Proposal for a Maintenance Management System Using Point Clouds

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April 17, 2024

ICCEPM 2024
The 10th International Conference on Construction Engineering and Project Management
Jul. 29-Aug.1, 2024, Sapporo

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Abstract
BIM (Building Information Modeling) is touted for efficient building maintenance and operation. However, transitioning from construction to maintenance poses challenges in information transfer and definitive data before completion. Existing structures often lack BIM, demanding more modeling. Additionally, few maintenance staff are skilled in BIM tools.On the other hand, there are studies utilizing point clouds for maintenance. Since point cloud data can record the current situation in 3D, it has advantages such as easily representing valve positions of equipment compared to deformed BIM data.Attribute information uses the international standard COBie, which can record and manage data necessary for building asset management.Point cloud data is broken down into groups of objects necessary for maintenance management by referencing the Common Specification for Building Preservation. Each decomposed object is assigned a corresponding Uniclass number.In this system, the point cloud data, which represents the shape information of the building, is decomposed into objects based on the Common Specification. Using COBie, the building database is created and tasks related to the objects are organized. Each database and system is then connected using Uniclass.By implementing this system, even buildings completed can easily create BIM data from point clouds. Furthermore, since it complies with the international standard COBie, maintenance tasks can be performed in a standardized format, serving as a bridge to the maintenance management system.
Key words: FM BIM Poindcloud COBie Uniclass

1. PURPOSE AND BACKGROUND

Building Information Modeling (BIM) holds promise for improving productivity in the construction industry and has seen numerous proposed advantages and applications during design and construction phases. However, the efficiency gains from utilizing BIM in maintenance and management phases are less documented. Additionally, the transition from construction to maintenance often fails to inherit necessary information, and some information only becomes finalized after completion. There is also a significant divergence between the information handled during design and construction phases and the information required for maintenance, leading to numerous challenges in operational BIM creation. [1]

Furthermore, for existing buildings, additional modeling is required, thus demanding more labor. There is also the challenge that few maintenance personnel have mastered BIM tools. [2] Previous studies have used point cloud data for maintenance, but converting point clouds into BIM data is still a necessity. [3] On the other hand, while numerous Facility Management softwares and Computerized Maintenance Management Systems (CMMS) have been released to streamline maintenance work, they are currently based on data collected from as-built drawings, necessitating re-entry of similar information at the beginning of maintenance tasks. [4] Additionally, the requirements vary for each company and building usage, making it difficult to use these tools directly on-site without customization, which can lead to increased costs. Therefore, there is a need for a comprehensive management system that can be customized by users to meet diverse requirements. [5] Hence, this research proposes a method that combines point cloud data, which does not require model creation, with BIM concepts to appropriately handle the complex web of maintenance data, focusing on the attribute information handled in maintenance.

2. PURPOSED CONTENT

In the study proposed, the system is referred to as the "FM Point Cloud Platform." The overall image of the "FM Point Cloud Platform" is shown in Figure 1. The "FM Point Cloud Platform" is a system that utilizes point cloud data for the maintenance management of existing buildings to realize detailed management based on 3D information. This system automates the segmentation of captured and synthesized point cloud data to identify equipment and components. It then uses the segmented point cloud data to facilitate the use of BIM and to construct a 3D index for document management. The "FM Point Cloud Platform" serves as the core interface that connects to each function. The "Point Cloud Viewer" possesses various functionalities. It automatically segments captured point cloud data to identify individual pieces of equipment and components, assigns Uniclass classification numbers to each object, enabling the use of BIM, and constructs a 3D index for management. Users can visually confirm the 3D data within a building through the point cloud viewer and ascertain the location and condition of maintenance equipment. Static data, which is confirmed at the time of building completion within the "FM Point Cloud Platform," is managed using the international standard format COBie. This data includes the basic specifications of buildings and equipment, as well as maintenance information, and can be viewed directly on the platform. Static data refers to information confirmed at the time of building completion and, except for equipment replacement, does not change over time, consistently referenced throughout the building's lifecycle. Dynamic data used during operation within the "FM Point Cloud Platform" is stored in a separate database, which accumulates information such as routine inspections and repair history. This information, like static data, can be viewed directly on the platform, but also allows for integration with existing inspection record tools used by companies through API connections. Dynamic data refers to information such as inspection records and repair histories that accumulate over the course of maintenance operations after the building is put into use. The "FM Point Cloud Platform" contains only the minimum elements necessary for maintenance management, but by equipping the point cloud platform with an API for information connection, it allows users to add desired functions independently. This study assumes that the process of identifying point cloud data of equipment and components within the acquired point cloud data has been performed.

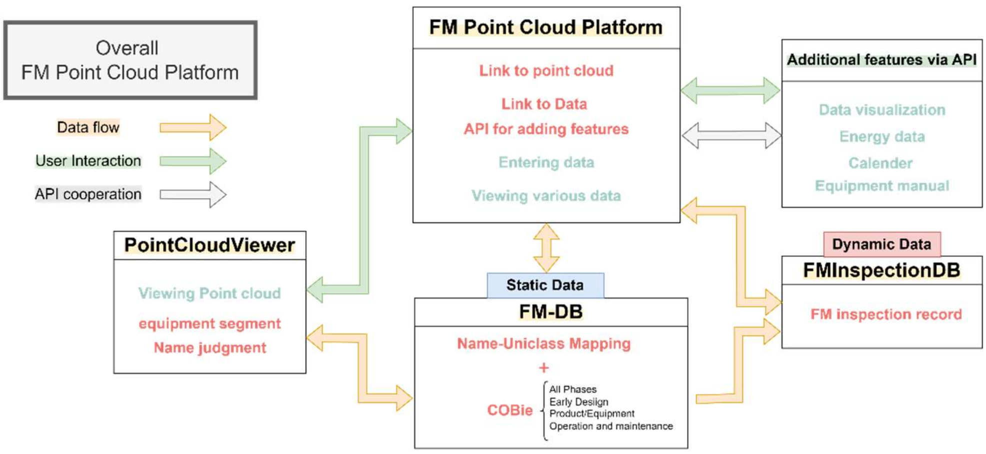

Figure 1. Overall FM Point Cloud Platform

3.ATTRIBUTE INFORMATION USED IN POINT CLOUD BIM

3.1. Information Management Using COBie

3.1.1.Reasons for Selecting COBie

The attribute information within the "FM Point Cloud Platform" utilizes COBie (Construction Operations Building Information Exchange), which is an international standard that records and manages the necessary data for building asset management. COBie is a data exchange method used for documenting BIM data. It functions as the standard format for transferring information accumulated in BIM post-construction to the maintenance phase, recording essential data such as equipment lists, product data sheets, warranties, and spare parts lists, which are crucial for operation and asset management support. COBie is structured to be used as a ledger for facilities, buildings, and equipment management, with templates provided in Microsoft Excel format. A COBie Excel file is composed of 19 sheets, designed to form a relational database. Additionally, COBie is defined as a subset of the widely used IFC standard format in BIM, hence it has high compatibility with IFC. BIM software like Revit supports the output of COBie sheets by utilizing add-ins. This study aims to manage point clouds of buildings without existing BIM models by assigning attribute information as if they were BIM, making traditional use of COBie sheets, which assumes the existence of BIM data, challenging for efficiency improvement. However, as COBie is currently recognized as the standard format for maintenance management and its attribute information is considered suitable for use in maintenance regardless of the presence of BIM data, the COBie format was adopted.

3.1.2.Investigation and Analysis of COBie Attribute Information

In implementing the COBie for the FM Point Cloud Platform, two types of investigation were conducted on the data elements of COBie. When initiating building conservation operations, completion drawings are available, but an investigation was carried out to determine to what extent the items in COBie could be filled from the completion drawings. The methodology involved creating a BIM model of the Shibaura Institute of Technology Toyosu Campus main building in Revit, setting up Interoperability Tools which is an add-in software for Revit, and conducting parameter mapping to produce COBie sheets from the information obtained from completion drawings. As a result, out of the 10 COBie sheets that could be output, the number of parameters that could be entered from the information in the completion drawings was 120 out of a total of 155 parameters, which is 77% of the total (excluding Description). For essential parameters, 35 out of a total of 40 parameters, or 83%, could be entered (Table 1). The parameters that could not be entered and the sheets that could not be output were clarified in terms of the input stage and the reference information source (Table 2). Furthermore, it became clear that data values that exist in the equipment list but not in COBie parameters could all be output to the Attribute sheet.

Table 1. Output results of COBie sheets

No	Sheet Name	Number of parameters	Number of parameters that could be entered	Ratio
		Overall	Overall	-
		Mandatory	Mandatory	-
1	Contact	19	19	100%
		4	4	100%
2	Facility	22	19	86%
		5	5	100%
3	Floor	10	9	90%
		2	2	100%
4	Space	13	12	92%
		3	2	67%
5	Zone	9	8	89%
		2	2	100%
6	Type	37	11	30%
		9	4	44%
7	Component	17	9	53%
		3	2	67%
8	System	9	7	78%
		2	2	100%
9	Attribute	13	11	85%
		4	4	100%
10	Coordinate	15	15	100%
		8	8	100%
Total (Only the sheets that were output)		164	120	73%
		42	35	83%
Total (Only the sheets that were output,Excluding 'Description')		155	120	77%
		40	35	88%

Table 2. Regarding parameters that

Sheet name	Parameter	Source of information
Facility	Description	Additional information
	ProjectDescription	Additional information
	SiteDescription	Additional information
Floor	Description	Additional information
Space	Description	Additional information
Zone	Description	Additional information
Component	Description	Additional information
	SerialNumber	View equipment specification
	InstallationDate	View equipment specification
	WarrantyStartDate	View equipment specification
	BarCode	Optional input during operation
	AssetIdentifier	Optional input during operation
	Area	View equipment specification
	Length	View equipment specification
System	ExtObject	Reference parameter for external data
	Description	Additional information
Attribute	Description	Additional information
	AllowedValues	View equipment specification

Sheet Name	Parameter	Source of information
Type	Manufacturer	View equipment specification
	WarrantyGuarantorParts	View equipment specification
	WarrantyDurationParts	View equipment specification
	WarrantyGuarantorLabor	View equipment specification
	WarrantyDurationLabor	View equipment specification
	WarrantyDurationUnit	View equipment specification
	ReplacementCost	View equipment specification
	ExpectedLife	View equipment specification
	DurationUnit	View equipment specification
	WarrantyDescription	View equipment specification
	NominalLength	View equipment specification
	NominalWidth	View equipment specification
	NominalHeight	View equipment specification
	ModelReference	View equipment specification
	Shape	View equipment specification
	Size	View equipment specification
	Color	View equipment specification
	Finish	View equipment specification
	Grade	View equipment specification
	Material	View equipment specification
	Features	View equipment specification
	AccessibilityPerformance	View equipment specification
	CodePerformance	View equipment specification
	SustainabilityPerformance	View equipment specification
	Area	View equipment specification
	Length	View equipment specification

3.1.3.Comparative Survey and Analysis of Current FM Software and COBie Items

To analyze the adaptability of COBie in Japan's maintenance management systems, a mapping was conducted to search for the appropriate COBie items from the equipment-related items of BIMMS (Building Information system for Maintenance & Management Support), which is used by Japanese public organizations. Three mapping methods were employed: 1. Items and COBie parameters that match perfectly and have equivalent data meanings, allowing for transfer, 2. Tracing the links of COBie parameters to search for appropriate data for the items (indirectly referenceable), and 3. Assigning Uniclass classifications to transfer COBie parameters. Using these methods, the BIMMS equipment-related items that can be transferred from COBie were clarified. During mapping, instead of assuming items with the same name are equivalent, the meaning of data is comprehensively judged based on the sheet where the item exists. Therefore, even if the same items are present in the sheets for equipment, components, and supplies in BIMMS, they are considered distinct. Example of mapping is shown in Table 3.

Table 3. Mapping Example

BIMMS Input Items		COBie Compatible Sheet Name (Tag Name)	
Service Life / Replacement Cycle	Useful Life/Refresh Cycle	Type(Name)→	Type(ExpectedLife) Type(DurationUnit)
	Expected Operating Time	Type(Name)→	Type(ExpectedLife) Type(DurationUnit)
	Replacement Cost (Unit Price)	Type(Name)→	Type(ReplacementCost)
	Estimated Useful Life	Type(Name)→	Type(ExpectedLife)
	Refresh Factor	Not applicable	

3.1.4.Mapping Results

The mapping results between the COBie sheets and the BIMMS sheets related to facility management data were as displayed in Table 4, showing a correspondence as indicated. Furthermore, the mapping for each item showed that 64% were transferable, indicating that more than half of the items were applicable. Items that did not correspond to COBie parameters were notably Japanese-specific standard numerical items such as legal depreciation years and man-hour rates. However, these items could be mapped using the Attribute sheet. Additionally, items that did not correspond, such as the condition of deterioration, usage status, cumulative operating hours, total number of breakdowns, and cumulative maintenance costs in the equipment/component/supplies ledger for the operational phase, were outside the scope of COBie and thus could not be mapped.

Table 4. Mapping results between BIMMS sheets and COBie sheets

BIMMS	**COBie**
Specification (Model) Ledger	Type Sheet
Equipment, Components, and Supplies Ledger	Component Sheet
Maintenance Procedures, Inspection Locations, Item Master	Job Sheet (Conditional)

3.1.5.Proposals Derived from the COBie Survey Findings

The investigations revealed that COBie items are generally usable; however, challenges have also become apparent. Given that COBie is a standard, it poses a challenge for direct use of localized or company-specific items. It is believed to be entirely feasible to adapt COBie to Japanese maintenance systems by adding these items to the Attribute sheet, as COBie sufficiently allows for customization of attribute information. Regarding operational information, which is outside the scope of COBie sheets, it is preferable to manage these not directly with COBie sheets but with a separate database dedicated to accumulating operational information. Therefore, the data used in "Point Cloud BIM" was organized into two categories: "static data" and "dynamic data." The database for managing the data used in "Point Cloud BIM" has been divided into "static data," which refers to information confirmed at the time of building completion and, except for equipment replacements, does not change over time and is consistently referenced throughout the building's lifecycle; and "dynamic data," which includes inspection records and repair histories that accumulate during the maintenance operations after the building goes into use. It was concluded that COBie could be used as the database for "static data

3.2. Information Coordination through the Utilization of Uniclass

3.2.1. About the Use of Uniclass

The construction information classification system is a structured system of all classes of information for edifices, such as buildings and infrastructure, and serves as the key for various information interoperability in computing. The significance of the construction information classification system lies in the standardization of terminology and the searchability of information. The reason for using Uniclass is that it complies with the international standard ISO 12006-2:2015 and is used worldwide. Classification codes are assigned to all types of information related to architectural projects, including product catalogs, minister-certified products, construction specifications, cost information, LCA data, and BIM objects. These codes can be used as keys to gather related information, enabling services that allow for cross-project information search and comparison across all project phases of an architectural project. This is expected to enable the effective use of information.

3.2.2.Research Content and Methodology

While the construction information classification system Uniclass can uniquely represent each type of information, it has not been clear whether its classification matches the categorization of equipment used in maintenance management in Japan. (Whether Uniclass can be used for maintenance management) Therefore, an investigation was conducted to map the work items from the "Section 3: Operation, Monitoring, and Routine Inspection & Maintenance" of the Japanese government facility's standard specifications, the Heisei 25 Edition of the Common Specifications for Building Conservation Operations, to Uniclass and to survey the rate of code assignment.

3.2.3.Assignment with the Common Specifications for Building Conservation Operations

Firstly, an extraction of the items related to materials and equipment listed in the Common Specification for Building Conservation Work was conducted, resulting in a total of 140 items. Among these, items that were not materials or equipment but descriptions of the work itself or space were excluded, amounting to 29 items. Therefore, the items considered to be materials or equipment totaled 111. These are displayed in Table 5, with the excluded items marked in gray. Subsequently, deliberation was made on which Uniclass codes to assign to the organized items. As the target items were materials and equipment (objects), it was decided to assign three of the 15 tables from Uniclass that represent building components and functions (EF - Elements/Functions), groupings of a single function (Ss - Systems), and detailed product groups (Pr - Products). Essentially, codes from the standard specification were assigned to sections as EF, to items as Ss, and to work items as Pr. Examples of the standard specification items categorized into Uniclass codes are shown in Table 6.

As a result, 89 items (80%) were identifiable as equipment or components. The equipment or components that could not be identified included water softening devices, low water level cut-off devices, water column pipes for water level gauges, and contact piping for water level detection (limited to steel boilers), among others. These items were considered as minor accessories of equipment and it was determined that they do not affect the identification of materials and equipment for management by maintenance personnel.

Table5. Extracted items from the Common Specification for Building Maintenance Work

Chapter	Section	Article	Work Item	Sub-Work Item	Detailed Work Item
3.電気設備	3.4.自家発電設備	3.4.1.自家発電装置	自家発電装置		
3.電気設備	3.4.自家発電設備	3.4.1.自家発電装置	配電盤		
3.電気設備	3.4.自家発電設備	3.4.1.自家発電装置	補機附属装置	始動用蓄電池装置	整流装置
3.電気設備	3.4.自家発電設備	3.4.1.自家発電装置	補機附属装置	始動用蓄電池装置	始動用蓄電池装置
3.電気設備	3.4.自家発電設備	3.4.1.自家発電装置	補機附属装置	始動用空気圧縮装置	始動用空気圧縮装置
3.電気設備	3.4.自家発電設備	3.4.1.自家発電装置	補機附属装置	燃料タンク・燃料移送ポンプ等	
3.電気設備	3.4.自家発電設備	3.4.1.自家発電装置	補機附属装置	冷却水タンク	
3.電気設備	3.4.自家発電設備	3.4.1.自家発電装置	補機附属装置	ラジエータ	
3.電気設備	3.4.自家発電設備	3.4.1.自家発電装置	補機附属装置	換気装置	
3.電気設備	3.4.自家発電設備	3.4.1.自家発電装置	補機附属装置	排気管・消音器	
3.電気設備	3.4.自家発電設備	3.4.1.自家発電装置	補機附属装置	バルブ	
3.電気設備	3.4.自家発電設備	3.4.1.自家発電装置	試運転		

Table6. Extracted items for electrical equipment and their assignment of Uniclass codes

Chapter	Section	UniclassEF	Article	UniclassSs	Work-Item	UniclassPr
3.電気設備	3.2.電灯・動力設備	EF_70	3.2.1.電灯・動力	Ss_70_80	照明器具	Pr_70_70
3.電気設備	3.2.電灯・動力設備	EF_70	3.2.1.電灯・動力	Ss_70_80	分電盤・照明制御盤	Pr_60_70_22_22
3.電気設備	3.2.電灯・動力設備	EF_70	3.2.1.電灯・動力	Ss_70_80	制御盤	Pr_75_50_18_17
3.電気設備	3.2.電灯・動力設備	EF_70	3.2.1.電灯・動力	Ss_70_80	電気自動車用普通充電装置・急速充電装置	Pr_65_72_97_29
3.電気設備	3.3.受変電装置	EF_70_30	3.3.1.受変電	Ss_70_30	盤類（配電盤・パイプフレーム・さく等）	Pr_60_70_22
3.電気設備	3.3.受変電装置	EF_70_30	3.3.1.受変電	Ss_70_30	特別高圧機器	EF_70_30_25
3.電気設備	3.3.受変電装置	EF_70_30	3.3.1.受変電	Ss_70_30	高圧機器	Ss_70_30_35
3.電気設備	3.3.受変電装置	EF_70_30	3.3.1.受変電	Ss_70_30	高圧機器	Ss_70_30_35
3.電気設備	3.3.受変電装置	EF_70_30	3.3.1.受変電	Ss_70_30	高圧機器	Ss_70_30_35
3.電気設備	3.3.受変電装置	EF_70_30	3.3.1.受変電	Ss_70_30	高圧機器	Ss_70_30_35
3.電気設備	3.3.受変電装置	EF_70_30	3.3.1.受変電	Ss_70_30	高圧機器	Ss_70_30_35
3.電気設備	3.3.受変電装置	EF_70_30	3.3.1.受変電	Ss_70_30	低圧機器	Ss_70_30_45
3.電気設備	3.3.受変電装置	EF_70_30	3.3.1.受変電	Ss_70_30	低圧機器	Ss_70_30_45
3.電気設備	3.3.受変電装置	EF_70_30	3.3.1.受変電	Ss_70_30	低圧機器	Ss_70_30_45
3.電気設備	3.4.自家発電設備	EF_70_10_30	3.4.1.自家発電装置	Ss_70_10_30	自家発電装置	Pr_60_70_65_05
3.電気設備	3.4.自家発電設備	EF_70_10_30	3.4.1.自家発電装置	Ss_70_10_30	配電盤	Pr_60_70_22_22

3.2.4.Uniclass Assignment for Point Cloud Objects

Without assigning Uniclass codes to the point cloud objects, they cannot be linked to various types of data, such as the standard specifications that have been mapped in this research. In other words, it is necessary to assign Uniclass codes to each point cloud object. Therefore, this paper proposes a method for assigning Uniclass to point cloud objects. At the beginning of operation and maintenance of a building, each piece of equipment is given a management number by the administrator. This management number is documented and used to manage most of the facility equipment. Furthermore, administrators compile an equipment ledger that summarizes which pieces of equipment correspond to each management number (see Table 7). Thus, by organizing the mapping between individual management numbers and equipment lists, as well as the mapping between equipment lists and Uniclass, it becomes possible to connect individual management numbers with other data through Uniclass codes (see Figure 2).

Table 7. Example of an equipment ledger where management numbers and material names are managed

Floor	Room Number	Room Name	Equipment Number	Manufacturer	Model Number	Serial Number
RF	-	6F各研究室	PAC-C-R-6B	三菱電機	PURY-P335SDMG4	6XW00049
RF	-	6F各研究室	PAC-C-R-6B	三菱電機	PURY-P280SDMG4	67W00047
6	06C25	蟹澤宏剛研究室	PAC-C-6B-05	三菱電機	PLFY-P45HMG9	38A04518
6	〃	蟹澤宏剛研究室	PAC-C-6B-06	三菱電機	PLFY-P45HMG9	38A04525
6	06B25	志手一哉研究室1	PAC-C-6B-07	三菱電機	PLFY-P45HMG9	38A04322
6	06B27	志手一哉研究室2	PAC-C-6B-08	三菱電機	PLFY-P56HMG9	38A07378

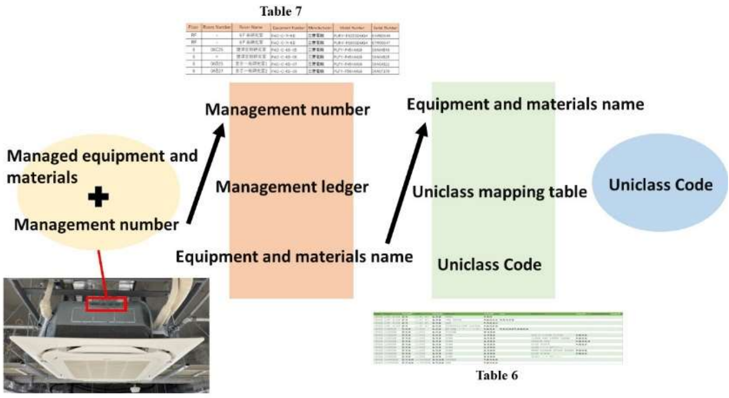

Figure2. The process of identifying Uniclass from a management number

3.2.5.Methodology for Retrieving Management Numbers from Point Cloud Data

The methodology for recognizing the series of management numbers affixed to equipment is examined in this study. Point cloud data primarily consists of coordinate and color information. Coordinate data is derived through calculations based on distances and angles measured by lasers. Color information is typically captured using cameras integrated within laser scanners, from which color data is extracted and assigned to individual points with coordinates. In essence, the acquisition of point cloud data is accompanied by image capture. For point cloud data containing character information intended for labeling, the process involves automatically recognizing the position and string of characters within the image and annotating the point cloud data with 3D labels. An example of reading the character string on a fire extinguisher is presented in Figure 3. The read strings are then associated with the corresponding objects. These management numbers facilitate the mapping to Uniclass, enabling the identification of equipment and the association with each piece of equipment's attribute information.

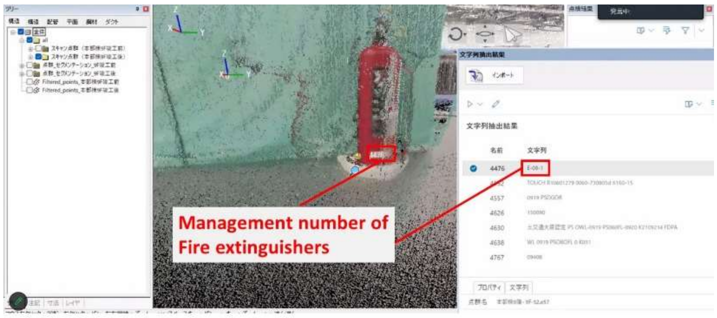

Figure3. Example of recognizing an affixed management number as a string

4.USE CASES DERIVED FROM INTERVIEWS

We developed scenarios assuming the implementation of the 'FM Point Cloud Platform' system in collaboration with Company A, which performs maintenance management tasks. The building targeted during scenario creation was the Toyosu Campus Main Building of Shibaura Institute of Technology, with Company A being the maintenance management contractor for the building in question. Here, we will refer to use cases in 'Emergency response tasks' and 'Ledger creation tasks' within maintenance management operations.

4.1.Use Cases in Emergency response operations

In emergency response operations, traditional protocol involved receiving malfunction notifications from central monitoring, conducting on-site investigations to identify the faulty equipment, verifying documents in the office, requesting vendor assistance, and finally, completing the task with a report. Introducing this system eliminates the need for on-site investigations by identifying the fault from point cloud data, which serves as a substitute for the surrounding context and retrieves essential repair information linked to the equipment. This information includes equipment specifications, external vendor contacts, tools and parts needed for emergency repairs, and equipment management numbers. Within the "FM Point Cloud Platform," this information is managed as "static data." Post-repair reporting is substituted by entering the corresponding results into the system. Additionally, a record of the response history is accumulated as "dynamic data." The benefits of the "FM Point Cloud Platform" include reducing back-and-forth trips between the site and the office during equipment information retrieval, consolidating dispersed information within the system for immediate access, enabling efficient initiation of emergency measures, and enhancing the automatic accumulation and searchability of past cases (see Figure4).

4.2.Use Cases in Ledger creation operations

In the traditional "Ledger Creation Operations," after the handover of a building, the construction company would provide the completion drawings (paper or CAD) from which equipment numbers are cross-referenced to identify inspection equipment, and the location information of equipment, based on management numbers attached to the equipment on-site, is plotted on the drawings to create a ledger. By introducing this system, the corresponding equipment can be confirmed through the "Point Cloud Viewer," and Uniclass numbers are assigned based on the management numbers. Then, the management numbers of the equipment are automatically mapped with the equipment's point cloud data and its "static data" within the "FM Point Cloud Platform," automatically creating a 3D digital ledger. The benefits of the "FM Point Cloud Platform" include the potential of the point cloud to substitute for drawings, the ability to ascertain accurate equipment location information without physical verification on-site, the reduction of ledger creation time due to semi-automatic generation, and improved searchability of equipment information (see Figure5).

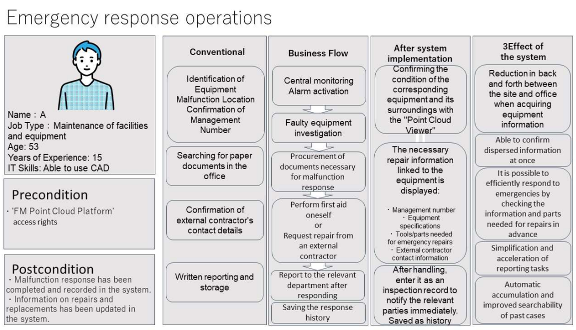

Figure4. Emergency response Operations

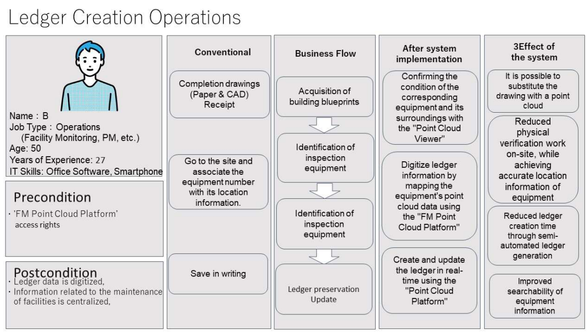

Figure5. Ledger creation Operations

5.CONCLUSION

In this study, we have explored the use of point cloud data for the improvement of maintenance operations. Utilizing the characteristics of the COBie format, we have divided the information used in maintenance into 'Static data,' which are the fundamental data consistently referenced throughout the building's lifecycle, and 'Dynamic data,' which includes inspection records and repair histories that accumulate over the course of the building's operation. We proposed the 'Point Cloud FM Platform,' a system that enables the easy creation of point cloud BIM data for buildings without BIM data post-construction. The system also facilitates the transition to maintenance systems by complying with the international standard COBie, allowing maintenance operations to be conducted in a standardized format.

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