Toward a Reference Architecture Framework for the development of interoperable construction digital platforms in Europe

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Abstract
DigiPLACE is a European project aiming at proposing a strategy roadmap, including the definition of a Reference Architecture Framework (RAF), for the development of interoperable construction digital platforms in Europe, based on an EU-wide consensus. Considering the already existing initiatives aiming at supporting the digitalization of the construction sector and that are fostering the development of digital platforms at different levels, the key aspect addressed in this paper is to propose an organic view able to include and/or combine these existing references into a comprehensive and structured vision, to highlight their interconnections and to improve the common understanding of the ongoing evolutions. The paper also identifies the gaps in this current landscape together with some possible answers/solutions, to facilitate and orchestrate the development of platforms based on a common vision, considering the will to create a level playing field for both construction stakeholders and digital services providers.

Keywords: Construction industry, Digital transition, Digital platforms, reference architecture framework

1 Introduction
DigiPLACE is a European project aiming at proposing a strategy roadmap for the development and deployment of construction digital platforms in Europe. It relies on the definition of a Reference Architecture Framework (RAF) for interoperable digital platforms, based on an EU-wide consensus involving a large community of stakeholders (including designers, contractors, building owners and managers, public and private clients, operators, construction products manufacturers, construction machineries companies, policy makers, educational institutions, software developers, value-adding resellers, industry associations, communities of practitioners,

technology advocates, individuals, etc.) within the construction sector as well as from nearby engineering and software fields. The objective is to identify and respond to construction stakeholders' needs, leveraging on available appropriate software applications and services, with a special focus on SMEs and micro-businesses. BIM and object-oriented representation of AEC (Architecture Engineering and Construction) has started to offer the promise of seamless communication of semantic data models between computer-based systems used from the design stage to the operation of the facilities. Still, the fragmentation of the sector and the diversity of actors and practices has hampered the development and use of common platforms and standards, creating a necessity for the previously introduced RAF for digital construction platforms.

An initial phase of the DigiPLACE project performed, among others: i) a detailed analysis of the level of implementation (in 2020) of digital technologies and tools in the European construction sector and of the existing solutions, in order to determine key aspects (so called "success factors") that the RAF should consider in terms of standardisation, interoperability, services provided, lifecycle, costs, usability, etc., and ii) an analysis of the needs, barriers and requirements captured from the industry.

The output of this work has been used first to define the high-level specifications and key use cases associated with envisioned digital platforms, and then propose a structured set of schemas and guidelines that constitute the DigiPLACE RAF. This framework considers the already existing initiatives and research aiming at supporting the digitalization of the construction sector and that are fostering the development of digital platforms at different levels (public and private, national, European or international). Considering the complexity of the subject and the peculiarities of the sector, the first point addressed in this paper is about proposing an organic view able to include and/or combine these existing references into a comprehensive and structured vision, in order to highlight their interconnections and to improve the common understanding of the ongoing evolutions (Kassem and Succar, 2017). The paper also identifies the gaps in this current landscape together with some possible answers/solutions, to facilitate and orchestrate the development of platforms based on a common vision, considering in particular the will to create a level playing field for both construction stakeholders and digital services providers.

The rest of the paper is organized as follows. Section 2 provides a synthetic state of the art about the existing initiatives and research related to the development of digital platforms in construction sector. Section 3 reports the methods used for the analysis and definition of the Reference Architecture Framework (RAF). Section 4 presents the structure and main elements of the RAF. Finally, section 5 summarizes the conclusion of the work including future developments.

2 Existing theories & previous work

Similarly to other industrial sectors, construction is seeing its own "digital Revolution", having benefitted over the last 3 decades from only modest productivity improvements (McKinsey & Company, 2017). For instance, digital tools and Building Information Modelling (BIM) are being progressively adopted across the built environment value chain to deliver cost savings, increased productivity, operations efficiency and quality, better environmental performance, etc. However, the fragmentation of the sector and the diversity of actors and practices has hampered the development and use of shared collaborative environments (the so-called CDEs: Common Data Environments) and associated standards (ISO, 2018a, 2018b). This led all stakeholders to call for a European-wide - and even world-wide - consensus on the definition, structure, accessibility and usability of such environments, thus moving from a project perspective to an inter-company and sector chain perspective (Rezgui et al., 2010a).

Several studies aimed to understand the characteristics of collaborative environments. For example, (Alreshidi et al., 2016) proposed a set of requirements for the development of a GovernBIM platform. (Wong et al., 2014)proposed a literature review of cloud-based BIM technologies presenting the main characteristics and functions of the analysed ones. (Shafiq et al., 2013) analysed existing model collaboration systems proposing a classification and list of features including user's perspectives.

On the policy side, the Final Report of (Working Group 2 - Digital Industrial Platforms, 2017), within the Digitizing European Industry Initiative of the European Commission, aimed to support

the creation of next-generation digital platforms, reflecting on how construction platforms should be approached at European level and considering how existing and planned EU-wide, national, and/or regional platform development activities could contribute.

Based on these considerations, DigiPLACE intended, during initial steps, to create a basis for the development of the RAF and to lay the groundwork for the rest of the project. It therefore performed a global description of the context of the digitalization in the construction sector, doing a comparison with other industrial sectors too, through different inventories, analyses and interactions with stakeholders – with a special focus on SMEs. These analyses enabled to highlight barriers & drivers, key aspects of digital platforms to include in the RAF, as well as the different implementation options existing on the market in terms of services offered, standards, interoperability, services provided, formats, lifecycle, costs, usability, etc. A brief overview of this work is provided below (a detailed description has been made in (David *et al.*, 2021).

Firstly, 300+ digital platforms and tools (specific to construction or generic ones used in any sector) have been listed[1]. Around 200 of them have been analysed, including a 1st clustering of platforms reflecting different use cases corresponding to the different phases of a construction project. This showed in particular that most of the platforms entered in the "collaborative platforms" category (i.e. platforms used by different team members in order to exchange data and documents, and that provide a better communication and a more effective project management), whether it is for the design, construction or operation & maintenance phase, or for a generic use.

Then, exchanges with stakeholders enabled to confirm that the construction sector remains little digitalized, with an important gap between large companies and SMEs. For the companies that are indeed digitalized in their daily activities, different tools are used - BIM and digital 3D drawing or modelling tools in the first place. Stakeholders suggested many advantages – or drivers – that are provided by such digitalization (project efficiency, better management, reduction of cost, easier tendering and communication with clients, standardisation of procedures, etc.) as well as obstacles that they usually face (lack of common standards/formats which hinders data exchanges with partners, high cost of software, lack of knowledge in the construction community which hinders the frontrunners, etc.). A number of exchanges also took place concerning good practices, with potential examples for the DigiPLACE RAF or needs in terms of national policies.

As a result of this work, 20 success factors have been identified[2], consisting in focus points that the DigiPLACE RAF should consider in order to fulfil the objectives of the project. As shown in Table 1, they are structured around 4 categories: technical aspects, demand and regulatory aspects, economic aspects and security aspects.

Table 1. List of the success factors identified

	TECHNICAL ASPECTS
1	Interoperability and sustainability
2	Collaboration enabler
3	Single entry point
4	Capacity to connect several platforms both at regional and national levels
5	Integration of both public and private data
6	Easier circulation of / access to services and products
7	Maintenance of data
8	Maintenance and update of the services
9	Adequate backup of data
10	Be customizable
11	Be scalable and dynamic (provide an environment able to integrate new/existing tools)
12	Efficient and fast data management and data queries

[1] The complete list is accessible in DigiPLACE deliverable D3.1 (ECTP et al., 2019)

[2] The complete list and description of the success factors is available in DigiPLACE deliverable D3.3 (ECTP et al., 2020).

	DEMAND / REGULATORY ASPECTS
13	Capacity to check compliance with regulations & certifications
14	Capacity to answer the demand/needs of every kind of stakeholder
15	Relying on the national level, by interconnecting with national platforms
	ECONOMIC ASPECTS
16	Identification of clear funding mechanisms / systems (analysis of the economic sustainability of the platform)
17	Identification of business cases for all stakeholders
18	Increase of the competitiveness for all the value chain
	SECURITY ASPECTS
19	Information and data security
20	GDPR compliance

The success factors have then been analysed, in order to assess how they are currently implemented or taken into account in some representative existing digital platforms and tools in several industrial sectors (construction, healthcare, automotive, aerospace), and further recommendations or research and development orientations for the development of the RAF and its associated Roadmap have been proposed.

The success factors, in addition to all the elements introduced above, composed the main inputs for the reflexion around the RAF, as explained below in the RAF definition methodology.

3 Methods

The research methodology used for the definition of the Reference Architecture Framework must be considered within the context of the activities performed in the DigiPLACE project, which are summarized by the Figure 1.

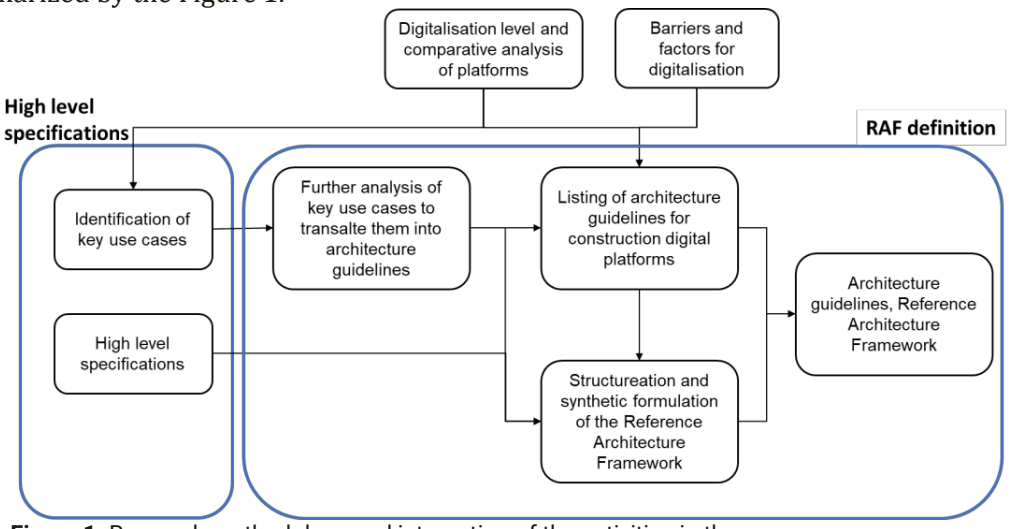

Figure 1. Research methodology and integration of the activities in the DigiPLACE project context (adapted from the Deliverable D5.2 "architecture guidelines")

Based on these elements, the methodology is divided into two main components, i.e. the development of the high-level specifications and the RAF definition. The high-level specifications were defined considering:

- The identification of key use cases for the platforms, taking into account five 'areas' that have been used to guide a consultation with construction stakeholders, so as to identify the main topics to tackle and then the related use cases. These 'areas' were a) common language, interoperability, standards b) rules and regulations, public services c) data and knowledge sharing d) environmental performance and e) business, market, and collaboration. To obtain a wide range of perspectives in the

identification of key use cases, the analysis and consultations were structured in three levels starting from an initial framework of areas, topics, and key use cases. First, an internal consultation involved the 26 DigiPLACE partners and linked third parties. Then, a dedicated workshop with the DigiPLACE Advisory Board has been organized to discuss the emerging use cases. Finally, a set of vertical workshops, one for each area, has been organized opening the participation to all the interested stakeholders.

- The specific scenarios of development, related to the above-mentioned use cases, to create an initial understanding of the possible platform(s) implementation. The analyzed scenarios were a) common language scenario, b) integrated rules scenario, c) integrated design process scenario, d) improved product performance scenario, e) securing of market and player scenario and, e) CE mark, smart CE scenario.

The key use cases resulting from the high-level specifications analyses were used to identify the main thematic areas of the RAF guidelines. The structure of the RAF has been defined by combining the high-level specifications scenarios and the initial analysis of the core thematic areas guidelines (CSTB *et al.*, 2021).

4 Findings

4.1 Presentation of the Reference Architecture Framework

4.1.1 Scope

The scope of the Reference Architecture Framework was refined throughout the project within dedicated discussions and workshops.

The RAF intends to propose **a comprehensive set of common guidelines for building and deploying interoperable digital platforms for the construction sector across Europe**. These include both public and private platforms, at either local or European scale (also keeping in mind that many private platforms are global).

The guidelines can be of different types:

- General guidelines applying to all existing and future digital platforms, related for example to interoperability, data security, data ownership or data sovereignty.
- Guidelines related to identifying tools and services that should be developed or generalized to support key use cases.
- Finally, in relation to the previous point, a special focus of the required public services and platforms, at both European and member states levels.

4.1.2 Purpose

The purpose of the RAF also matured during the project. It first derives from the observation that the digitalization of the construction sector is a complex process, involving many different dimensions that are difficult for the stakeholders to capture in a global way: regulations, standardization works, public and private platforms and initiatives, disruption of business models, skills, etc.

A first-level ambition is thus to **put the existing references and initiatives into a comprehensive and structured vision, highlighting their interconnections**. All the stakeholders involved share the will to improve the common understanding of the ongoing evolutions and educate themselves on the disrupting potential of digital platforms for the sector.

Beyond this, the framework intends to identify the gaps in this current landscape together with the actions to be carried out to answer them, in order to facilitate the development of platforms, and to ensure that they are aligned on a common vision, with different aspects:

- Comply with European principles and support European interests.
- Create a level playing field for both construction stakeholders and digital services providers.

- More generally, support the identified underlying objectives, that are reminded in detail in deliverable 5.1 of the project (D5.1: Platform Specifications); sustainability, competitiveness, single market, etc.

4.1.3 Overview of the framework

As depicted in Figure 2, the guidelines have been structured according to:

- Core guidelines, regrouped under the label "enable interoperability and data sharking in construction", and divided in two pillars:
  - Pillar 1: interoperability, common language and processes.
  - Pillar 2: control over the use of data.
- Guidelines related to four identified areas of application, regrouped under the label "leverage interoperability and data sharing in construction":
  - Environmental performance.
  - Large scale data sharing, European big data platform for the construction sector.
  - Business, market and collaboration.
  - Public services and initiatives.

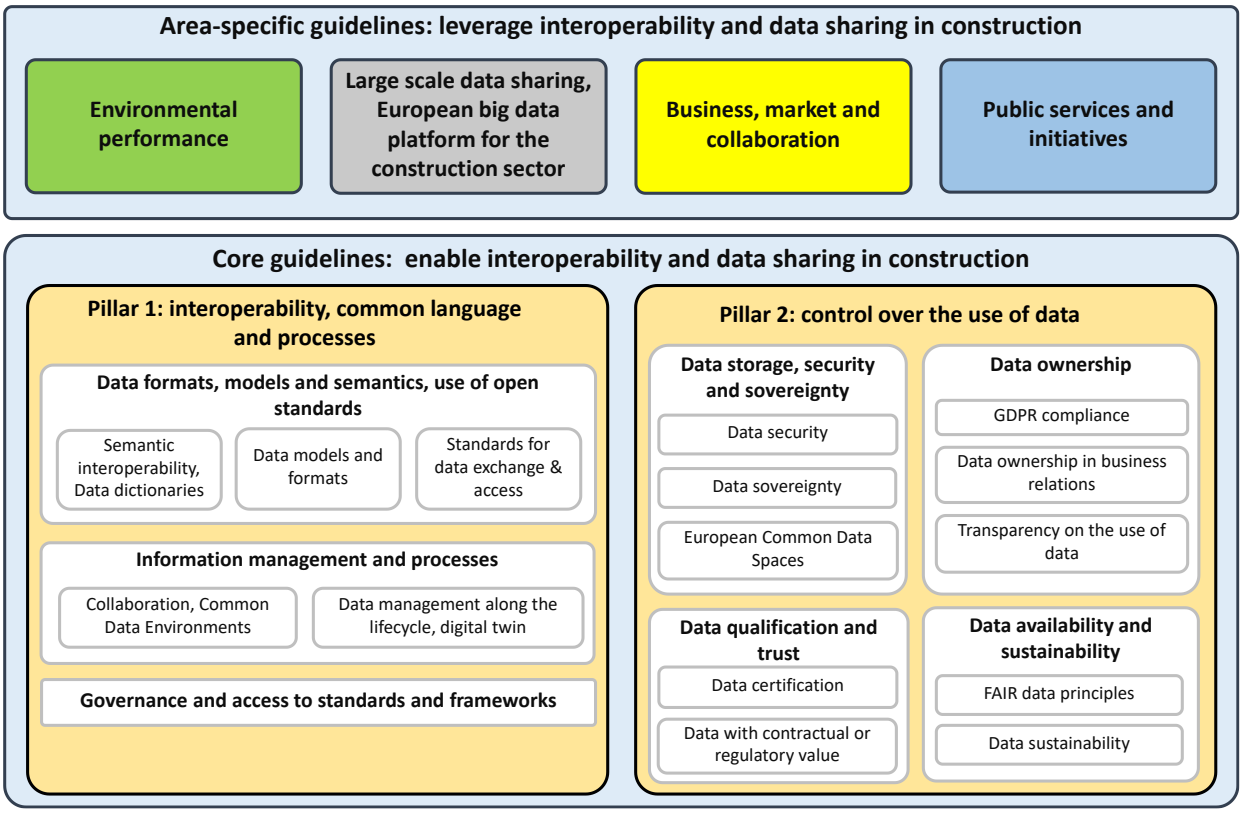

Figure 2. overview of the Reference Architecture Framework

4.2 Focus on the perimeter of future public platforms

4.2.1 The important role of public authorities in the digitalization of the construction sector

One chapter of the framework focuses on the role of public authorities in the digitalization of the construction sector. They are involved in multiple ways:

- They set up the regulatory framework for construction and for digital services.
- They manage the related public services, part of which are digitalized or could be digitalised.
- As part of their policies, they support measures to improve e.g. the performance of the building stock, as well as the security and health of inhabitants, for which digitalization can be a key enabler.

- They own public data that should be made available to construction stakeholders.
- They build, own, and manage public assets, relying on public procurement, which can be an important driver for digitalization. In addition, data relating to public assets is often strategical and shall comply with cyber-security principles, as included in the RAF (e.g. railway networks, airports, etc.).
- In relation with all previous points, they can set up public digital platforms (or support public/private initiatives), either to provide new services, or as part of the digitalization of existing ones.

4.2.2 The perimeter of future public digital platforms

The term "public platforms" should be considered in a broad sense. Even if the platform itself is public, it can give access to third party services and/or datasets. Furthermore, such platforms can be governed and financed through public-private schemes, involving industry stakeholders alongside public authorities.

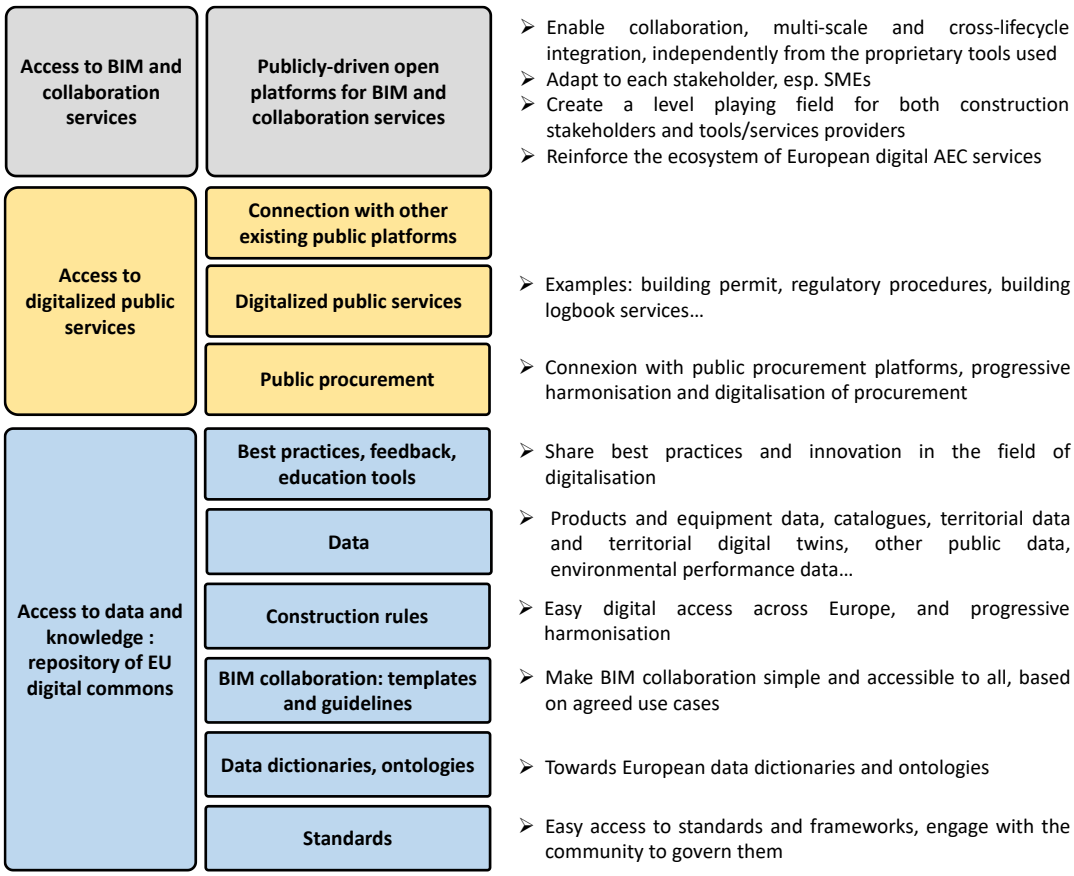

Figure 3. Proposed perimeter of future public digital platforms

Figure 3 synthetizes the possible perimeter of such public platforms, which can be divided into three main categories of content as following described.

Access to data and knowledge: this category includes, but is not limited to, the access to public data. During the DigiPLACE project, the idea emerged of setting up a repository of EU digital commons, thus providing an easy and centralized access to different kinds of material that need to be shared to achieve a successful digitalization of the sector: digitalization standards, data dictionaries and ontologies, guidelines and templates to facilitate BIM-based collaboration in particular for smaller players, or digital access to construction rules. The platform should also provide educational content, and support the sharing of best practices. The data made available is not necessarily limited to public data. Public platforms could include access to products and

equipment catalogues, or offer a framework for the large-scale sharing of other private data (big data platform). Finally, territorial digital twins could constitute an innovative way to access part of the data.

Access to digitalized public services: this category includes access to digitalized building permit processes, or to services related to future building logbooks. The connection with public procurement platforms can also be part of it.

Access to BIM and collaboration services: the opportunity to set up publicly-driven open platforms for BIM and collaboration services has been explored. The idea is to provide an open architecture to integrate services in meaningful workflows for identified use cases, with standard ways to integrate data between services. The French platform Kroqi[3], developed as part of a national plan dedicated to BIM[4], constitutes an interesting example. Several arguments have been identified in favor of such public platforms:

- Provide a BIM and collaboration toolkit readily accessible by all stakeholders, including SMEs, and that can be used to answer the requirements related to the use of BIM in public procurement.
- Give an impetus to the digitalization of the construction sector, in a transitory phase.
- Create a level playing field through a platform that is opened equally to all providers, and designed to: i) promote innovation and new entrants (esp. small players), ii) guarantee market access to all stakeholders independently from proprietary platforms, iii) ensure a fair distribution of value across the value chain, and iv) reinforce the ecosystem of European digital AEC integrating different services into consistent workflows.

Many of the mentioned services already exist, either at European level or in some member states. Some will be created (e.g. big data platform, territorial digital twins, or publicly driven open platforms for BIM and other digital services), and some already existing will evolve in the context of digitalization (e.g. adding digital rule checking tools to existing construction rules portals, or adding BIM processes to existing public procurement platforms). Finally, for both existing and new services, the purpose of the European platform will be to provide a single-entry point to all public digital services related to the European construction sector.

4.2.3 European versus national platforms

The future European platform would actually be articulated with a network of national platforms. Some services are likely to be proposed at European level, while others would remain at the level of National platforms. Taking example of access to construction rules, a National platform would give access to National rules, and would redirect towards the European platform to access all common European rules. Access to digitalization standards and big data platforms would sit primarily at European level, while access to digitalized public services such as building permit is more likely to remain at National level, as it varies depending on national regulatory contexts.

4.3 An example of possible application: European platform for products & equipment data, and its use in BIM models and digital supply chain

Two of the key use cases of future digital platforms that have been identified during the project relate to product and equipment data:

- Allow a seamless access to products data, readable by machines, and automatic matching between manufacturers' products and BIM data.
- Optimize the supply chain based on the integration of manufacturers' BIM objects into BIM models, including construction equipment data.

A section of the Reference Architecture Framework proposes a focus on standardization issues related to product data, explaining the key role of semantic interoperability, and describing how ongoing evolutions (e.g. the implementation of ISO 23386 and ISO 23387) support the emergence of a common digital language, designed in consistency with a common technical language.

[3] https://www.kroqi.fr/
[4] https://plan-bim-2022.fr/

The different layers of the future repository of European digital commons, as described above, can be mobilized to support the identified use cases:

- Give access to the related standards, together with implementation guidelines.
- Define and share European data dictionaries and ontologies related to products and equipment data, aligned with European regulations (e.g. Construction Products Regulation - CPR). An adapted governance should also be installed.
- Provide guidelines and templates related to the use of products and equipment data in BIM processes.
- Share best practices and feedback.

Concerning the access to the data itself, further works are required to precise the positioning of public platforms, and their interactions with the different stakeholders (e.g. product manufacturers producing the data, or designers using the platform). Public authorities will first have a key role in **setting up the proper governance framework.**

They will ensure the consistency with regulatory frameworks (e.g. CPR, existing and future regulations related to Life Cycle Assessment and environmental footprint of products and buildings, or future frameworks resulting from ongoing initiatives on circular economy or building logbooks). Connections can also be made with public procurement platforms.

Finally, publicly driven open platforms for BIM and collaboration services would aim to include services allowing all stakeholders to actually implement the corresponding workflows. Further research is required to precise this vision, and make digital supply chain a reality.

5 Conclusions

This paper presented the Reference Architecture Framework for interoperable digital platforms developed in the DigiPLACE project. The RAF has been developed starting from a solid analysis of the context considering i) the analysis of existing platforms ii) comparative analysis with different sectors iii) analysis of barriers and iv) identification of the success factors.

The RAF is intended to approach the development of platforms in construction sector from a horizontal perspective able to integrate all the possible aspects that can be related to platforms development, at different scales and within the different scopes that platforms can consider. Future works, that are already under development in the DigiPLACE project, will focus on vertical actions to identify how the proposed RAF can be used to provide tangible impacts in the developments of digital platforms in constructions. This analysis will result in the definition of a strategic roadmap where the different actions will be integrated in a temporal perspective identifying the possible scenarios that may result from their application at European and National levels.

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