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LEVERAGING BLOCKCHAIN FOR CIRCULAR ECONOMY: A DIGITAL PRODUCT PASSPORT PLATFORM FOR BIM-BASED DESIGN

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Abstract

This paper proposes a tool integrating a Digital Product Passport (DPP) system with a BIM library plugin to support modular construction and circularity. DPPs store essential product data, including history, technical characteristics, environmental impact, and reuse potential, structured using Product Data Template standards compatible with BIM. The platform allows designers to access reusable products' DPPs via the BIM library and import this data into their BIM models. By addressing lifecycle information gaps, this system enhances sustainable decision-making, reduces waste, and leverages modular construction's strengths in disassembly, recovery, and reuse to promote sustainability and a circular economy in the construction industry.

Introduction

The research presented in this paper was conducted as part of the project "R2UTechnologies - Modular Systems" which seeks to develop an innovative solution in Portugal within the domain of prefabrication and modular construction to meet the increasing demands of the global market. To address the issue of low material efficiency, various strategies can be adopted, including measures to reduce the generation of Construction and Demolition Waste (CDW) and to promote recycling or reusability. Two critical concepts adopted at different stages of the value chain and aligned with this project are Design for Disassembly (DfD) and Digital Product Passports (DPPs) (EEA and ETC/WMGE, 2020).

A significant challenge in circular supply chain management is the lack of accurate product data, which limits the potential for circularity. DPPs serve as a vital tool to provide this necessary data, facilitating informed decision-making in the context of a circular economy (Sesana, Rivallain and Salvalai, 2020).

Relationship between DPPs and the R-Strategies for a Circular Economy

Digital Product Passports (DPPs) constitute a critical instrument in facilitating the transition toward a Circular Economy by providing standardized and comprehensive data regarding a product's materials, components, and lifecycle (CE-RISE, 2023). This structured repository of information enables informed decision-making and enhances the efficiency of resource management. Specifically, DPPs play a pivotal role in the implementation of R-Strategies, an established hierarchical framework designed to optimize resource utilization, minimize waste generation, and maximize the retention of value throughout a product's lifecycle. These strategies encompass a spectrum of actions aimed at waste prevention, material repurposing, and value recovery.

The R-Strategies framework is classified into three primary categories: short loops, medium loops, and long loops (Daphne and Malooly, 2023). Short loops prioritize the optimization of product use and manufacturing processes, ensuring resource efficiency and waste minimization at the earliest stages of the value chain. Medium loops emphasize the extension of product lifespans through systematic approaches such as maintenance, repair, and refurbishment. Conversely, long loops focus on the continuous utilization of materials through advanced recovery and recycling methodologies. Notably, short-loop strategies are particularly effective in mitigating environmental impact, as they intervene at the initial phases of production and consumption, thereby reducing the need for new resource extraction.

DPPs serve as an indispensable tool in supporting both medium- and long-loop strategies by furnishing precise and structured data essential for their implementation. Within medium-loop strategies, DPPs facilitate maintenance, repair, and refurbishment (R4 and R5) by providing detailed records, including maintenance schedules, repairability metrics, and documentation of prior modifications. Furthermore, they offer critical insights into disassembly procedures, identification of reusable components, and assessments of material quality, thereby enabling key processes such as remanufacturing (R6), repurposing and reconditioning (R7).

In the context of long-loop strategies, DPPs significantly enhance the efficiency and safety of recycling and resource recovery efforts. By providing extensive data on material composition, quantity, and potential contaminants, they ensure the viability of recycling (R8) and recovery (R9) strategies. Moreover, they enable the systematic monitoring of hazardous substances, thereby promoting the safe and responsible reintegration of materials into the production cycle.

Objectives

The BIM unit within the R2UTechnologies project is dedicated to the development of two inter-connected platforms: a BIM library plugin and a DPP platform. The primary purpose of the BIM library is to store and distribute BIM objects that represent modular construction units, structured in alignment with standards governing the development of Product Data Templates (PDTs). The DPP platform, on the other hand, is designed to manage and distribute DPPs throughout the product life cycle utilizing blockchain technology.

Additionally, these platforms are interconnected via an Application Programming Interface (API), which facilitates the exchange of DPP data with the BIM library. This integration allows designers to access detailed information about reusable, real-world products and seamlessly incorporate such data directly into their 3D models.

The overarching objective is to enable these platforms to operate collaboratively, fostering a connection between suppliers of refurbished products and designers involved in new projects. This synergy aims to promote the circularity of sustainable products. Figure 1 illustrates the system architecture proposed in this research.

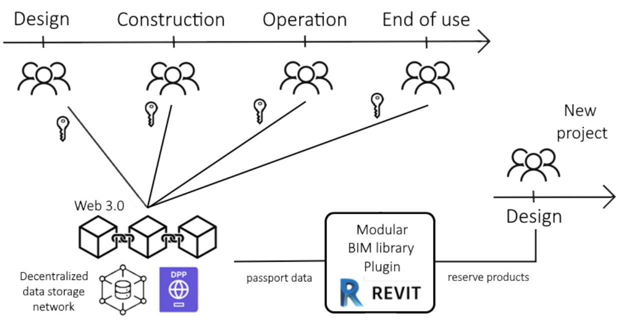

Figure 1: Overview of the system architecture of the R2UTechnologies BIM and DPP platforms

Implementation of the DPP platform

Digital Product Passports

The systematic collection of standardized information about building materials is critical for developing models capable of calculating material flows, which facilitate the construction sector's transition toward a circular economy paradigm (Heinrich and Lang, 2019). Comprehensive knowledge of material locations, technical characteristics, expected lifespans, and potential for reuse and recycling enables existing structures to be treated as material banks, a key element in establishing viable secondary raw material markets (Luscuere, 2016).

This information can be collected and distributed through Digital Product Passports (DPPs), which serve as identity documents for materials and products.

The objectives of DPPs are as follows:

- To provide detailed information on the technical characteristics of construction products.
- To enable the description and traceability of: (i) product usage, (ii) modifications throughout their life cycle, (iii) their implementation within constructions, and (iv) their interactions with constructions and other products.
- To evaluate the feasibility of product recovery, reuse, and recycling.

The European Union's Ecodesign for Sustainable Products Regulation (ESPR), which came into effect in July 2024, introduced new measures and core elements to promote sustainability and enhance legal compliance. Among these measures is the DPP, designed to consolidate essential information about products and materials. The DPP aims to improve sustainability practices and strengthen adherence to regulatory requirements. The complete implementation of the DPP is scheduled for 2030, with incremental adoption of delegated acts to further refine its requirements. These acts will specify critical elements such as data carriers (e.g., QR codes, NFC, and RFID tags), essential data attributes, and timelines for mandatory compliance, tailored to specific product categories.

Although a fully standardized structure for the DPP is yet to be finalized, preliminary guidelines for the required data have been established. These include:

- Unique product identifiers and Global Trade Identification Numbers (GTINs).
- Relevant commodity codes, such as the Integrated Tariff of the European Communities (TARIC) code.
- Compliance documentation and voluntary certifications, including EU Ecolabels.
- Information on substances of concern.
- Instructions regarding the installation, use, maintenance, repair, disassembly, recycling, and disposal of the product, as well as essential warnings and safety information.
- Details about the manufacturer and importer, including unique facility identifiers and unique operator identifiers.

This framework underscores the EU's commitment to creating a robust and sustainable regulatory environment, facilitating the transition toward a circular economy. DPPs represent an essential tool for addressing challenges related to the storage and exchange of material and product data. Presently, much of this critical information remains unknown or is not shared among the various stakeholders within the construction industry's value chain (BAMB and TUM, 2019). Both the Ecodesign for Sustainable Products Regulation (ESPR) and the Construction Products Regulation (CPR) emphasize the necessity for DPPs to adhere to EU standards for data management, such as EN ISO 23386 and EN ISO 23387. By structuring DPP properties and property groups in alignment with these standards, interoperability is ensured, enabling this data to be effectively utilized within the context of BIM.

Hurdles of DPP implementation and proposed solution

The construction industry faces significant challenges in implementing these passports, with two of the most critical being the extended lifespan of constructions and the inherent fragmentation of the sector. The construction industry experiences three primary types of fragmentation: horizontal, vertical, and longitudinal. Horizontal fragmentation pertains to the multitude of actors operating within a single stage of a project, vertical fragmentation arises between different project stages, and longitudinal fragmentation occurs as project participants disband upon project completion (Mehran, Poirier and Forgues, 2022). These forms of fragmentation impede the seamless flow of information and the effective sharing of knowledge among stakeholders (Fellows and Liu, 2012).

Given that constructions typically have lifetimes ranging from 30 to 100 years, ensuring the integrity of these passports throughout the entire life cycle is imperative. Recognizing that the future cannot be predicted with certainty, where forecasts represent scenarios with varying probabilities, it is crucial to consider and mitigate associated risks. One promising approach to developing robust and enduring solutions is the adoption of decentralized systems, such as blockchain technology. This technology can also improve supply chain management and reduce associated costs, leveraging its inherent transparency and capacity for traceability (Jabbar *et al*., 2021). For these reasons, the proposed platform is grounded in Web3 technologies. Blockchains, being decentralized systems, do not depend on a central authority, making them inherently robust. The combination of economic incentives, such as mining rewards, and fault tolerance (i.e., the capability to operate reliably even when some nodes fail or act maliciously) ensures the consistent functionality of block-chains. Furthermore, the trustless nature of blockchain technology provides a compelling incentive for stakeholders across the value chain to share their data more freely. This is made possible as the data can be stored privately and secured through cryptographic methods, ensuring confidentiality and security.

The creation and permission to access DPPs within the context of blockchain technology can be facilitated through the use of smart contracts. These contracts are self-executing code that automatically triggers when the predefined conditions encoded within them are met (Stodt *et al*., 2024). Smart contracts are visible to all participants, enhancing transparency and trust by providing assurance to all parties that, once the conditions are satisfied, the contract will be executed without the need for intermediaries. This transparency does not compromise user privacy, as privacy control features, an essential requirement for many stakeholders along the value chain, can be incorporated to safeguard sensitive information.

The platform offers two distinct privacy settings for passports: public or private. When a passport is designated as private, users retain the ability to selectively share specific parts of the data with others. Custody and sharing control are managed through the use of non-fungible tokens (NFTs). Each passport is linked to a corresponding NFT, which establishes custody of the passport. The custody NFT further enables users to create or revoke permission NFTs, which can be transferred to other users to grant access to the passport's data. This token-based approach to data control is inherently portable, allowing tokens to be exchanged among users to delegate custody or permissions for accessing the passport data. This approach provides a more flexible and scalable solution for sharing control, in contrast to role-based access mechanisms, where access is rigidly confined to the specific set of addresses designated by the custody token holder (Hunhevicz *et al*., 2023). Furthermore, these permission tokens can be linked to specific role tags, ensuring compliance with the "Need-To-Know" principle. This approach effectively mitigates challenges associated with data privacy and confidentiality, which are critical considerations in the development of DPPs (Ducuing and Reich, 2023).

Figure 2 illustrates the sharing control page of a DPP, where users can generate permission tokens and distribute them to grant access to passport data. Although transferred tokens cannot be recovered by the custody holder, the ability to activate or deactivate their access rights is retained. Additionally, the custody token can be sent to another address, effectively reassigning ownership of the passport to a different stakeholder.

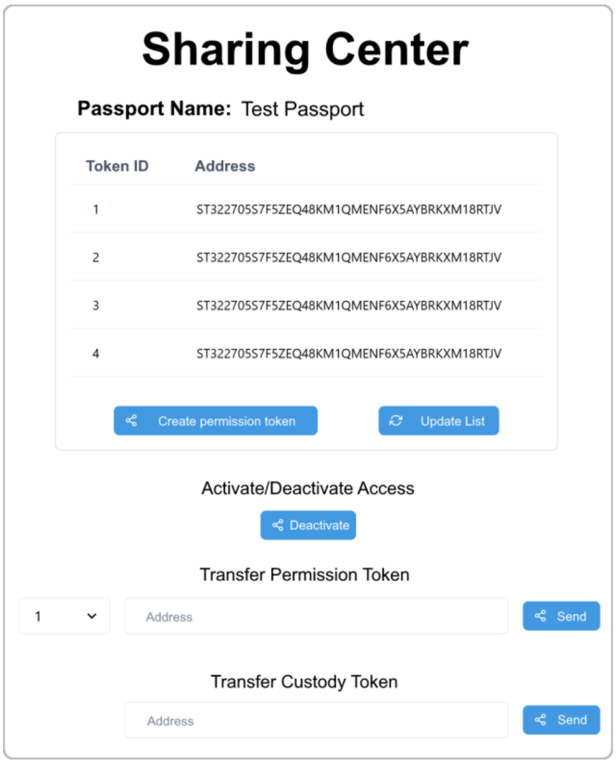

Figure 2: Sharing center of a DPP

Token management can become more user friendly by utilizing the Bitcoin Name System (BNS). The BNS is a protocol designed to convert complex wallet addresses into human-readable names, functioning similarly to the traditional Domain Name System (DNS), which maps IP addresses to domain names. Through BNS, users can associate ".btc" domains with their Bitcoin and Stacks wallet addresses, improving readability and facilitating easier identification of address ownership.

Unlike certain solutions that employ a hybrid mechanism where the platform is controlled by a central entity utilizing blockchain in its backend to enhance passport data management without the user's explicit awareness, the approach adopted in this platform enables users to log in directly via their cryptocurrency wallet browser extension, granting them true ownership of their data. The platform leverages the Gaia decentralized storage system, which stores data off-chain (i.e., outside the blockchain) and facilitates access through the provision of the appropriate authentication token. While on-chain storage solutions like IPFS are designed for immutable, censorship-resistant, permanent storage, they do not offer users control over their data, as modifications or deletions are not possible once the data is deployed. Conversely, off-chain storage offers users high performance and availability for data reads and writes while still preserving the benefit of avoiding reliance on centralized trust entities. However, the metadata of all the passports is stored in a traditional MySQL relational database management system. This architectural decision was implemented to address scalability constraints inherent in decentralized storage systems. Gaia's architecture, which functions as an object storage system utilizing key-value pairs, presents limitations in query capabilities and data relationship management. The absence of complex querying mechanisms and relational data structures in Gaia would necessitate the retrieval of complete datasets prior to client-side filtering, an inefficient approach that would impose significant computational and bandwidth overhead.

The implemented dual-storage solution optimizes system performance by leveraging MySQL's robust querying capabilities for metadata operations while maintaining the benefits of decentralized storage for comprehensive passport data. This approach ensures efficient data retrieval and filtering operations while preserving the system's scalability.

The DPP platform was implemented as a web3-based platform using React, leveraging Stacks, a Bitcoin Layer-2 solution specializing in smart contracts. The application employs different encryption mechanisms based on the chosen privacy setting, as detailed below:

- *Public passport*: The data is unencrypted, making it freely accessible to all users.
- *Private passport*: The data is encrypted at the user session level. Decryption is restricted to the logged-in user possessing the corresponding public-private key pair that generated the encryption.
- *Shared passport*: The data is encrypted at the application level. This enables the application to regulate permission based on tokens generated for the passport. Any logged-in user holding a valid token associated with the passport can view its contents.

Additionally, users who share their passports retain the capability to designate specific data as private. Such data remains inaccessible, even to individuals possessing tokens associated with the shared passport. This is achieved through a layered encryption process. First, the designated private data is encrypted at the user session level. Subsequently, the entire data is encrypted at the application level. This dual-layered encryption ensures that even after decryption by the application, user-designated private data remains encrypted and inaccessible to others.

The platform currently comprises three main sections:

- *Passports*: Displays all the passports currently stored on the platform (Presented in Figure 3).
- *User Area*: Contains all passports created by the logged-in user.

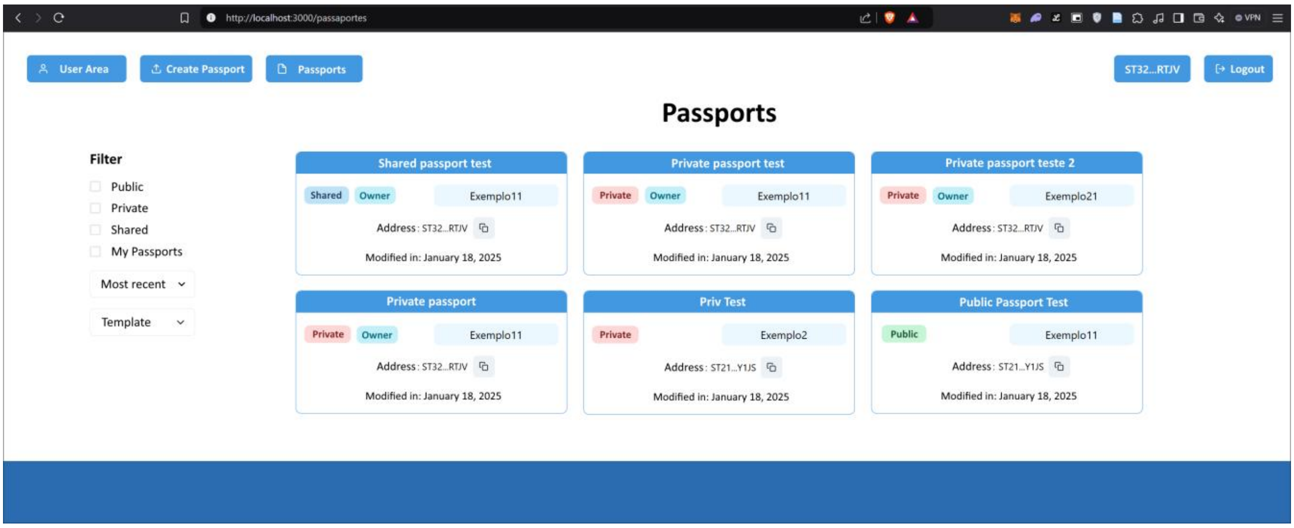

Figure 3: "Passports" page of the DPP platform

- *Create Passport*: Enables users to create new passports.

The *Passports* section displays passport metadata that is maintained in a MySQL relational database management system. Both the *Passports* and *User Area* sections include filtering options based on the type of passport (public, private, or shared) and the type of PDT. Additionally, they offer options to sort the content by specific criteria, such as alphabetical order or recency.

The platform provides three types of passports: Building (Level 1), Modular Unit (Level 2), and Component (Level 3), each associated with a specific set of PDTs. These passports can be organized into a hierarchical structure, where higher-level passports encompass groups of lower-level ones. When creating a new passport, users can choose any of the levels as the starting point. The passports are structured as JSON files and include various groups of data, some common to all passport types and others specific to their type (Table 1).

Table 1: Common and specific data contained within the passport JSON file, according to its type

Common Data	Specific Data
Name, Passport ID, URL. ID of selected PDT. Set of properties derived from the selected PDT. Files (e.g., any file relevant to the data required by the preliminary ESPR guidelines). Custody and permission token data (token URI and holder address).	*Building type*: Set of modular units that constitute the building. *Modular Unit type*: History (e.g., projects in which it was used or modifications) and the set of components comprising the unit. *Component type*: History (e.g., its usage and modifications).

The JSON file is fully interoperable between the BIM authoring software plugin and the DPP platform. Using the plugin, users can generate a JSON file containing the data from their BIM model. This file can then be submitted to the DPP platform to automatically create a complete hierarchical structure of passports. Conversely, users can download the JSON file from the DPP platform and import it into the BIM library via the plugin. For publicly accessible passports, it is more convenient to use the BIM library, as the data can be directly imported from the 'Passports' subsection within the product section.

Figure 4 illustrates the passport creation page, where users can select the starting level and construct a hierarchical collection of passports.

Integration of the DPP platform with BIM authoring software plugin

The BIM library plugin was developed as a WPF application plugin for Autodesk Revit, utilizing C# for the application logic and XAML for the user interface design. The initial prototype of the BIM library was designed in Figma, serving as a preliminary model for the application's development. The API is built using Next.js API Routes, providing serverless endpoints that handle database queries to retrieve passport data. It's integrated directly into the Next.js application, allowing seamless communication between the frontend and the MySQL database.

The BIM library allows users to consult product and manufacturer information, import BIM objects along with their respective data and update the 3D model. Products and manufacturers contain their own section, where this information is structured and organized within different subsections. The "passports" subsections within the product pertains to the DPP platform, where designers can browse publicly accessible passports obtained from the DPP platform. This section is equipped with comparison and visualization tools for DPP data, specifically focusing on sustainability-related information. These features are enabled through an API that provides access to publicly available DPP data for specific products. Figure 5 illustrates the DPP data presentation page, where users can view and directly import the data into their 3D models. Additionally, a comparison tool is offered, allowing users to compare the data of up to three different passports. Figure 6 presents the comparison window. The plugin also offers the ability to export BIM object data and automatically structure it in accordance with the selected passport data template. The user can subsequently import this file into the DPP platform during the passport creation process, where it will automatically populate all relevant data fields.

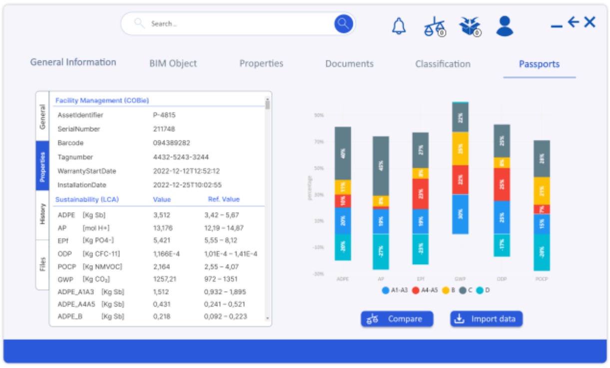

Figure 5: DPP data presentation page

Figure 6: DPP data comparison window

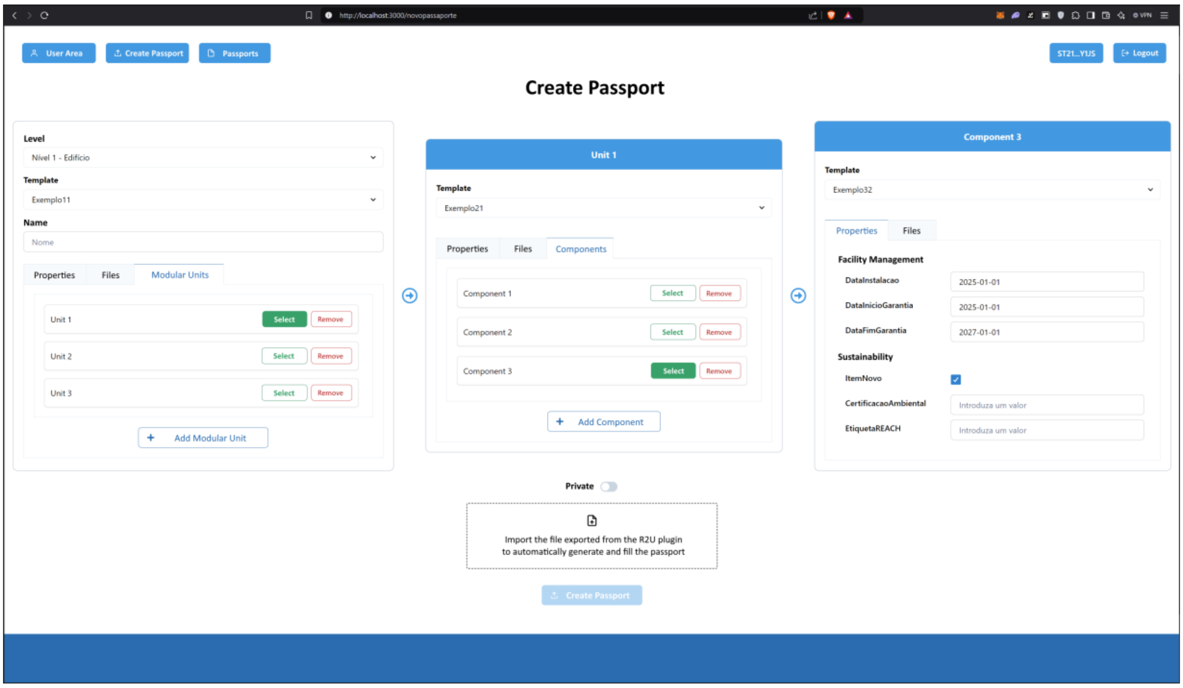

Figure 4: Creation and edition of a collection of DPPs, with panels representing the building (left), modular unit (middle), and component (right) levels

Discussion

When developing blockchain-based solutions for use cases that require a high volume of transactions and extensive data processing, it is imperative to address scalability challenges. Limited scalability adversely affects transaction throughput and associated fees, which are critical factors in passport management systems and may undermine the economic viability of such business models by reducing cost efficiency. The proposed approach integrates an off-chain storage mechanism to mitigate these burdens while preserving data privacy. This is achieved through a cryptographic validation framework that ensures secure user authentication for data access. However, this approach compromises certain aspects of data immutability, as it does not maintain a recorded history of modifications.

One of the primary areas of focus within the contemporary blockchain landscape is the issue of scalability, namely throughput scalability, which refers to the number of transactions a blockchain can process per second. Proposed scaling solutions are generally categorized into two broad groups: Layer 1 (L1) scaling, which involves modifications to the base protocol (on-chain), and Layer 2 (L2) scaling, which operates atop the mainchain (off-chain). Among the various strategies under exploration, four approaches have emerged as the most promising:

- L1 scaling: Sharding and sidechains.
- L2 scaling: Zero-Knowledge Rollups (Zk-Rollups) and Optimistic Rollups.

Current consensus within the field suggests that rollups, a form of L2 scaling, represent the most promising direction. Rollups function by processing batches of transactions off-chain and subsequently submitting cryptographic proof of the results to the mainchain for verification. The two principal types of rollups differ in the kind of proofs they provide. Zk-Rollups employ validity proofs that are cryptographically verified, providing enhanced speed and security. However, despite these performance and security benefits, they are more technically complex to implement and computationally intensive due to the use of advanced proof systems such as zk-SNARKs or zk-STARKs. Nonetheless, Ethereum's scaling roadmap asserts that rollups could potentially deliver over a 100-fold increase in throughput and a substantial reduction in transaction costs. However, the full realization of these benefits may require considerable time and further technological maturation. Although much of the discourse surrounding scalability solutions has centered on smart contract platforms such as Ethereum, it is important to recognize that scalability is also a pertinent topic within the Bitcoin ecosystem. A notable example is the Lightning Network (LN), a widely adopted Layer 2 solution for Bitcoin. LN enables rapid and high-volume transactions through off-chain state channels, with only the final settlement data being recorded on the Bitcoin blockchain (Liao *et al.*, 2024). Another notable development within the Bitcoin ecosystem is the ongoing work on the BitVM protocol. This protocol is based on rollup technology and aims to enhance Bitcoin's limited programmability, which is currently constrained by its restricted set of Opcodes (operation codes). BitVM introduces a framework that enables the verification of complex off-chain computations and transactions, which are otherwise difficult to perform or authenticate directly on the Bitcoin network. In doing so, it seeks to extend Bitcoin's functional capabilities while preserving its core principles of security and decentralization. As blockchain technology advances and scalability improves, on-chain solutions may become increasingly more attractive, offering the advantage of maintaining a comprehensive, immutable, and easily auditable record of all data modifications.

Although an immutable record of all data versions is not maintained, versioning is still recorded within the adopted solution to support data validation. When updating DPP data, the application stores a cryptographic hash of the updated data in a smart contract, together with the corresponding version number and the timestamp of the latest block. Once the transaction is executed, the resulting transaction ID is stored in a centralized MySQL database. Ideally, this transaction ID would also be recorded within the smart contract. However, due to technical constraints that prevent access to the transaction ID during contract execution, this is not currently feasible. Including the transaction ID in the smart contract would require a second transaction, which would result in higher costs and increased latency. Storing the transaction ID in a centralized database does not pose a security risk, as transaction IDs are immutable and cannot be altered, with the only potential consequence being data loss. Users can enter the transaction ID into a blockchain explorer to retrieve all associated information, including input parameters such as the passport URL, the hash of the data, the version number, and other relevant data. To verify the authenticity of the data, users may upload the corresponding JSON file into the application. The application then computes its hash, searches the smart contract for a matching entry, and informs the user whether the data is valid. If the data is valid, the application also provides the version number, the date it was published to the network, and indicates whether any newer versions exist.

The adoption of blockchain-based methodologies in the construction sector is also an important topic of discussion, particularly because this industry has historically demonstrated resistance to digital innovation. In a study conducted by Wang et al. (2022), models were used to assess the acceptance of blockchain technology within the construction industry. The study examined the intention to adopt blockchain through a survey of industry practitioners. It combined the Technology Acceptance Model (TAM) with the Technology–Organization–Environment (TOE) framework to explore the relationship between various influencing factors and the perceived usefulness and ease of use of blockchain systems. The identified factors were categorized as follows:

- Technological factors: Relative advantage, compatibility, technological maturity, and perceived cost of adoption.
- Organizational factors: Organizational readiness.
- Environmental factors: Policy and competitive pressure.

The study found that the relative advantage of blockchain, primarily characterized by transparency, traceability, tamper resistance, and automation features, significantly increases perceived usefulness. These characteristics are regarded as key drivers for the active adoption of blockchain in the construction industry. The study also found that compatibility between blockchain technologies and existing workflows is essential for the successful promotion of these systems in the construction sector. While policy was not shown to have a significant effect on perceived usefulness, competitive pressure was found to be the variable with the greatest impact. In general, the perceived usefulness of blockchain technology had a stronger influence on the intention to adopt it than the perceived ease of use. An example of practical adoption is demonstrated by Circularise, a blockchain-based digital product passport platform developed to improve traceability and regulatory compliance across supply chains. The platform has shown significant potential in reducing errors and fraud, enabling open infrastructures that support multiple vendors, and automating bookkeeping and reporting by integrating with existing Enterprise Resource Planning (ERP) systems such as SAP. This integration is particularly important, as it addresses compatibility challenges and aligns with the factors that have been identified as critical to adoption. These features also contribute to increased competitive pressure, which, as indicated by the study, can positively influence the adoption of blockchain technology.

Furthermore, the hierarchical structure of the DPP platform presented in this paper enhances the organization of passports, improving clarity while optimizing data storage and potentially reducing associated costs. By consolidating all passports within a single JSON file, the system effectively manages them as a unified entity. However, this design does not preclude the ability to decouple passports from the hierarchy when necessary, allowing them to function independently.

Data standardization is integral to the clear and consistent identification of properties, serving as a cornerstone for interoperability across the DPP platform and the BIM library. By harmonizing data formats and definitions, standardization enables precise information exchange and interpretation, thereby minimizing errors and facilitating seamless workflow integration. Standardization enables both comparison and automated data import, provided that the PDTs of the BIM objects align with those of the passports. Moreover, it facilitates the automated execution of diverse analytical processes, including environmental assessments. Through the enforcement of consistent data structures, standardization enables LCA tools integrated within BIM authoring software to accurately recognize and interpret the attributes of these PDTs and DPPs.

Conclusions

Blockchain technology presents both advantages and limitations. Key benefits include enhanced traceability, transparency, network resilience, and enabling individuals to exercise full ownership over their data, rendering it an appealing alternative in various contexts. Nonetheless, data ownership introduces inherent challenges. Data becomes irretrievable if the cryptographic credentials necessary for access are lost, as blockchain systems are designed to operate without reliance on third-party intermediaries. Certain market solutions adopt a hybrid approach by incorporating centralized authorities, which compromises data privacy. However, these solutions continue to leverage blockchain's fundamental features of traceability and transparency on the backend. These considerations must be meticulously analysed when developing solutions tailored to the specific requirements of a particular use case. By addressing lifecycle information gaps, the proposed system has the potential to enhance sustainable decision-making, reduce waste, and leverages modular construction's strengths in disassembly, recovery, and reuse to promote a circular economy in the construction industry.

Declaration of AI Use

AI tools were used to assist with grammar checking and improving the clarity of language. No content was generated using AI.

Acknowledgments

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References

BAMB & Technical University of Munich. (2019) Materials Passports - Best Practice. Available at: https://www.bamb2020.eu/wp-content/uploads/2019/02/BAMB_MaterialsPassports_BestPractice.pdf.

Circular Economy Resource Information System (2023) How Digital Product Passports and RE-Srategies Will Guide the Sustainable Transition. Available at: https://ce-rise.eu/news/how-digital-product-passports-and-r-strategies/.

Daphne, T. & Malooly L. (2023) R-Strategies for a Circular Economy. Available at: https://www.circularise.com/blogs/r-strategies-for-a-circular-economy/.

Ducuing, C. & Reich, R.H. (2023) Data governance: digital product passports as a case study. Competition and Regulation in Network Industries.

European Environment Agency & European Topic Centre on Waste and Materials in a Green Economy. (2020) *Construction and Demolition Waste: challenges and opportunities in a Circular Economy*. Available at: https://www.eea.europa.eu/en/analysis/publications/construction-and-demolition-waste-challenges/ (Accessed: 11 December 2024).

Fellows, R. & Liu, A. M. (2012) Managing organizational interfaces in engineering construction projects: addressing fragmentation and boundary issues across multiple interfaces. Construction management and economics 30, issue 8.

Heinrich, M. A. & Lang, W. (2019) Capture and Control of Material Flows and Stocks in Urban Residential Buildings. In: IOP Conference Series Earth Environmental Science 225 012001. Brussels, Belgium.

Hunhevicz, J., Bucher, D. F., Hall, D. M., Soman, R. K., De Wolf, C. & Honic, M. (2023) Web3-based role and token data access: the case of building material passports. In: 2023 European Conference on Computing in Construction and the 40th International CIB W78 Conference. Crete, Greece.

Jabbar, S., Lloyd, H., Hammoudeh, M., Adebisi, B. & Raza, U. (2021) Blockchain-enabled supply chain: analysis, challenges, and future directions. Multimedia Systems. Multimedia Systems 27(4):1-20.

Liao, G., Wang, T., Yang, Q., Xia, Y., Shi, L., Zhao, X., Wu, X., Zhang, S., Chan, A. & Yuen, R. (2024) Programming on Bitcoin: A Survey of Layer 1 and Layer 2 Technologies in Bitcoin Ecosystem. 10.48550/arXiv.2409.19622.

Luscuere, L. (2016) Materials Passports: Providing Insights in the Circularity of Materi-als, Products and Systems. In: Sustainable Innovation 2016. Circular Economy Innovation & Design, Epsom, UK.

Mehran, D., Poirier, E. & Forgues, D. 2022. Impact of Fragmentation on Value Generation-Towards a BIM-Enabled Lean Framework. In: 30th Annual Conference of the International Group for Lean Construction. Edmonton, Canada.

Sesana, M.M., Rivallain, M. & Salvalai, G. (2020) Overview of the available knowledge for the data model definition of a building renovation passport for non-residential buildings: The ALDREN project experience. Sustainability 12(2):642.

Stodt, F., Maisch, N., Ruf, P., Lechler, A., Riedel, O. & Reich, C. (2024) Collaborative Smart Production Supply Chains with Blockchain Based Digital Product Passports.

Wang, X., Liu, L., Liu, J., & Huang, X. (2022). Understanding the Determinants of Blockchain Technology Adoption in the Construction Industry. *Buildings*, *12*(10), 1709. https://doi.org/10.3390/buildings12101709