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BIM-FM INTEGRATION THROUGH OPENBIM: SOLUTIONS FOR INTEROPERABILITY TOWARDS EFFICIENT OPERATIONS

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SUMMARY: *Facility Management (FM) faces ongoing challenges related to data interoperability and information loss during the transition from construction to operation phases, compromising asset management efficiency. Although Building Information Modeling (BIM) can optimize the flow of information exchange by offering a single, centralized model, the lack of standardization and interoperability issues between BIM and FM limit the full exploitation of its advantages. This study aims to develop a solution that integrates BIM and FM, using open standards like IFC to mitigate data loss and ensure continuous updates of BIM models throughout the construction and commissioning phases. The proposal aims to provide the facilities team with a BIM model containing the minimum necessary and reliable common information for the start of operations. The methodology adopted is based on Design Science Research (DSR) and includes the development of an artefact composed of four components: (1) a compendium of minimum common information requirements for various assets, (2) a web platform for continuous management of this information, (3) a Representational State Transfer API (Application Programming Interface) that ensures interoperability between different systems, and (4) an add-on for the Blender system, utilizing Bonsai (previously known as BlenderBIM) as the IFC modeler, which guarantees bidirectional data exchange between the web platform and BIM models, ensuring continuous verification and updating. The results show that the proposed artifacts are effective in mitigating interoperability difficulties, centralizing critical information, and continuously verifying data. The use of IFC promoted greater flexibility and standardization, resulting in more efficient and integrated asset management. The proposed solution offered a practical and sustainable approach for the construction industry, significantly contributing to the improvement of operational processes and information management throughout the asset lifecycle by decoupling from the limitations imposed by proprietary software.*

KEYWORDS: *BIM, FM, Facility Management, IFC, Bonsai, Interoperability, openBIM.*

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1. INTRODUCTION

Facility Management (FM) is an organizational function that integrates people, properties, and processes within the built environment, aiming to improve people's quality of life and increase the productivity of the core business. By optimizing support processes, FM allows organizations to focus on their core activities, ensuring the efficient availability of services (ISO, 2018a). With the evolution of FM practices, the adoption of specialized technologies, such as facility management software, has become crucial for achieving greater operational efficiency. However, the effectiveness of these practices directly depends on the quality of available asset information. The transition of information between construction and operation phases often faces challenges, such as data loss and difficulties in accessing critical information for asset management (Tsay et al., 2022; Sacks et al., 2018).

In this scenario, Building Information Modeling (BIM) emerges as a powerful technology to optimize facility management by centralizing all relevant information in a shared digital model. By consolidating detailed data about each building component, BIM provides managers with organized and reliable information, fundamental for efficient management (Pishdad-Bozorgi et al., 2018). This facilitates more accurate decision-making throughout the building's lifecycle, minimizing redundancies and planning errors (Bonanomi, 2015).

However, the integration between BIM and FM still faces technical obstacles, mainly due to the lack of interoperability and standardization between BIM models delivered at the end of construction and FM systems. The incompatibility between the software used during the construction and operational phases compromises the transfer of essential data, limiting the effective use of digital technologies and resulting in data loss and rework (Desbalo et al., 2024; Goonetillake et al., 2023; Matarneh et al., 2020; Pärn and Edwards, 2017). Furthermore, the scarcity of practical studies on the collection, development, and delivery of this information hinders the development of effective solutions, directly affecting BIM's potential to optimize facility management (Tsay et al., 2022).

A promising solution to mitigate these interoperability problems is the use of open standards, such as openBIM. These standards adopt open, non-proprietary data formats, ensuring greater flexibility and accessibility of information across various platforms. This facilitates the integration of different systems, promoting more efficient and economical management of construction projects (Becerik-Gerber et al., 2012; Kim et al., 2018; Mirarchi et al., 2018). Additionally, ISO 19650-1 recommends the use of such standards to ensure consistency and quality of information throughout the building's lifecycle (ISO, 2018b).

In addition to information losses caused by interoperability issues, there are also significant failures resulting from the lack of a clear definition of asset information requirements, such as materials, technical specifications, and maintenance systems (Becerik-Gerber et al., 2012; Matarneh et al., 2020). This lack of definition compromises the efficient transfer of data to the teams responsible for building operation and management. Another critical challenge is the absence of continuous information updates during construction, as modifications are often not incorporated into BIM models. This compromises the integrity of essential information, negatively affecting asset management throughout its lifecycle (Matarneh et al., 2022; Love et al., 2014).

This article proposes an artifact composed of a set of components designed to facilitate the integration and efficient management of asset information in the BIM model at the end of the construction phase, with the goal of enhancing interoperability and ensuring the continuous updating of model data. The proposal includes a review of common informational requirements for different types of assets, the development of a web platform to centralize and manage this information, the creation of a Representational State Transfer (REST) API to enable data exchange between systems, and the implementation of a specific add-on for Blender. Blender was chosen for this research due to its capability to become a BIM software and IFC modeler through the Bonsai add-on (formerly known as BlenderBIM), with the aim of ensuring greater interoperability and data consistency throughout the process by adopting open standards.Thus, the study aims to minimize information loss during the transition between construction and operation phases, offering a practical and applicable solution to the construction industry. By promoting the use of non-proprietary data formats, the research seeks not only to improve interoperability but also to enhance the quality of information, contributing to more integrated, efficient, and sustainable facilities management, benefiting both the professional and academic sectors.

2. LITERATURE REVIEW

The operation and maintenance phase, being the longest and most expensive in a building's lifecycle, accounts for approximately two-thirds of the total investment in a project (Amorim, 2022). In this context, the adoption of technologies that optimize costs and processes during this stage becomes indispensable. Among these technologies, BIM stands out for its proven effectiveness in project management and construction execution. However, its application during the operational phase remains limited, compromising the potential efficiency and automation that could be achieved in this stage of a building's lifecycle (Sheik et al., 2023; Wong et al., 2018).

Although the successful use of BIM in the initial stages of design and construction suggests an efficient transition to the operational phase, several limitations prevent its full utilization. BIM models delivered at the end of construction are often not utilized by operations teams due to the inadequate or inaccurate presentation of information. Consequently, facility management (FM) teams need to adapt these models to meet their needs, resulting in less efficient processes and limiting the benefits of technological integration (Ashworth et al., 2022; Rogage and Greenwood, 2020; Motamedi et al., 2018).

Several studies have identified the main barriers to the use of BIM for facilities management. Among the most relevant challenges are: the lack of knowledge among owners, interoperability issues between BIM and FM systems, and concerns regarding the reliability and consistency of data (Goonetillake et al., 2023; Leygonie et al., 2022; Lin et al., 2022; Matarneh et al., 2022a; Tsay et al., 2022). For example, the lack of technical knowledge among owners is a critical factor that hampers the definition of essential information requirements for the operational phase. Despite ISO 19650-3 guidelines assigning responsibility for these requirements to owners, this task is often neglected in practice. As a result, BIM models delivered at the end of construction lack essential information or contain unnecessary data, rendering them unsuitable for efficient asset management (Matarneh et al., 2022a; Marmo et al., 2020; Munir et al., 2020; Rogage and Greenwood, 2020)

To further understand these difficulties, Cavka et al. (2017) conducted a study identifying the main challenges owners face in defining information requirements. These include a lack of knowledge about the lifecycle needs of assets, inexperience with BIM to determine which data should be effectively exchanged and managed, and uncertainty about how to properly request this information. Additionally, many owners lack the resources and expertise to evaluate the quality and compliance of BIM models, which compromises their proper use during the operational phase, even when model delivery is mandated at the end of construction. Case studies in Canada reinforced the critical need for standardization of this information to ensure efficient management in a BIM environment, highlighting the necessity to formalize information requirements for effective project delivery and lifecycle asset management.

Furthermore, interoperability between BIM and FM systems remains one of the biggest obstacles (Goonetillake et al., 2023; Matarneh et al., 2020c; Pärn and Edwards, 2017). Efficient integration of these technologies is essential to ensure seamless information exchange, a goal pursued by open standards such as IFC and COBie. These standards provide flexibility and facilitate integration between different systems, promoting effective collaboration (Mirarchi et al., 2018; Kim et al., 2018; Becerik-Gerber et al., 2012). However, the limited adoption of these standards still represents a significant barrier to improving interoperability (Patacas et al., 2015). Additionally, the continued use of static documents such as CAD, PDF, and Excel spreadsheets complicates information retrieval during the Operation and Maintenance (O&M) phases, further hindering facilities management (Leygonie, Motamedi, and Iordanova, 2022).

At the same time, data reliability in as-built BIM models is another significant challenge. Issues such as inconsistencies between the model and real-world conditions, inaccessible information, and misaligned data compromise decision-making and operational efficiency (Brous et al., 2014; Munir et al., 2020). In a study conducted in Taiwan, Lin et al. (2018) identified critical issues in as-built models, such as inaccessibility, incorrect location, misalignment with field conditions, and inconsistent detailing. These factors highlight the need for quality assurance processes and robust data management strategies to ensure compliance with established standards and promote efficient operations.

Given these challenges, various efforts have been made to verify the reliability of delivered BIM models, aiming to ensure data accuracy and the presence of relevant information. Specialized tools and software are being developed to address these discrepancies, facilitating information control in as-built models and improving asset management.

Matarneh et al. (2020c) developed a generic set of information requirements for facility management systems, designed for integration into as-built BIM models. This standardization aims to optimize interoperability between BIM and FM systems, promoting greater efficiency in facilities management. The study included an extensive literature review and practical case analyses, highlighting the importance of standardization as a central element to facilitate information exchange and enhance management processes. On the other hand, specialized tools have also been employed to validate and complement delivered BIM models.

Oliveira et al. (2024) used Power BI to create an interactive dashboard that improves the efficiency of asset information management. Other tools, such as the Autodesk Revit COBie Toolkit and Solibri Model Checker (SMC), have been used to validate COBie files and create automated verification systems that ensure data compliance with client requirements (Altwassi et al., 2024).

Integration frameworks represent another area of progress. Goonetillake, Ren, and Li (2023) proposed a framework based on Business Process Model and Notation (BPMN) to model processes and capture data linked to 3D models in IFC format. Other approaches include the BIM-FM platform developed by Tsay, Staub-French, and Poirier (2022), which facilitates information transfer between BIM and other systems via .csv files, and the solution by Matarneh et al., which stores IFC data in COBie format within cloud databases, promoting greater integration and accessibility during the operational phase.

These efforts represent significant advances in the quest for solutions enabling BIM data integration with facility management systems. However, continuous improvements in interoperability, standardization, and information reliability are still necessary to ensure effective and sustainable asset management throughout buildings' lifecycles.

The tools identified in the studies assist in verifying and delivering information at the end of construction. However, they all operate in a unidirectional flow, where a file—whether in proprietary or open format—is used to verify and complement information, generating a new output format. In this process, the original project model ceases to be updated, and new information is stored in separate files, compromising data continuity and integration. As a result, there is no direct and continuous integration between the BIM model and the facility management system.

Based on the identified gaps and challenges, this study proposes the following solution: a set of tools utilizing non-proprietary formats that establish a bidirectional flow of information, enabling continuous verification and updating of the project's IFC file. This approach aims to overcome the limitations of unidirectional flows, enabling dynamic updates and information enrichment. As a result, it promotes more efficient and integrated asset management throughout the project lifecycle, representing a significant advancement in the practical application of BIM and information management in the construction industry.

3. METHODOLOGY

3.1 Executive Sequence

Given the pragmatic and solution-oriented nature of this research, which aims to propose a solution to an existing problem, the Design Science Research (DSR) method proposed by Simon (1996) was chosen. After identifying the problem, a systematic literature review was conducted to identify the state-of-the-art research in the area. The results obtained, as well as their limitations, were detailed in the previous section.

To achieve the proposed objective, an Artefact comprising four components was developed, each with a specific purpose. Together, these components form a cohesive system, as described below:

Component 1: It consists of the analysis of scientific publications, standards, and international documentation on asset management, with the objective of identifying the essential information requirements for the operational phase. The result will be a compendium of the minimum necessary information, facilitating the identification of requirements by owners, without specifying exactly which data must be included in the model, but offering an initial list of common requirements for any Asset Information Requirements (AIR).

Component 2: Development of a web platform for the registration and management of asset information present in the IFC model. The platform will allow continuous verification and updating of this information, facilitating data management throughout the construction and commissioning phases, with the support of an intuitive interface.

Component 3: Creation of a REST API (Representational State Transfer Application Programming Interface) that integrates data stored on the web platform with other systems and applications, ensuring interoperability of asset information.

Component 4: Development of an add-on for Bonsai that allows users to create asset records on the web platform (Component 2) or directly send information to it. Additionally, the add-on retrives updated information from the platform using the API (Component 3) to access and manipulate asset data registered in Component 2 directly in Blender. It also supports inserting this information into the IFC file, enabling efficient bidirectional data flow between Bonsai and the web platform.

After the presentation of the Artefact, the process involves the registration of selected assets for verification on the web platform. This step is conducted by a technical representative at the end of the construction phase or during commissioning, using the add-on. This approach eliminates the need to directly access BIM software to update information, allowing site personnel to perform updates via the web platform from any device. This ensures centralized and organized data visualization. The choice of a web platform aims to centralize information, avoiding reliance on decentralized, non-standardized personal spreadsheets, or other electronic or physical formats that hinder standardization. Additionally, the platform allows the creation of new assets directly if they were not imported from the model or not planned in the original model. In such cases, the corresponding GUID (Globally Unique Identifier) for the new object created in the IFC model can be entered later. At the end of commissioning, the add-on retrives this information and associates it with the respective objects. Any modifications made directly in the BIM software can also be sent back to the web platform, ensuring continuity of integration and a constant flow of information. Figure 1 illustrates the operational flow between the components of the Artefact.

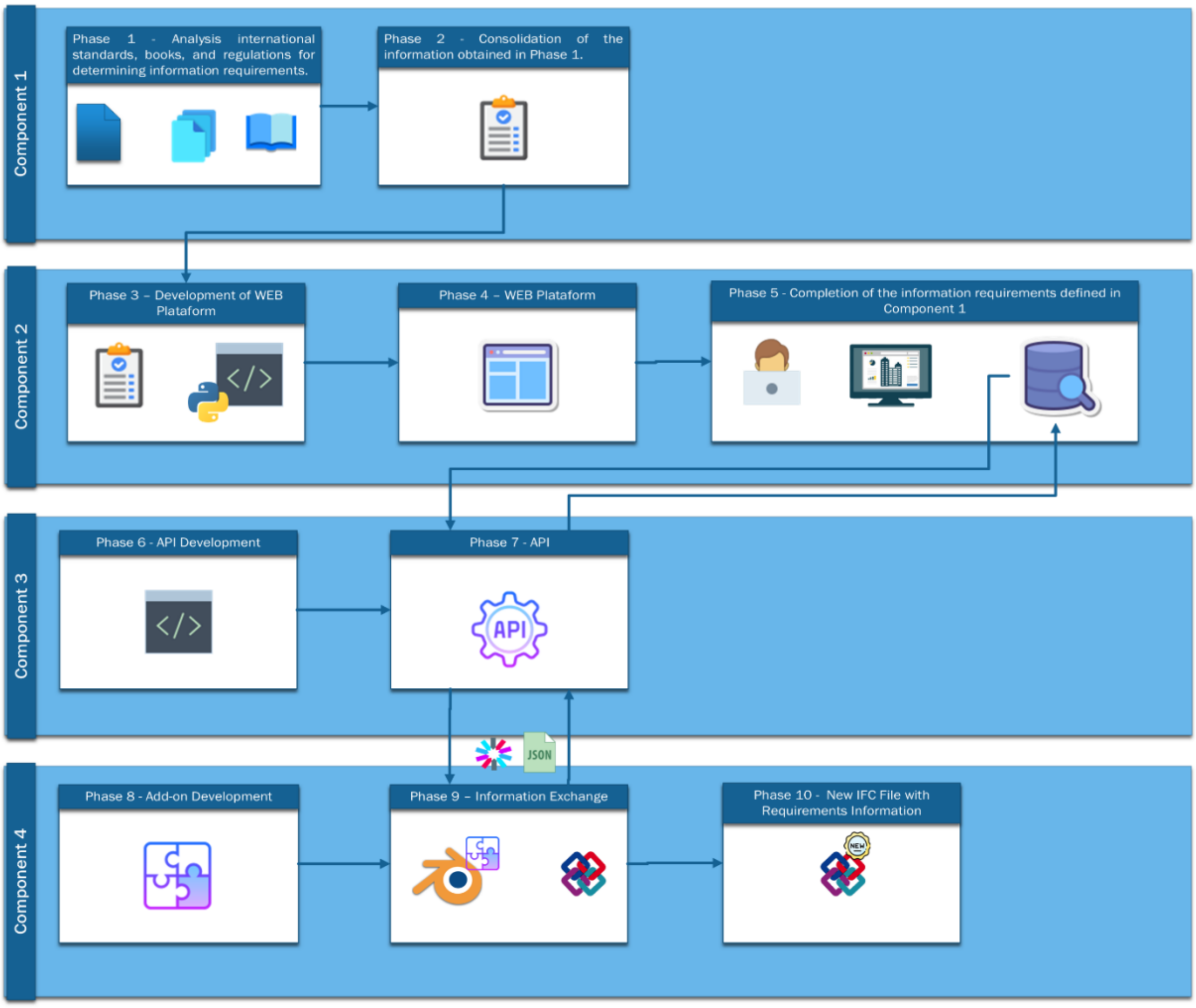

Figure 1: Operation flow of the artifacts.

Once the artifact is developed, the workflow for its use will follow the process map, as presented in Figure 2. Both the Manager and the Technical Responsible will utilize the components of the artifact to achieve more efficient management of the information within the model.

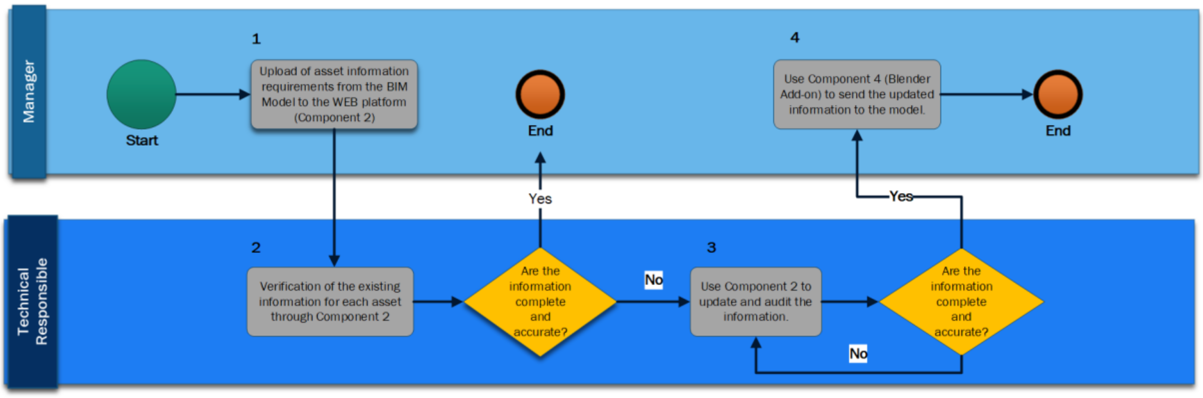

Figure 2: Process Map.

The methodology for the development of the components that constitute the Artefact will be presented next.

3.2 Development of the Artifact

3.2.1 Compoment 1: Development of Common Information Requirements for Assets

To identify and select common information requirements for assets, three sources were analyzed: scientific publications, international standards, and the Noteworthy BIM Publications (NBP).

During the systematic literature review, the study by Matarneh et al. (2019) stood out, which reviewed standards, best practices, and case studies, covering 21 publications. The study conducted a quantitative analysis to identify the frequency of occurrence of information requirements in the publications and a qualitative analysis of these requirements through a questionnaire applied to 191 facility management professionals in the United Kingdom.

In order to update and complement the study by Matarneh et al. (2019), some modifications were made. Two contemporary and relevant standards for BIM and asset management were incorporated: ISO 19650:2020-Part 3: Operational Phase of The Assets and BS 8210:2020 Facilities Maintenance Management — Code of Practice (BSI, 2020; ISO, 2020). These replaced the obsolete standards PAS 1192-3:2014 and BS 8210:2012, used in the original study.

Additionally, a search for Noteworthy BIM Publications (NBP) in the area of asset management was conducted to incorporate more data into the study. NBPs are widely recognized for promoting standardization and innovation in the construction industry (Kassem et al., 2015). Among the most relevant publications identified are: the "CDBB - Asset Information Requirements (AIR) - Guidance" from 2020, the "CIC BIM for Asset Management and Facility Management Case Sharing" from 2021, the "ABAB Asset Information Requirements Guide: Information required for the operation and maintenance of an asset" from 2018, the "The Crown State - Asset Information Model Requirements" from 2016, and the most recent version of "UCL Estates - Employer's Information Requirements," released in 2022.

The first four publications were not included in Matarneh et al. (2019), and an update was made by replacing the UCL Estates (2017) publication with the most recent version from 2022.

In total, four new publications were added to the initial study, and three were replaced due to obsolescence. The new publications were analyzed to identify the frequency of occurrence of information requirements. The consolidated results are presented in Table 1, with additional details provided in Appendix A.

Table 1: Information Requirements.

Information Requirements	Frequency	Information Requirements	Frequency
Warranty Information	23	Inspection Reports	6
Asset Location	21	Room Tag	6
Manufacturer/Supplier Information	20	General Installation Information	6
Identification Number	19	GIS Coordinates	6
Asset Description	17	System/Equipment Performance	5
Spatial Information	14	Regulations and Legal Compliance	5
Serial Number	13	Asset Condition	5
Preventive Maintenance Schedules	13	Life Cycle Cost	5
Asset Specification	13	Risk Assessments	5
Classification	13	Design Criteria	4
Asset Name	12	Performance Code	4
Barcode Information	11	Occupancy Rate	4
Systems and Associated Subsystems	10	Capacity	4
Brand and/or Model	10	Installation Guide	3
O&M Manuals	10	Operations Sequence	3
Spare Parts Information	9	Master Plans	3
Replacement Cost	9	Accessibility Performance	3
Installation Date	9	Certificates	3
Expected Service Life	8	Contracts	3
Maintenance History	8	Ownership	3
Purchase Information	8	Equipment Lists	2
Sustainability Performance	8	Control Panels/Valves Location	2
Delivery Documentation	7		

3.2.2 Component 2: Web Platform Development

For the development of the web platform, the Python programming language was chosen, widely recognized for its strong presence in academia and for offering a wide range of resources and support (Marowka, 2018). Additionally, Python is compatible with the IfcOpenShell library, essential for manipulating IFC files in Blender and Bonsai, tools that will play a crucial role in the subsequent stages of the research.

The platform's backend was implemented using the Django framework, selected for its robustness and its ability to accelerate the development of secure and complex web applications. The main advantages of Django include component reuse, ease of maintenance, and built-in security.

HTML and CSS were employed for frontend development, along with the Bootstrap library, which is widely used for creating modern and responsive web interfaces

The platform, named "Assets" (Figure 3), was designed to allow user registration and permission configuration in its administrative area. This feature ensures that create, read, update, and delete (CRUD) operations are performed according to specific authorizations, guaranteeing data integrity and security.

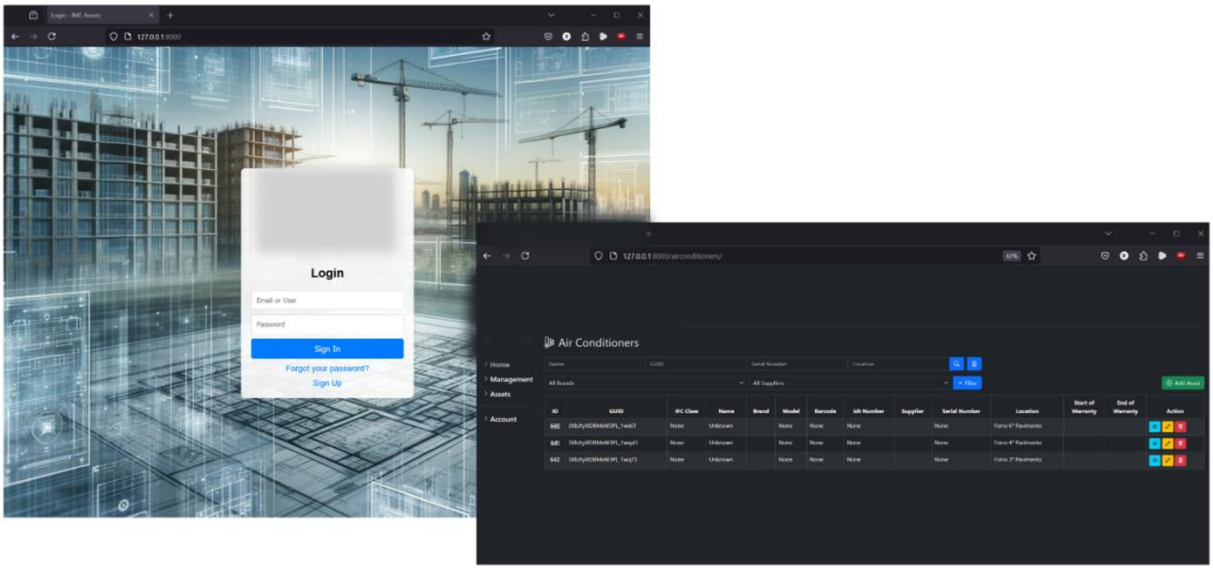

Figure 3: Assets Web Site.

As previously mentioned, asset registrations can be performed directly on the platform, either through automatic submission from Compoment 4 or manually on the site itself. As illustrated in Figure 4, the platform allows searches by name, GUID, serial number, or supplier (1). Additionally, the platform enables the creation of new assets (2) or the viewing and editing of already registered information (3).

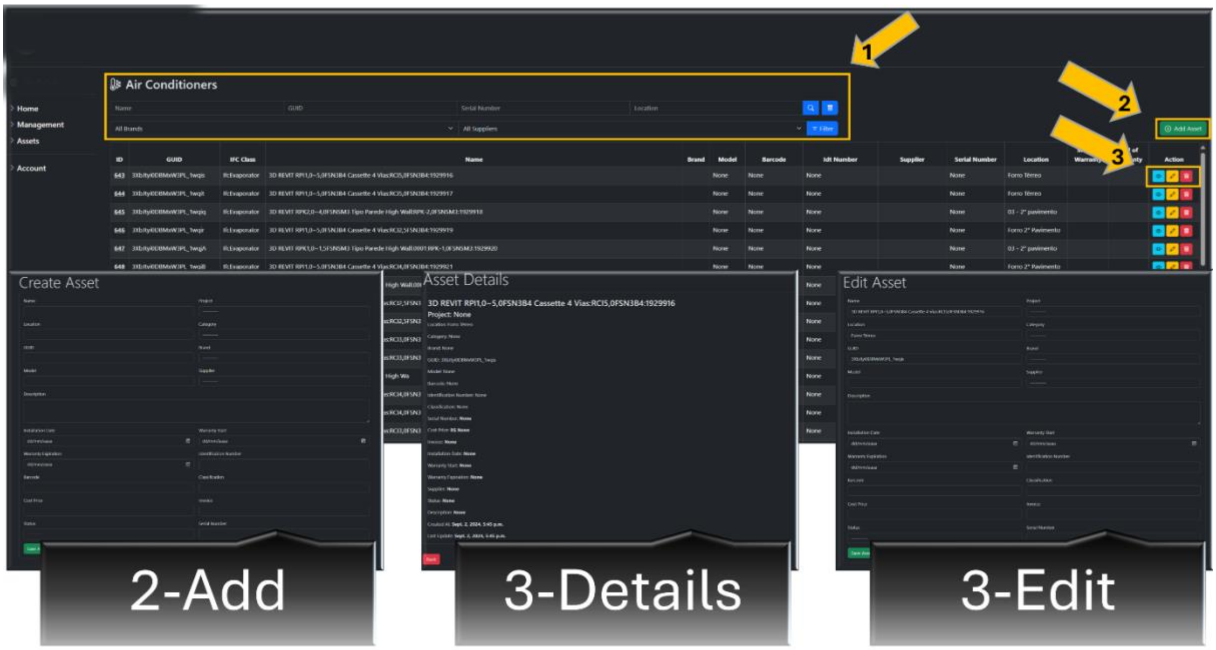

Figure 4: Creation, Delete and Edit Options.

The database was implemented using SQLite, a native Django solution chosen for its lightweight nature and ease of implementation, which are ideal characteristics for this small-scale project. However, in case the platform needs to be scaled for production environments, it is feasible to replace SQLite with a more robust database.

Database Modeling

Based on the information requirements identified in Component 1, the database was computationally modeled to ensure the presence of the minimum necessary information at the end of the construction phase and the beginning of the operational phase.

The prioritization of information requirements for platform implementation was defined using the Pareto method (80/20 rule). Table 2 presents the accumulated percentage of this analysis. Specific data for the operational phase, such as maintenance schedules and operation manuals, were excluded from the initial implementation, as they will be developed during the operational phase. This data is outside the scope of this research, which focuses on the interface between the end of construction and the beginning of operation.

Table 2: Information Requirements and Accumulated Percentage.

Information Requirements	Frequency	Accumulated Percentage
Warranty Information	23	6.13%
Asset Location	21	11.73%
Manufacturer/Supplier Information	20	17.07%
Identification Number	19	22.13%
Asset Description	17	26.67%
Spatial Information	14	30.40%
Serial Number	13	33.87%
Preventive Maintenance Schedules	13	37.33%
Asset Specification	13	40.80%
Classification	13	44.27%
Asset Name	12	47.47%
Barcode Information	11	50.40%
Systems and Associated Subsystems	10	53.07%
Brand and/or Model	10	55.73%
O&M Manuals	10	58,40%
Spare Parts Information	9	60,80%
Replacement Cost	9	63,20%
Installation Date	9	65,60%
Expected Service Life	8	67,73%
Maintenance History	8	69,87%
Purchase Information	8	72,00%
Sustainability Performance	8	74,13%
Delivery Documentation	7	76,00%
Inspection Reports	6	77.60%
Room Tag	6	79.20%
General Installation Information	6	80.80%

GIS Coordinates	6	82.40%
System/Equipment Performance	5	83.73%
Regulations and Legal Compliance	5	85.07%
Asset Condition	5	86.40%
Life Cycle Cost	5	87.73%
Risk Assessments	5	89.07%
Design Criteria	4	90.13%
Performance Code	4	91.20%
Occupancy Rate	4	92.27%
Capacity	4	93.33%
Installation Guide	3	94.13%
Operations Sequence	3	94.93%
Master Plans	3	95.73%
Accessibility Performance	3	96.53%
Certificates	3	97.33%
Contracts	3	98.13%
Ownership	3	98.93%
Equipment Lists	2	99.47%
Control Panels/Valves Location	2	100.00%

After this analysis, the requirements presented in Table 3 were selected for implementation in the web platform's database.

Table 3: Selected Information Requirements.

Information Requirements	Information Requirements	Information Requirements
Warranty Information	Asset Description	Installation Date
Asset Location	Serial Number	Purchase Information
Manufacturer/Supplier Information	Classification	Delivery Documentation
Identification Number	Asset Name	Environment Tag
Barcode Information	Brand/Model	General Installation Information

The warranty information will be divided into two elements: warranty start and warranty end, with the intent of using Property sets already present in the IFC format. Regarding manufacturer and supplier information, it will be necessary to separate them, as in many cases, especially in bidding processes, the supplier of the item is not responsible for its manufacturing.

As for the supplier, the database table will be structured and modeled according to the "Contact" tab in the COBie format to ensure full compliance with this standard. This table will include data such as email, category, company, phone, OrganizationCode, Street, Town, StateRegion, PostalCode, and Country. The "category" element is an enumerated type in the IFC format and, in this case, will be filled with the value "SUPPLIER." Figure 5 presents the database modeling.

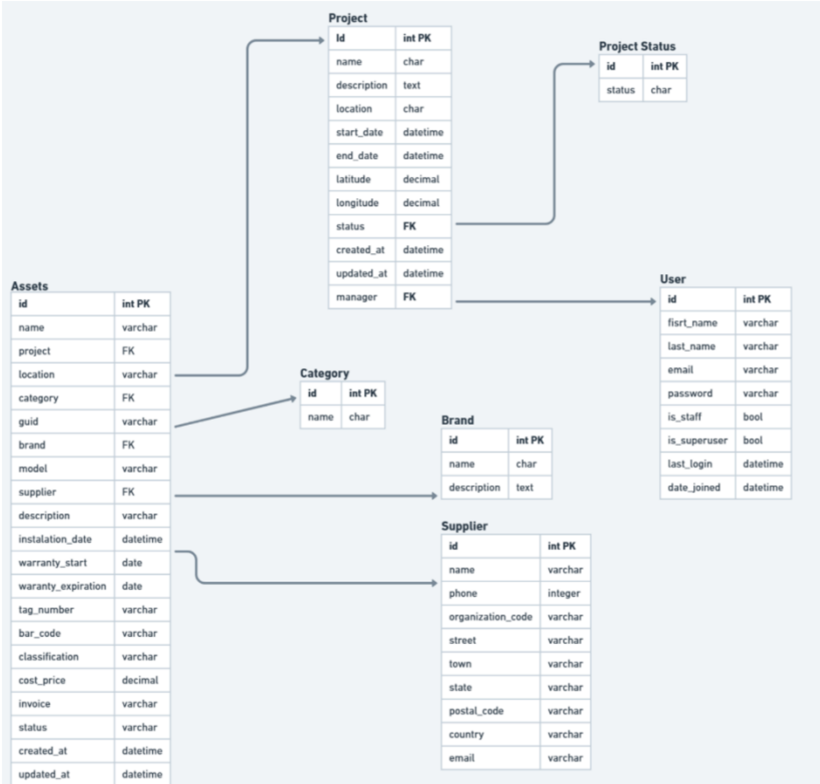

Figure 5: Data Base modeling.

3.2.3 Component 3: Development of the REST API

The third component developed in this study is a REST API (Representational State Transfer Application Programming Interface) , with the main goal of allowing the integration of the web platform with other systems. The API facilitates communication and data sharing between the platform and external applications, promoting interoperability and expanding the reach of the information stored in the database.

An API is a set of definitions and protocols that enables integration between different systems and software. It allows the sending and receiving of data, acting as a bridge between applications, without the need to know the internal details of its functioning. This is essential for creating modular and interoperable systems, where different components can be developed, updated, and maintained independently.

The REST API adopts a resource-oriented architecture, where each resource is identified by a URL (Uniform Resource Locator) and manipulated through HTTP methods. Among the methods used are GET, to retrieve information; POST, to create new resources; PUT/PATCH, to update existing resources; and DELETE, to delete resources.

The development of the REST API was carried out using the Django REST Framework (DRF), which integrates seamlessly with Django, facilitating the construction of robust and scalable web APIs. DRF offers tools such as data serialization, permission control, and authentication, enabling efficient creation of API endpoints. The choice of DRF was made due to its close integration with Django, which was already used in the development of the platform's backend, ensuring consistency and simplicity in the development process.

When a request is made to one of the API's endpoints, the system returns a list in JSON (JavaScript Object Notation) format, containing the data registered on the platform, as shown in Figure 6. JSON is a lightweight and widely used format for data exchange between server and client in web applications, structuring information in key-value pairs.

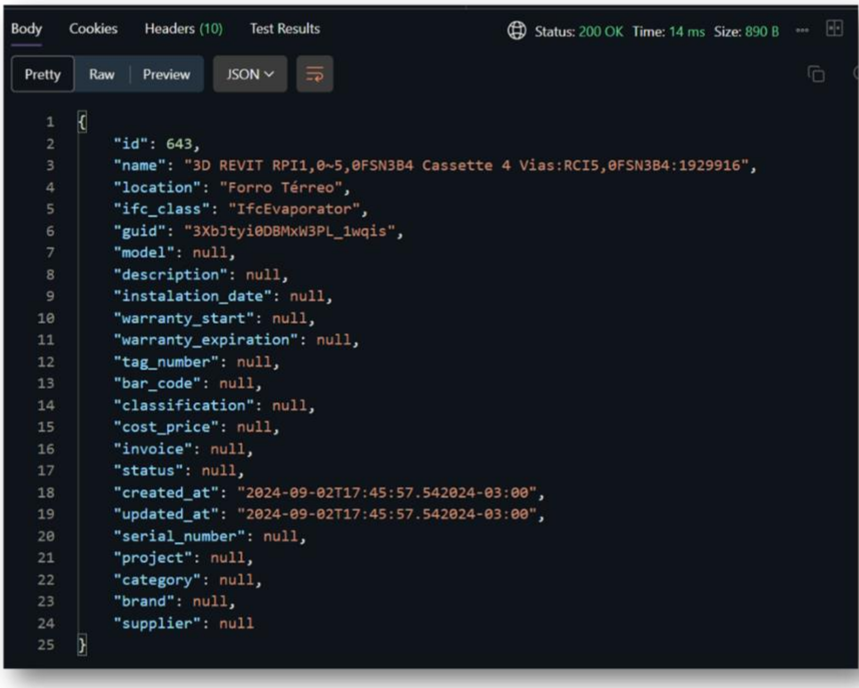

Figure 6: JSON Response.

To ensure data security and access control, a token-based authentication mechanism was implemented. This system requires the user to generate a token on the web platform, which contains their identification credentials. When a request is made to the database, the token is sent along with the request, allowing the user's authorizations to be verified. If the user has the necessary permissions, a response in JSON format is sent, as illustrated in Figure 7 (1). If the authorizations are insufficient, the request is denied, as shown in Figure 7 (2).

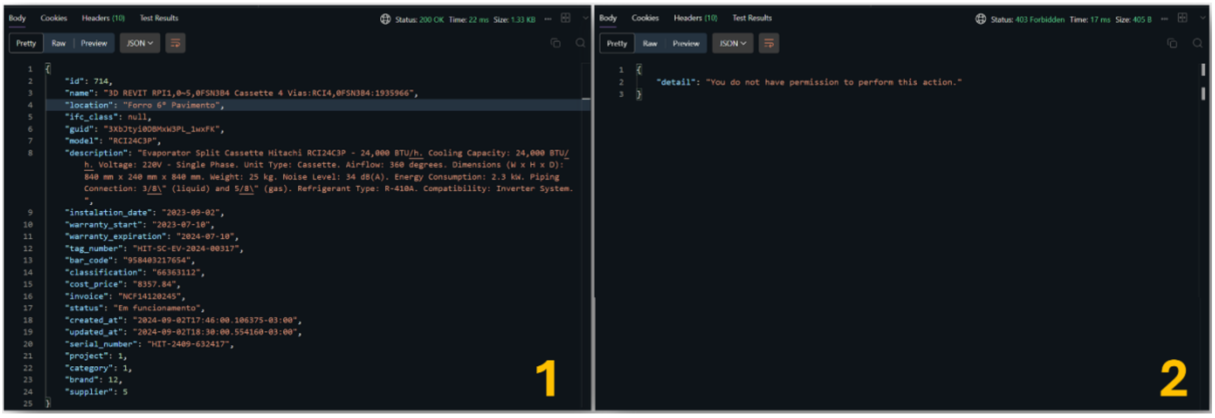

Figure 7: (1) Authorized requests in JSON format; (2) Unauthorized requests.

For the implementation of this authentication mechanism, JWT (JSON Web Token) was used, a technology widely adopted for its efficiency and robustness in terms of security. JWT ensures that only authenticated and authorized users can perform create, read, update, or delete operations on the database, reinforcing the protection of the data stored on the platform.

3.2.4 Component 4: Development of the Add-on for Blender

The fourth component consists of an add-on that functions as a communication interface between the model visualized in Bonsai and the database of the web platform developed in Component 2. An add-on is an extension that adds extra functionalities to software. In this case, the developed add-on allows the user to receive information registered in the database, as well as create, edit, and transmit changes directly to the database. This ensures a bidirectional flow of information and data consistency between the components.

The development of Component 4 (Figure 8) was carried out in Python due to its compatibility with the APIs of Blender and Bonsai. Additionally, the IfcOpenShell library was used, which allows reading, modifying, and writing data in IFC files. This library was employed to include additional data, such as attributes and property set collections, in the objects managed by the model.

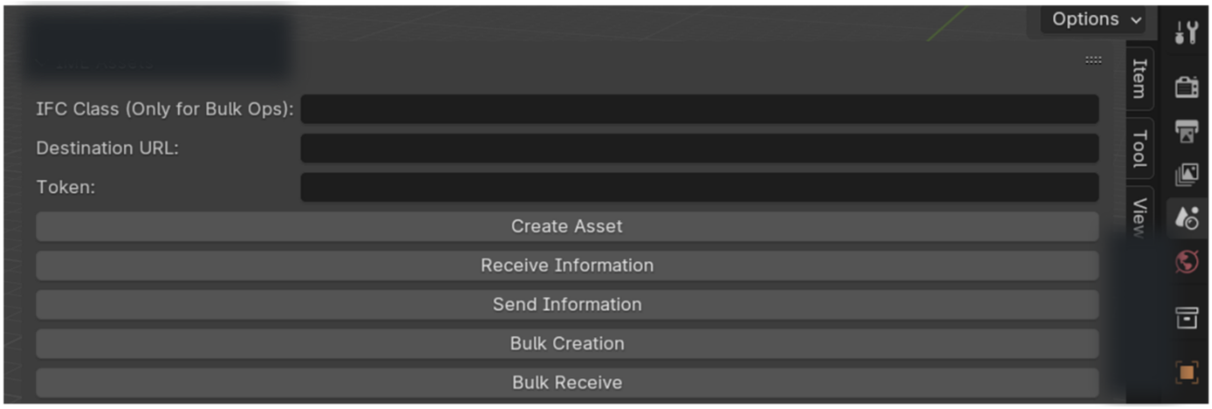

Figure 8: Add-On View.

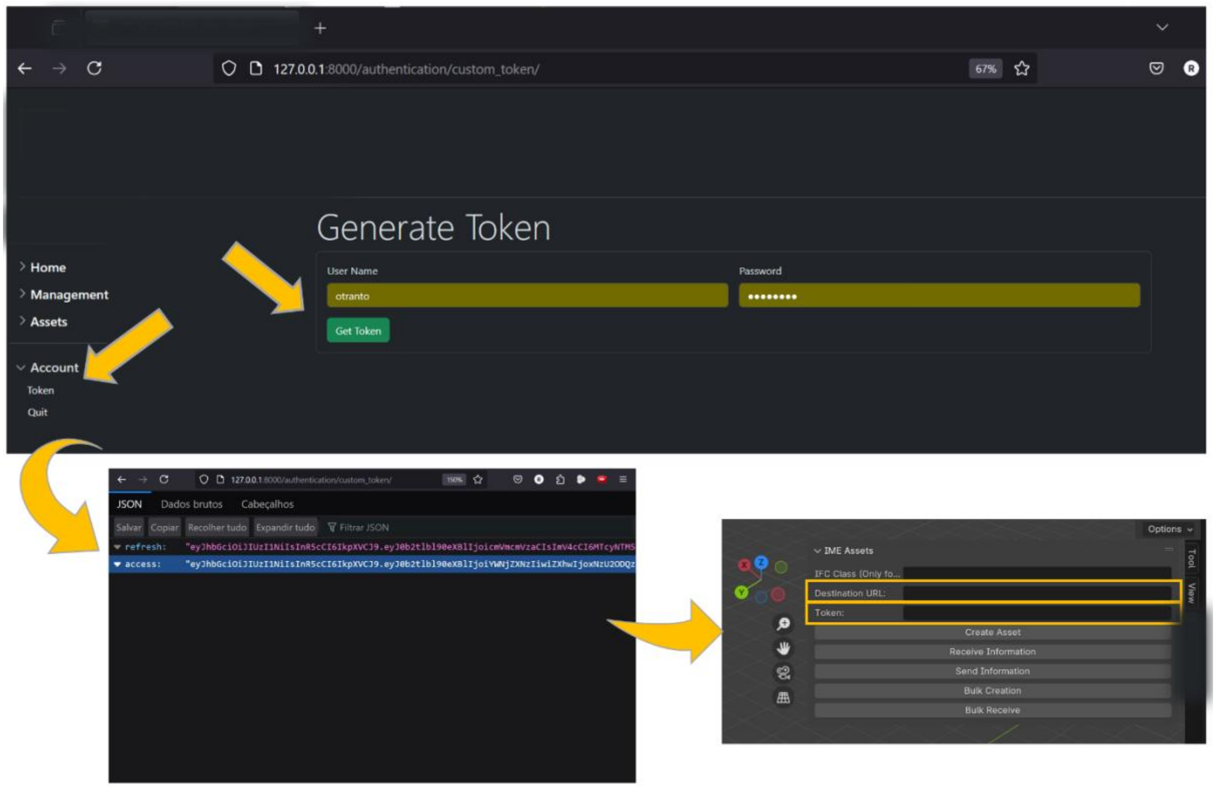

Figure 9: Operation of the artifacts.

Table 4: Relationship between information requirements and IFC.

Category	Specification	IFC Schema Object Type	Class or Pset Name	Planned Pset	Attribute Name or Enumerated Type
Identification Data	Name	Attribute	-	Not applicable	Name
	Description	Attribute	-	Not applicable	Description
	Identification Number	Attribute	-	Not applicable	GlobalId
	Tag	Attribute	-	Not applicable	Tag
Category	Name	Pset	Pset_ManufacturerTypeInformation	Yes	Manufacturer
	Name	Class	IfcActor; IfcOrganization;	Not applicable	MANUFACTURER
Supplier Data	Name, Organization Code, address, city, state, postal code, phone, and email	Class	IfcActor; IfcOrganization;	Not applicable	SUPPLIER
Product Data	Model	Pset	Pset_ManufacturerTypeInformation	Yes	ModelLabel
Product Data	Barcode	Pset	Pset_ManufacturerOccurrence	Yes	BarCode
	Serial Number	Pset	Pset_ManufacturerOccurrence	Yes	SerialNumber
Warranty Data	Warranty Start Date	Pset	Pset_Warranty	Yes	WarrantyStartDate
	Warranty End Date	Pset	Pset_Warranty	Yes	WarrantyEndDate
Purchase Information	Acquisition Date	Pset	Pset_ManufacturerOccurrence	Yes	AcquisitionDate
	Invoice Number	Pset	P_New	No	Invoice
Classification	Classification Code	Class	IfcClassification	Not applicable	ReferenceTokens
General Installation Information	Installation Date	Pset	Pset_InstallationOccurrence	Yes	InstallationDate

The logic of operation for Component 4 is described as follows: the user initially specifies the IFC class corresponding to the assets they wish to register on the site, using the 'IFC Class' field. Then, the destination URL is provided in the 'Destination URL' field, as configured on the web platform. The next step involves generating a token on the web platform, containing the user's identification information. After entering the token in the corresponding field in the add-on, the user can initiate the process of creating, sending, and receiving information between Bonsai and the web platform.

By selecting an object and clicking on 'Create Asset,' a record of that asset is created in the database. From that point, the user can use the 'Send Information' option to send updates made directly in the model, synchronizing the changes with the database. Alternatively, by clicking on 'Receive Information,' the data from the web platform is imported into the model, ensuring that both remain updated and synchronized. Additionally, if the user wishes to create all information for a specific class on the site or receive all information for that same class, they can use the 'Bulk Create' and 'Bulk Receive' options, optimizing the data management process. Figure 9 illustrates the detailed operation of the artifacts.

A crucial aspect of this process is the correct insertion of information in the IFC 4.3 format, according to the ISO 16739-1:2024 documentation. This ensures both data model integrity and interoperability with other software. Information in the IFC model can be assigned as class attributes, property sets, or through the creation of custom property sets. It is essential that data is correctly allocated to avoid the creation of unnecessary custom property sets, thereby ensuring greater standardization and efficiency in information management.

To ensure compliance, it is necessary to review Component 1 and carefully determine the correct allocation of information in the IFC format. Table 4 presents the relationship between the selected information requirements and their allocation within the IFC format.

4. CASE STUDY

The case study focuses on an educational building in Brazil with a total area of 7,068.42 m², designed to meet both accommodation and educational needs, as shown in Figure 10. The building includes a basement, ground floor, six floors, and a rooftop, which will house air conditioning condensers, solar panels, photovoltaic panels, and technical rooms for gas water heating.

Figure 10: Annex building of the educational building.

The case study will address the HVAC project of the annex, focusing on the air conditioning system. The cassette-type evaporator units will be connected to the condenser units via ventilation ducts, as illustrated in Figure 11. An analysis of the evaporator units in the same figure reveals that the objects, as displayed in Bonsai's side panel, lack essential information about these assets. This issue affects all evaporator units in the HVAC system.

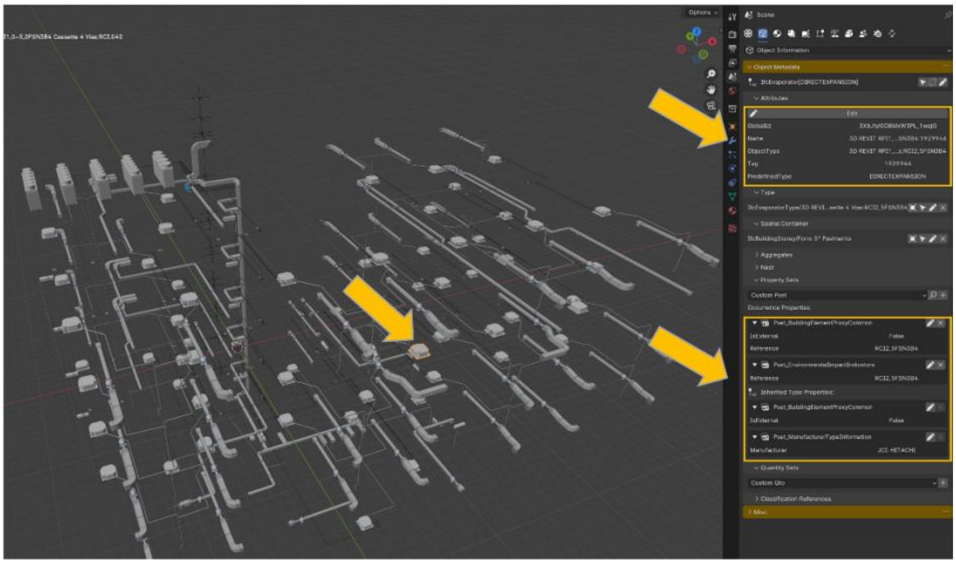

Figure 11: HAVC Project.

Due to the lack of information in the model, the information management process was initiated using the created Artifact. The process began as indicated in block 1 of the process map, presented in Figure 2, where the construction manager uploaded all the information of the assets to be managed to the web platform. For this, the Bulk Creation option of the add-on (component 4) was used to send all air conditioning unit records to the web platform (component 2) at once, starting the information management process. The IFC class of the objects, the destination URL corresponding to the endpoint created to receive the data on the web platform, and the user's token were then provided.

Figure 12 illustrates the described process, as well as the web platform with all the data loaded. In total, 84 air conditioning units were registered on the platform.

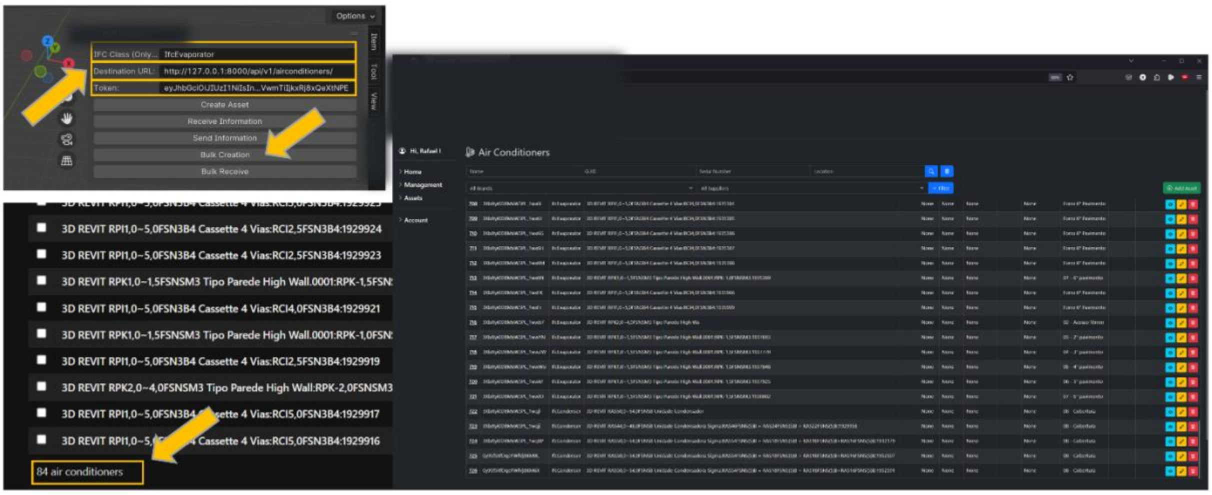

Figure 12: Use of the Artifact.

After the assets were entered into the web platform, the information was verified by the technical managers, as indicated in block 2 of the process map in Figure 2. Then, the editing and updating phase of the information began, also as outlined in block 3 of the process map, a procedure illustrated in Figure 13 (1). After the registration was completed, the existing information was verified. Once the information was audited, it was necessary to transfer it from the web platform to the BIM model, as per block 4 of the process map. For this task, the add-on provides two options: the first allows the information to be retrieved individually through the "Receive Information" option; the second enables bulk import using the "Bulk Receive" option. After the import, the information is correctly registered in the IFC file and assigned to the corresponding attributes or Property Sets, as shown in Figure 13 (2).

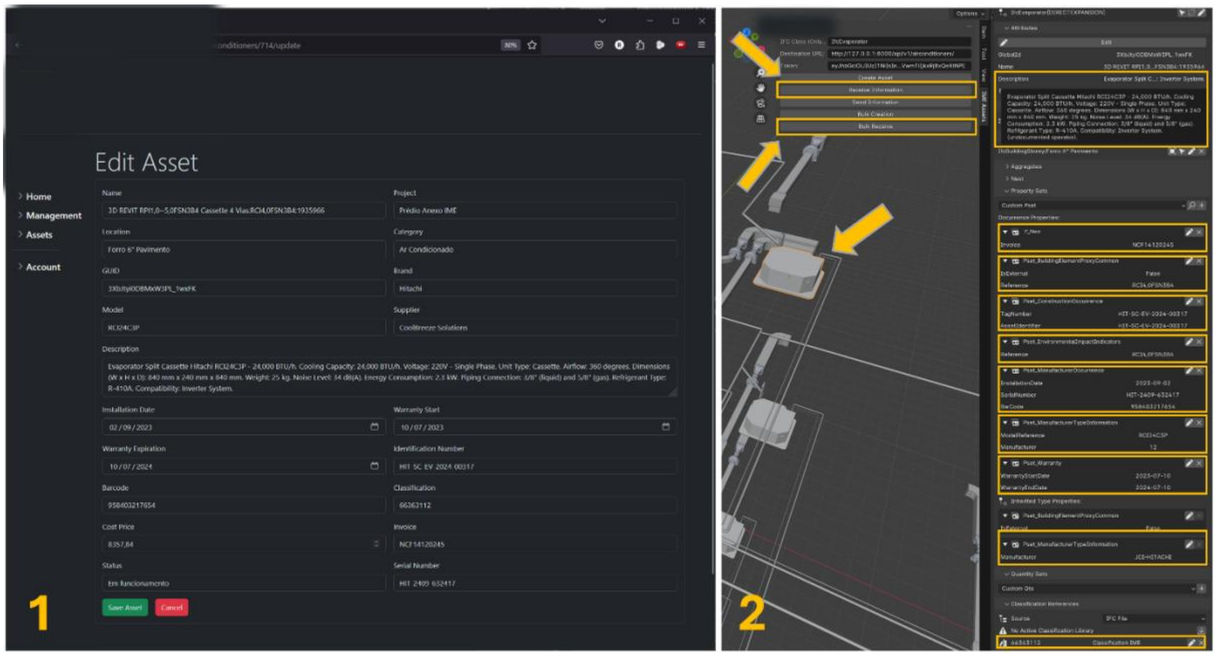

Figure 13: (1) Information editing; (2) Information transferred to the BIM model.

5. DISCUSSIONS

The results obtained in the case study satisfactorily reflect the initial objectives of the work, which aimed to improve asset information management at the interface between the construction completion and the start of the operational phase using BIM.

Throughout Component 1, it was possible to update the work previously carried out by Matarneh et al. (2019) and provide a list of common information requirements for various assets, with the aim of assisting owners unfamiliar with BIM, FM, or both to begin defining the information requirements for their assets.

The development of the web platform in Component 2 provided an effective environment for the creation and management of asset information. The choice to use a web platform proved strategic, as it allowed quick access to data through browsers, regardless of the operating system or device used, without the need for additional installations. The platform's security was ensured through an access management system, with specific authorizations assigned to each type of user.

The developed platform demonstrated effectiveness by allowing the auditing of information by different stakeholders involved in building management, effectively addressing the challenges related to data accuracy and consistency, as discussed by Munir et al. (2020) and Brous et al. (2014). This significantly reduced the risk of compromising decision-making while increasing the efficiency of asset management operations.

Additionally, the centralization of asset data in a single interface facilitated visualization and editing before its incorporation into the BIM model. This approach addressed concerns highlighted by Tsay, Staub-French, and Poirier (2022), who pointed out that traditional methods often failed to provide useful data to owners, demonstrating the need for a continuous validation process to ensure compliance with information requirements.

The implementation of the API with access control to the database, using tokens to ensure that changes were made according to user permissions, ensured interoperability between Component 2 and Component 4. Moreover, the use of the JSON format for data exchange allowed this information to be easily retrived by other BIM software, websites, or applications, expanding the possibilities for integration and use for various purposes.

Finally, the developed add-on proved effective in consuming information from the web platform and sending data back to this platform, ensuring a bidirectional flow of information. This functionality ensured that both the web platform and the BIM model handled in Bonsai remained consistently updated with the same information. Additionally, all data entered into the model was correctly allocated in the appropriate locations, according to the IFC 4.3 schema, reinforcing the tool's commitment to interoperability. This ensures that Facility Management (FM) tools or others that need to access this information can retrieve it efficiently, thanks to the correct allocation of data.

It is important to highlight that, as a modular solution was developed, all components—except for the add-on (Component 4)—can be used with other BIM software such as Revit or Archicad. The fact that the API works with a neutral format like JSON allows the data to be read and utilized not only in other BIM but also in non-BIM solutions. This enables broader applications, including integration with tools such as Microsoft Excel, Power BI, or other institutional automation systems.As for the limitations, only common information requirements were used, as it is understood that specific information will vary according to the AIR, which in turn will be the result of each organization's goals developed in their OIR.

6. CONCLUSION

This study presented an innovative solution proposal for the challenges faced in the integration of Facility Management (FM) with Building Information Modeling (BIM), emphasizing the importance of interoperability and effective asset information management throughout the building lifecycle. Through the development of the Artifact, it was possible to create a bidirectional flow of information that minimizes data loss and ensures continuous updates between BIM models and management platforms, with the aim of providing, at the end of construction, a BIM model structured with the minimum necessary and reliable information to initiate the operational phase.

The results demonstrated that the web platform and the REST API were effective in centralizing and disseminating information, addressing data accuracy and consistency issues, as discussed by several authors throughout this work. Additionally, the add-on for Blender proved crucial for practical integration between the BIM model and the web platform, reinforcing the commitment to interoperability and ensuring that the information is always updated and properly allocated within the IFC 4.3 schema.

Although the study achieved its objectives, some limitations were identified, such as the focus on common information requirements. Future research could explore the application of the developed Artefact and its components in other BIM software or mobile devices, as well as in different types of assets, thereby expanding the impact and applicability of the proposed solutions.Thus, it is expected that this work will contribute significantly to the field of Facility Management and BIM, offering practical tools that can be adopted by the construction industry to improve information management and ensure the sustainability of assets throughout their lifecycle.

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APPENDIX A

No.	Information Requiremnts	References
1	Design Criteria	4,7,12,14
2	Delivery Documentation	1,4,5,9,15,17,20
3	Spare Parts Information	2,4,5,6,8,9,15,16,17
4	Manufacturer/Supplier Information	1,2,3,4,5,8,10,11,12,13,15,16,17,18,19,20,21,22,24,25
5	Serial Number	2,4,5,6,10,11,15,18,19,20,22,24,25
6	Asset Location	1,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,23,25
7	Warranty Information	1,2,3,4,5,6,8,9,10,11,12,13,14,15,17,18,19,20,21,22,23,24,25
8	Replacement Cost	1,4,10,11,12,15,17,18,20
9	Installation Guide	2,4,9
10	System/Equipment Performance	4,7,9,12,25
11	Expected Service Life	10,11,15,17,18,20,24,25
12	Operations Sequence	4,7,14
13	Maintenance History	1,2,4,7,8,12,14,16
14	Preventive Maintenance Schedules	1,2,4,7,8,9,12,14,15,16,17,21,24
15	Inspection Reports	2,4,7,9,12,14
16	Master Plans	4,7,17
17	Asset Name	2,3,5,8,10,11,15,18,19,20,24,25
18	Systems and Associated Subsystems	3,4,5,7,10,12,15,18,24,25
19	Equipment Lists	4,17
20	Asset Description	3,5,7,8,10,11,12,13,14,15,16,18,19,20,22,23,25
21	Identification Number	1,2,5,6,8,9,10,11,12,13,15,16,17,18,21,22,23,24,25
22	Spatial Information	1,2,3,5,7,9,10,11,12,15,18,20,23,24
23	Regulations and Legal Compliance	2,5,9,12,17
24	Brand and/or Model	2,9,15,16,17,18,19,23,24,25
25	Installation Date	1,5,12,15,16,17,22,23,25
24	Asset Specification	1,2,4,8,10,12,13,14,15,16,17,20,22
25	Purchase Information	1,2,6,9,12,14,16,25
28	Barcode Information	2,5,8,9,10,11,15,18,20,24,25
29	Performance Code	5,15,17,22
30	O&M Manuals	3,7,9,12,13,14,17,20,22,23
31	Classification	2,3,5,6,10,11,15,17,18,20,22,23,24
32	Asset Condition	5,12,16,17,24
33	Life Cycle Cost	2,5,12,16,17

34	Room Tag	10,11,18,20,23,25
35	Accessibility Performance	7,15,17
36	Certificates	2,9,13
37	Sustainability Performance	5,9,10,12,15,17,22,23
38	General Installation Information	2,3,5,10,11,14
39	Contracts	12,17,23
40	Occupancy Rate	5,7,9,14
41	Capacity	5,6,7,18
42	Ownership	12,17,23
43	GIS Coordinates	3,9,10,12,14,15
44	Risk Assessments	5,9,12,14,17
45	Control Panels/Valves Location	2,4

Sources: [1] Lu et al. (2018); [2] Farghaly et al. (2018); [3] UCL (2017); [4] Cavka, Staub-French e Poirier (2017); [5] CIBSE (2017); [6] Thabet e Lucas (2017); [7] Yang e Ergan (2017); [8] Lin et al. (2016); [9] Mayo e Issa (2016); [10] MoJ (2016); [11] UoR (2016); [12] ISO (2020); [13] Wang et al. (2013); [14] Becerik-Gerber et al. (2012); [15] BSI (2014a); [16] BSI (2020a); [17] BSI (2012b); [18] USC (2012); [19] Pennsylvania State University (2011); [20] GSA (2011); [21] Hunt (2016); [22] CDBB (2020); [23] CIC (2021); [24] ABAB (2018); [25] The Crown Estate (2016).