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Data Cooperatives as a Catalyst for Collaboration, Data Sharing and the Digital Transformation of the Construction Sector

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Abstract: Digital federated platforms and data cooperatives for secure, trusted and sovereign data exchange will play a central role in the construction industry of the future. With the help of platforms, cooperatives and their novel value creation, the digital transformation and the degree of organization of the construction value chain can be taken to a new level of collaboration. The goal of this research project was to develop an experimental prototype for a federated innovation data platform along with a suitable exemplary use case. The prototype is to serve the construction industry as a demonstrator for further developments and form the basis for an innovation platform. It exemplifies how an overall concept is concretely implemented along one or more use cases that address high-priority industry pain points. This concept will create a blueprint and a framework for further developments, which will then be further established in the market. The research project illuminates the perspective of various governance innovations to increase industry collaboration, productivity and capital project performance and transparency as well as the overall potential of possible platform business models. However, a comprehensive expert survey revealed that there are considerable obstacles to trust-based data exchange between the key stakeholders in the industry value network. The obstacles to cooperation are predominantly not of a technical nature but rather of a competitive, predominantly trust-related nature. To overcome these obstacles and create a pre-competitive space of trust, the authors therefore propose the governance structure of a data cooperative model, which is discussed in detail in this paper.

Keywords: digital platforms; data sharing and exchange; digital transformation; data cooperatives; interoperability; data sovereignty; construction industry; value networks; productivity; capital project performance

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1. Introduction

The aim of this conceptual paper is to demonstrate that secure, trusted and sovereign data exchange can be enabled for the construction industry using various governance innovations including a data cooperative legal structure combined with digital federated platforms. Digital platforms have the potential to enhance the level of organization in the construction industry's value creation systems and increase collaboration among players [1]. Applied to construction projects, planning and production processes can be much better organized and lead to frictionless, low-waste collaboration. The possibilities of digital platforms go far beyond Building Information Modeling ("BIM") [2–5]. Digital platforms can therefore be understood as mobilization platforms [6,7]. They are the digital manifestation of a value network of different stakeholders who want to achieve a common goal [8,9]. In this case, the common goal is to create a sustainable built environment [10].

The platform is therefore not only used to map the project structure, but also to organize the structured exchange of data. According to Hagel [7], digital platforms therefore consist of an ecosystem with governance structures, i.e., regulatory structures, and a set of standards and protocols to digitally organize interaction in a complex multistakeholder environment. Platforms, therefore, do not replace a traditional project structure, but support and enable it. They form a meta-organization for joint and coordinated action toward a higher-level overall goal with maximum impact. Platforms can provide a process-driven platform approach for more efficient processes in planning and implementation, based on more agile and systemic value chains [11].

Thinking one step further, a digital platform can evolve into a trusted learning system (Figure 1) which is supported by artificial intelligence ("AI") [12]. Of course, under limiting conditions, this is also possible in value networks that organize themselves analogously, i.e., without a digital platform. However, digital platforms can accelerate systemic learning enormously. Innovation can be defined as the acceleration of performance improvement of such platforms [1,13,14].

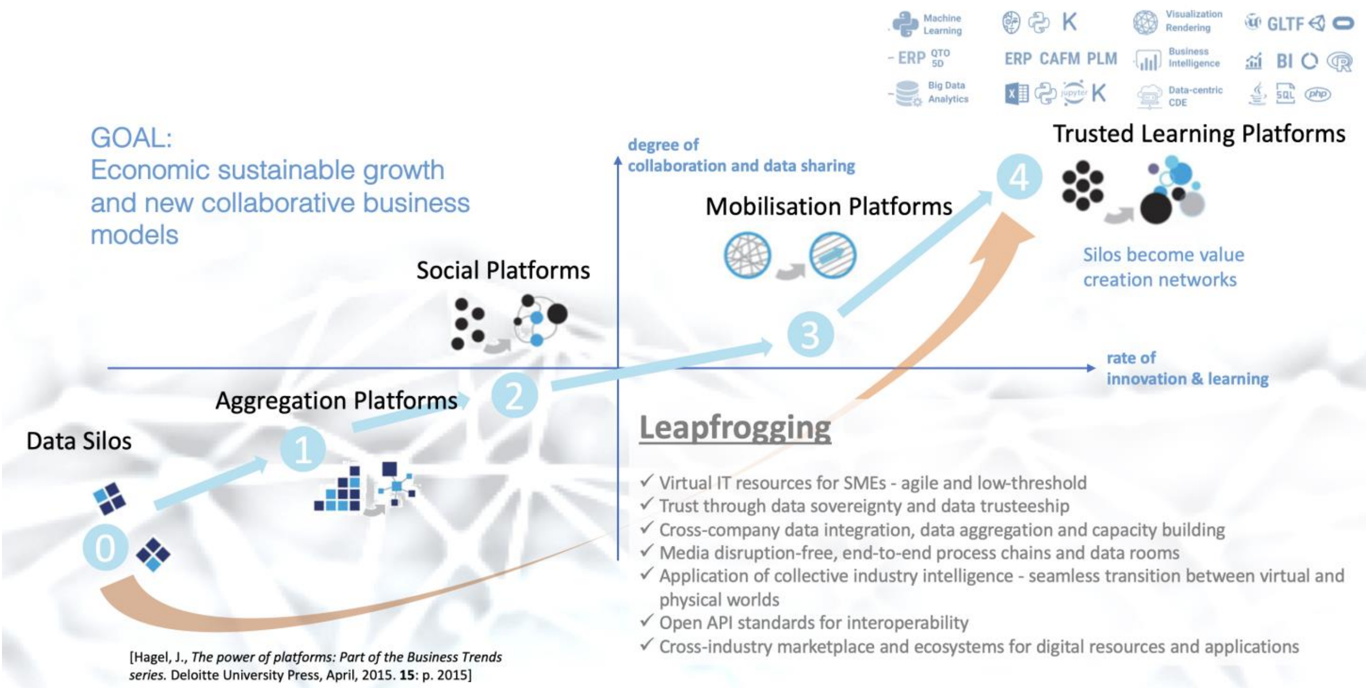

Figure 1. The vision of a data cooperative in construction: From data silo to trusted learning platform. Evolution of platforms; adopted from [7] (reprinted with permission) and based on authors' own research and depiction.

To enable the exchange and aggregation of data in a project environment, the various stakeholders must be willing to share their data. This is the case when the respective stakeholders see a clear benefit from it and can also decide sovereignly who and in what way their data can be further used. That is, the data provider remains in possession of the data and makes it available to the data consumers, who in turn offer digital services or use the data for processing [15].

One way to realize this is a so-called federated data infrastructure [16]. A federator guarantees secure exchange of data between data providers and data consumers. The term "federated" means that balanced and fair regulation ensures that the various stakeholders as a whole benefit from the data exchange [17,18]. The prerequisite for data exchange in a multi-stakeholder environment is therefore not only based on technical implementation, but also on fair and transparent regulation that is implemented in a trustworthy manner via an institution authorized for this purpose, the "federator" [19].

The participation in a so-called digital construction-project platform of small and medium-sized enterprises ("SMEs") is enabled by the federated and big-data-architecture [1] in such a way that this companies are incentivized to take part in the value creation network [20].

For users, a digital platform is made up of various applications [21]. The applications are not developed by the platform operator; instead, development is left to the market to exploit the full innovation potential. The platform creates an appropriate digital organization (design) for this purpose and also regulates the exchange of data. It forms the innovation and development framework for external software developers. The platform thus offers the opportunity to place new applications in a context with new or existing business models [22].

Particularly worth mentioning are business models based on smart services and data apps, use of data for AI services and to improve processes, marketplace for data and services for e.g., standardized construction supervision and quality monitoring, and incentive effects through cooperation for improved processes [23].

It should be emphasized here once again: Transparent data sovereignty is essential for the development of such a digital platform [24]. The regulatory framework of the platform therefore plays a decisive role. It can only be created as a cooperative regulatory framework that takes into account the different interests of the players involved in construction and balances out any conflicts of objectives that arise [25]. The digital transition is also an essential enabler of ecological, circular and low-carbon solutions as well as increased productivity by benefiting and connecting all steps in the building life cycle. However, it should be noted that digitalization is not the goal but one of the means towards a more sustainable and more resilient construction ecosystem [26].

In this paper, we will first discuss the research methodology we used to develop an experimental prototype for a federated innovation data platform. This will be covered in Section 2. Next, in Section 3, we will delve into the current state of digital transformation in the construction industry, including an examination of the trend towards increased market concentration. In Section 4, we will propose a suitable federated reference architecture framework, discuss cooperative governance, and identify and prioritize potential use cases. Finally, in Section 5, we will provide a summary, note any limitations, and suggest future directions for this research.

2. Research Methodology

The research project aimed to develop an experimental prototype for a federated innovation data platform along a suitable exemplary use case. The prototype was to serve as a demonstrator for further developments and develop the basis for a project-based digital innovation platform. It should exemplify how an overall concept is concretely implemented along one or more use cases. This will create a blueprint and a framework for further developments, which will then be further established in the market in a demand-oriented manner. The research project will thereby also illuminate the perspective of different business model innovations as well as the overall potential of possible platform business models.

The innovations of the research and development project consisted of the following work packages (WP, see also Figure 2):

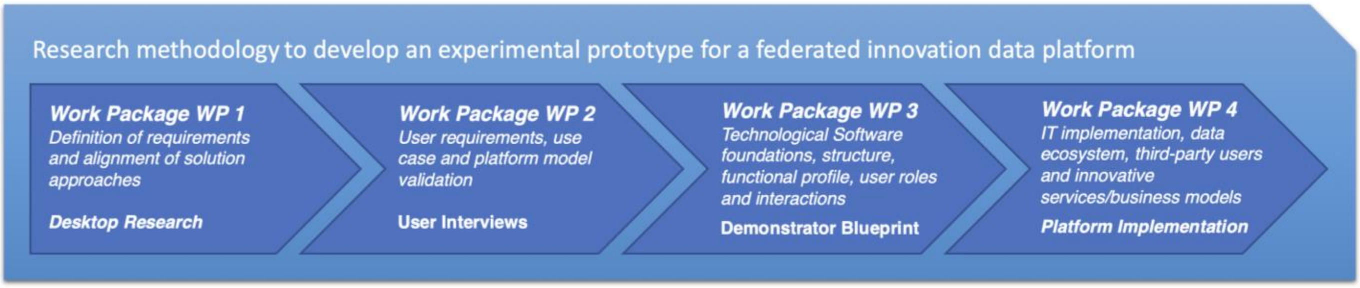

Figure 2. Research methodology consisting of desktop research (WP1), user interviews (WP2), demonstrator blueprint (WP3) and platform implementation (WP4); based on authors' own depiction.

- WP 1 Definition of requirements and alignment of solution approaches (desktop research): A targeted identification was carried out by means of a pre-selection of possible convincing, exemplary and scalable use cases for the federated innovation platform as well as design of a conceptual and structured framework for the innovation platform with regard to its general applicability. The subject and goal of the first work package was a comprehensive inventory of the intended application context and the resulting business, IT, data, and governance-related requirements and framework conditions. The basis for this was a literature research on existing state-of-the-art examples in the area of federated innovation/data platforms and the evaluation of existing industry surveys, i.e., desktop research. Likewise, existing, fundamentally comparable or related approaches and current implementation initiatives, e.g., from the *Industry 4.0* context and development projects were evaluated in terms of content and methodology and classified in the state of the art of federated platforms and methods. Against this background and on the basis of the preliminary work of the project participants, a detailed finetuning and further differentiation of the envisaged solution approaches was carried out, also with regard to the mutual fit of the individual approaches for the implementation of the intended overall concept. It is important to note that a secondary research approach has certain limitations. For example, the data used may not be current, or may not be directly related to the specific research question. Additionally, the authors may not have access to all the relevant data and information needed to conduct the research.
- WP2 User requirements, use case and platform model validation (by means of member, expert, user interviews): Validation of the hypotheses as well as the use case pre-selection of the desktop research with the help of member, expert or user interviews. The decision-making basis was provided by telephone interviews and video conferences with selected members of the Bavarian Construction Industry Association (*Bayerischer Bauindustrieverband e.V.*, Munich, Germany), which were engaged to iteratively test and deepen existing use case ideas. The object and goal of the second work package was the concrete determination of requirements and potentials as well as the conceptual development of an implementation strategy for the federated innovation platform that can be implemented in software terms with a focus on the user experience. For this purpose, suitable user requirements were developed and critical components as well as user pain points were identified. The results were used to align the structure of the federated platform and the accompanying activities accordingly. The bilateral member survey was also an important element of the work plan, as this is where trust in a future data ecosystem is already established and potential project champions for the implementation phase are identified.
- WP3 Technological Software foundations, structure, functional profile, user roles and interactions (Demonstrator Blueprint): A blueprint of a regulatory concept for the Federated Innovation Platform was developed, which takes into account the different interests of the involved stakeholders regarding their data sovereignty. For this purpose, an exemplary concept was created as a prototype for the selected use case.

Based on the framework conditions and technical principles systematically specified in WP1 and WP2, WP3 aimed to develop a scalable software-technical platform system environment and associated central functional mechanisms, as well as to map them in a high-performance, practice-oriented test environment (IT hardware, server landscape, cloud services, etc.). As part of this task and to realistically map the use case, the corresponding interface requirements of the specialist modules and data flows were formalized, specialist components to be integrated were specified and configured according to the state of the art (in-house and third-party services), hardware and cloud services were defined and set up, and software engineering principles for aspects of data management, federated platform functions and user interaction were implemented (Figure 3).

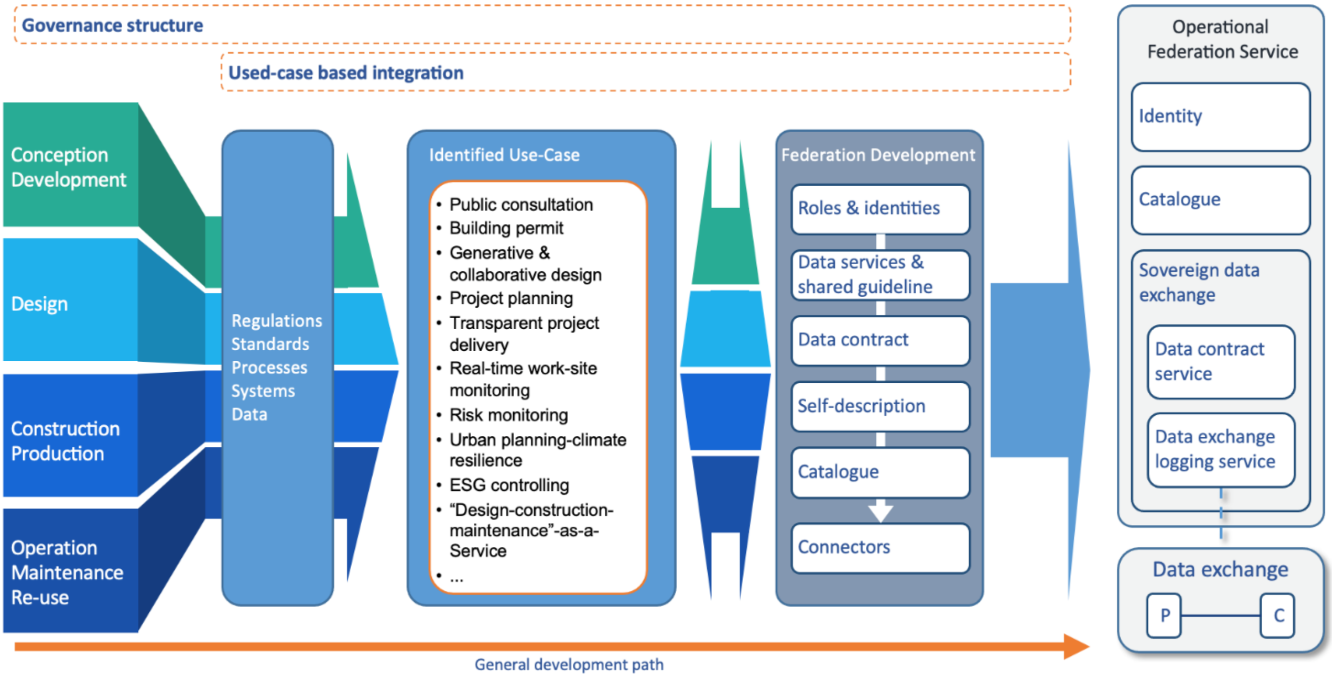

Figure 3. The Federated Innovation Platform prototype (WP3 and 4): A visual representation of the platform's regulatory concept, user roles and interactions, and integration of in-house and third-party services, showing how data flows and interface requirements are formalized, and how hardware and cloud services are set up and configured according to the state of the art. Depicting also the software engineering principles for data management, federated platform functions and user interaction that are implemented in the platform (from authors' own research and depiction of federated infrastructure platform concept [1,11] according to IDSA Reference Architecture model. Reprinted/adapted with permission from Ref. [27]).

- WP4 IT implementation, data ecosystem, third-party users and innovative services/ business models (platform implementation): The design and implementation (i.e., programmatic implementation) of the IT concept for the Federated Data Platform studied in depth in WP3 was prototyped based on the use case identified in WP2. Based on the framework conditions and technical foundations systematically specified in WP1, WP2 and WP3, as well as the demonstrator blueprint, the present work package aimed at implementing the federated platform and the exemplary use case. The concrete coordination of the work package contents WP4 resulted from WP1 to WP3 in coordination with the project sponsor.

3. Digitalization in the Construction Sector

3.1. Data Is the New Oil

According to Clive Humby, 2006, "Data is the new oil" [28]. The general public has been made familiar with this quote by the Economist in 2017 [29], which states that data has replaced oil as "the world's most valuable resource". For all its valid criticisms, Humby's quote is still accurate in many ways (see also [30]):

(1) The world's most valuable resource is no longer oil, but data [9]: However, aggregating data creates value exponentially at zero marginal cost and the digital transformation is more than just about cost efficiency.
(2) Data is increasingly valuable as an input to large-scale AI systems and economy-wide processes of technological investment and innovation.
(3) A large-scale infrastructure is needed to collect, cleanse, and share data. Infrastructure that must be built, funded, and regulated as part of large-scale projects in both the public and private sectors. Much like Standard Oil had a monopoly on oil refining [31], we have a monopolized and compartmentalized landscape for data refining and transmission. A landscape that is ripe for review, much like Standard Oil was.
(4) Disputes over data ownership, use, and sovereignty are increasingly becoming a national and international challenge [32]. They create tensions over technological interdependence and drive state and regional agendas. Access to data is more and more seen as an issue of national security and the national technology agenda, as much as a critical contributor to the domestic new economy [33].

But data as the new oil leaves out important perspectives. It's being misunderstood in ways that have real implications for how we think about and regulate data [30]:

(5) Data encompasses everything from huge data sets that capture the web browsing data of millions of people to hospital patients records that often contain sensitive information. We can't look at these two data sets in the same way; and we shouldn't. And we can't use or protect them in the same way either. So, we can't just swap one record for another: they're highly context-specific, they're not interchangeable, they need to be protected and managed as such, and that needs to be performed flexibly, with individual and community decision-making.
(6) Right now, the law focuses largely on two kinds of data: (a) personal information, such as our social security numbers, and (b) intellectual property, copyrights and patents. However, today's evidence shows that the new oil age was not triggered by any of the above types of data (a or b). In fact, it is about a different kind of data, which is sometimes called (c) data exhaust [34]. These are the data we generate and that are captured as we move through the world today: data such as where we are, what we buy, who we talk to, what we write, who we swipe right, e.g., according to Tinder's core mechanics, and even the temperature we set our home to. Such data are no longer just used to sell us advertising. It is also being used to train algorithms that may have decision-making power over us or even try to mimic our intellectual abilities. These kinds of data that we are focusing on are subject to network effects that are obviously not present in natural resources such as crude oil. In terms of productive use, data are only truly meaningful and valuable in aggregate and its entirety. This creates incentives for the monopolized data collection we observe: e.g., a person's Facebook data, for example, is worth about seven cents only. The aggregate data of all Facebook users, on the other hand, is worth billions of dollars. As a consequence, Facebook earned about 208 dollars from each North American user annually (as per 2021/2022 data [35]). Typical AI applications rely on access to massive amounts of data and ideally on good quality data, but the current ecosystem often trades quality for quantity. In addition, most of these data are essentially collective: when a user makes a Facebook post and another user likes that post. Can you then claim that the "like" is independent of the post? When an email is sent and then responded to, who owns what part of that interaction? Who then owns the metadata of the exchange?

The types of data produced today are difficult to attribute to individuals, and because of network effects, data are valuable primarily because they can be used to predict the behavior of the people we are connected to. Therefore, these kinds of data are highly networked and interdependent, and at this stage highly collective.

(7) It is important to highlight that data are not just a passive and finite resource like oil that can be extracted. [36]. On the contrary, data are limitless and actively created through social interaction. It is a product of collective work—not some millennia old natural process. This is particularly relevant when we think about the data that train AI systems. Large-scale models such as Generative Pre-trained Transformer 3 ("GPT-3") [37], an autoregressive language prediction model that utilizes deep learning to generate text similar to human language is not a completely autonomous AI accomplishment, but rather the opposite [38]: those projects only work because they are trained on hundreds of billions of words initially written by humans capturing centuries of human history and culture, everything from books to Wikipedia articles [39]. Likewise, referring to "oil" as a metaphor for data suggests that data primarily function as a resource for economic gain at the cost of social cohesion and climate change. By treating data as the new oil, humanity already witnesses the risks and limits of a new dependency. This time, the new dependency is not about fossil fuel-based industrialization and hyper-globalization [40], but of hyper-digitalization. The digital transformation has already led to an uneven global concentration of digital resources and a heightened demand for digital sovereignty [41]. The former has been critically associated with "surveillance capitalism" [42] and "techno-feudalism" [43], which has manifested in the rise of digital monopolies and oligopolies constraining markets and data access, and threatening democratic values and fundamental rights. The latter, digital sovereignty, is the legitimate response toward the former, seeking to prevent and mitigate the disruptive impact of hyper-digitalization. The problem is not one of sovereignty or the right to make independent policy and technology choices but the line separating sovereignty from nationalism and protectionism. Like capitalism, technology lacks the intrinsic value of social and environmental good. Thus, to navigate and manage the digital transformation successfully, new governance models are necessary that serve society, protect privacy, ensure cybersecurity and digital market integrity, and help accelerate the decarbonization of the economy [44].

3.2. Industry-Specific Challenges

In the 21st century, infrastructure and building construction must adapt to shifting demographics by being climate-friendly, strong, and economically feasible, while still promoting growth and shared wealth [1].

The construction and real estate industry is noteworthy for its ability to readily adjust to the demands of a highly competitive market [45,46]. Very flexible, interconnected and open project-based networks of many different, often medium-sized companies along the construction value chain create a very high degree of market agility. Thanks to this extremely powerful structure, the construction and real estate industry is able to implement the most diverse and also technically highly demanding construction projects. This agile and project-based network structure poses a major challenge for digitization. So far, the IT industry has not been able to provide adequate solutions for this, especially when it comes to secure and sovereign data exchange between companies via shared data spaces. Solutions have been developed primarily for sectors in which individual companies assume complete responsibility for a product or service to be marketed, i.e., also fully control the data technology processes.

The network structure in construction initially contradicts central data management, as there is no so-called process owner [47]: the owner, architect, authority, engineering consultants, project controllers, subcontractors and their subcontractors, suppliers, etc. work together in a project, but each stakeholder more or less in its own data environment [48]. Some data can be protected from access by other stakeholders or uninvolved parties through modern IT programs, but this requires considerable administrative effort, which in the practice of a larger construction project is too complex to provide real protection.

There is no central party that is logical from the organizational structure and manages the IT system with all the data. The various stakeholders involved in construction cannot provide that. Even large construction companies cannot take over platform control because they are only involved at a very late stage in the value chain. By then, the essential planning steps have usually already been completed. Instead, network effects, economies of scale and lock-in-effects currently lead to a "winner-takes-it-all" situation (Figure 4).

3.3. Industry-Specific Challenges: SUMMARY

Commonly identified key challenges for the sector can be summarized as follows [49]:

(a) A unique combination of product, process, and team that does not allow for repetition as jobsites change;
(b) The data process is characterized by collaboration but lacks clear top-down leadership and is fragmented, making it difficult for a general contractor to serve as a leader, as is typically seen with a global integrator or Original Equipment Manufacturer ("OEM") in other industries;
(c) Non-existent market or technology leadership with the simultaneous participation of a large number of small companies;
(d) The construction site involves significant amounts of manual, low-skilled work, and the core construction and engineering knowledge is slow to change, with limited investment in ongoing education and training;
(e) The construction industry faces slim profit margins and tight timelines, which limit the ability to invest in large-scale research and development or experimentation with new technologies;
(f) The lack of standardization in many construction processes hinders the implementation of corresponding digitalization efforts; and
(g) A national and international standardization framework (DIN, CEN, and ISO) required for digital collaboration is still in its infancy.

However, despite the overall challenges, the importance of the construction sector should not be underestimated: According to [50], the EU's industrial construction sector employs approximately 24.9 million individuals and contributes 1158 billion Euros in value added, making it the second largest sector after retail, accounting for 9.6% of the total EU value added. The aggregate size of the global construction market was valued at more than US$10 trillion in 2022 and is predicted to reach US$15 trillion by 2028 [51,52]. The construction industry is dominated by micro and small enterprises, with 99.9% of the 5.3 million firms in the EU being SMEs. These companies account for 90% of employment and 83% of the total value added. The fragmentation of the industry is emphasized by the fact that around 90% of these companies are microenterprises, responsible for 45% of employment and 32% of the total value added. Therefore, a platform solution must both reflect the dominance of SMEs in the sector and provide an effective means to address the fragmentation of the construction ecosystem [50].

Figure 4. "The winner takes it all"—Growing market concentration of platforms shown in the field of Building Information Modeling ("BIM") between 2006 and 2020 (reprinted with permission from [53]).

A comprehensive survey of the European construction industry [54] regarding the state of the sector's digital transformation revealed the following findings:

(a) The industry is facing limited to average digitization, mainly utilizing it for communication and file exchange rather than for creating value and digital innovation;
(b) In this context, there are still major differences between subsectors in construction, i.e., high acceptance or maturity among planners versus low acceptance or low digitization maturity among SMEs. Likewise, between company sizes, i.e., limited acceptance of digital tools such as BIM among SMEs while BIM is already seen as a starting point for many digital transformation processes and other technologies among large contractors today;
(c) Predominantly, market forces are the main reason for starting or expanding digitization. Digitization drivers are therefore requirements from customers, project partners as well as competition.
(d) Despite having limited impact on digitization decisions, companies highly value all public or private initiatives aimed at promoting digital information sharing with construction partners, including government incentives, public funding, and public procurement; and
(e) Companies cite the following principal barriers to successful digital transformation: (1) cost, (2) ICT skills, and (3) embedded work culture immediately followed by (4) "lack of knowledge".

Based on the industry-specific challenges summarized above, appropriate responses must be found. The necessary strategies and recommendations to overcome these challenges can be summarized as follows [49]:

(1) Improved interoperability is an essential, if not the most important, prerequisite for all types of trust-based collaboration among construction stakeholders, which will thereby also greatly enhance innovation, i.e., process improvement and new software development, and the overall supply of construction services, i.e., competition.
(2) Urgent action is required to promote and widely support the creation of standards for optimized interoperability. This includes not only enhancing digital processes, but also standardizing data exchange through specifications for information delivery, data dictionaries, file formats, and API interfaces.

(3) To prevent a proprietary lock-in, data exchange standardization should only be done using open standards. This will improve the integration of construction data throughout all phases and applications, foster collaboration among leading standards organizations and committees, and strengthen data connections with the construction product and element suppliers.
(4) An important factor in facilitating the collaboration process at the project level is the increased adoption of standards for organizing and digitizing information (e.g., [55]) and translating them locally into protocols and software templates to facilitate or enable the entire ecosystem, especially resource-poor stakeholders (e.g., SMEs), to collaborate under real-world conditions on the jobsite.
(5) Platforms can play a crucial role in accelerating digitization in the industry by breaking down barriers and silos and transforming them into value networks. This can be achieved by combining functionalities, integrating construction knowledge, connecting with product data from the supply industry, and providing connectivity. Platforms can also assist construction companies in complying with technical standards and simplify the process, leading to immediate efficiency gains and driving innovation in digital tools.
(6) SME-centered technologies and SME-centered platforms should facilitate, not hinder, their digital transformation. Specific, visibility measures are needed to make SMEs aware of current (unknown-to-them) solutions and thus promote supply to more than 80% of the market, e.g., through intuitive low-threshold plug-and-play tools specifically customized for construction SMEs.
(7) Digital platform solutions that take into account SMEs' financial, collaborative, and technical capabilities and aspirations by offloading their IT resources while respecting data ownership and data certification, i.e., trusted data, will have a positive long-term impact on SMEs' digital transformation. Platforms could thus provide the basis for better coordination, collaboration and cooperation between SMEs and other key stakeholders on projects.
(8) National, regional, and municipal authorities can support the digital transformation of the construction industry by facilitating digital interactions, such as computer-readable building codes, digital building permits, digital performance checks, and by promoting their own digital initiatives or mandating selected digital tools for various actions.
(9) Digital skills shall be built at all levels of the construction sector, and digitally skilled personnel shall be trained for the sector by taking lifelong learning and retraining for granted. To achieve this, specific networks, tools for support, and demonstration centers should be established, and digital literacy levels should be raised among all stakeholders, in addition to increasing awareness.
(10) Support tools and demonstration centers shall be targeted at SMEs. A localized, pragmatic approach is needed to reach all subsectors and build trust. SMEs require straightforward tools with a compelling value proposition, hands-on training, and ongoing education programs based on current best practices. Industry clusters could play a key role in driving digital transformation, addressing specific challenges, providing information, networking, and fostering collaboration.

3.4. Responses and Developments of the Industry Sector

For years, the construction industry has been pursuing the goal of data-networked cooperation between all parties involved in a construction project. Better cooperation and data sharing among construction stakeholder would be highly valuable. However, the fragmented value creation network is on the one hand a great strength of the business sector, but on the other hand, it is a weakness if a higher level of digitization is to be achieved, at least, that is the case when one tries to transfer the previous digitization concepts to the construction industry.

However, the question arises as to whether the construction industry must adapt to the existing concepts of digitization or whether concepts should not be found that utilize and retain the specific character of the industry as a strength. It is to be considered that the construction sector adapts highly to the requirements of the market. Construction projects are inherently decentralized, as there is no single coordinating body that centralizes decision making throughout a building's lifecycle. Instead, multiple independent stakeholders interact in a network with the building over time, from design to operations and maintenance, to the demolition and recycling of materials. However, because they are all dealing with the same physical asset, intensive collaboration between these stakeholders is indisputably required.

According to Werbrouck et al. [56], few industries are as fragmented as the construction sector, where countless actors are involved during the lifecycle of a facility, from direct actors such as the architect, the owner, a construction company and a building manager, to indirect data providers such as governments or geo-institutes. This "federated" reality is in contrast to the previous digital concept of a "centralized" cloud server, which is a "common data environment" (CDE). Therefore, Werbrouck et al. proposes a basic infrastructure for a "federated CDE" that uses domain-independent web specifications for (access-controlled) data federation [56].

The construction industry has been working on a consistent step in this direction for many years with the development of BIM (Building Information Modeling). The idea behind this is that all parties involved in a construction project handle all necessary processes—from planning to demolition—via a central data system.

Recently, this collaboration has been shifting more and more to specialized cloud-based ecosystems defined in ISO 19650, which is called Common Data Environments (CDEs). These CDEs are usually provided by major BIM tool vendors (e.g., AutoDesk, Aveva Group, Bentley Systems, Hexagon, Nemetschek, Trimble, etc.) and offer the most seamless integration possible with these often-commercial BIM related tools. However, the larger the scope of the project, the greater the likelihood that the stakeholders will not all be using the same ecosystem. After all, they represent different disciplines, so the data models they use are likely not aligned. To overcome these data-sharing challenges, the use of Semantic Web technologies for building lifecycle information management (BLC) has become increasingly important in recent years. Project contributions from different stakeholders can be hosted on different servers with this, but they remain semantically connected and clearly part of the same overall project [56].

According to Oraskari et al. [57], a Common Data Environment (CDE) serves as a shared source of information for construction projects, where data is collected, managed, and shared among stakeholders. Oraskari [57] proposes the use of *buildingSMART*'s BIM Collaboration Format (BCF) as the digital component of the CDEs in the AEC domain. Unlike the decentralized nature of the AEC industry, CDEs are typically centralized, and thus, he suggests a distributed environment for BCF as an example for further development in CDE distribution and data management. This would allow for the centralized benefits of a single source of truth for project data while providing a decentralized architecture for authentication and stakeholder control of their data.

In summary, it can be deduced from the above that a Common Data Environment (CDE) can certainly be established even in a very fragmented environment. However, this naturally requires regulatory agreements to which the market participants, both on the part of the software providers and the users, adhere. The central question here is who will take on this regulation and how it will be enforced in the market. It should be particularly emphasized at this point that the very dynamic changes in the technology of data platforms also require very dynamic and agile regulation. The usual approach of the construction industry in such a fragmented market to create uniform rules for all market participants involves in particular standardization procedures. However, this approach is not suitable in this dynamic environment; it is far too slow.

For this reason, it is the extremely fast-developing IT companies in particular that are creating quasi-standards through market monopolization. This is a key reason why even in recent years, a few globally active IT companies have become monopolistic market leaders, increasingly moving into the center of industrial value creation and even more increasing their dominance via network, scale and lock-in effects by developing new AI-based business models based on the data they aggregate. The construction and real estate industries are also increasingly affected by these developments.

4. The Search for a Suitable Platform Architecture

For the construction sector, we therefore propose a federated organized data network that promotes the data sovereignty of the construction and real estate industry with concrete measures and guarantees in the long term:

- The technical basis for such a federated CDE is a digital platform for the construction and real estate industry;
- The regulatory basis is implemented through a data cooperative of companies involved in the value chain of planning and constructing built environment.

This can be effectively achieved by creating federated digital platforms for construction projects based on use cases, vision, and governance.

4.1. Federated Reference Architecture Frameworks

Digital platforms facilitate active involvement throughout the lifecycle and ensure effective governance based on a common vision. The DigiPLACE project [49,58,59], which is funded by the European Commission, Directorate General for Communications Networks, Content and Technology ("DG CONNECT"), started with the idea to understand the following (Figure 5):

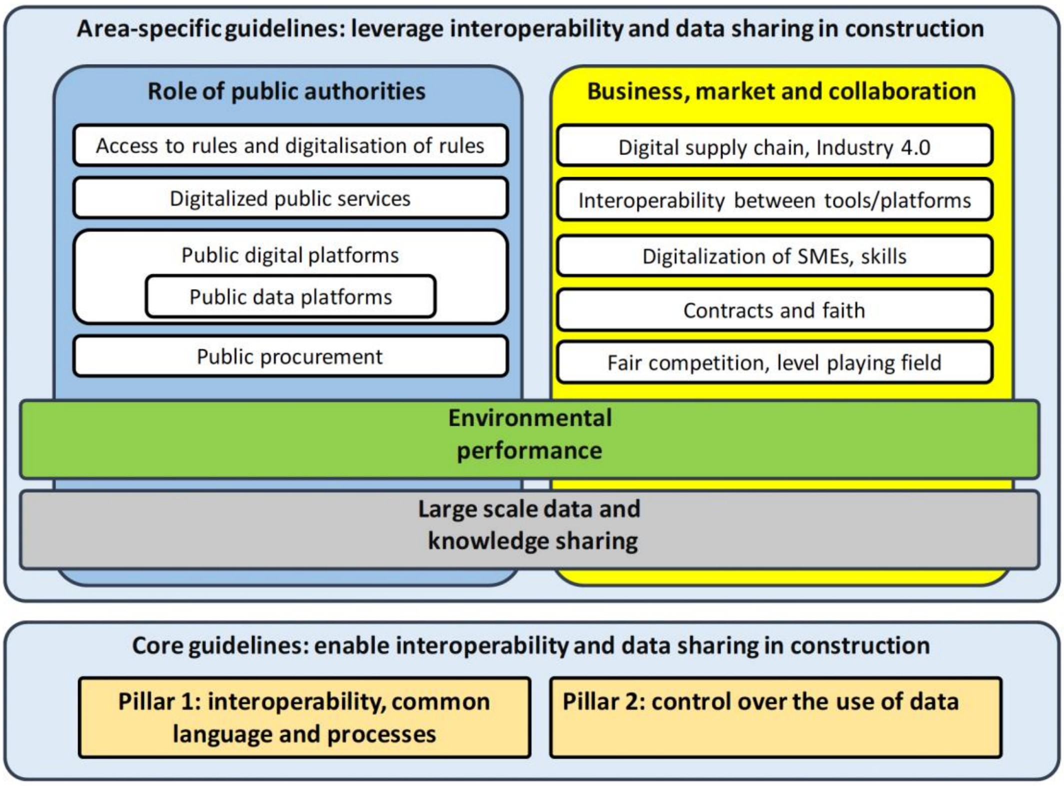

Figure 5. Reference Architecture Framework for construction digital platforms (reprinted with permission from [59]).

(a) How digital platforms can be developed in the context of the construction sector;

(b) How the construction supply chain can be integrated with such platforms; and
(c) How the diverse stakeholders base can benefit from it [26]. DigiPLACE's Reference Architecture Framework ("RAF") brings together the different views of stakeholders and creates a common understanding of the requirements for interoperable platforms.

The RAF is organized into two main blocks: (A) the core policies that enable interoperability and data exchange, and (B) domain-specific policies that leverage interoperability to create benefits and a strong value proposition. The first block covers aspects such as common language and processes and control over the use of data. In the second block, use cases have been identified in the following four separate areas:

(1) Environmental performance, e.g., BIM-based life cycle analysis ("LCA");
(2) Large-scale data exchange via business-to-business ("B2B") or business-to-government ("B2G") platforms;
(3) Business, market, and collaboration, e.g., BIM-based project collaboration; and
(4) Public services and initiatives, e.g., digital building permits, digital construction diaries.

In Ref. [1], the concept of a data platform for the complete value chain in infrastructure development was proposed. The platform is the digital manifestation of a value creation network with a large number of participants. The platform enables the targeted exchange of data between the stakeholders and therefore not only needs to standardize data interfaces but also needs to design a basic architecture for this purpose. This is necessary so that an organizational structure can be introduced into the network of different applications and so that the platform can be organized. The authors of this article propose a module structure for this purpose as well as a layer model that is based on the RAMI structure of Industry 4.0.

Ref. [1] outlines that platform creators and important participants should consider five dimensions in the iterative process of "systems convergence and platform emergence" to maximize the benefits of this transformation process, as shown in [1] Figure 6: governance, design, protocols, implementation, and use case scenarios.

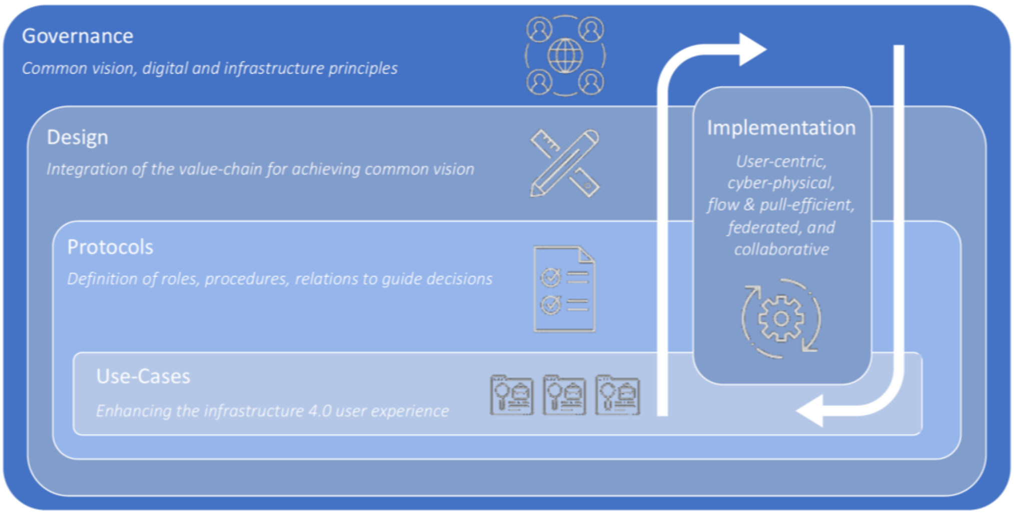

Figure 6. Five dimensions of implementing a mobilization and learning platform (authors' own research and depiction [1]).

We do not wish to go into detail on the technical implementation in this context. However, it should be emphasized here that extensive regulation will be required for technical implementation. In this context, we must therefore also answer the question of who will establish these regulations in the construction and real estate sector. The regulatory framework relates not only to the technical exchange of data but also to regulations governing the structure in which the various parties involved can interact with each other and ensure their data sovereignty. The following chapter therefore proposes a data cooperative as a solution to this central issue.

4.2. The Data Cooperative Model and Platform Model Validation

As a regulatory institution, the authors of the article propose the establishment of a "data cooperative" in the construction and real estate industry. The cooperative follows a similar basic model as DATEV eG ("eingetragene Genossenschaft") [60] in the 1960s. It was a catalyst for electronic data processing in financial accounting. The envisioned current cooperative goals reflect the cooperative digital transformation of the tax accountancy industry, which could thus be a blueprint for the construction and real estate industry: "The open DATEV ecosystem (software, cloud services, integrative platforms) forms a media-break-free extension of the process chain that can be mapped end-to-end. In this way, the workflow within companies, but also between companies and DATEV's members, the tax consultancies, is optimized on a broad basis" [60].

Data cooperatives can create an institutionalized governance framework for the participants as well as a trust space for sharing data across corporate boundaries [26]. The basic idea is to establish a cooperative whose purpose is to create a common data space. With a cooperative, a legal form is deliberately chosen whose explicit and legally binding purpose is cooperation for the benefit of the members (GenG §1) [61]. On the one hand, cooperatives have a long tradition, which in Germany goes back to the Cooperative Act of 1867 [62]. In particular, cooperatives are established for the joint procurement of goods (e.g., for farmers or bakers), for joint production and joint distribution (e.g., for vintners and winegrowers or in the timber wholesale trade) or in banking (e.g., the Volks- and Raiffeisenbanken) [63].

The cooperative model is not only proven and popular in the SME environment, it also offers many other advantages as an institutional framework for sharing and refining data across companies: from the creation of a defined and legally secured cooperation structure to the scalability and openness of the membership structure, the establishment of a neutral organization that is responsible for joint data management and utilization, and the claim of cooperation inherent in the cooperative model. Moreover, when it comes to new technologies, such as artificial intelligence (AI) and data analysis, small and medium-sized enterprises (SMEs) in particular often find it increasingly difficult to compete with international corporations. A significant reason for this is that SMEs cannot build up the data assets needed to develop and deploy analytics and AI methods. A data-cooperative model could overcome this problem [64].

One of the main reasons for this is that SMEs' data are limited in scope and richness. Current AI approaches are characterized in particular by the fact that they can include a large number of parameters and perspectives in an analysis and thus enable holistic solutions for a given problem context. A single, specialized SME, on the other hand, can often only provide an excerpt of the required data. In addition, there is the question of the resources to be made available. For example, employing data scientists is difficult to justify economically for many SMEs [65].

The fundamental thing that sets data cooperatives apart is that this is a collective approach to the stewardship of this data. It is an approach that understands that one, the data we produce by moving through the world is an exhaust, it is valuable and it is the product of work. Two, most of these data are collective and they are most productive and most accountable when treated that way. Data such as this cannot be owned, but it absolutely must be governed. The way that data cooperatives do this is by forming a new technical and institutional layer that would exist between those that have data and those that use. It is accomplishing all the tasks the industry is lacking right now: mediating data flows, governing data use, reuse, storage, and transfer, preserving privacy, and also building the high-quality data sets we increasingly need to enable competition and unlock innovation [66].

4.3. Identification and Prioritization of Suitable Use Cases

Recently, the utmost importance of identifying and prioritizing suitable use cases (Table 1) has been acknowledged by industry experts [67], who postulate that certain practices will enable construction companies to move beyond isolated pilot projects and unlock the value of digitization across the enterprise (Figure 7): These practices include

Table 1. Pre-selected exemplary and scalable use cases for the federated innovation platform. The prioritization is based on a non-representative industry survey in which we asked the following question: Which of these known use cases should be prioritized for open standardized interfaces (APIs) and collaborative federated data spaces in the context of data cooperatives for the construction and real estate industries? (* survey of 61 experts from construction and 23 experts from real estate industry, highest priority > 10 points, high priority > 7 points, top 3 priorities in **bold**).

Use Case Title	Use Case Examples	Category	Priority *
Standardized purchasing platforms	e.g., e-quote, e-purchasing, e-contract, e-delivery bill, etc.	commercial management	construction (8.93), real estate (4.61)
Smart commercial processes	e.g., digital invoice verification, costing, controlling, bonds, insurance, hedging, etc.	commercial management	construction (**9.72**), real estate (**7.78**)
Easy Health, Safety, Environment (HSE)	e.g., HSE statistics/documentation, work releases, environmental permitting procedures, etc.	health and safety	construction (6.80), real estate (1.44)
Intelligent construction logistics	e.g., synchronization with the production process, material tracking, supply chain optimization, customs/import/export permits, etc.	logistics, supply chain management	construction (**12.46**), real estate (5.09)
Agile design coordination	e.g., collaborative openBIM, digital surveys, digital design management, digital as-built/mass determination, etc.	asset design	construction (9.66), real estate (5.70)
B2Public data sharing in the public interest	e.g., digital stakeholder management, issue/sentiment tracking, etc.	data sharing	construction (6.21), real estate (1.96)
Collaborative quality and defect management	e.g., material testing, manufacturing protocols, digital defect management and documentation, as-built documentation, preservation of evidence, etc.	asset production	construction (9.54), real estate (7.65)
Lean Construction 4.0	e.g., networking of production data, collaborative kinematics/operating characteristics tracking, cycle planning/control, predictive maintenance, etc.	asset production	construction (**10.41**), real estate (5.44)
Intelligent contract controlling	e.g., change management, acceptances, digital contract management, smart contracts, approvals, etc.	commercial management	construction (9.10), real estate (5.91)
Cooperative workflow management	e.g., document management, rights management, construction diary, protocols/reports paperless construction site, etc.	asset communication	construction (9.53), real estate (5.17)
Data fiduciary services for smart collaboration	e.g., pre-competitive Big Data/KI analysis of historical construction and operational data, etc.	data sharing	construction (7.25), real estate (4.17)
Digital sustainability management	e.g., ESG compliance and tracking, LCA tools, carbon pricing, material passports, total cost of ownership, etc.	asset communication	construction (7.77), real estate (**11.35**)
Digital HR management	e.g., time recording, access/work/special permits, driver's licenses, BG Bau, etc.	asset production	construction (8.71), real estate (2.13)
Use case innovations	e.g., other case studies that have not yet been or cannot be mentioned here	innovation management	construction (2.74), real estate (0.87)
Intelligent operating concepts	e.g., PropTech, digital tenant/asset/facility MGMT, etc.	asset operations	construction (7.07), real estate (**8.17**)
Collaborative project development	e.g., digital RE development tools/databases, real estate FinTech, digital crowdfunding, etc.	asset development	construction (8.48), real estate (3.13)
Digital building permits	e.g., open, standardized interfaces with the public sector for faster and more transparent approval processes	asset development	construction (9.30), real estate (7.57)

* based on industry survey.

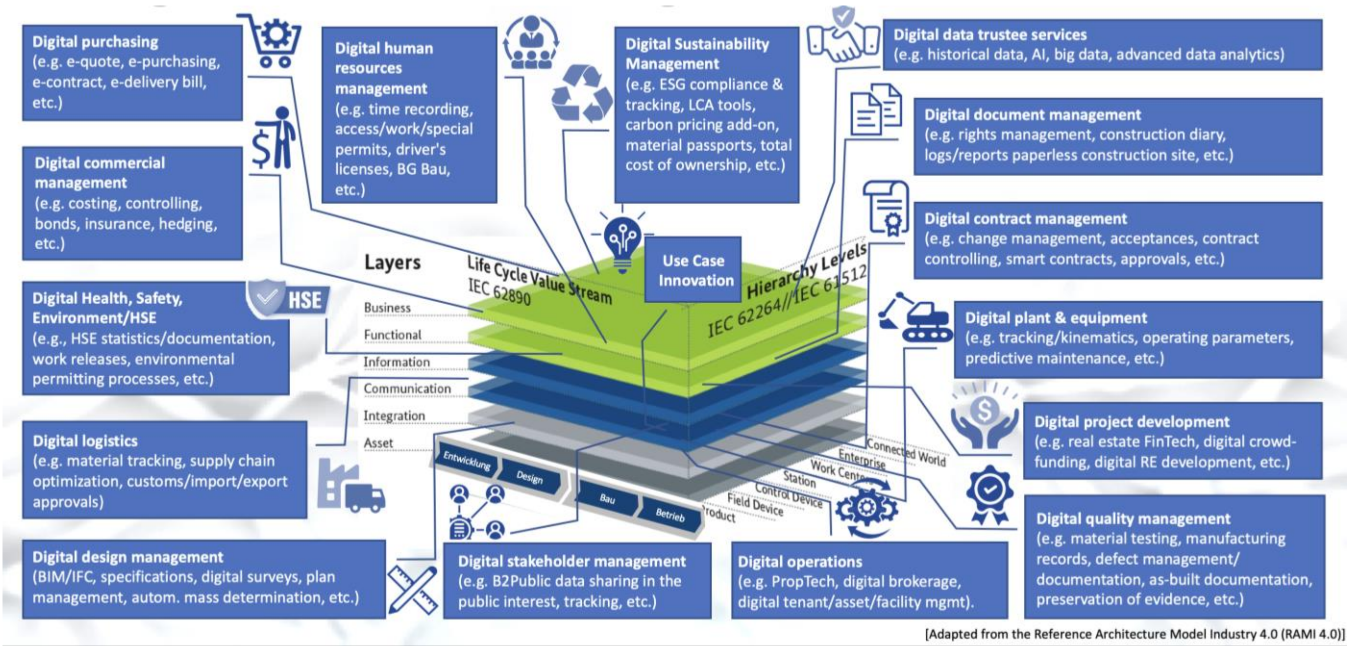

Figure 7. Exemplary use cases of a data cooperative: digital interfaces, data exchange formats and structure, adapted from the Reference Architecture Model Industry 4.0 (RAMI 4.0, reprinted with permission of [68]).

(a) Focusing on fixing pain points rather than installing IT solutions;
(b) Implementing digital use cases that drive collaboration;
(c) Retraining and restructuring engineering teams;
(d) Aligning project baselines to capture value; and
(e) Linking projects to create impact across the enterprise.

4.4. Governance Structure of the Data Cooperative

To reduce the risks while harnessing the opportunities of the digital transformation, a promising multi-layered governance model has emerged from this study. The study clearly suggests that not technology alone but governance is a crucial dimension of addressing the sector's challenges and enabling data sharing. Governance should not be seen as a structure restricting multistakeholder industrial activity but rather as the possibility of collaboration across organizational boundaries following shared principles. The proposed governance model combines hard principles (laws and regulations) and soft principles (values, standards, and procedures). Thus, governance compliance and conformity should provide the certainty and trust needed for data sharing alongside the sector's value chain and within a multi-cloud environment. It increases efficiency and provides industrial and digital governance capacity and capability that is usually lacking with small and medium-sized businesses. The proposed governance model is comprised of four types of governance (Figure 8):

(1) Organizational governance;
(2) Digital governance;
(3) Industry governance;
(4) Project governance.

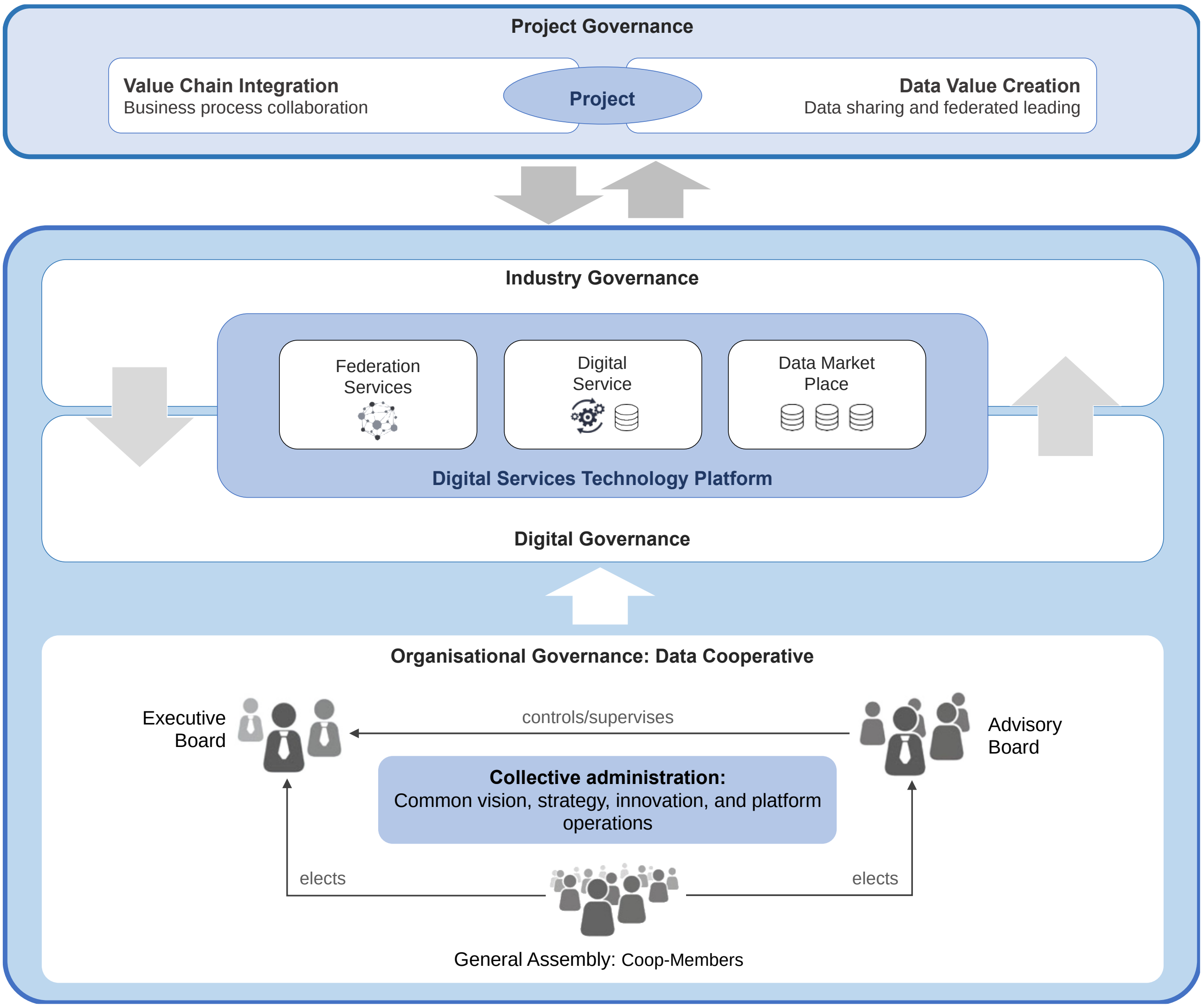

Figure 8. Types of governance for trustworthy digital collaboration (authors' own research and depiction).

(1) Organizational governance: The cooperative functions as the legal–organizational foundation of the learning platform. The cooperative is comprised of coop members representing the infrastructure industry and jointly steering the data cooperative. As the coop members are also platform participants—i.e., data providers, users, and project collaborators—the underlying organizational governance of the cooperative ensures a high level of trust. The main decision-making bodies of the cooperative are the general assembly, the advisory and executive boards. Based on an equal voting system where each coop member has one vote, the members elect the chairperson and members of the executive and advisory boards during the general assembly. The cooperative jointly determines the vision and strategy of the cooperative and platform priorities. In spite of the political nature of a cooperative, different governance mechanisms within the cooperative ensure decision-making agility. The cooperative remains open to new members; that is, any new member can join the cooperative but must adhere to its statutes. A separate legal entity that belongs to the cooperative could be used for managing the operations of the digital technology platform. The organizational governance complies with the legal requirements of the respective national cooperatives act.

(2) Digital governance: Digital governance is a common framework for accountability, roles, decision making, and change management with the objective to ensuring trustworthy digital collaboration. Digital governance requires the compliance with

cybersecurity, data privacy, data governance regulations and their technological implementation. Conformity is reached through certification and the implementation of digital technology standards. As the landscape of digital regulations, certifications, and technology standards has become very complex, the data cooperative with its digital platform provides governance capability and capacity which is often lacking with small and medium-sized businesses. However, digital governance remains a multistakeholder responsibility given the federated, decentralized, and multi-cloud environment of the learning platform and existing onsite legacy systems of platform participants. Yet, the data cooperative can determine the required standard and level of digital trustworthiness to which its members and platform participants must comply.

(3) Industry governance: Industry governance systematizes the application interfaces (APIs) that are provided by the platform and the underlying business process of the applications and data spaces. Industry governance interacts with digital governance and the digital platform as it enables the digital integration and thus collaboration between platform participants alongside the infrastructure and data value chains. Industry governance is mainly determined by an existing landscape of infrastructure regulations, standards, and business processes. Its complexity is highlighted by the Reference Architecture Model as depicted in Figure 7. In addition, here, small and medium-sized businesses strongly benefit from the industry governance provided by the digital technology platform.

(4) Project governance: The project constitutes the center of collaboration between platform participants and prioritizes the digital assets and applications needed for collaboration. During a project, the platform either helps to integrate processes during the planning or delivery phase of an infrastructure project or to reuse and aggerate data for analysis and learning. The former is the area of enterprise resource planning, and the latter is the area of data science. In this context, project governance is a management framework for decision making and incorporates elements of industrial and digital governance as well as the governance framework of project/platform participants.

Overall, the design and implementation of such a multi-layered governance model does not and should not happen at once in terms of a complex turnkey project. Instead, the governance model manifests subsequently and with agility, which is driven by the use cases (see Figure 7) selected and prioritized by the stakeholders and members of the data cooperative.

5. Conclusions

This concept paper seeks to demonstrate how a combination of governance and technology innovations, such as the legal framework for a data cooperative and digital federation, can enable secure, trustworthy, and sovereign data sharing within the construction industry. The former enables platform participants who are members of the cooperative to co-determine the principles and strategy of a data-sharing platform; the latter ensures decentralized data management and maintaining control of shared data. The paper presents and discusses the main results of the design and development of an experimental prototype for a data-sharing platform. It has become very clear that governance, rather than technology, plays a central role in addressing the challenges of the infrastructure sector and accelerating its digital transformation. Trust was identified as the most critical dimension for achieving a data-sharing platform. A data cooperative as an overarching legal–organizational structure managing a digital platform seems to manifest the required level of trust. This hypothesis was fundamentally confirmed by numerous expert interviews with Chief Executive Officers (“CEOs”) and Chief Technology Officers (“CTOs”) in the Bavarian construction industry, which we will leave anonymous at this point. While a data cooperative in combination with the data-sharing platform and a federated digital architecture prevents individual platform participants from dominating software applications and data and monopolizing them in the long term, it enables increased collaboration and innovation on the other hand. It also provides industrial and digital governance and standards that increase the efficiency, technological capabilities, and capacity of its participants and, most importantly, engage, enable, and accelerate the digital transformation of small and medium-sized enterprises in the overall process because it addresses several key challenges that SMEs face in their digital transformation. A data cooperative accelerates SME digital transformation by fostering collaboration and providing a framework for sharing resources, knowledge and navigating industry best practices. The authors therefore expect SMEs in particular to benefit greatly from a collaborative and federated data platform.

The limitations of this concept paper must be explicitly acknowledged. In the present context, the focus of the paper is only on the design and platform architecture development of the presented prototype for a data-sharing platform within the construction industry, with a particular emphasis on the governance and trust aspects of the platform. Consequently, the concept does not yet provide concrete information on the actual implementation methodology of the platform, or an assessment of its potential for success, including the incorporation of the roadmap to implement the proposed data cooperative. The presented results are based on expert interviews, which provide valuable insights into the topic and the overall resonance of the industry, especially in this initial phase. However, there is currently a lack of reliable data, such as actual usage data including user experience data during the use of the prototype or evaluations of concrete discussions during the founding phase of the data cooperative and the associated negotiations between the founding members. This is where the success of the proposed concept will first become apparent. Additionally, the study is limited to the specific context of the construction sector, and it would be beneficial to further explore and strategically exploit the potential applicability and generalizability of the results from other industries.

Future directions for this paper include the implementation of a specific use case selected by the constituent members of the data cooperative to test the implementation and capabilities of the data-sharing platform, measuring the impact of the platform on small and medium enterprises, and exploring the potential applications of the platform within the Bavarian construction industry. The authors plan to establish a data cooperative and data platform with a federated digital architecture and a robust governance structure, ensuring a high level of trust among all participants. The scalability of the data-sharing platform will be evaluated, and the security and privacy implications will be explored under real-world conditions.

In addition, the authors plan to investigate the potential of the platform to be applied to other prioritized use cases for the construction industry and to develop strategic partnerships with key stakeholders in these areas to promote the use and adoption of the data sharing platform.

As part of the G20/T20 Taskforce TF-2: Our Common Digital Future: Affordable, Accessible and Inclusive Digital Public Infrastructure [69], the authors intend to conduct a comprehensive study of the economic and societal impact of the data-sharing platform and use this information to inform the development of policies and regulations that support the platform's continued growth and success. This study will be a key step toward realizing the vision of a fully digitalized and connected construction industry that drives innovation, efficiency and sustainability.

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