Improving Metadata of Non-Fungible Tokens for Multipurpose BIM Data Distribution

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Abstract

In the rapidly advancing digitization of the Architecture, Engineering, and Construction (AEC) industry, end-users of buildings are seeking a diverse supply of Building Information Modeling (BIM) data to meet their intended use. However, in a Common Data Environment (CDE) managed by a specific organization, the project-oriented platform philosophy, management structure, and security risks make it difficult to release and distribute data to third parties other than project members. One potential solution is the public release of BIM data using blockchain technology. However, there is insufficient research on how to record the contents of large volumes of BIM data in a blockchain and improve data searchability from users and applications.

Therefore, this paper proposes a metadata, IFC Catalog, created by summarizing information from Industrial Foundation Classes (IFC), a standard specification for BIM data representation, with the perspective of minting it as Non-Fungible Tokens (NFT). The IFC Catalog consists of JSON data composed of Static Fields extracted from IFC and Custom Fields tailored to the purpose of the data. It is lighter in comparison to the BIM data itself, allowing users to easily review its content in applications for searching, buying, and managing NFTs. In the created minimum viable product, it was possible to display information from IFC files recorded in the IFC Catalog on the application interface with simple controls. This implementation demonstrated that large volumes of BIM data can be stored using blockchain technologies and in doing so, improved the data searchability.

Keywords

Building Information Modeling, IFC, Metadata, Blockchain, Non-Fungible Token, Data Retrieval

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1. Introduction

BIM contributes to digitization in the AEC industry in terms of structuring and making building information machine-readable throughout the entire building life cycle [1]. In particular, during the operations and maintenance phase (O&M phase) it is said to bring potential benefits for various activities including facility management (FM), energy management (EM), and others [2], [3]. A number of specific BIM utilization methods for these applications have been extensively discussed in past studies [4], [5].

When the use of BIM data or the data converted from BIM data becomes a de facto standard, it is easily predictable that the sufficient availability of data meeting requirements directly impacts the convenience for users of the built environment. After construction is completed the necessary BIM data should be continuously updated to reflect the current conditions and changes in information [6]. Furthermore, stakeholders using BIM data throughout the building's lifecycle can be numerous, and it is essential for these organizations or individuals to securely share necessary data between themselves while also ensuring the handover of work. When handovers occur, they need to provide or share the latest version of data. However, despite these evident demands existing, BIM data is rarely distributed sufficiently for various use cases and end-users, and it is seldom updated throughout its long lifecycle [7].

1.1. Challenges in BIM Data Publication and Distribution via CDE

One reason for this situation is the insufficient establishment of processes and platforms dedicated to the publication and distribution of BIM data. Currently, sharing BIM data on an agreed upon data platform called the Common Data Environment (CDE) is recommended by ISO19650, the international standard for information management in the building life cycle [8]. However, the following issues need to be addressed in order to publish and distribute BIM data to an unspecified number of users on CDE.

There are security risks: such as data tampering, since these platforms are managed by specific vendors and project managers, there are cybersecurity risks such as data manipulation and denial of access during the long building life cycle [9].

Difficulty in maintaining platforms throughout the entire building lifecycle: Buildings have long lifespans, often spanning centuries, which can exceed the lifespans of building management companies or companies creating BIM data. In addition, each platform incurs maintenance costs. This makes it difficult to maintain and manage data throughout the lifecycle of a building on a centralized platform that relies on a specific organization.

The platforms are not oriented to be shared externally: in general, these platforms are intended to be used within a specific project or organization. Therefore, it is less commonly utilized as an open distribution point for BIM data aimed at end-users.

Data and logs are scattered across multiple platforms: Current BIM data delivery operations may hand over copies of files from the original data owner to different personnel at certain points in time. This means that files may be duplicated and stored on multiple platforms, making it difficult to determine which file is the latest and correct version. Additionally, since many current CDE systems have closed log management within each platform, recording edits and access rights logs when data is on another platform is not possible.

In the O&M phase, there are fewer processes in place to approach data producers: when needed or to ensure that incentives are given to data producers, particularly when compared to the design and construction phase.

Therefore, a process or a platform for BIM data publication and distribution that is different from existing CDEs that overcomes the above issues is considered necessary.

1.2. Blockchain and NFT

As a solution to the issues related to the scope of data publication, security, and platform lifespan within the CDE, the introduction of blockchain technology and Non-Fungible Tokens (NFT) can be considered.

Blockchain is a distributed digital ledger that enables autonomous, decentralized data management without the need for centralized servers or administrators, allowing data to be recorded in a semi-permanent and virtually tamper-proof manner [10]. Particularly in a public blockchain, any individual or organization can send a transaction and confirm whether a transaction is valid [11], thereby demonstrating the authenticity of the data history record to an unspecified number of end-users. In addition, Ethereum and many other chains can use "smart contracts" that automatically execute a pre-embedded program when certain conditions are met. These ‘smart contracts’ are open-source, human-readable, high-level programs that are stored on a blockchain, execute without human intervention, and are implemented in such a way as to avoid the risk of downtime, censorship, or fraud [12], [13].

NFT is a token on a blockchain that grants uniqueness and ownership to digital asset. The token is a unique digital file that is stored on a blockchain network, with any changes in ownership verified by the global network and logged in public [14]. The NFT can transfer ownership of the data to other interested parties simply by transferring it to the new data owner on a blockchain [15]. Also, depending on the definition of the smart contract, it is possible for the initial data creator, that is, the one who initially minted the NFT, to set both the initial sale price and other types of contracts related to that NFT, such as royalties and fees received with each NFT transaction, [16], thus contributing to the creation of new incentives for data supply by data creators. Furthermore, the use of a "token gating" mechanism that grants access to content, events, and merchandise only to specific token holders is expected to not only provide exclusive access to specific content, but also to further add value to content ownership [17], [18].

By preserving BIM data using a blockchain and distributing NFT of BIM data, current BIM challenges may be directly addressed and overcome. Being decentralized and publicly verifiable, BIM transactions and data can be made both more secure and more accessible, leading to legitimate channels to approach data producers far beyond the earlier AEC phases. The persistence of a blockchain means that legacy software issues can be overcome, and data is unified in a single verifiable source. BIM data is typically very large, so how the data is stored on the blockchain must be considered, to ensure privacy of the producer as well as searchability of the contents. This could be resolved through effective use of metadata.

1.3. NFT Metadata for BIM

Based on the above, it can be said that NFT-ization of BIM data has the potential to solve the platform and incentive issues in the public distribution of BIM data by CDEs in the O&M phase described above. However, the issues regarding blockchain use and searchability that BIM data itself poses must be considered.

First, due to the substantial size of BIM data, which can reach several gigabytes, storing the entire file on a blockchain is challenging and becomes impractical due to the computational costs involved [19]. This issue itself is often addressed by referencing BIM data stored in off-chain storage such as the Inter Planetary File System (IPFS) [20] or by importing only a portion of the BIM data into a blockchain [7], a method that is somewhat well established.

Another problem stems from the complexity of BIM data. BIM data can be seen as a vast database that structurally encompasses information required throughout the entire lifecycle of a building. However, due to its comprehensive nature, determining whether the information end-users require is included at the necessary level of detail can be challenging. Furthermore, the current BIM process allows the data schema to be extended according to the intended use of the BIM data, often resulting in extended properties being used as essential items in specific systems or applications [21]. Furthermore, one BIM file may be used as a database or source for many systems.

Metadata is used to identify and explain the content of the NFT. Therefore, when creating NFT metadata specifically for BIM data, consideration should be given to the extensibility of these properties and the versatility of their use as described above. The current standard for NFT metadata is currently insufficient to capture the complex contents that would be the contents of a BIM file.

The current challenges of BIM data access, such as information security, legacy platform maintenance, and distributed unorganized data are all potential advantages of utilizing NFTs and Blockchain technologies. By tokenizing BIM data and credentials using standardized and robust metadata, the BIM data can be stored in a single blockchain source that is more secure, more enduring and more robust than current fragmented centralized and scattered systems.

2. Research Question and Expected Contribution

The goal of this research is to create an ecosystem using blockchain technology to publicly release construction data with appropriate access rights and provide incentives to data creators. However, as mentioned in Section 1.3, to efficiently enable versatile BIM data to be published and distributed as NFTs, a dedicated metadata format is believed to be necessary. Therefore, in this paper, we propose an extension to the ERC metadata format standard that can structure and describe information that can define the purpose of BIM data, whether the necessary properties are included, and the relevant property values. Defining the appropriate metadata format will not only allow BIM data to be published to blockchain-based systems at low cost, but will also make it easier to determine if the required information is included. Furthermore, this will contribute to improved searchability of the entire BIM data, not just the NFT and blockchain-based systems.

The remainder of this paper is organized as follows. Section 3 describes blockchain-related research and standard specifications in the construction industry that are relevant to the discussion in this paper. Section 4 describes the structure of the metadata proposed in this paper. In Section 5, we will mint the actual metadata as NFTs and validate the performance of the metadata by displaying information on a sample application. In Section 6, we discuss the results of the implementation followed by limitations and future work, Section 7. Finally, we conclude in Section 8.

3. Related Works and Standards

3.1. Blockchain/NFT Use in the AEC Industry

The application of blockchain and NFTs has been explored and validated in prior studies in the AEC industry [22]. Many of these studies share two common themes: the improvement of transparency using blockchain's traceability and the enhancement of governance models through the specification of self-executing capabilities of smart contracts [23]. In particular, the integration of BIM and blockchain is said to improve the security and efficiency of contract signing, project modification, asset management, and supply management [11] and a number of studies including system implementations, have been published [7].

Previous researchers have explored different approaches to importing or linking BIM data to a blockchain. For example, Dounas et al. proposed a method where BIM data is stored in the widely used distributed storage IPFS [20], and the hash value (CID) and version number of the BIM data obtained in IPFS are recorded in a blockchain smart contract [24]. Tao et al. proposed a Distributed Common Data Environment (DCDE) framework that aims to fulfill the existing CDE role with high transparency and traceability by not only managing BIM data updates but also storing related images, documents, and BIM Collaboration From at (BCF) files in IPFS and then recording file CIDs, status codes indicating the purpose of transaction creation, and other information in transaction[9]. In order to record the latest status of files while eliminating redundancy in BIM data distributed and recorded on a blockchain, Xue and Lue proposed a semantic differential transaction (SDT), which shares and accumulates only the changes in the BIM data and integrates them with smart contracts [25]. These use cases all demonstrate implementations and practicalities of linking BIM data to a blockchain.

Although NFT use in the AEC industry is limited, studies focusing on data uniqueness and data asset values have been observed. Hamledari and Fischer aim to improve the slow payments, information asymmetry, and low productivity due to inefficient contracting practices caused by current industry practices, and propose a method that uses reality capture solutions as an oracle to autonomously transfer real-space product flow to cash flow autonomously using blockchain smart contracts [23]. Here, the NFT is used to manage the payment and transfer of prior privileges for each construction unit. Dounas et al. use Dynamo (Autodesk, Inc.) [26] connected to a smart contract on the Ethereum blockchain and a Python script to generate ERC-721 tokens for topology files representing architectural components as non-manifold topology [27] graphs, registering them as unique digital objects [19]. Since the design of the building is recorded on a blockchain along with the topological interdependencies of its components, this approach enables collective ownership of buildings and provides future designers access to the data of building components when reusing the building, potentially turning modules of building data into a source of funding for decentralized financial applications.

Teisserenc and Sepasgozar envision a comprehensive architecture that uses blockchain technology to solve issues in each dimension (ranging from 3D to 8D and contractual dimension) of the data contained in BIM and Digital Twin. With the contract governing 7D and 8D, they attempt to tokenize green asset metadata into the NFT to enable notarization of environmental data and to enhance trading and monitoring of tokenized green assets [15]. Cassilo et al. propose a framework for creating NFTs of BIM families (objects) using the ERC-1155 standard to ensure ownership and copyright illumination of BIM families [16] . Here, metadata is used that conforms to the ERC-1155 standard and includes family names, object types, and any IFC [28] properties listed in parallel.

3.2. Description of Metadata for NFTs or Other Datasets

Even before NFT metadata, metadata has been used to summarize and search datasets in the literature and on the Web. DCMI Metadata Terms [29], Data Documentation Initiative (DDI) [30] and Data Catalog Vocabulary (DCAT) [31] are examples that can be used as metadata schemas for a wide variety of data sets. These schemas are described primarily in the Resource Description Framework (RDF) vocabulary [32]. They summarize and classify the contents of the applicable dataset by using predefined fields as needed.

Although various encodings and data formats can be used in the NFT, it has become the de facto standard to store metadata as a JSON object encoded into UTF-8byte strings [33]. Usually, the NFT metadata includes information such as the name of the NFT, the URI of the source file, and the description. In the ERC-721 and ERC-1155 standards used by many NFT projects, the format of metadata used is described in the official documentation [34], [35] and is expected to be referenced by URIs linked to tokens through dedicated functions. At the time of writing this paper, OpenSea [36], the world's largest NFT marketplace, has also established dedicated metadata standards to control information display within the marketplace application [37]. For example, the background color of transparent images or the URL of a YouTube video. Furthermore, it allows users to freely add attributes in an array format for each item, enhancing search capabilities for items and representing rarity within the same NFT collection.

Whilst there is significant work in how to practically link BIM data to blockchains, there is currently no processes or standardization in how to represent this information, or how to securely distribute or access that information. A standardized metadata schema is one method in which this challenge can be approached and is a currently unexplored avenue of research. This paper will describe the proposed metadata extension to include BIM data, making it indexed and searchable, and will implement a minimum viable product for discussion.

4. Methodology

4.1. Metadata Creation Policy

In this paper, the JSON-format used in the ERC standard was adopted as the file format for metadata. In addition, IFC [28], the standard formats for BIM data exchange, was used as the BIM data source. ISO 19650 recommends the use of Model View Definition (MVD) files. MVD is a subset of the information within the IFC file at a resolution appropriate for the purpose for which the data is being passed. The MVD can be used to extract the necessary parts of the data according to the application or to extend the data with additional fields as needed. [8]. In other words, although they follow the same data scheme, they handle data with very different contents depending on the purpose of use. Here, as in Cassilo et al. [16], if relevant properties are extracted from an unspecified number of BIM data and recorded in parallel within metadata, it could make it challenging to discern the purpose behind the creation of the BIM data and its corresponding property relationships. This issue not only affects human readability but also whether applications reading the metadata can easily represent these relationships in the user interface (UI). In addition, relying heavily on the application side to create and interpret the data will result in metadata that is dependent on a specific application or platform. In other words, the metadata should be commonly used on all platforms, and the configuration should be such that the display of information on the UI is controlled by each application. Therefore, this paper proposes a method to describe the information for identifying files (e.g., file name, IFC data schema, Global Unique Identifier (GUID), author or organization information) contained in most IFC files and additional information whose nature varies greatly from one IFC file to another, each in an appropriate structure.

4.2. Creating IFC files and metadata

The IFC file was created using Revit 2023 to contain the six pieces of information listed in Table 1; File Name, Version of the IFC Schema (IfcSchema), GUID of the IfcProject (IfcGuid), IfcOrganization, IfcPerson, and IfcApplication.

Table 1. Examples of properties included in an IFC file.

Property Name	Value (Example)	Description
name	test-IFC-01	The name of the BIM file.
IfcSchema	IFC4	IFC data schema. Example; IFC2x3, IFC4.
IfcGuid	0E5d9Z0CHAaOrNJAXRZMk_	Grobal Unique Identifier of the IFC Project.
IfcOrganization	test-organization	The organization name which authored the IFC file.
IfcPerson	test-user-01	Auther’s name, the data author or producer.
IfcApplication	Autodesk Revit 2023 (JPN)	The name of the application which is used to create the IFC file.

The IFC Catalog was manually created as metadata in JSON-format, extracting some of the IFC properties and additional information, such as purposes of the file or Level of Details of objects. The IFC Catalog consists of two parts: The Static Field and the Custom Field, which describes information according to the intended use (Figure 1). This is because the contents of the IFC vary greatly depending on the application, and it was thought appropriate to display metadata from which the necessary information was extracted for each application.
The Static Field contains an IPFS URI that stores the IFC file itself and a thumbnail image, the filename extracted from the IFC file, the schema, the GUID ofIfcProject, IfcOrganization, IfcPerson, IfcApplication, and a Descriptionfield to describe the purpose for which the file was created.

To accommodate the inclusion of information for multiple purposes, the Custom Field was designed by defining an "attributes" field as an array and adopting a format in which information is entered within it, as shown in Figure 1. The array is a two-layered JSON-format with an associative array of "Title," which is the name of the use, on the first layer and "Properties," which is defined for each catalog title, on the second layer. This approach allows a single file to cover multiple uses and evaluation items, making it easy for data creators to showcase them.

```
{
    "name": "test-ifc-01",
    "description": "test ifc file 1",
    "external_url": "http://localhost:8080/ipfs/QmcHreVyotPAD...",
    "image": "http://hoge2.ipfs.localhost:8080/",
    "ifc_guid": "0E5d9Z0CHAaOrNJAXRZMk_",
    "ifc_schema": "IFC4",
    "ifc_application": "Autodesk Revit 2023 (JPN)",
    "ifc_organization": "test-organization",
    "ifc_person": "test-user-01",

    "attributes": [
        {
            "catalog title 1": {
                "description":"description text",
                "test-string-1":"string-value-1",
                "test-number-1":0
                    :
            }
        },
        {
            "catalog title 2": {
                "description":"description text",
                "test-boolean-2":true
                    :
            }
        }
    ]
}
```

Static Field

Custom Field

Figure 1: IFC catalog Sample

5. Use Case: Verification of IFC Catalog usability through application implementation

The minimum viable product was constructed to verify whether IFC Catalog information can be displayed as NFT information. A locally closed environment was selected because it was determined that this system was in the concept phase and not at the stage of publishing data and contracts on a public blockchain. In fact, it is possible to implement a public blockchain based implementation by switching the network on which it is deployed.

5.1. Concept Architecture

The minimum viable product implemented in this study consisted of three major components: Storage, Blockchain, and Application (Figure 2). The storage component contained the IFC file (which serves as the reference for NFT), thumbnail image, and an IFC Catalog with two URIs and corresponding property samples. The blockchain component recorded the combination of the NFT owner's wallet address and the URI of the IFC Catalog in the storage component in a smart contract (IFCNFT Contract). The application component was responsible for displaying the information on the NFTs possessed by the connected wallet, that is, the IFC Catalog. Details of each component are described below.

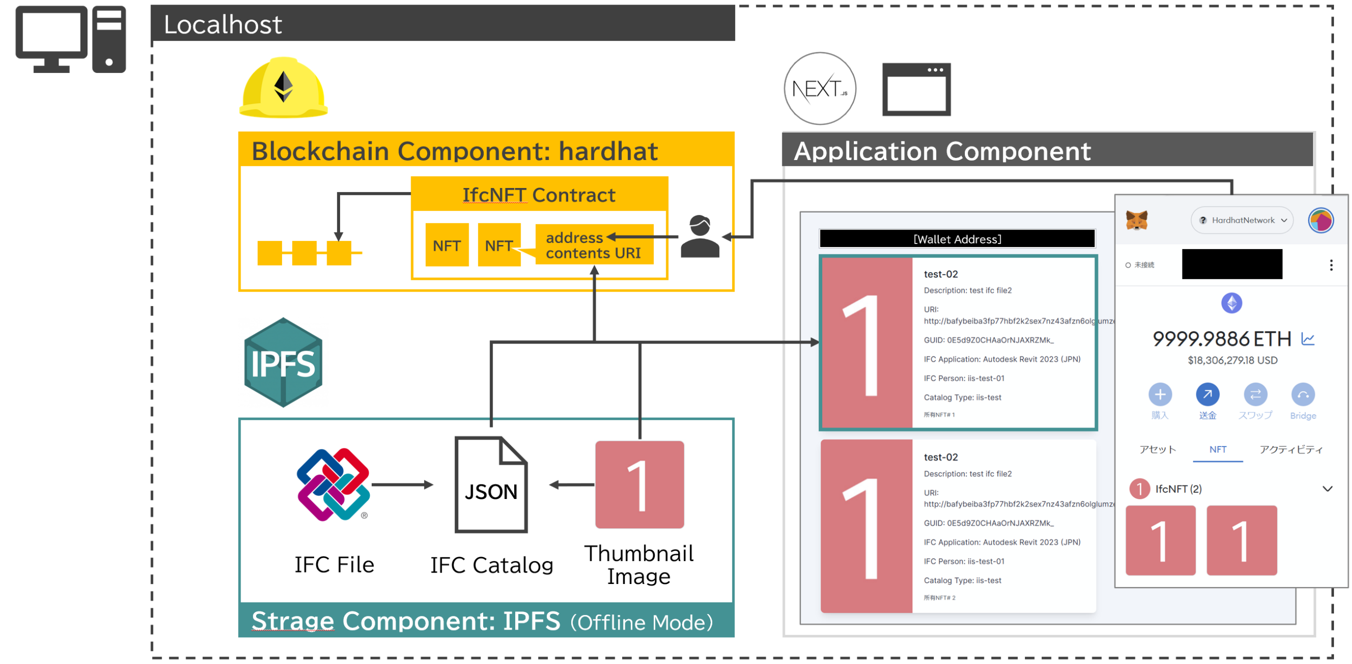

Figure 2: Overall system architecture

5.2 Storage Component

For the storage section, IPFS [20] was used. IPFS is a mechanism for implementing a distributed file system, in which multiple nodes are connected peer-to-peer and files are redundantly copied between the connected nodes, allowing for virtually semi-permanent distributed storage of files without the intervention of a centralized administrator. Therefore, it is often used as a file storage system for blockchain systems, which are also decentralized platforms. Contents stored in IPFS are hashed and assigned a Contents ID (CID), a unique fingerprint for each content. This CID is used to search for content.
First, IFC files and thumbnail are stored in the local IPFS, and the URIs of each IFC file and thumbnail image created using the obtained CID were recorded in the IFC Catalog. Furthermore, the IFC Catalog was stored in IPFS, and URIs created in the same manner were used for the NFT mint mentioned later. As a precaution, IPFS is originally intended to be used in connection with other nodes. For this study, IPFS was not connected to other nodes in order to complete the system within the local environment.

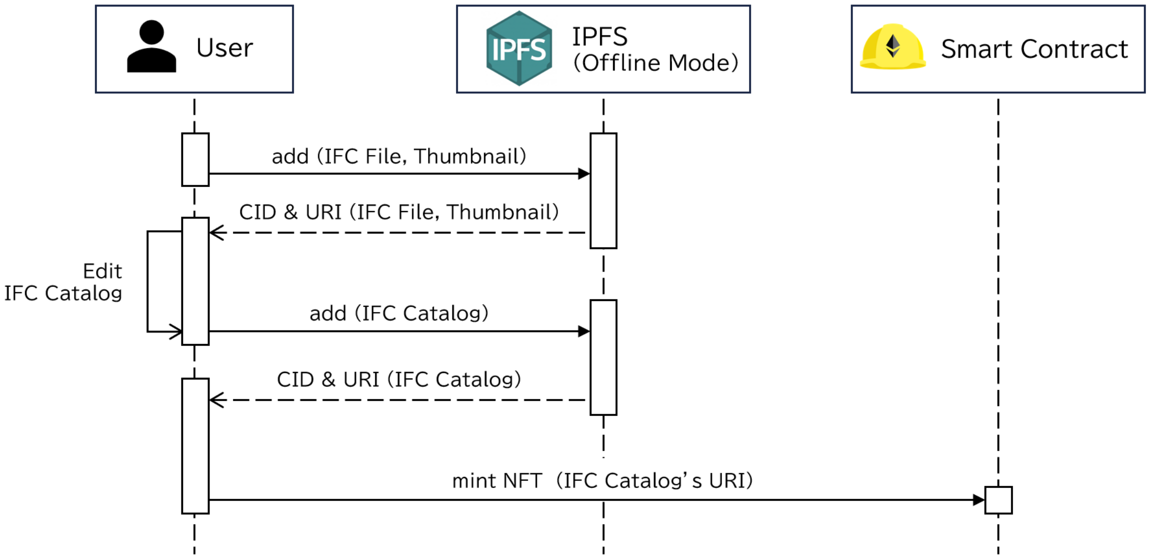

Figure 3: Sequences

5.3. Blockchain Component

Hardhat [38] was used for the blockchain component. Hardhat is a development and testing environment for Ethereum. In this paper, we created a virtual Ethereum network in our local Hardhat environment and a smart contract to mint NFTs was deployed to it. The Solidity [39] program defining the smart contracts was implemented by inheriting the ERC721-related contracts defined in OpenZeppelin [40], the development framework for Ethereum smart contracts (Figure 4). Here, we implemented a function that mints the NFT, that is, associates the owner's address to the URI of the IFC Catalog. In addition, the process of deploying the contract and minting the NFT was implemented separately in JavaScript code.

```
pragma solidity ^0.8.9;

import "@openzeppelin/contracts/token/ERC721/ERC721.sol";
import "@openzeppelin/contracts/token/ERC721/extensions/ERC721URIStorage.sol";
import "@openzeppelin/contracts/token/ERC721/extensions/ERC721Enumerable.sol";
import "@openzeppelin/contracts/access/Ownable.sol";
import "@openzeppelin/contracts/utils/Counters.sol";
import "@openzeppelin/contracts/utils/math/SafeMath.sol";

contract IFCNFT is ERC721Enumerable, ERC721URIStorage, Ownable{

    using SafeMath for uint256;
    using CountERC for CountERC.Counter;

    CountERC.Counter private _tokenIds;

    event NFTMinted(address indexed to, uint256 indexed tokenId, string uri);

    constructor() ERC721("IFCNFT", "IFC") {}

    function mintNFT(address to, string calldata uri) external onlyOwner{
        _tokenIds.increment();
        uint256 newTokenId = _tokenIds.current();
        _mint(to, newTokenId);
        _setTokenURI(newTokenId, uri);
        emit NFTMinted(to, newTokenId, uri);
    }
    :
    :
}
```

Figure 4: A segment of Solidity source code

5.4. Application Component

In the application component, Next.js [41] was used to implement a user interface that displays the contents of metadata minted in the NFT under the deployed contract (Figure 5). Static Field items in the IFC Catalog are called by directly specifying the field name, while the Custom Field items (under attributes) are mapped to the key and value of Properties as text, with the Title as the heading for each case. In the implemented application, it was possible to list the NFT information of the IFC Catalog for each IFC file (Figure 6).

```
<div className="ifcCatalog1">
   <hr></hr>
   <p className="staticField_truncate"><b>IFC File URI:</b> <a href={item.externalURI}
target="_blank& quot;>{item.externalURI}</a></p>
   <p className="staticField"><b>IFC GUID:</b> {item.ifc_guid}</p
   <p className="staticField"><b>IFC Schema:</b> {item.ifc_schema}</p
   <p className="staticField"><b>IFC Application:</b> {item.ifc_application}</p
   <p className="staticField"><b>IFC Organization:</b> {item.ifc_organization}</p
   <p className="staticField"><b>IFC Person:</b> {item.ifc_person}</p
   <p className="staticField"><b>Token ID:</b> {item.tokenId.toNumber()}</p>

   <div>
      {item.attributes.map((attribute, index) => {
      const title = Object.keys(attribute)[0];
      const properties = attribute[title];
      return (
      <div key={index}>
         <hr></hr>
         <h6 className="customFieldTitle">{title}</h6>
         <ul>
            {Object.entries(properties).map(([key, value]) => (
               <li key={key} className="customFieldProperty">
                  <b>{key}:</b> {typeof value === 'boolean' ? value.toString() : value}
               </li>
            ))}
         </ul>
         </div>
      )
   })}
</div>
```

Figure 5: Implementation of Static Field and Custom Field display (className was simplified)

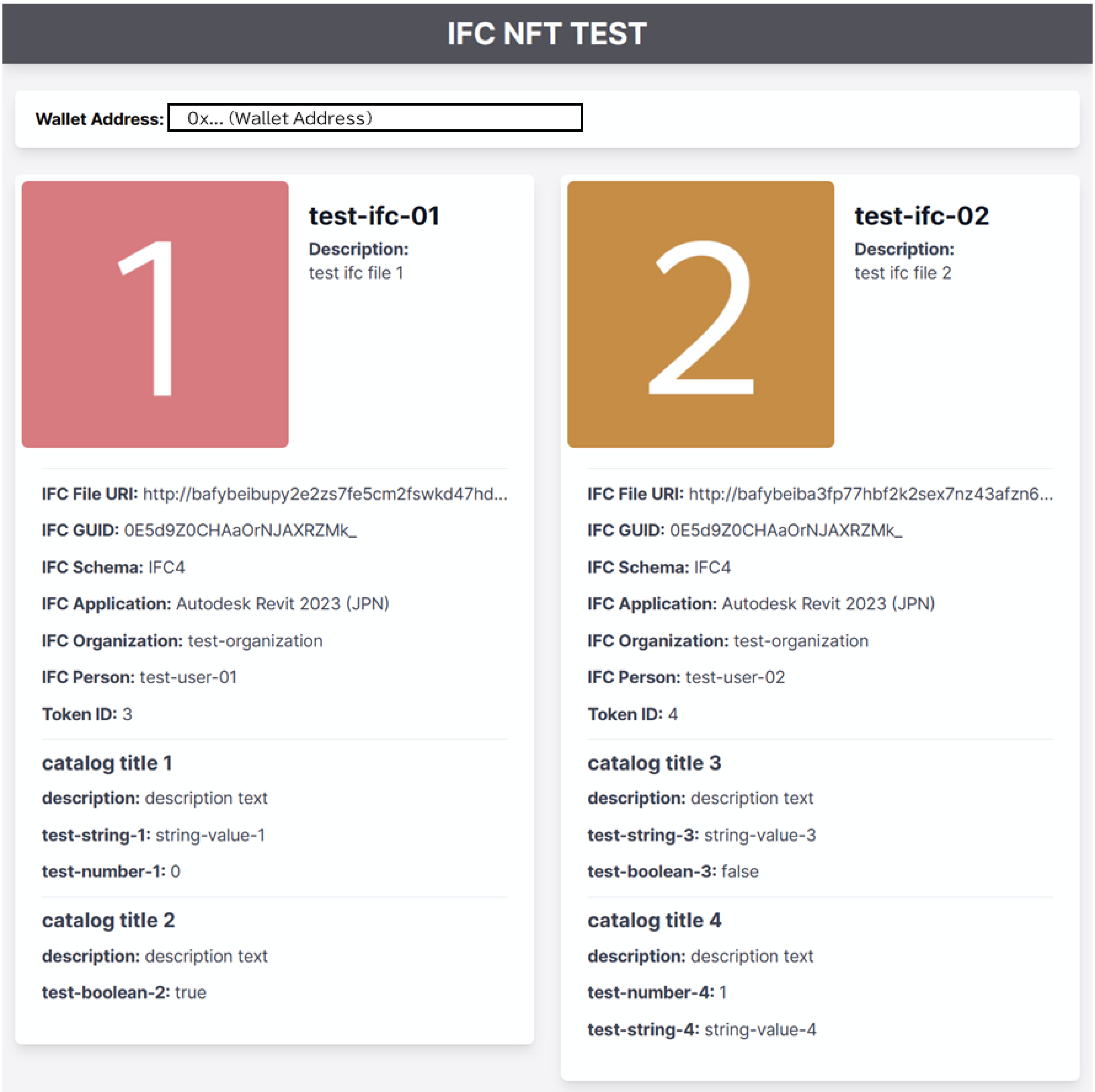

Figure 6: Application interface

6. Discussion

The implementation in the previous sections allowed us to prototype an application that uses IFC Catalog's NFT to display a summary of BIM data for a wide variety of purposes. It can aggregate and present the information required for searching BIM data through a simple algorithm.
The IFC Catalog is in a simple JSON-format, which is useful for publishing summaries of IFC information in a platform-independent manner. Additionally, it allows data creators to easily add or expand catalog information, contributing to enabling the data creators to freely showcase the contents of IFC files to data users. However, for major applications, it would be good to define IFC Catalog standards for each application. For example, when publishing IFC files with the aim of displaying models in AR applications or on map spaces in appropriate locations, the IFC Catalog needs information about the geographical coordinate system to be referenced and information for converting from the IFC file's coordinate system to the geographic

coordinate system to be referenced. These can be standardized following the data description methods of IFC4 Reference View. Even if there is no scheme within IFC that can be used as a reference, it would be good to have certain guidelines for those who define a new IFC Catalog. Alternatively, a generative AI such as GPT-4 [42] could be used to generate an IFC Catalog from IFC files and additional inputs. Furthermore, it would be desirable to establish a dedicated repository for publishing the guidelines and IFC Catalog documents so that these guidelines and the generated IFC Catalog can be commonly used by many people.

In addition, if IFC Catalog output could be incorporated into other standard operations, it would lead to further operational efficiency and reliability assurance. For example, if IFC Catalogs can be exported at the same time as validation checks using the Information Delivery Specification (IDS), this not only saves time in creating IFC Catalogs, but also verifies the authenticity of the IFC Catalog generation process.

The implementation demonstrated in this paper does not assume that the source BIM data will be updated, and that the IFC Catalog will be uploaded to IPFS and cannot be edited later. However, the BIM data representing a building or buildings is updated multiple times during its lifecycle, therefore, the ability to link multiple versions of tokens is necessary. For example, Gebreab et al. [43] use dynamic composable NFTs as digital representations for regularly updated medical devices. They embed replacement parts and certificate documents in the parent-child structure of NFTs, allowing them to capture and reflect reprocessing processes through the evolution of tokens. Similarly, even in the NFT for BIM, it may be possible to display the relationship between versions using a parent-child structure of tokens of old and new versions, and so on.

To return to the BIM challenges presented in Section 1.1;

There are security risks: by being tokenized and stored on the blockchain, tokenized metadata and BIM data stored in IPFS will be redundant across countless nodes, making data tampering virtually impossible. Another is the use of token-gating and other methods of data access control, which allows for controls such that only users in possession of tokens can access the relevant BIM data and content. There are still inherent security risks with how the primary source of the BIM data stored, and that will be vulnerable to targeted attacks, this implementation adds a further layer of security to accessing the source data, through the use of smart contracts and consensus algorithms.

Difficulty in maintaining platforms throughout the entire building lifecycle: a platform is no longer required to access or interface with the source BIM data. Assuming it is not stored in a proprietary format, the platform only needs to enable sufficient storage and security for access permissions, reducing platform operation costs and removing platform dependance.

The platforms are not oriented to be shared externally: As the blockchain is open, searchable and persistent, distribution of BIM data and assets has been simplified. External stakeholders can consult the relevant blockchain for the BIM metadata to find the data source they require. The minimum viable implementation has demonstrated how this metadata can be provided meaningfully, yet minimally.

Data and logs are scattered across multiple platforms: Whilst the aggregation of data and logs has not been directly addressed in this implementation, the use of metadata being unified onto a single blockchain means there is a single entry point in which to search for relevant information. The data can remain as it is, scattered and across multiple platforms, but unifying where it can be found overcomes this challenge, as data repositories can no longer be lost over time, especially if the source data is stored with redundancy.

In the O&M phase, there are fewer processes in place to approach data producers: The source data is now indexed and searchable, meaning that interested third parties can speculatively search for potential information, and the data produced can be contacted. This does not address issues such as the original data producer no longer being associated with the data or the property owning company.

7. Limitation of Study and Future Work

The scope of this paper is to examine the data format of the IFC Catalog and to verify whether the information in the IFC Catalog can be visualized in an application, and minimum viable implementation was presented. Therefore, we have not systematized the NFT generation process or implemented the token transfer process associated with NFT trading. In addition, because this study was implemented and verified entirely in a local PC environment, it does not fully examine the operational costs and risks in public blockchains and public repositories. Therefore, future research should define specific use cases and then consider how to implement the entire system in a comprehensive manner, including smart contracts, solutions to be used as storage, applications to serve as interfaces, and operations.

8. Conclusion

With the rapid digitization of the AEC industry, BIM data created for a wide variety of purposes can be delivered to the building or system user and kept updated. However, the realization of such a platform for the publication and distribution of BIM data has challenges, such as maintaining the platform over a long period of time, dealing with the risk of data tampering, and understanding the purpose of maintaining these data. The NFT-ization of BIM data not only enables the publication and distribution of IFC file information within a blockchain-based, semi-permanent ecosystem without relying on specific marketplaces but also provides a promising solution by offering data creators appropriate incentives. However, to efficiently present the content and purpose of BIM data in an easy-to-understand manner to end-users, a dedicated metadata format is needed.

This study proposed IFC Catalog, a metadata format that structurally expresses the uses of IFC files and the properties required for each use, for the purpose of publication and distribution of BIM data. IFC Catalog is a simple JSON-format metadata that allows data providers to easily record data purpose and additional information even for IFC files that have multiple purposes and is well-suited for information display in applications.

The authors have built a minimum viable product for an application that displays NFT information in the IFC Catalog, and confirmed that the information in the IFC Catalog can be displayed on the interface in a structured manner with simple controls. This supports BIM data delivery both in terms of information search and display by computer and information confirmation by human vision. In the future, additional considerations are required from the perspective of information searchability and operational efficiency. These considerations include standardization of IFC Catalogs for IFC files with major applications, methods for mechanically generating IFC Catalogs from MVD concepts, and handling updates to the original IFC files. These issues will be addressed through verification with specific use cases in the future.

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Declaration of competing interests

The authors declare that they have no competing financial interests or personal relationships that might affect the research reported in this paper.

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抄録

急速に進む建築・エンジニアリング・建設（AEC）業界のデジタル化において、建築物のエンドユーザーは、使用目的に応じた多様なビルディング・インフォメーション・モデリング（BIM）データの供給を求めている。しかし、特定の組織が管理する共通データ環境（CDE）では、プロジェクト指向のプラットフォーム理念、管理構造、セキュリティリスクにより、プロジェクトメンバー以外の第三者にデータを公開・配布することが難しい。解決策の一つとして、ブロックチェーン技術を活用した BIM データの一般公開が考えられる。しかし、大容量の BIM データの内容をどのようにブロックチェーンに記録し、ユーザーやアプリケーションからのデータ検索性を向上させるかについての研究は不十分である。
そこで本稿では、BIM データ表現の標準仕様である IFC（Industrial Foundation Classes）の情報を要約し、NFT（Non-Fungible Token）としてミントする観点から作成したメタデータ「IFC Catalog」を提案する。IFC Catalog は、IFC から抽出した Static Fields と、データの目的に合わせた Custom Fields で構成される JSON データである。IFC Catalog は BIM データそのものに比べて軽量であるため、ユーザーは NFT の検索、購入、管理のためのアプリケーションで簡単にその内容を確認することができる。作成された最小実行可能プロダクトでは、IFC カタログに記録された IFC ファイルの情報を、簡単な操作でアプリケーションインターフェース上に表示することができた。この実装により、ブロックチェーン技術を使用して大容量の BIM データを保存できることが実証され、データの検索性が向上させることができた。