of low-emission vehicles in public procurement of vehicles and transport services. The directive establishes provisions for the inclusion of environmental and energy performance criteria in the technical specifications for public procurement of road transport vehicles. It aims to ensure that public procurement processes consider the environmental impact and energy efficiency of vehicles.

EU Renewable Energy Directive (RED II) promotes the use of renewable energy in transport, including the construction sector (European Commission, 2023). It sets targets for the share of renewable energy in the transport sector and encourages the use of renewable fuels like biofuels, advanced biofuels, and renewable electricity.

CEAP is the Circular Economy Action Plan, in which the European Commission's summarized action plan describing how to act to reach a circular economy. A key is sharing of product and material information throughout supply chains to enable effective circularity and empower consumers and public buyers to make informed choices (European Commission COM(2020) 98) (European Commission, 2020). *DPP* (Digital Product Passport) is a part of the European Commission's Circular Economy Action Plan, where products are specifically required to have some key circularity and sustainability information digitally attached to the product (European Commission COM(2020) 98, sections 2.1 and 6.3) (European Commission, 2020)

CIRPASS is a Digital Europe Program (DIGITAL) project that develops a model and a pilot digital product passport (DPP) system for the electronics, batteries, and textiles sectors. The project is focused on the technical feasibility and support for circular economy strategies, stakeholder needs, economic viability, and guidance for the introduction of the circular economy. The DPP system will be gradually piloted and introduced (CIRPASS, 2022).

Proposal for a *Directive of the European Parliament and of the council on substantiation and communication of explicit environmental claims (Green Claims Directives*) aims to substantiate and present explicit environmental claims. The proposal also regulates environmental labels, which are defined as a type of environmental claim. According to the proposal, products that only meet legal requirements should not have the right to market any environmental benefits. It is welcomed and deemed to be an important starting point in the work to make sustainable products the norm. An important part is that environmental claims must be pre-checked by an accredited inspector before they can be used in marketing. In addition, the directive contains requirements for monitoring with subsequent sanctions for traders who violate the requirements. Regulating the widespread occurrence of false or unclear environmental claims and arbitrary or incorrect environmental labels is considered very important to strengthen consumer confidence in differences in the environmental performance of different products.

For example, in Sweden, there is an initiative called *Fossil Free Construction and the civil engineering sector (Fossilfritt Sverige, 2019)*. The Swedish government aims to promote fossil fuel-free construction sites by setting targets and implementing measures to reduce emissions. This includes changed composition of raw materials, electrification and efficiency improvements in production and transport processes, greater use of renewable fuels in production and transport processes, more efficient transport, planning for circular flows, and efficient use of resources as well as optimization of energy and climate performance from a lifecycle perspective, in the construction and operation phase (Fossilfritt Sverige, 2019). Overall targets in the roadmap are the following:

2022: Actors in the construction and civil engineering sectors have mapped their emissions and set climate targets.
2025: Greenhouse gas emissions demonstrate a declining trend.
2030: 50% reduction in greenhouse gas emissions (compared with 2015).
2040: 75% reduction in greenhouse gas emissions (compared with 2015).
2045: Net zero greenhouse gas emissions.

At the 31 July 2023 the European Commission announced the adoption of the Delegated Act on the first set of European Sustainability Reporting Standards (ESRS). It means that for the financial year of 2024 the requirements stated in the European Sustainability Reporting Standards (ESRS) will need to be adopted for all large organizations for reports published in 2025 (European Commission, 2022). This sets many new requirements for verifiably reporting a large number of sustainability parameters for the whole life cycle of an organization's business. Even though the requirement does not directly apply to SMEs, those will anyway need to provide the same type of information to enable their large customers to compile their reports. In addition, in March 2023 the European Commission released a proposal for a directive on the substantiation and communication of explicit environmental claims (Green Claims Directive) (European Commission, 2022). This proposal suggests strong regulation regarding the verifiability of any sustainability claims from organizations in general. This will likely include claims such as quantifications of carbon emissions from transport operations, utilization of energy-efficient logistics, or decent work conditions for people in the material handling sector.

2.4 Looking ahead

It has been shown how logistics information have positive effect of the use of ITS applications dedicated to vehicle support in road freight transport enterprises, improving the energy efficiency of transport and reducing the negative impact of transport on the natural environment, reducing transport time while increasing connectivity and logistics customer service (Kadlubek, 2022). The authors continue also with mentioning other significant areas assisted by ITS applications, such as the infrastructure of the road freight transport support, their policy management assistance, electromobility assistance, reducing exhaust emissions support, electric drives use, or energy use minimizing by road freight transport enterprises.

We may also expect much progress as the application of digital twins develops. Omrany (2023) predicts that digital twins have tremendous potential for enhancing supply chain management and logistics in the construction industry, but that they, due to a lack of uniformity in interfaces, protocols, and standards currently present a challenge. They predict that it becomes necessary to especially investigate interconnection theories and standards that can support heterogeneous multi-source domains.

Tong (2018) predicts that the value of ITS for the transportation sector implies that transportation engineers will be expected to have knowledge in areas such as information technology, communication science, computer algorithm, human factor safety engineering, public engagement, business and legal environments, and social media management and that standards organizations will have to work on setting up protocol architectures that are interchangeable, interoperable and expandable.

During 2023 an international standard for how to quantify and report greenhouse gas emissions from transport chain operations was published (ISO, 2023). This standard provides guidance both on how to calculate such emissions from individual vehicles, but also how to allocate different emissions onto the goods transported by transport chains. This standard may also provide good guidance for how to allocate impacts caused by for example particle emissions, noise, impacts on biodiversity or water, or even road safety not only to individual transport routes but to the goods being transported.

In addition, the EU requirements for sustainability reporting (European Commission, 2022) and for substantiation of sustainability claims (European Commission, 2023) mentioned in 2.3 both imply a need for an emphasis both on the digitalization of acquisition and compilation of sustainability data for goods transports in general and for the more complex construction project transports in particular.

3 An example from the sector

As NCC participates in one of the pilots in LL22 and has implemented much of the working method, we felt it was important to describe their case to get a picture of how far they have come.

In the process of digitizing and improving various parts of their operations, NCC has focused on implementing methods to verify deliveries and conducting receiving inspections.

This transformation has resulted in a more organized approach to managing contracts, workflows, and procurement processes. NCC now has the capability to validate information, exchange data, and generate reports for effective follow-up. For instance, it ensures compliance with sustainability requirements, aligns project execution with budgetary constraints, and optimizes supply chain management seamlessly.

Before NCC embarked on the digitalization process, they had an overview of what occurred between procurement and payment, but the process required a lot of administration. Now, with a digitalized system, the company can better track and monitor each step of the process, and the data collection requires much fewer administrative resources. NCC is introducing a digital receiving inspection to link deliveries to specific products or items via standardized article codes i.e. GTIN. This provides the company with improved traceability and the ability to follow up on each item with its associated characteristics and data, including environmental information.

A significant aspect of NCC's work is building a comprehensive article registry database that includes both physical products and generic items. This enables the company to connect purchases and usage, for instance using BIM models to identify where specific items are employed.

NCC has also focused on circular mass management and the handling of contaminated materials. By utilizing standards like BEAst (The Construction Industry's Electronic Business Standard, part of Peppol), the company can track the economic aspect of the business while concurrently incorporating sustainability data. NCC is also striving to enrich items with more detailed information to attain a more complete picture of sustainability aspects.

One of the major challenges identified by NCC is getting a broad group of individuals with specialized expertise to understand the tasks required in the subsequent chain. There is a need to improve the ability to see the big picture in order to leverage the more detailed information system that NCC is building up.

Regarding carbon dioxide emissions, NCC and the Swedish Transport Administration are working with templates to establish a solid starting point. They measure emissions per hour, per kilometer, and so forth. Together with subcontractors, they also work to reduce emissions through optimized driving behavior and loading, offering real-time transfers and advice. Transparent data gathering from all parties enables and facilitates the optimization and evaluation of entire projects and their impact and progress.

In the field of contracting, an information system based aided by, amongst other, QR codes and geofencing, automatically follows up on vehicle movements and ensures they pass through the correct locations and perform their tasks as planned. The data is shared transparently through the reports of Advanced Despatch Advice, making it easier for drivers to report their routes.

By using geofencing and heatmaps, NCC can visualize and analyze data to ensure that construction areas are properly configured and optimized. This reduces downtime and increases efficiency for all parties involved.

NCC has experienced positive outcomes in their pilot in FEDeRATED Lab22, working with the Swedish Transport Administration. The Transport Administration's internal support system, ELSA, receives and manages information from the BEAst electronic report (Advanced Despatch Advice). The company has automatically reported real-time registered excavation materials and vehicle carbon dioxide emissions to ELSA. This process provides verified data from the point of origin to reporting, which is beneficial for administrative costs and data quality.

4 Managing the sustainability performance of transport operations

Figure 1 shows examples of decision-makers that need to have access to up-to-date sustainability data throughout a construction project, specifically the following:

1. The management of the construction project holds the responsibility both for how the contracted transports carry out and for performance targets where the construction operations do not exceed construction emission or noise thresholds.
2. The logistics planning department is responsible for the establishment of operational plans for how the sustainability requirements can be met while at the same time achieving the objectives.
3. For the operational construction and logistics to realize the plans according to performance restrictions need to have guidance and feedback via available information systems.
4. Transport purchasers are responsible for establishing clear contracts with transport providers, with regards to thresholds and performance targets, but also with regards to how to report data and verify compliance, e.g., which data forms and formats to use.
5. Key stakeholders of the sustainability information are legislators and the customer of the resulting construction. The overall transport compliance with laws and regulations and the sustainability performance of the total construction are of significance to citizens and the brand value of the final owner.

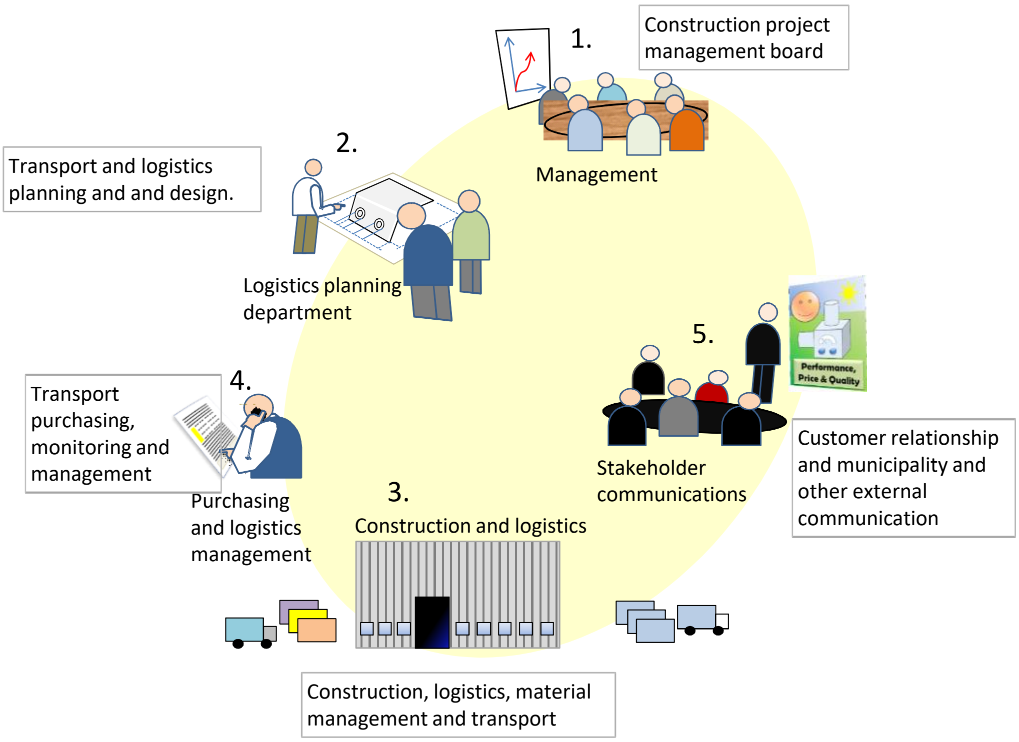

Fig. 1. Stakeholders of sustainability data [adapted from 3].

Taking into consideration that all decision makers throughout the construction project have many different contact points, transport occurrences, transport operators, etc. over a stretched period, it is a challenge to keep track of all communication channels, from requirement setters down to operations, and again back up to reporting and decision making and control, unless there is a well-operating information system connecting them all. This paper addresses that challenge.

Control system. Figure 2 shows a simplified overview of a control system, which is used here to present the aim for a well-designed digitalized management information system. The parts of the model are presented below.

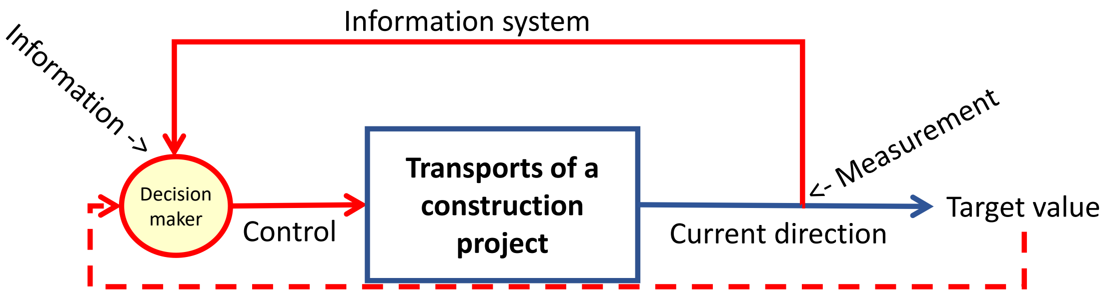

Fig. 2. The control system for a well-designed digitalized management information system for transports of a construction project.

Transports of a construction project that demonstrates all transports within the mandate of the management of a construction project. The 'box' may also represent any partial transport or segment of the route, depending on who is the decision maker.

Target value is a threshold value that does not exceed any other sustainability performance values.

Measurements made somewhere throughout the entire system of transport, such as goods, distances, emissions, fuel use, etc.

Current direction, i.e., current sustainability performance operates.

Information System, i.e., channeling information relevant to the decision maker.

Information that is acquired from the measurement of transports, is calculated and compiled to mediate meaningful information to decision maker(s).

Decision Maker: in this context, any of the five different decision-makers introduced in Figure 1.

Control is a mandated response from a decision maker intended to align the results in the system *Transports of a construction project* to the target.

Section 3 presents how a combination of the data format standard BEAst, and in particular BEAst Eco, and the ISO 14033 standard for acquiring and compiling the information may be used to establish the Information system in Figure 2 to coherently, flexibly, effectively, and efficiently provide relevant information to the decision makers exemplified in Figure 1.

4.1 Significance of data formats

Data formatting may best be described as a set of rules that specify where to put which data or information in a file or document. One example of a well-known type of data format is the bank account table, looking something like Table 1 below.

Table 1. Bank account (1).

Transactions	**Transaction date**	**Booking date**	**Amount**	**Total**
Price account	2023-01-06	2023-01-08	-75,00	392,89
Price service	2023-01-06	2023-01-08	-75,00	467,89
Rate	2022-12-31	2022-12-29	3,50	542,89
Transaction	2022-12-23	2022-12-27	-10 700,00	539,39

The title of the columns, in bold at the first row, specifies what type of information to enter into or read from the cells under that header. If this is not specified and if one is allowed to write any information in any of the fields, the data becomes pretty much useless. One may for example consider another bank account table, similarly meaningful but different, specifying another order of the columns of the table, like Table 2 below.

Table 2. Bank account (2).

Transactions date	Booking date	Transaction	Amount	Total
2023-01-06	2023-01-08	Price account	-75,00	392,89
2023-01-06	2023-01-08	Price service	-75,00	467,89
2022-12-31	2022-12-29	Rate	3,50	542,89
2022-12-23	2022-12-27	Transaction	-10 700,00	539,39

It is easy to see that the two tables contain the same information and that it is just arranged in another order. However, if the columns were not specified with where to find which information the translation between them would not have been obvious.

Table 3 represents yet a third way to look at the same information, but where the rightmost column now includes other information. It is easy to see that the information is related, but the column does not give the same information as in Tables 1 and 2.

Table 3. Bank account (3).

Transactions	Transaction date	Booking date	Amount	Aggregated transactions
Price account	2023-01-06	2023-01-08	-75,00	-154 692,89
Price service	2023-01-06	2023-01-08	-75,00	- 154 617,89
Rate	2022-12-31	2022-12-29	3,50	-154 542,89
Transaction	2022-12-23	2022-12-27	-10 700,00	-154 000,00

The examples provided through Tables 1, 2 and 3 are intended to introduce the significance of data formats, and to exemplify why it is important to use formats to store and exchange data, why it is important to be careful when mapping data from one formatting to another, and why one even must be very careful when interpreting and merging data from formats being seemingly similar or even almost the same.

BEAst Eco and PEPPOL are formats that are developed for partly the same purposes, but it is still very important to be careful about exactly which data field in one of the formats relates to exactly which data field in the other format, and how the data in that data field is related to the other data fields in each of the two formats.

4.2 Significance of verifiability

Section 2 presents not only late knowledge and trends in digitalization and emphasis on sustainability efforts in the transport and construction sectors and the sector of their combination but also which new possibilities and requirements are introduced from newly released standards and regulations with regards to sustainability reporting and their verifiability.

5 Methodology

The three standards BEAst, PEPPOL and the ISO 14033 standard were developed in different contexts and for partly different purposes. Here we present the standards and how they are used in this context.

5.1 BEAst standard

The BEAst standard is a standard format for the construction sector's data exchange, in particular concerning business and logistics transactions. BEAst[1] stands for "The Construction Industry's Electronic Business Standard". It is a network of just over 100 leading companies and organizations from various parts of the construction sector that work together in a non-profit association to develop common standards and methods for digital communication in collaboration with Nordic and international organizations. The focus is on the processes for procurement, purchasing, logistics, and invoicing (BEAst, 2023).

Of particular interest for sustainability management is that BEAst includes the component BEAst Eco, which is a special module intended to follow up on fuel consumption and emissions from deliveries, such as climate data. The purpose of BEAst Eco is to track environmental loads from transports to and from construction sites. BEAst Eco can support reporting how far a vehicle has driven, what kind of fuel has been consumed, and the environmental classification of the engine. Table 4 shows that the BEAst Eco has prespecified entries for emissions of carbon dioxide, particles, nitrogen oxide, and more.

Table 4. BEAst Eco specification of emissions from the transport vehicle.

Element och struktur				
Term nr	**Element**	**Förekomst**	**Elementspecifikation**	
			Format: Tag:	XSD Data types::decimal Carbon dioxide
T6376	—Kväveoxid	0..1	Definition: Format: Tag:	**Uppföljning av ett uppdrags utsläpp av kväveoxid. Ska rapporteras i kilogram.** XSD Data types::decimal Nitrogen oxide
T6377	—Partikelmateria	0..1	Definition: Format: Tag:	**Uppföljning av ett uppdrags utsläpp av partikelmateria. Ska rapporteras i gram.** XSD Data types::decimal Particulate matter
T6378	—Kolväte	0..1	Definition: Format: Tag:	**Uppföljning av ett uppdrags utsläpp av kolväte.** XSD Data types::decimal Hydro carbon
T6379	—Motortyp	0..1	Definition: Length: Format: Tag:	**Miljöklassning för den typ av motor som använts för uppdraget, t.ex. med värdet 'Euro 6' för lastbil och värdet 'EU-steg 4' för maskiner.** 0 .. 17 SDDb::String17 Engine type

BEAst Eco does not specify how the data that is entered into the system should be measured, calculated, or compiled. The format allows for the data to be calculated in any way the user wants. This means that data could equally well represent only the last transport leg or a full transport contract. This is a strength regarding the flexibility of the format used, but it also gives room for misunderstanding and needs for further standardization. Therefore, to make use of this flexibility in the BEAst Eco data message format, we suggest combining it with the standard for quantitative environmental information, presented in Table 5.

[1] In Swedish: "Byggbranschens Elektroniska Affärsstandard"

Table 5. Principle for an extended BEAst Eco specification for general sustainability reporting.

T6380	Körsträcka	0..1	Definition: Format: Tag:	**Körsträcka i kilometer som använts i uppdraget.** XSD Data types::decimal Driving distance
T63805	Geographical trace	Vector of time logged GPS-positions	Definition: Format: Tag:	Geographical route of the transport as carried out during the mission Data type::Large string formatted as time logged GPS positions GPS trace
T6381	Körtid	0..1	Definition: Format: Tag:	**Körtid i timmar som använts till uppdraget.** XSD Data types::decimal Driving time
	Drivmedelsleverantörsgrupp			
T6001	Partneridentifikation			
T6427	Drivmedelsleverantör			
	Uppföljning			
T6375	Koldioxid		Format: Tag:	XSD Data types::decimal Carbon dioxide
T6376	Kväveoxid	0..1	Definition: Format: Tag:	**Uppföljning av ett uppdrags utsläpp av kväveoxid. Ska rapporteras i kilogram.** XSD Data types::decimal Nitrogen oxide
T6377	Partikelmateria	0..1	Definition: Format: Tag:	**Uppföljning av ett uppdrags utsläpp av partikelmateria. Ska rapporteras i gram.** XSD Data types::decimal Particulate matter
T6378	Kolväte	0..1	Definition: Format: Tag:	**Uppföljning av ett uppdrags utsläpp av kolväte.** XSD Data types::decimal Hydro carbon
T637850	Audible noise	Vector of time logged GPS-positions	Definition: Format: Tag:	Geografisk sträckning av transporten som den genomförts under uppdraget Data type::Large string formatted as time logged GPS positions GPS trace
T637851	Infranoise	Vector of time logged GPS-positions	Definition: Format: Tag:	Geografisk sträckning av transporten som den genomförts under uppdraget Data type::Large string formatted as time logged GPS positions GPS trace
T637852	Night noise	Vector of time logged GPS-positions	Definition: Format: Tag:	Geografisk sträckning av transporten som den genomförts under uppdraget Data type::Large string formatted as time logged GPS positions GPS trace
T637853	Contribution to biodiversity loss	Vector of time logged GPS-positions	Definition: Format: Tag:	Geografisk sträckning av transporten som den genomförts under uppdraget Data type::Large string formatted as time logged GPS positions GPS trace
T637854	Net contribution to road transports	Vector of time logged GPS-positions	Definition: Format: Tag:	Geografisk sträckning av transporten som den genomförts under uppdraget Data type::Large string formatted as time logged GPS positions GPS trace
T637855	Ethical sourcing of resources	Vector of time logged GPS-positions	Definition: Format: Tag:	Geografisk sträckning av transporten som den genomförts under uppdraget Data type::Large string formatted as time logged GPS positions GPS trace
T637856	Peak effect charging time	Vector of time logged GPS-positions	Definition: Format: Tag:	Geografisk sträckning av transporten som den genomförts under uppdraget Data type::Large string formatted as time logged GPS positions GPS trace
T637857	System transport optimization	Vector of (Horizontal at leel L, Vertical at depth D)	Definition: Format: Tag:	System level at which optimization is performed Data type::Large string formatted as time logged GPS positions GPS trace
T637858	etc.	Vector of time logged GPS-positions	Definition: Format: Tag:	Geografisk sträckning av transporten som den genomförts under uppdraget Data type::Large string formatted as time logged GPS positions GPS trace
T6379	Motortyp	0..1	Definition: Length: Format: Tag:	**Miljöklassning för den typ av motor som använts för uppdraget, t.ex. med värdet 'Euro 6' för lastbil och värdet 'EU-steg 4' för maskiner.** 0 .. 17 SDDb::String17 Engine type
T6382	Förnyelsebart drivmedel	0..1	Definition: Format: Tag:	**Andel förnyelsebart bränsle i procent.** XSD Data types::decimal Renewable fuel

Table 5 presents the principle for a BEAst Eco specification for general sustainability reporting. The current BEAst Eco specification includes only fuel type and consumption, distance, carbon dioxide, Nitrous oxide, Particles and Hydrocarbons, to account for the combustion engine's environmental loads, a specification that allows for general sustainability reporting may need to allow for a wide range of impacts, such as audible noise, infranoise, night noise, contribution to biodiversity loss, net contribution to road transports, ethical sourcing of resources, peak effect charging time, system transport optimization, and other aspects of how each vehicle, each transport and whole construction transport system impacts its environment, the health and the quality of life surrounding the transport route, through the full life cycle of the different vehicles, routes, fuels and planning of the transports and general material handling.

Though this reasoning may seem far-fetched today, some variation of such data will likely become regular for transport vehicles. We may soon see how combinations of sensors on and inside vehicles are connected and interoperate with logistics and traffic control systems, with city- and infrastructure-based noise, vibration, air quality, and energy balancing sensors and systems at local and regional levels, and that such data are streamed to road, city and construction project logistics sustainability monitoring and management.

5.2 PEPPOL standard

With the launch of BEAst Supply 4.0, in 2022, BEAst has been adapted to the PEPPOL (Pan-European Public Procurement Online) data standard, which in turn complies with the international standard ISO/IEC 19845:2015 for business data exchange and trade (ISO/IEC, 2015). Adaptation of the Swedish construction sector's BEAst data exchange format into an international standard will facilitate the exchange of data throughout both transport and supply chains.

PEPPOL includes a more generic approach to emissions (see Table 6) than what BEAst Eco does (see Table 5). Table 6 presents how a specific environmental emission is to be reported, with details about the type of environmental emission as well as a value, the precise calculation method, its identification code, etc. This opens up the type of examples represented in Table 5, such as emissions of different types of noise and vibrations. However, to allow for also other types of sustainability data, such as localized impact on biodiversity, net contribution to traffic, etc. even more generalized sustainability data structures need to be added. At this level of our work, we do not request or need that. Here it is only stressed as a potential path toward general, digitalized construction sector transport sustainability management, monitoring, and reporting data systems.

Table 6. The PEPPOL generic approach to transport emissions.

714	EmissionCalculationMethod	A class to define how an environmental emission is calculated.								
	<					Emission Calculation Method. Details		2.1	ABIE	Emission Calculation Method
715	CalculationMethodCode	A code signifying the method used to calculate the emission.								
^		0..1	Code			Emission Calculation Method. Calculation Method Code. Code		2.1	BBIE	Emission Calculation Method
716	FullnessIndicationCode	A code signifying whether a piece of transport equipment is full, partially full, or empty. This indication is used as a parameter when calculating the environmental emission.								
^		0..1	Code			Emission Calculation Method. Fullness Indication Code. Code		2.1	BBIE	Emission Calculation Method
717	MeasurementFromLocation	A start location from which an environmental emission is calculated.								
^		0..1	Location			Emission Calculation Method. Measurement From_ Location. Location		2.1	ASBIE	Emission Calculation Method
718	MeasurementToLocation	An end location to which an environmental emission is calculated.								
^		0..1	Location			Emission Calculation Method. Measurement To_ Location. Location		2.1	ASBIE	Emission Calculation Method
740	EnvironmentalEmission	A class to describe an environmental emission.								
	<					Environmental Emission. Details		2.1	ABIE	Environmental Emission
741	**EnvironmentalEmissionTypeCode**	A code specifying the type of environmental emission.								
^		1	Code			Environmental Emission. Environmental Emission Type Code. Code		2.1	BBIE	Environmental Emission
742	**ValueMeasure**	A value measurement for the environmental emission.								
^		1	Measure			Environmental Emission. Value. Measure		2.1	BBIE	Environmental Emission
743	Description	Text describing this environmental emission.								
^		0..n	Text			Environmental Emission. Description. Text		2.1	BBIE	Environmental Emission
744	EmissionCalculationMethod	A method used to calculate the amount of this emission.								
^		0..n	Emission Calculation Method			Environmental Emission. Emission Calculation Method		2.1	ASBIE	Environmental Emission

5.3 ISO 14033 Environmental management – Quantitative environmental information – Guidelines and examples

The international standard ISO 14033 - Quantitative environmental information – Guidelines and examples (ISO 14033, 2019) provides a general structure for quantitative systems analytical information. The framework was initially developed to fill the gap between the many quantitative environmental management systems analytical methods and their dependence on and relationships with metrological facts and data (Carlsson and Pålsson, 2000; Carlsson and Pålsson, 2001; Fracchia et al., 2012). The framework guides the acquisition, compilation, reporting, and verifiability of quantitative data for purposes of environmental or sustainability management.

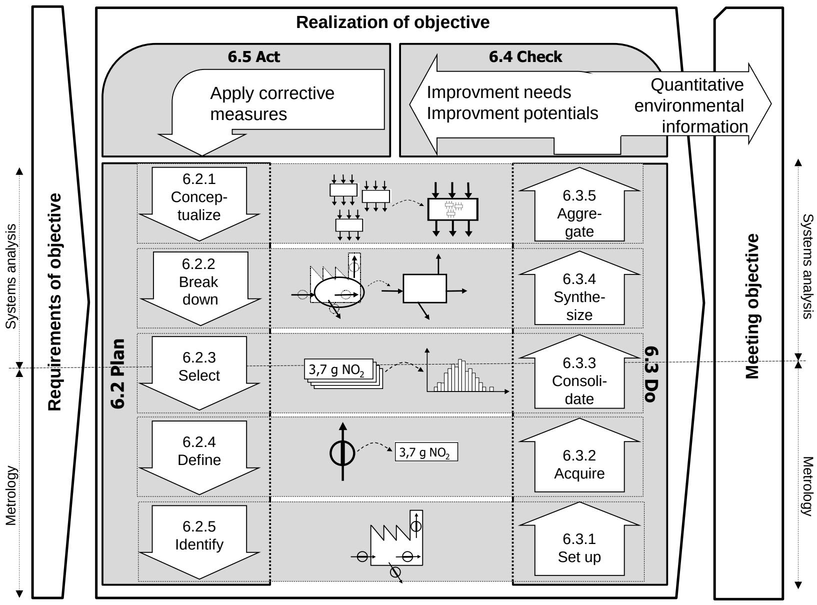

Fig. 3. Framework of ISO 14033 – Quantitative environmental information [adapted picture from 1].

Figure 3 represents the ISO 14033 standardized framework. It can be read from left to right, from top-down or bottom-up, or as a Plan-Do-Check-Act (PDCA) loop.

From left to right: From left enter requirements for sustainability data (*Requirements of the objective*) and the resulting data is delivered to the right in the figure (*Meeting the objective*). Typical sustainability data requirements are all resource use, waste, and emission from a production facility, a carbon footprint (GHG reporting Scope 3) for an enterprise, or a quantification of the biodiversity and social impact from mineral resource extraction.

From top-down or bottom-up: Viewed from top-down, the framework provides a structure for planning how to acquire data for the specified need. Viewed from the bottom-up the framework provides a structure for how to acquire data.

As a PDCA loop: Viewed as a PDCA loop the framework provides a structure both how to establish a verifiable data acquisition and information compilation plan, how to perform the acquisition and check, as well as how to check the resulting quality and how to perform a continual improvement of a reporting system.

One practical result of applying the framework is that it shows how to bridge fact-based data taken from any data source or measurement and stepwise establish a higher system level of fact-based data without losing verifiability. The framework is simple and universal, hence can serve as a template for any information acquisition compilation and reporting project or system with ambitions to maintain verifiability.

Figure 4 shows how the framework in the standard ISO 14033 can repeatedly be used to establish transparent and verifiable information reporting routines or information systems. From the bottom-up, the figure represents how data from different data sources are aggregated into stepwise higher system levels. From the top-down, the figure may either represent a breaking down of information into its need for basic data sources (measurement, literature, or expert), or a review of a report into its fundamental data and data treatment (Carlsson, 2020).

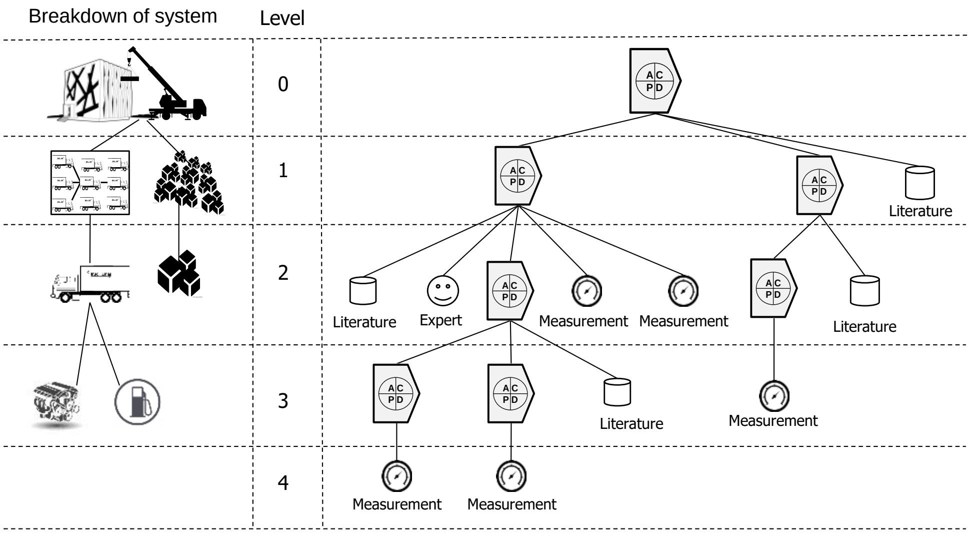

Fig. 4. Applying the framework of ISO 14033 for transparent and verifiable information systems design. Picture adapted for the context of this research. (The symbol with the letters PDCA represents the framework in Figure 3.)

5.4 Combining BEAst Eco and ISO 14033

BEAst Eco is a standardized message for the exchange of environmental data about transports related to construction projects within the practically applied BEAst data exchange standard. The BEAst standard allows equally well very detailed data or very aggregated data down to the engine, good or transport route up to the transport supplier company or entire construction project. Partly due to this flexibility of the format, the BEAst Eco message has no specified requirements or guidelines for how the environmental data should be measured or otherwise prepared before being entered into a BEAst eco message. The framework and intended application of the ISO 14033 standard is based on the system aggregation flexibility as do the BEAst standard. It handles equally well any detailed directly measured data from, for example, the real-time fuel consumption of a truck, as it manages total reporting of all emissions from all transports of a transport company or a construction project. In addition, ISO 14033 provides guidance on how to structure specifications for how environmental data should be measured and prepared. Therefore, these two standards may be combined into a resulting specification where ISO 14033 guides how sustainability data shall be specified when communicated and BEAst Eco indicates the format for digital exchange of sustainability data in the construction sector. This can be implemented so that a BEAst Eco message is supplied with a digital reference to where documentation structure according to the ISO 14033 for each quantitative data can be accessed.

6 Top-down and bottom-up mapping for strategic digitalization

Digitalization needs and opportunities are mapped from a *top-down* perspective, from top management[2] down to individual data sources, represented by vehicle sensors and a combination of sector-based, company-based, and technology and project-specific databases (section 6.1), and from a *bottom-up* perspective, where various existing data sources are assessed, linked in and mapped with regards to the value of their information content from the viewpoint of key transport sustainability decision points (section 6.2). These two vertical directions of mapping to connect decision-making with data sources are done with the intentional purpose of utilizing digitized data to provide decision-making people and machines with relevant information for both strategic and real-time sustainable management of all transports related to a construction project.

6.1 A top-down perspective: realizing the need for data and digitalization

The circled numbers (1) – (4) in Figure 5 show the order, in which to carry out a top-down mapping for setting up a sustainability management information system that fulfils the needs at different decision points throughout the construction site transport system: (1) identifies total aggregated sustainability information needs for all construction project transports; (2) breaks down the total transports into relevant categories, such as per good type and supplier; (3) identifies what measured and otherwise acquired data is needed to meet the information needs and specifies calculation routines for aggregation of data at each level, and (4) documents measurement points and calculation routines using the ISO 14033 structure, implements calculation and data transfer routines into different appropriate software systems, stores calculated data and references to document into the BEAst Eco format, and utilizes appropriate network technology to forward the data and to realize the system design.

[2] Here, top management represents the ultimate user for the digitalized information, to emphasize that all information ultimately benefits the sustainability performance of a total construction project. However, most collected data will be aggregated, interpreted and acted upon before reaching top management.

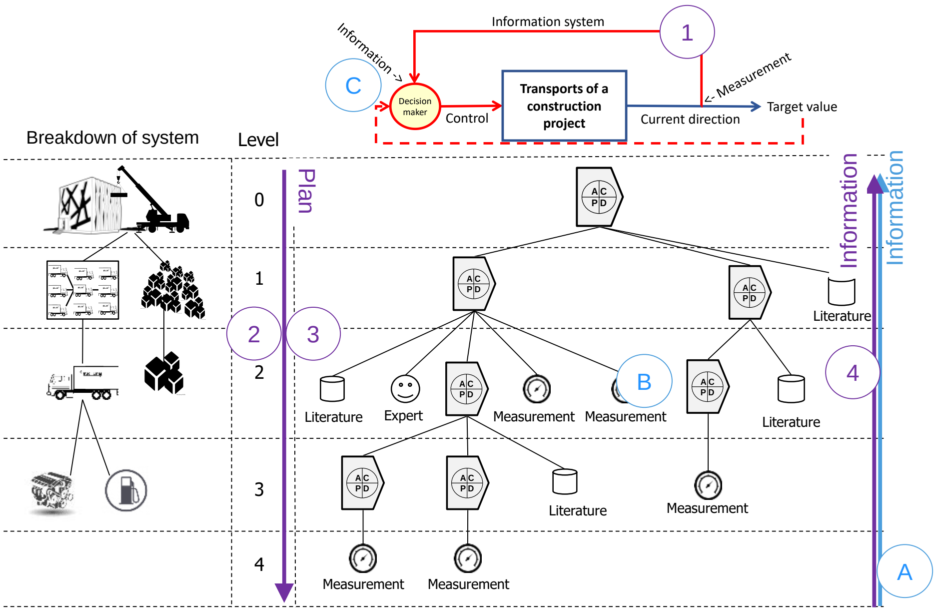

Fig. 5. Top-down (1-4) and bottom-up (A-C) view of information system design strategy.

A practical example of applying the ISO 14033 framework hierarchically is the following: a construction project management team (C) needs information about how all transports of the entire construction project performs with regards to its greenhouse gas emissions. For this reason they need to measure all transport greenhouse gas emissions (1). But this is not done by the managers themselves. They delegate the task to their Greenhouse gas threshold executive manager. This executive manager (Level 0) plans to get all her data from Level 1 (2) (3). Level 1 means one logistical supply chain manager, one material storage manager, and a database of greenhouse gas emission factors for different transport fuels and other energy sources. She will calculate the emissions as soon as she gets the other data from Level 1. In turn, the logistics manager will need to consult her Level 2, i.e. here databases to know how to allocate the goods of the different transport legs onto this specific construction project, as well as adjust some of these allocations due to facts by calling the different transport leg managers. She will also get a lump of fuel calculations collected from the transport legs at Level 3. Based on this she at Level 1 can combine these Level 2 data with measured data about the amounts of transported goods. She is not aware that the data at Level 3 is acquired from within two different transport companies who to a great degree measure their distances (Level 4), but who combine these data with fuel consumption factors acquired from a database at Level 3. The other transport leg that the Greenhouse gas threshold executive manager acquires data from at Level 2 also is a combination of measurements at Level 3 and fuel factors at Level 2.

6.2 A bottom-up perspective: take advantage of existing data

The light blue circled letters (A) – (C) in Figure 5 represent viewpoints, from which to carry out a bottom-up investigation of how to utilize and digitalize data from already available measurements, data registers, or administrative systems throughout the different transport systems of a construction project. (A) maps existing data and register their data specification and registration quality, level of digit readiness, system interconnectedness, data format, etc. (B) examines how data could be shared, communicated, and be made understandable, together with a rough estimate of the cost of such work at different decision levels. (C) performs a utility-based cost-benefit analysis for making the information available for decision-making and control at different decision points throughout the transport system.

Combining the ISO 14033 framework and the BEAst Eco message format for such a bottom-up purpose provides much value. Through the use of the ISO 14033 framework structure, the value of existing data sources is improved by harmonizing how their data and their calculations are specified. The availability of such high-value data is then made available via the common message format of BEAst Eco. Together they efficiently establish an effective and high-quality digitalized information structure as indicated by Figure 5.

For large construction projects, the technical and digital level of the transport fleet is typically heterogenic, in the sense that the vehicles are built by different companies, and both the level and maturity of the digitalization and digital interoperability of the vehicles are different. Taken together, for a construction project to get a good view of their available data, they need to establish some routine to acquire knowledge about the type and sorts of heterogeneity from the transport providers. They may do this by letting the Transport sustainability manager require that (A) all transport providers for all vehicles of all their suppliers compile a list of the technology level of their level of digital maturity level, together with the digital maturity level of each of the managerial level coordinating the transports, all the way from vehicles up until the construction level project. With this in hand, the Transport sustainability manager may review the situation and provide a map (B) of which level of quality of the data is possible to achieve, which transport suppliers need to shape up if they will be contracted, and which type of manual data handling that might be needed for the transports to be manageable from a sustainability point of view. When a sufficient level of information quality is considered to pass from vehicles and goods transports up to the construction project management team (C), the project can safely say that they have a functioning sustainable transport management system.

7 Conclusion and recommendations

The research has provided new concepts, terms, and possibilities to describe digitalization status, gaps, and potential designs, as well as the possibility to analyze the potential of information system modules before they are implemented. In particular, it demonstrates how to graphically show which data is under-utilized or missing and which data is considered useful.

This research has shown that the combination of the two standardized structures of BEAst Eco and ISO 14033 provides highly versatile building blocks for a management system for strategic digitalization. By applying the framework of ISO 14033 for top-down and bottom-up vertical digitalized data acquisition and flow and the BEAst standard for horizontal data networking and exchange, it was shown how to facilitate digitalization for transparent data-driven sustainability management of construction transports, including strategically efficient multi-use of data.

The Plan-Do-Check-Act loop of ISO 14033 is the driver for continual improvement and may be the core of a digitalization strategy management system. Most construction companies already work with management systems based on a fact- and decision-based continual improvement process, similar to a Plan-Do-Check-Act. They can, therefore, recognize and seamlessly adapt the proposed management system structure based on either top-down or bottom-up gradual system improvement models. A gradual implementation immediately puts the digitalization strategy into effective use by engaging everyone from the operational to the strategic level and all in between throughout the organization.

Integration of the standards is intended to not only be made within individual organizations or projects but to be a part of the construction sector's transformation to higher efficiency, quality, and sustainability performance. Therefore, both a formal and a practical harmonization needs to be done, preferably implemented as a formal standard with broad consensus throughout the sector. In addition, a fruitful implementation should encompass not only the transport but also the total construction projects. It is worth noting that in 2022, the BEAst standard was mapped onto the PEPPOL[3] standard [8], which implies that the work presented in this article has a more universal and global value than was originally intended.

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Certification development
RISE rapport 2024:17
ISBN 978-91-89896-62-8