New ways of data governance for construction? Decentralized Data Marketplaces as Web3 concept just around the corner.

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Abstract. In the upcoming era of distributed technological integration known as Web3, the built environment will need to adapt. Solving the most significant social, environmental and economic challenges will likely require new approaches to data sharing and efficient data management. This will need to occur within organizations, across software tools, and between partners. However, today's approach of data fragmentation and a scattered system of data islands prevent efficient data usage in the construction industry. The question that now arises is whether the decentralized marketplace approach has the potential to make construction data sets more uniform, efficient, and usable for all stakeholders through distributed technological integration. Therefore, this paper's contribution is to provide a conceptual starting point and possible research stream approach towards this question. Doing so by outlining current data management challenges and discussing them in comparison with already existing web3 approaches in research and industry.

1. Introduction

In today's digital economy, data is considered as one of the most important assets for businesses and society in general. New technological developments, such as mobile computing, the Internet of Things (IoT) and many more, lead to a continuous increase of applications, creating enormous potential added value for companies by generating information. They represent the foundation of a data-driven economy, the so-called data economy, on whose foundation new types of digital services and even new business models are emerging (Farboodi and Veldkamp, 2021). More and more industries are recognizing the benefits of data and its aggregation. Unfortunately, the Architecture, Engineering, and Construction (AEC) industry tends not to be one of them (Yan *et al.*, 2020).

To successfully manage a construction project's planning, construction, and operation stages, intensive and continuous communication is necessary among its stakeholders (Homayouni *et al.*, 2010). Throughout the life cycle of a project, these ongoing communications are often accompanied by the generation of large amounts of data in various formats and characteristics. The utilized data are no longer limited to governed database records but include data in non-traditional standard formats. Resulting in files containing data in structured, semi-structured, or unstructured formats whose complexity makes data processing and usability increasingly challenging.

In addition, the collaboration process is characterized by fragmentation, non-standardized collaboration, and actors and skills (Hall *et al.*, 2018). As a result, while the process of data handover between phases and the effective transfer of data is of significant value, it presents substantial challenges to industry practitioners. The critical issue in the field has been, and remains, how to achieve interoperability among the multiple models and multiple tools used throughout the different phases of a project (Poirier *et al.*, 2014).

To date, the majority of research on AEC data management, interoperability, and exchange operates with an underlying assumption that the data exchange and data flow occurs within a centralized system (centralized databases & control monopoly of platforms). However, the current growth of decentralized web3 approaches to data management and exchange provides

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an opportunity to understand how a decentralized data marketplace approach might evolve in construction. To further explore this concept, this paper conducts a comparative review in order to address the following questions:

- What are the data management approaches and applications of recent years in construction?
- How has there already been an influence of web3 concepts of the current state of data management practices in construction?
- What are decentralized data marketplaces, how have they been applied in other industries, and how do they offer a novel approach to solving current barriers in construction?
- How do decentralized data marketplaces compare to past centralized data management strategies?

2. Data Management Challenges in Construction

Today, the industry faces a major challenge to improve the efficiency and effectiveness of the integrated design and construction process (Lee *et al.*, 2005). In particular, the industry today is at a point where data and information must permeate a multi-layered and complex system in a machine-readable manner. This can be considered from three perspectives.

Figure 1: Perspectives on Data Management Challenges

2.1 Lifecycle Management of Data

Projects in the construction industry are characterized by many stakeholders from different companies and disciplines involved across different life cycle stages (Wu and Zhang, 2019). Therefore, continuous and intensive data generation and document exchange are essential for successfully handing over information between phases. As the project progresses, the volume of data continues to increase. Empirical data shows that individual file sizes currently range from megabytes to gigabytes, with a clear trend toward increasing file sizes.

Despite the long life cycle of decades of buildings, the actual life cycle of project data is short, concentrated in the design and construction phases (Huang *et al.*, 2021). Data is often constantly revised until the completion of a construction process, then delivered, archived, and occasionally accessed thereafter for building operations or facility management. Over time, they transition from an active to an inactive state. Therefore, it would be beneficial for companies and organizations to bring all project data under their control. The data becomes a real asset that can be used throughout the building lifecycle, especially for building operations and maintenance.

2.2 Data Silos and Islands of Automation

Driven by digital transformation, the industry increasingly uses Building Information Modeling (BIM), integrative methodologies, and corresponding digital tools (Klinc and Turk, 2019). The total amount of data in a construction project is often enormous, located in encapsulated systems with different formats and forming so-called silos of information (Corry *et al.*, 2014). Scholars and practitioners argue that data integration and its democratizing are the key factors for improving data management in construction.

With its numerous specialist disciplines and interdisciplinary dependencies, the construction industry resulted in an ecosystem of variety of software tools. These tools are tailored for different tasks and, in most cases, work well independently in their application domain. However, the challenge repeatedly referred to is that this ecosystem forms a landscape of islands of automation (Hannus *et al.*, 1997). Applications control their specific data without inherently sharing them with others. Therefore, the collaboration between architects, engineers, and contractors is still constrained by the heterogeneity of application models in general and the often lack of defined collaboration processes. There is hardly any possibility to use information from architectural design and the ongoing construction process to analyze the quality of construction works (Scherer and Schapke, 2011).

2.3 Information Loss and Interoperability

Interoperability is a recognized paradigm for connecting heterogeneous data systems into synergistic entities that enable more efficient use of information resources. If based on open standards, whether for file-based or server-based data exchange, it has many theoretical benefits.

Existing technologies can connect data in a federated environment, making it increasingly easy for stakeholders to access the information they need. However, the quality of the available information is also a decisive factor in determining its usefulness. The information exchange still heavily relies on the handover of files, for example, the 2D drawings and 3D models of a project. Such files are not machine-readable inherently, which means the information cannot be comprehensively interpreted and processed by computers. The information consistency can only be checked manually.

Moreover, the changes across disciplines and phases are time-consuming and costly. Errors are hard to detect and cause more significant problems in the further phases of the project. This inconsistency of information exchange is known as information loss. It is estimated that disorganized and poorly managed information, or a lack of linkage between documents and information, is often one of the leading causes of construction time delays.

Two commonly reported interdependent hurdles for achieving the interoperability of integrated building information within the construction industry have been the fragmented industry actor landscape and the heterogeneous adoption of IT among these actors (Laakso *et al.*, 2012). In addition, Abanda (2015) defined three types of interoperability barriers; conceptual, technological, and organizational.

2.4 Current Data Management Approaches in Construction

The AEC industry is solving the outlined challenges above by accelerating its digital progress rather on an application-specific level, i.e., with the advent and application of various digital technologies such as Building Information Modeling (BIM) or pertinent platforms. Therefore, several efforts have been made to promote BIM creation, sharing, integration, collaboration, and knowledge management throughout the lifecycle of a project. Two different types of methods for interoperability and collaboration based on BIM have been introduced.

The first approach is methods based on ontologies and semantic web concepts. Specific domain ontologies improve collaboration and decision-making by representing problem-solving domains for different disciplines. The second approach is based on the Industry Foundation Classes (IFC) format. IFC enables different participants, provided with heterogenic systems and applications, to simplify their exchange of information and enhance collaboration (Ismail *et al.*, 2017).

On a more technological level, cloud computing and platformization offer new opportunities for data management in the AEC industry. This can enable for example, a cloud-based common data environment (CDE). A CDE is a collaborative and integrative data platform solution for construction stakeholders that can serve individual projects while connecting enterprise-level processes. CDE applications begin with the planning phase but can act as the single source of data further along the lifecycle of an asset and for different purposes (Valra *et al.*, 2021). For example, Honic (2019) proposed how a CDE could digitally map an object with material passports to capture and store data for building materials and products. In a broader perspective, Bucher and Hall (2020) proposed that using linked data and ontologies can enable a three-dimensional ecosystem consisting of CDE's and digital mock-up platforms (e.g., digital twins).

Despite their potential, the widescale adoption of BIM and related concepts has been delayed as companies struggle with the lack of full internal and external data integration (Ullah *et al.*, 2019). Although most agree that new technologies such as BIM and CDEs are important, implementation still suffers from fragmented systematic data integration and weakening interoperability. Hence, there is a need for a common data foundation that can be used efficiently in a vendor-neutral way. In addition, there is a lack of a technological solution that democratizes access to data in a wide range of areas.

3. Web3 in the Construction Industry

3.1 Overview of Web3

Using the idea of a more autonomous, intelligent, and open internet, the inventor of the World Wide Web, Tim Berners-Lee, coined the term for today's web 3.0 as the semantic web (Berners-Lee and Hendler, 2001). This emerging concept offers a way to improve current data organization and management methodologies. The underlying principle is to categorize and store information in such a way that a system can learn what a particular piece of data means. In other words, data is being organized in such a way that programs are capable of understanding it in the same way a human would, enabling them to generate and share better content. Furthermore, the semantic web propagates an increased decentralization of information, focusing on consistency and accessibility (Staab and Stuckenschmidt, 2006).

Today, the content of the Web is designed to be consumed and interpreted by humans. However, most of this content cannot be automatically combined, aggregated, and condensed into new statements. Automatic processing by computers requires additional forms of data, called metadata, or data about data. Web3 is therefore understood by making web content readable by machines. To do this, new data distribution protocols are being developed that actively work together to form a fundamental network that enables artificial intelligence. A duality is thus emerging so that the web is no longer just a means to an end but also a network for non-human communication and automated data exchange.

Data within web 3.0 will be connected in a decentralized manner. This represents an evolution from the current generation of the Internet (web 2.0), where data is mainly stored in centralized repositories and encapsulated in documents (Alabdulwahhab, 2018). Representing a similar situation as in the construction industry. While earlier approaches to automatically linking data from different sources required the laborious creation of global metadata systems, newer approaches proclaim a data format that makes it easier to link data. The concept of directly connected data is termed *Linked Data*. In the past, expensive data integration has been a stumbling block in data publishing. In fact, to integrate two data sources, both semantics and syntax must be aligned. *Linked Data* is therefore built on a set of design principles to provide machine-readable data on the Web for use by the network.

In addition to machine-readable data, web 3.0 also creates the opportunity for storage and provision by decentralized systems (Jara *et al.*, 2014). For example IPFS aims to solve the web data's typical availability problems, such as the limited lifetime of content, firewall blocks, and out-of-business services (Benet, 2014). It uses cryptographic checksums of file contents to address and link data, which originates in GIT, BitTorrent, and distributed hash tables.

While the development of IPFS is primarily aimed at file systems, so-called blockchain databases can transform conventional storage systems. The advantages of such blockchain-like technology are decentralized control, tamper resistance, value generation, and transmission (Orjuela *et al.*, 2021). Research and use of these technologies are mostly missing in construction, whereas it seems interesting to replace current cloud-based, highly centralized solutions with such approaches. Therefore, future research approaches should not only be on technological feasibility but also the consideration of the fundamental redesign of today's data organization as well as its impact on data availability.

3.2 Approaches to Web3 in Construction

Construction scholarship and consulting reports have identified the advantages of web 3.0 concepts over the past decade. For example, (Pauwels *et al.*, 2011) formulate why and how web of data technologies (e.g., rdf, owl) can be beneficial for BIM. They outline use cases and their benefits situated in interoperability, linking data and logical inference. Farghaly (2018) formulated a framework for how the transfer of BIM model data to Asset Information Model (AIM) platforms might proceed. By defining a process map and connecting existing ontologies, this work aims to improve building assets information management.

Various ontologies have been developed so far. Generic ontologies such as ifcOWL can map the established IFC data structure (Pauwels *et al.*, 2017). Specific ontologies approach different data sets commonly used for building services engineering or cost calculations. However, the use of ontologies for multi-domain BIM methodologies is only just emerging (Rasmussen *et al.*, 2019).

In addition, the use of commonly used tools such as the CDE is being investigated by scholars from a more decentralized, web-based point of view (Tao *et al.*, 2021). Werbrouck (2019) formulated a CDE using decentralized data structures. Structuring information based on linked data and a web-wide graph opens up the possibility for digital agents to semantically interpret and use this data with minimal human intervention. In this regard, Oraskari (2018) discussed the possibility of federated building models in a collaborative AEC/FM setting. Based on the limitations of cloud data, i.e., limited content lifetime, limited resources, blocking firewalls, and unavailable services, this study addresses both the benefits and limitations of IPFS technology for implementing linked building data. Poinet (2021) pioneered an innovative open-source data framework to address the interoperability challenge. Introduced as *speckle*, the framework allows users to establish a flexible and data-driven dialogue between stakeholders in the design phase. Namely, the basic schema structure is not restricted to proprietary or industry-standard formats. However, it allows defining one's own domain-specific object models.

Overall, Web3 approaches in the construction industry are flawed in one respect. Even though they promise interoperability and vendor-neutral data access, most implementation are still technologically centralized (Soman *et al.,* 2020). This can create a barrier to stakeholder participation when technologies are still highly dependent on specific cloud platforms owned by others. There is a need for an open access, vendor-neutral, and decentralized data foundation. Furthermore, it should be added that specifically the use of ontologies and linked data approaches offers a possibility to link heterogeneous data sets. Nevertheless, in principle, these technologies do not create a system that incentivizes data sharing and seamless collaboration across phases and between actors.

4. Decentralized Data Marketplaces and Data Governance

4.1 Overview and Application in other Industries

In other industries, businesses and organizations have realized that data-driven decisions are far more effective than the traditional trial and error methods and intuitions (Frazzon *et al.*, 2018). As a result, they started generating data out of every operation and started analyzing the data to figure out opportunities to perform better, accelerate growth and enhance operational efficiency. But, similar to the construction industry, these data are often kept in data silos. The data owned by one organization can be useful for another, but unfortunately, sharing data between organizations is not stimulated. In addition, if data is generated and collected, one can observe a gap between the use and collection of this data. On the one hand, data collectors accumulate data from producers such as sensors, machines, and users. On the other hand, there are various data consumers such as analytics tools, artificial intelligence platforms, and models.

In recent years, numerous digital solutions have emerged whose primary business model is trading raw and processed data and offering data-related services. They exist as both centralized and decentralized. In other words: data sale has been practiced for a long time, but the data marketplace is a relatively new business model and refers to an intermediary service for data exchange (Ghosh, 2018). Most digital data marketplaces tend to have a centralized structure. Today's platforms provide an infrastructure for data exchange by acting as a digital intermediary. In addition, the marketplace operator acts as an overview agent, brings together supply and demand, and coordinates pricing. In this context, it is not possible to exclude that platform operators may abuse their control over the platform infrastructure and manipulate the market for their benefit. Data exchange and trade in the construction industry are primarily between different system actors, i.e., companies. Studies show that the business models of B2B platforms have not been able to show the same economic effects as the platforms in the B2C sector. The possible reason for this is a lack of trust (Hunhevicz and Hall, 2019). As a result, most platform users in the B2B sector try to create and operate their own platforms. Moreover, there is usually no exchange of information between individual platforms, which means that positive network effects no longer come into play.

Different researchers show that decentralized systems help increase trust in data and its processing. No entity takes a superior role. Therefore, the participants can trade with each other and exchange information that would otherwise not be shared while providing privacy, anonymity, transparency, and access control. These solutions often possess an in-built trust layer that enables data providers and consumers to build value on top of a trustless and censorship-resistant protocol, which promotes an open platform where anyone can join and add value to the network and community. By using blockchain, or more general, distributed ledger technology as the censorship-resistant building block, such concepts of marketplaces developed primarily from using specific parts of this technology (smart contracts). There are a few examples to mention here.

The most well-known project, *Ocean Protocol*, offers two main services (Ocean Protocol Foundation, 2020). A *Data Ecosystem Platform* and a decentralized *Data Marketplace*. The former facilitates control of data access, allowing owners to upload and store their data while retaining full control when monetizing the data for buyers. The data marketplace facilitates the selling and buying of data by connecting sellers and buyers around the world.

Another project is the *Enigma* (rebranded *Secret*) data marketplace (Zyskind *et al.*, 2015). It vision to complement a blockchain of any kind with an off-chain data network. Introduced as a decentralized privacy-preserving content management and data exchange protocol, it leverages the privacy guarantees of a specific trust network for data encryption and access management, as well as the decentralized data storage solution of IPFS.

Streamr focuses on the open and fair exchange of real-time data (Streamr, 2017). The marketplace offers access to paid and free data sources. The uniqueness is that the data is collected via an off-chain network, whereby larger amounts of data can be processed efficiently. However, the solution currently runs on a centralized structure which leads to the emergence of a superior third party.

Various research has examined the differences between centralized approaches of specific platforms such as data marketplaces and decentralized approaches. As a result, a decentralized approach enables the following benefits.

- Independency of any central server hosted by a third party (Ranchal *et al.*, 2010)
- Resistance to data tampering (Aniello *et al.*, 2017)
- Minimal manipulation of ratings and references (Shakeret al., 2021)
- No monopoly power of market platform operators (Vergne, 2020)
- Peer-to-peer data connections with seamless payments (Ramachandran *et al.*, 2018)

5. Discussion

As introduced above, the AEC industry has been diagnosed with some lack of digital systemic changes to reduce the industry' data fragmentation, improve communication efficiency and effectiveness, and reduce the high costs due to lack of data democratization among its system participants. Over the decades, many researchers working on changing this status quo have proposed many techniques and methods to improve data management issues, and a series of guiding standards and specifications have been developed in standardization organizations. However, these outcomes are often based on multiple perspectives, from different stakeholders' points of view, tailored to their countries, fields, and organizations' characteristics.

The high productivity of academic results does not imply that they can directly interface with reality and impact. On the one hand, new technologies leading the industry need to be popularized, learned, and understood by more practitioners. On the other hand, professional knowledge is constantly being cited in the process of ambiguity; many new technologies arise, are interrelated, may replace each other, or may function together. This difficulty highlights a certain impasse and the desirability of a completely new approach.

This approach, in the context of decentralized data marketplace and their potential application to construction industry challenges (see section 1.2) are twofold.

On the one hand, using a marketplace, decentralized or not, offers a certain impact on the quality of the submitted data. A particular quality standard needs to be met for successfully sharing or selling datasets. This standard can be defined by a central authority or a peer-to-peer mechanism. On the other hand, seamless access to a data distribution protocol allows the data to remain in a kind of silo solution, but the project phase dependency partially fades as the silo is part of a larger network. This gives a natural incentive or intrinsic motivation for the efficient handling, and cross-phase use of generated data within a company since breaking clear phase transitions no longer reduces the value of the data.

Decentralized data marketplaces operate similarly to their centralized counterparts. The key difference is the level of privacy and security provided by having two decentralized components in the web3 technology stack. In other words, the data owners have a secure and smooth access to their data, while maintaining privacy and confidentiality. This is because ownership never shifts to a central entity, meaning the data creator is paid for the data, not an intermediary. As a result, participants in the network are motivated to make their data available collaboratively while at the same time benefiting monetarily. In addition, as described above, incentive mechanisms encourage data providers to adhere to a particular data format standard. A decentralized approach reinforces that since intermediaries do not co-benefit from a data transaction compared to a centralized solution.

Moreover, the decentralized architecture based on the web3 technology stack offers the advantage that the implementation of an incentive system is simpler due to the characteristics of the decentralized trust layer

6. Conclusion

This paper attempted to encourage a discussion on the use of decentralized data marketplaces and provide a line of reasoning for further research on decentralized data marketplaces in construction. This by highlighting that data management in the construction industry still has certain limitations, although well advanced and addressed with various approaches. Therefore, whether these specific marketplaces offer a possible solution for further developing data governance and improving data-based, collaborative efficiency in construction, this contribution represents a first thought-starter in this direction. Still, these approaches have not yet been studied in detail, especially for the underlying data storage systems and different data characteristics. More detailed implications and impacts are therefore to be elaborated in future research.

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