Built Heritage Digital Documentation Through BIM-Blockchain Technologies

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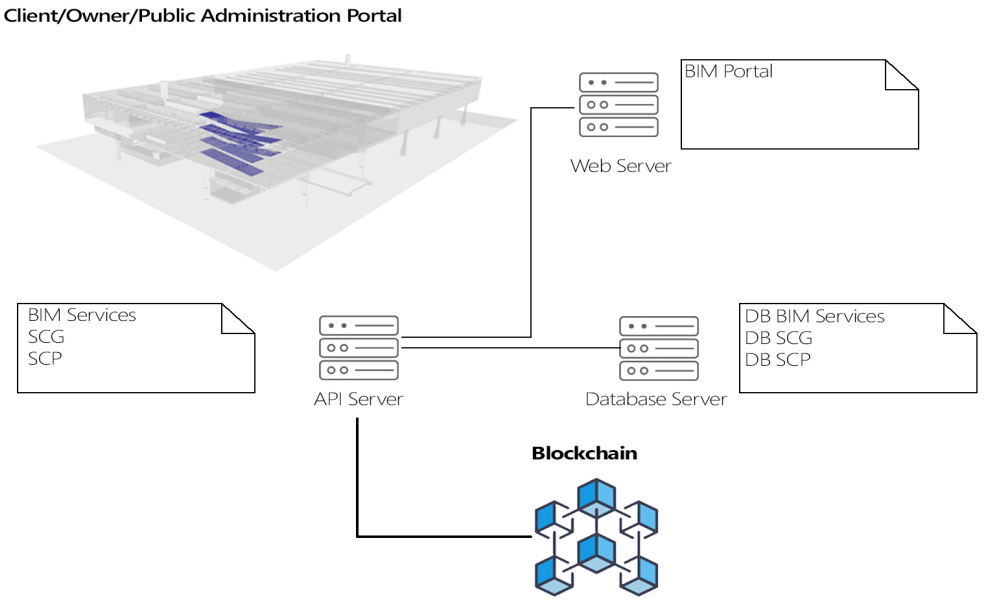
Abstract

Despite rising digitisation, the construction industry continues to be marked by redundancy, multiplication, and, at the same time, a lack of transparency and disaggregation of data and information, resulting in inadequate project life cycle management in terms of time, cost, and quality. This paper presents the results of the development of a TRL 4-5 ICT application based on the integration of Building Information Modeling and blockchain technologies, with the goal of fostering digitisation processes in the supply chain in the direction of greater information flow transparency, knowledge-based organizations, and decision-making processes based on unambiguous ordered data. The initiative, which began as a broader industry research cooperation, now includes a university spin-off, companies that operate as system integrators, and leaders in the customisation of BIM solutions for the built heritage value chain.

Keywords
digital documentation, BIM-blockchain, common data environment (CDE), bigdata.



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Introduction

BIM (Building Information Modeling) tools are increasingly being utilized to show that knowledge can be organized sharing integrated digital information systems that support all phases of the construction life cycle. Following the United Kingdom's lead in initiating the digitisation process in 2009, a number of Member States have taken numerous steps to encourage the use of BIM tools, which are widely recognized as the most effective driver for a more widespread digital transformation of the construction sector [Daniotti 2020]. In the national context, the adoption of the new Public Procurement Code, Ministerial Decree 560/2017, which made the use of BIM tools essential, achieved a similar impact; currently, the compulsory requirement corresponds to contracts with a value of less than five million euros. Furthermore, the aforementioned scenario has sparked a broad drive in the industry to adopt Building Information Modeling tools independent of mandatory requirements, particularly when it comes to interventions on the built environment. Specifically, the Agenzia del Demanio advertised more than 110 BIM tenders worth more than 200 million euros between November 2018 and December 2020. Fifty-five tenders were awarded for architectural, structural, and plant engineering surveys, diagnostics, and a technical and economic feasibility plan for assessing the built heritage's seismic risk.
The use of analogue information tools, as well as redundancy and duplication of data on the one hand, and information gaps on the other, continue to characterize the sector, resulting in inefficiency in design and construction processes, delays, poor risk management capacity [Nawari 2019], and conflictual behavior. Contracts specify how the parties involved will behave. Transparency and clarity of information become crucial needs as a result. The expanding number of testing of blockchain technologies in the construction sector, which are also connected with BIM technologies, demonstrates the supply chain's growing interest in the advances offered by this technology to address structural inefficiencies in the value chain [Autodesk 2020].

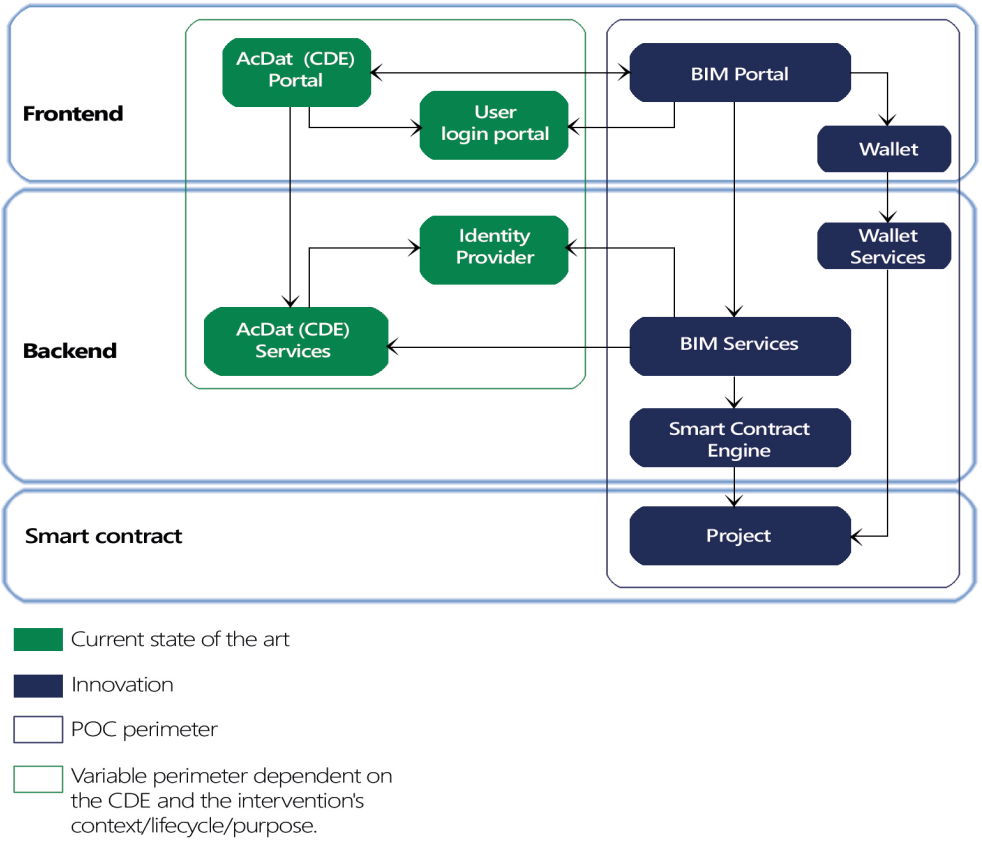

Fig. 1. Benchmarking state of the art and implemented innovation.

"Blockchain technology can help overcome stagnant production in construction, with respect to employment, by improving contract management, enabling greater transparency in supply chains and providing the technological backbone needed to combine aspects of the circular economy, BIM, IoT systems and smart sensors. It adds a new layer to tamper-proof network infrastructure for value and information" [ARUP 2017]. As decentralised ledgers [Benahmed 2020], based on consensus mechanisms, incentives, cryptography and peer-to-peer systems, which associate units on the ledger (currency or digital transactions) blockchains shift the aspect of security and trust from a local system, a database, to a global system. The contribution illustrates the results and products of the first phase of a technological roadmap, aimed at the digitalisation of the construction sector, initiated by economic operators and public bodies belonging to the High Technology Network of Emilia-Romagna, which aims at transferring, among others, digital skills to different productive sectors. Raise>up, a spin-off of the University of Ferrara, and the company Harpaceas, a leader in the development of BIM-based solutions for the construction market, have developed an integration solution between blockchain technology and the BIM platform (CDE, Common Data Environment), creating the innovative startup Innovation Chain (Fig. 1). In this sense, the project fits into the primary objective of Emilia-Romagna's S3 smart specialisation strategy, with reference to the objectives of the 2021-2027 cohesion policy and the United Nations 2030 Agenda, as it envisages, in the medium term, the involvement of different enabling technologies: Internet of Things (IoT); Big Data, as an essential requirement for the implementation of analytics functionalities supporting IoT integrations [Campos 2020]; Cloud manufacturing (cloud computing). Surveying, diagnostics, structural and seismic safety analysis, energy efficiency and risk management are just the main areas of investigation that increasingly require the adoption of protocols and standards to assess the quality of results, comparability of outcomes and data analysis, in view of a performance modelling based on Bigdata.

Methodological Approach

The functional analysis used to develop the system requirements took into account the following factors: the amount of digitalisation of Italian businesses, with a focus on cloud computing adoption [Bianchini 2020]; the domestic BIM-based market; the forms of blockchain technology (permissionless or public, permissioned, private).
Similarly, the characteristics of the life cycle of intervention on an existing building have been considered, such as: the numerous and frequent updates to the state of the art, which determine continuous updates of the BIM model; the number of actors involved in the processes of intervention on an existing building, due to the multiple and interdisciplinary specialist knowledge required for the various purposes that the project requires.
According to the authors, the large number of transactions involved in the application of integrated BIM and blockchain technologies makes it difficult to apply the study's goals to the development, implementation, and validation phase – model and code chacking – of architectural, structural, and MEP models, both in the state of art and during the design phase. This is owing not just to the existing high transaction costs on the researched blockchain systems, but also to avoid further overloading the actors' activities. Consequently, it was decided to operate at the level of the data sharing environment, CDE.
BIM is the technology and method for applying project collaboration to the value chain of the created intervention, according to BIM standards.
Moreover, CDE is the standard currently in use that allow professionals with Connecting teams, models, and project data in a single environment, assuring a single, trustworthy source of project information with participants having access to only what they are authorized to see; assuring a highly secure and neutral environment with a complete audit record of the asset to be deployed; reducing the time and effort required to verify, update, and re-issue data; allowing for the extraction of the most recent approved data from the shared area as need-

ed and according to the level of authorization; minimizing the need for ongoing coordination meetings to determine whether models are correct and to address issues such as "clashes" between federated models; allowing information to be reused to assist construction planning, estimating, cost planning, facility management, and a variety of other downstream tasks; reducing the amount of time and money it takes to create shared knowledge.
At a higher level, the CDE ensures the most effective collaboration between all actors in the process, according to current standards, when it comes to the development and implementation of the model for the many disciplines.
The model through which the conformity of the implemented solution is defined, as well as the type and number of actors responsible for uploading, verifying, and validating the starting point for defining the different user categories, is the way in which information is exchanged, verified, approved, and finally stored in the CDE.
Therefore, processes and sub-activities are defined, as follows: project creation; project launch; team definition; project deadline; onboarding; milestones check; BIM model approval; model checking; code checking.

Information Management Thruogh BIM-Blockchain Solution

Blockchain technology has gained acceptance outside of the financial, banking, and insurance industries [Deloitte 2020]. In parts of the literature on low-cost housing, notably non-market rents, there is a rising interest in applying blockchain technologies to the disciplines of social housing and collaborative housing (sometimes known as subsidised housing).
Blockchain technologies were first and foremost used in the management of community services, or proximity, with the opportunity for asset managers to redistribute value within product and service purchasing networks, due to the possibility of certifying the digital identity of information, a document, a contract, or a service [Ethereum 2018].
However, the same opportunity could be provided by applying the same approach to the management of real estate assets, namely, the joint management of services that meet the community's needs in terms of personal services as well as behaviors that influence building performance, particularly energy performance.
However, few investigations in this area have yet to be launched. In this regard, the current research is part of a project to assess the technical and economic feasibility of integrating BIM and blockchain technologies into the asset management of ACER, Azienda Casa Emilia Romagna of the province of Reggio Emilia, Emilia-Romagna, Italy.
The findings of this phase of research led to the identification of: the phase of the intervention's life cycle to which technological integration should be applied; the most appropriate type of blockchain technology to be applied; the conditions, opportunities, and constraints for the development of subsequent implementations.
As a result, the first phase of the study focused on functional analysis in terms of actors, processes, and macrofunctionality, in order to define the activities and digital objects, documents, models, etc., undergoing notarisation.

Functional Analysis: Actors, Processes and Macrofunctions

The following actors have been identified for the Project Management perimeter:
- Project Teams (P1 – Pn), Teams related to different disciplines (Architectural, Structural, Plant Engineering);
- Project Manager (PM), Project manager for the client;
- BIM Manager (BIMm), Responsible for the coordination of the BIM project for the client;
- BIM Coordinator (BIMc), For project team and headquarters (only for large projects);
- BIM Specialist (BIMs): BIM specialist for the project team;
- BIM Specialist (BIMs): BIM specialist of the project team;
- Single Project Manager (RUP), (only for public projects) is in charge of project planning,

design, contracting and execution;
- Contract Executive Director (DEC1 – DECn), (only for public projects);
- CDE Manager: only for large contracts.

Definitely, the design of the platform consisted of the following phases:
- definition of the logical architecture;
- definition of the storyboard for the system actors;
- definition of the integration flows between the components;
- definition of Smart Contracts;
- definition of integration methods.

The verification and validation cycle of the various development phases planned starts after an initial project start-up phase and the onboarding of the actors involved. The delivery and approval of models, the verification of model interference, and the verification of mandatory/contractual requirements are all part of these phases. At the end of each phase, the current phase's status and state of the project are verified and validated. The validation of a phase results in the closing of the current phase and the beginning of the following one until the validation of the final scheduled phase and, as a result, the project's completion. The hash is validated if the check is successful, and the flow proceeds as before. If the hash verification process fails, or the model and code checking technique fails, observations are communicated and saved to BIM resources, where they can be traced. Consequently, the BIMm corrects the problems, and the system gets the repaired models, converts them to hash, and uploads them. The procedure is then re-run (Fig. 2).
Similarly, the functional analysis of the site management phase was carried out.
The innovative component is placed between the collaborative environment in which the various project teams work and share documents and the common data repository (AcDat or CDE) and manages the "gates" of passage between the various processing modes. The new component's features are available as a user interface (web/mobile) as well as APIs that may be accessed by other systems. The component saves the major actions, status changes, and the unique fingerprint (hash) of documents in an immutable and certified fashion (time stamp, cryptographic signature) using Smart Contracts that run on blockchain.
The AcDat/CDE holds its role as a common repository of data and processes, while the Collaborative Environment holds its function as an integrated model viewer and repository navigation interface.

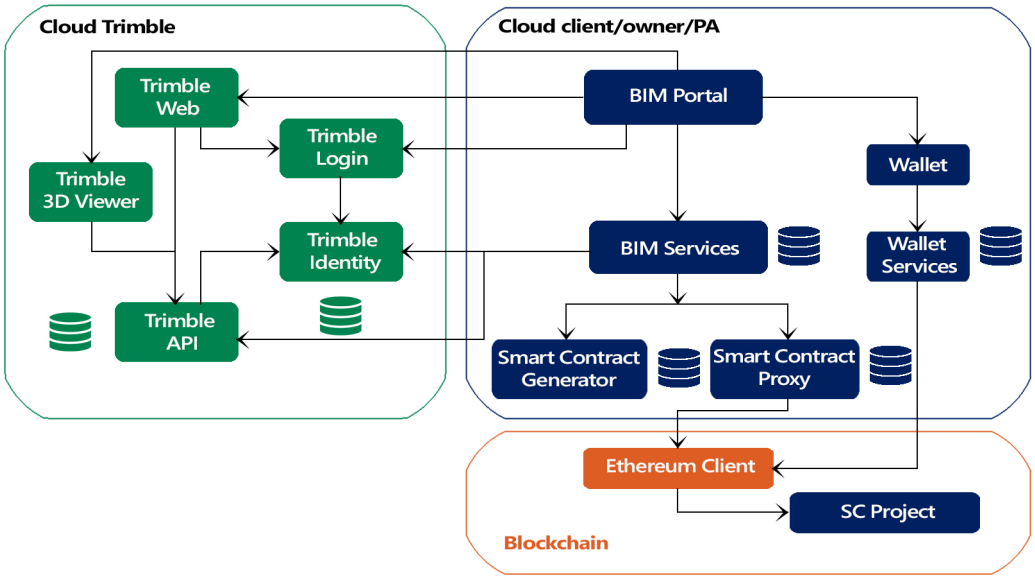

Fig. 2. Software architecture.

Some potential development scenarios were considered when defining the characteristics of the Backend and, in particular, the Frontend. There are three different possibilities for integrating the frontend components, none of which are necessarily alternatives, depending on the CDE to be integrated and the business proposal:
- ACDat Portal and BIM Portal are separate applications but the user can switch from one to the other without logging in again: SSO (Single Sign On);
- BIM Portal includes ACDat Portal (e.g. as iframe);
- ACDat Portal includes BIM Portal functionality (product extension).
While on the Backend:
- BIM Services call ACDat Services (like REST APIs or Web Sevices) to query the repository or modify it using an authorization token issued by the shared Identity Provider.

Sustainability of Integrated BIM Blockchain Solutions

In order to assess whether to construct ad hoc solutions and when to leverage existing goods or solutions to be integrated and/or customized, a "Make or Buy" analysis approach was used for the platform's technical design, with reference to the various components.
It was able to move to the cost evaluation as a result of the choices/assumptions made for the succeeding software and hardware design phases (Fig. 3).
As a result, conditions such as the public or private nature of the actor for whom the solution is developed, the complexity, in terms of the purpose of intervention on the existing heritage and the management of the life cycle, which characterizes the existing building under examination, the phase or ph of the existing building under examination are determining factors in the current context of technological development of both BIM solutions and blockchain technologies.

Components	Make or Buy	Note
AcDat	Buy	Integration with an existing product that provides the essential integration interfaces is suggested for AcDat (API and Identity Provider). If the product does not allow for suitable integration at the user interface level, the API can be used instead, and the integrated interface can be developed in the BIM Portal. Trimble Connect was used as a reference for planning and cost estimation.
BIM Portal	Make	Innovative component to be developed
BIM Services	Make	Innovative component to be developed
Smart Contract Engine	Buy	Smart Contract Generator and Smart Contract Proxy microservices provided by GFT under opensource licence
Project	Make	Smart Contract to be developed
Wallet + Wallet Services	Make/Buy	There are a few possibilities: - Development of a cloud wallet; - Integration of Metamask; - Integration of other third-party wallets. It was decided to create a Cloud Wallet for the design and cost analysis.
Blockchain	Buy	There are a few possibilities: - Development of a cloud wallet; - Integration of Metamask; - Integration of other third-party wallets. It was decided to create a Cloud Wallet for the design and cost analysis.

Fig. 3. Make or Buy analysis.

Consequently, the platform architecture was developed using the functional analysis performed throughout the design and site management phases. The identified solutions differ in the addition of a new AcDat for the construction phase, as well as the introduction of new and unique smart contracts, such as:
- Construction, Smart Contract for site management;
- Checklist, Smart Contract for the management of the technical-professional suitability checklist;
- Rubbish, Smart Contract for waste disposal management;
- Supply, Smart Contract for supply management;
- WorkPackage, Smart Contract for work management.

Conclusions

"Blockchain could help reverse stagnant construction output in relation to employment by simplifying contract administration, enabling greater transparency in supply chains and providing the technological backbone needed to incorporate components of the circular economy, BIM, IoT systems and smart sensors. It offers a new layer to the internet infrastructure for tamper-proof exchange of value and information" [ARUP 2017]. Blockchain technologies allow a higher level of system automation to be integrated into the information infrastructure, which theoretically guarantees immutability, uniqueness and makes it difficult to tamper with information. Therefore, these attributes provide an opportunity for innovation and transparency in the management of the lifecycle of manufactured goods to all production and value chains, with particular reference to the sectors most marked by controversy and corruption.
More specifically, in the construction industry, the technological innovation provided by the integration of blockchain and key enabling technologies [Raed 2019] presents itself as a tool to promote the certification of phase and product quality throughout the project lifecycle, as well as its management. Taking into account the developing field of data collecting, analysis, and modeling for the understanding of existing architectural heritage, which is increasingly characterized by the use of integrated digital technology, it is possible to identify a future application and experimentation area for integrated BIM-Blockchain and IoT technologies.
Definitely, surveying, diagnostics, structural and seismic safety analysis, energy efficiency, and risk management are some of the main research areas that are increasingly requiring the adoption of protocols and standards to assess the quality of information, results comparability, and data analysis in order to model performance using Bigdata. However, it is obvious that there are still significant barriers to widespread adoption of integrated digitization approaches, which are the same barriers that underpin the adoption of the technologies in question. On the one hand, there are regulatory issues, which are a major topic of debate in EU Member States right now.
The costs of a technology that was initially conceived for the financial, banking, and insurance sectors, on the other hand, are still unsustainable for the construction sector, which is dominated by small, medium, and micro enterprises. In the medium term, solid scalable solutions are required so that blockchain technologies can be broadly adopted in markets with weaker economic/financial margins than their origin markets.
Finally, the amount of digitisation of supply chain actors appears to be insufficient, or not uniform, in order to achieve the next step of industrialisation of processes required by blockchain technologies. Once more, the construction industry looks to be the most resistive to the adoption of new process models and procedures.
The construction industry appears to be the most resistant to the adoption of new process management models and approaches, both because of intrinsic characteristics and because of actors' unwillingness to execute a truly collaborative process.
According to the authors, the ability to access specialized resources on a competitive basis in public-private partnerships as well as the scalability of innovation are the main drivers for fostering new and subsequent maturity steps in the transition, which has already begun, from a proto-industrial to an effective industrialised construction value-chain.

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