# A BIM-based Framework for Building Depreciation Estimation through Maintenance Management Integration

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**Keywords:** Building Information Modeling (BIM), Depreciation, Operation and Maintenance, Facility Management, Cost Estimation, Common Data Environment (CDE), Property Valuation

**Abstract:**

This paper proposes a framework for dynamic depreciation estimation by integrating Building Information Modelling (BIM), cost estimation datasets and maintenance data from Computerized Maintenance Management Systems (CMMS) or Facility Management Systems (FMS). The framework operates within a Common Data Environment (CDE), a centralized platform that consolidates and synchronizes data across various systems. By leveraging interoperability standards such as Industry Foundation Classes (IFC) and Construction-Operations Building Information Exchange (COBie), the framework facilitates seamless data exchange and integration. Maintenance records, asset conditions, lifecycle data and costs of building work items are systematically tracked within the CDE, enabling real-time updates and comprehensive visibility into the state of building components. This integration provides a robust foundation for accurate and condition-based depreciation estimation, enhancing property valuation practices by reflecting the actual wear, usage and maintenance history of building assets.

## 1. Introduction

Depreciation is a fundamental aspect of property valuation, particularly under the cost approach, where an asset's value is derived from the sum of land value and reconstruction costs, deducted by depreciation (Jafary et al., 2024). Depreciation represents the decline in asset value over time due to three primary factors. First, physical deterioration occurs as an asset's useful life diminishes through regular wear and tear, ultimately impacting its structural and functional integrity (Francke and van de Minne, 2017). Second, functional obsolescence arises when design standards shift, materials become outdated, or an asset fails to meet evolving technological or quality expectations (Wilhelmsson, 2008). Finally, external or economic obsolescence reflects value loss from external influences beyond the owner's control, such as shifts in local infrastructure, environmental conditions or broader market trends (Mansfield and Pinder, 2008). Physical deterioration is closely linked to maintenance practices for building components, which is essential for preserving asset conditions and mitigating depreciation over its lifecycle (Francke and van de Minne, 2017). Thus, an accurate depreciation estimation relies on an efficient maintenance management system.

Building Information Modeling (BIM) serves as a centralized platform, capturing every aspect of a construction project from design and construction to operation. It enables extensive visualization capabilities and enhances collaboration among stakeholders. Although BIM has been widely adopted in the design and construction phases, its application within Operations and Maintenance (O&M) remains limited (Wijeratne et al., 2024). Furthermore, to maximize BIM's potential in maintenance management, it must be integrated with digital platforms like Facility Management Systems (FMS) or Computerized Maintenance Management Systems (CMMS). Such integration facilitates real-time data sharing and monitoring of asset conditions, maintenance schedules and repair history, providing a solid, data-driven foundation for optimizing asset performance over the building's lifecycle (Gao and Pishdad-Bozorgi, 2019).

Interoperability standards like Industry Foundation Classes (IFC) and Construction-Operations Building Information Exchange (COBie) support this integration by enabling structured data exchange between BIM and these platforms. IFC supports comprehensive data transfer across different software systems, while COBie streamlines asset data handover, providing essential information on building components and maintenance requirements (Chen et al., 2018; Condotta and Scanagatta, 2023). This paper proposes a framework for dynamic depreciation estimation through the integration of BIM and maintenance management systems, leveraging these standards to enhance data accuracy and continuity across the building lifecycle. By incorporating real-time maintenance data, the proposed framework aims to provide a more precise approach to calculating depreciation, reflecting the actual state and usage of each building component.

## 2. Background

### 2.1 Depreciation

One of the primary property valuation methods is the cost approach, which utilizes the Depreciated Replacement Cost (DRC) method to estimate a property's market value. This is achieved by adding the market value of the land to the cost of reconstructing the building while deducting any accumulated depreciation as of the valuation date (Fattinnanzi et al., 2020).
According to Foundation (1997), except for land, most physical assets, including buildings and infrastructure, have finite useful lives, meaning their service potential declines over time until it is fully consumed or lost. This depreciation process is influenced by several key factors:


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- Physical deterioration: Caused by wear and tear due to prolonged use, exceeding the level that routine maintenance can restore. Over time, the building's components degrade, impacting structural integrity and functionality.
- Technical obsolescence: Occurs when technological advancements render certain building materials, systems, or design features outdated and comparatively inefficient. Buildings that fail to incorporate modern technologies may experience reduced efficiency and increased operational costs.
- Economic (or commercial) obsolescence: Results from external market conditions, such as declining demand for a particular property type, changes in land use policies, or shifts in economic activity that reduce the asset's relevance or profitability.

Each factor contributes to the gradual reduction in a property's value over time, necessitating accurate depreciation estimation to ensure reliable valuation (Foundation, 1997). While buildings are typically assigned an overall useful life, individual components within the asset, such as structural elements, finishes and installations, deteriorate at different rates depending on their material properties and maintenance history (Copiello and Bonifaci, 2018).

Maintenance plays a crucial role in mitigating physical deterioration, as studies show that poorly maintained buildings experience significantly higher depreciation rates than well-maintained ones. Indeed, proactive maintenance can extend the lifespan of individual components, preserving asset value (Francke and van de Minne, 2017). Given this complexity, an integrated and dynamic system for recording maintenance activities related to specific building components is critical for accurately assessing depreciation. By systematically tracking repairs, replacements and refurbishment activities, a data-driven approach ensures that depreciation calculations reflect the actual state and remaining service life of each component rather than relying on generic age-based assumptions (Copiello and Bonifaci, 2018; Manganelli and Tataranna, 2020).

## 2.2 BIM and IFC to COBie

The COBie standard is the most widely used format designed to enhance information capture during the design and construction phases, ensuring that relevant data is available for O&M while reducing the reliance on paper documentation for facility managers after project completion. Since COBie operates within BIM systems, its development followed the Model View Definition (MVD) approach, which specifies a subset of IFC entities and attributes necessary to meet specific exchange requirements in BIM environments. Over time, COBie was further refined to align with the open IFC data schema, and today, it is recognized as a standard MVD and a defined subset of the IFC schema (Condotta and Scanagatta, 2023). As COBie follows the IFC schema, it benefits from the IFC's open and structured data exchange format, which enhances interoperability between different BIM and facility management software (Shin et al., 2022).

COBie is typically delivered in a spreadsheet format or as part of an IFC model. It consists of multiple interconnected worksheets (tables) that capture key information about the building's components, systems, spaces and maintenance requirements. The logical grouping of COBie tables is illustrated in Figure 1, categorizing key datasets for facility management. Accordingly, among the various COBie tables, three key sheets—Job, Spare and Resource—are particularly important in capturing maintenance-related data during the O&M phase, ensuring facility managers have structured and accessible records for asset upkeep. An example of a COBie "Job" spreadsheet, which details maintenance tasks and service records, is shown in Figure 2.

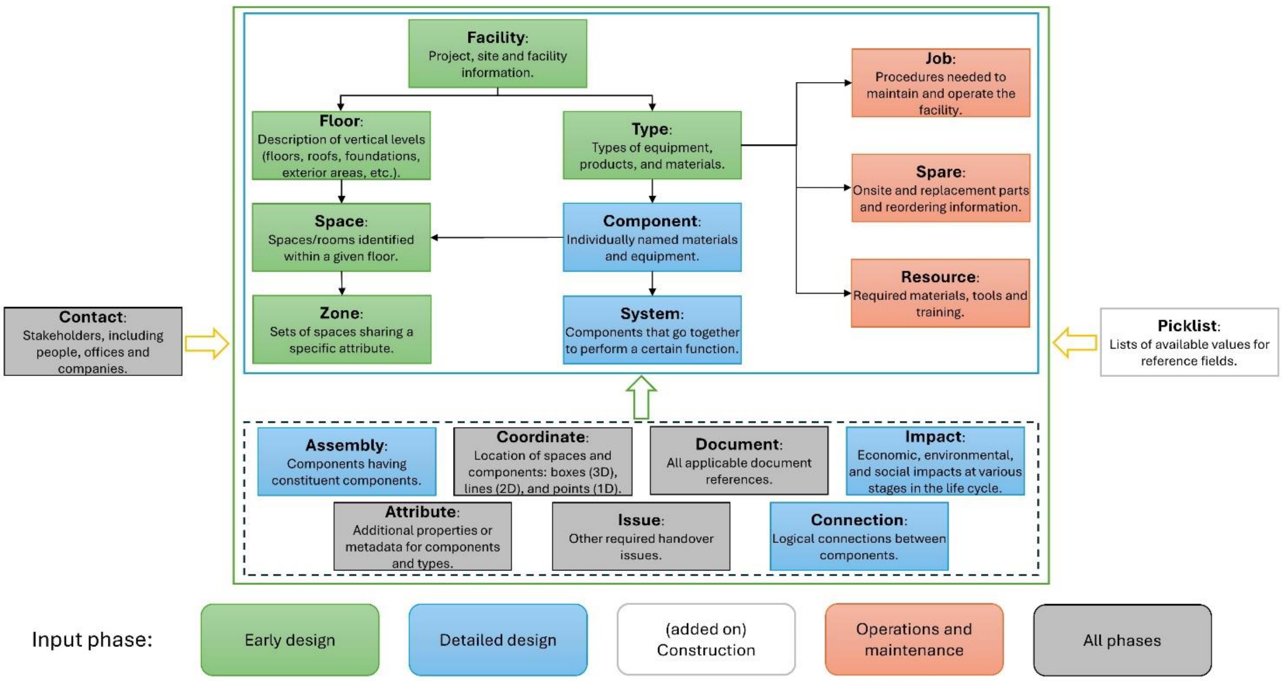
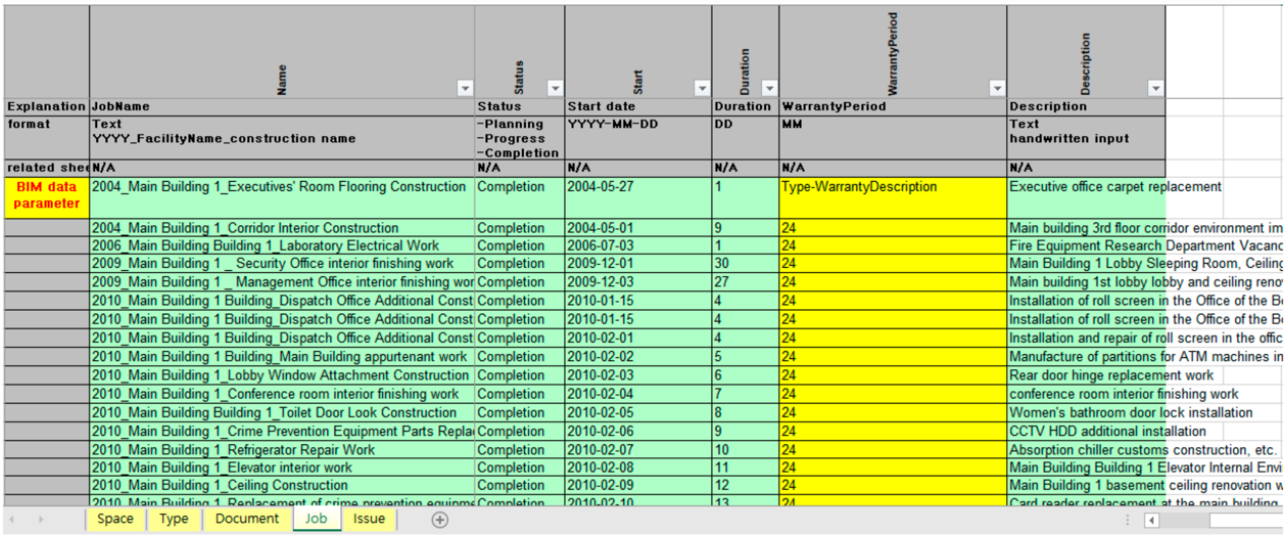



Figure 1. COBie data schema showing the relationships among worksheets (adapted from Autodesk, 2024a; Shide, 2020; William East et al., 2013).



| | Name | Status | Start | Duration | WarrantyPeriod | Description |
|---|---|---|---|---|---|---|
| Explanation | JobName | Status | Start date | Duration | WarrantyPeriod | Description |
| format | Text<br>YYYY_FacilityName_construction name | -Planning<br>-Progress<br>-Completion | YYYY-MM-DD | DD | MM | Text<br>handwritten input |
| related shee | N/A | N/A | N/A | N/A | N/A | N/A |
| BIM data parameter | 2004_Main Building 1_Executives' Room Flooring Construction | Completion | 2004-05-27 | 1 | Type-WarrantyDescription | Executive office carpet replacement |
| | 2004_Main Building 1_Corridor Interior Construction | Completion | 2004-05-01 | 9 | 24 | Main building 3rd floor corridor environment im |
| | 2006_Main Building Building 1_Laboratory Electrical Work | Completion | 2006-07-03 | 1 | 24 | Fire Equipment Research Department Vacanc |
| | 2009_Main Building 1 _ Security Office interior finishing work | Completion | 2009-12-01 | 30 | 24 | Main Building 1 Lobby Sleeping Room, Ceiling |
| | 2009_Main Building 1 _ Management Office interior finishing wor | Completion | 2009-12-03 | 27 | 24 | Main building 1st lobby lobby and ceiling reno |
| | 2010_Main Building 1 Building_Dispatch Office Additional Const | Completion | 2010-01-15 | 4 | 24 | Installation of roll screen in the Office of the B |
| | 2010_Main Building 1 Building_Dispatch Office Additional Const | Completion | 2010-01-15 | 4 | 24 | Installation of roll screen in the Office of the B |
| | 2010_Main Building 1 Building_Dispatch Office Additional Const | Completion | 2010-02-01 | 4 | 24 | Installation and repair of roll screen in the offic |
| | 2010_Main Building 1 Building_Main Building appurtenant work | Completion | 2010-02-02 | 5 | 24 | Manufacture of partitions for ATM machines in |
| | 2010_Main Building 1_Lobby Window Attachment Construction | Completion | 2010-02-03 | 6 | 24 | Rear door hinge replacement work |
| | 2010_Main Building 1_Conference room interior finishing work | Completion | 2010-02-04 | 7 | 24 | conference room interior finishing work |
| | 2010_Main Building Building 1_Toilet Door Look Construction | Completion | 2010-02-05 | 8 | 24 | Women's bathroom door lock installation |
| | 2010_Main Building 1_Crime Prevention Equipment Parts Repla | Completion | 2010-02-06 | 9 | 24 | CCTV HDD additional installation |
| | 2010_Main Building 1_Refrigerator Repair Work | Completion | 2010-02-07 | 10 | 24 | Absorption chiller customs construction, etc. |
| | 2010_Main Building 1_Elevator interior work | Completion | 2010-02-08 | 11 | 24 | Main Building Building 1 Elevator Internal Envi |
| | 2010_Main Building 1_Ceiling Construction | Completion | 2010-02-09 | 12 | 24 | Main Building 1 basement ceiling renovation w |
| | 2010_Main Building 1_Replacement of crime prevention equipme | Completion | 2010-02-10 | 13 | 24 | Card reader replacement at the main building |



Figure 2. An example of the COBie "Job" spreadsheet (adapted from Chung et al., 2021).

### 2.3 BIM-based BoQ

BIM has transformed construction cost estimation by offering a faster, more accurate and data-driven approach compared to traditional 2D methods (Wahab and Wang, 2022). Integrating BIM with cost estimation software enables sophisticated Quantity Take-Off (QTO) and pricing workflows (Babatunde et al., 2019). The IFC-based QTO facilitates automation in identifying and quantifying materials (Akanbi and Zhang, 2023; Ma et al., 2013).

The construction cost estimation process begins with a work breakdown, where a project is divided into individual components to enable precise cost assessment (Lee et al., 2014). This is followed by QTO, a detailed process that quantifies building elements, materials and work items (Khosakitchalert et al., 2019). Once the QTO process is completed, cost estimates are assigned to each work item to generate a Bill of Quantities (BoQ) (DelPico, 2012; Tayefeh Hashemi et al., 2020). This involves applying unit cost rates to identified and quantified work items (Laptali et al., 1995).

In the Australian context, Construction Cost Indexes (CCIs) such as the Australian Institute of Quantity Surveyors (AIQS) Building Cost Index (BCI) and the Rawlinsons Australian Construction Handbook provide essential market-based cost data. These indexes support accurate cost estimation by periodically tracking trends and construction cost fluctuations, ensuring that BoQ pricing remains aligned with industry standards.

### 2.4 Data-driven Facility Management

Facility management is a holistic approach to operating, maintaining and enhancing buildings and infrastructure to align with organizational objectives. Maintenance activities represent a significant portion of facility management costs among its various functions. Organizations increasingly rely on digital tools such as CMMS and FMS to optimize maintenance processes and improve decision-making. These systems serve as key data sources, enabling facility managers and maintenance teams to track asset conditions, schedule repairs and ensure operational efficiency (Chen et al., 2018; Condotta and Scanagatta, 2023).

CMMS and FMS platforms record a wide range of facility-related data to support efficient asset management and maintenance planning. According to Chen et al. (2018), data recorded in CMMS/FMS can be categorized into three main groups, as presented in Table 1.

| Category | Data captured |
|---|---|
| Maintenance inspection data | Inspection record: Activity, building ID and component IDs, cost details, date and time details, condition level, location, inspection team information, comments, etc. |
| Maintenance request data | Maintenance request: Activity, building, work order, maintenance team and maintenance request IDs, cost estimation details, problem type, repair type, requestor's details, emergency level, supervisor's details, request status, location, date, etc. |
| | Required maintenance trade: Trade type<br>Work type, cost details, date and time details, inspection task and maintenance_request_IDs, total hours, comments, etc. |
| | Required tool type: Tool type, work request ID, cost details, date and time details, total hours, comments, etc. |
| | Required resources: Equipment type, material type, estimated and actual costs, estimated and actual quantities, work request and component IDs, status, date and time, quantity required, comments, etc. |
| Work order data | Work order: Activity, building, work order, maintenance team and maintenance request IDs, cost details, date and time details, emergency level, problem type, supervisor, location, etc. |
| | Assigned materials, equipment and tools: Material, equipment or tool type and ID, quantity used, associated work order ID, cost details, date and time of use, etc. |

Table 1. Data categories recorded in CMMS/FMS.

### 2.5 CDE

According to ISO (2018), CDE is an "agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process". A CDE is a centralized digital platform used to store, manage and share project-related data and documents throughout the lifecycle of a project. It ensures that all stakeholders have access to the latest, approved information in a structured and controlled manner (Autodesk, 2024b), as presented in Figure 3. Oracle (2024) lists the key features of a CDE as:

- Comprehensive audit trail and security.
- Efficient information management.
- Centralized and controlled access.
- Authorized data extraction.
- Facilitating reuse of information.
- Optimized review and approval process.
- Enhanced coordination and clash detection.

CDEs are commonly used in BIM workflows, ensuring smooth coordination across different project phases, from design and construction to O&M.

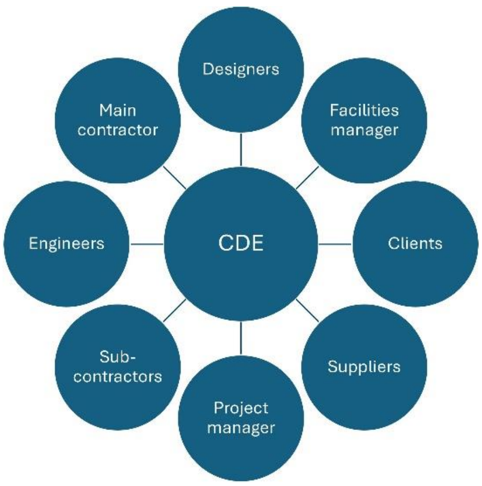



Figure 3. Information flow in a CDE.

## 3. The Proposed Framework for Depreciation Estimation

### 3.1 Initial BIM Setup and Cost Estimation

The first step of the framework involves creating a BIM model or using an existing one, which not only captures the building components' 3D geometry and spatial relationships but also establishes the foundation for initial cost estimation and structured data management. This BIM model needs to be exported in IFC format to ensure data interoperability. From the IFC model, COBie data is then generated, providing a structured, tabular dataset that captures essential asset information, including component names, locations, warranties, expected life cycles, etc.

Additionally, a BoQ is created based on the BIM model. This process begins with meticulously breaking the building into individual components. This stage involves extracting information about walls, floors, doors, windows and other elements from the BIM file. Subsequently, each identified element and sub-element is systematically quantified through a QTO, following measurement and classification standards. In Australia, the Australian Standard Method of Measurement of Building Works (ASMM), developed by the AIQS, provides detailed guidelines for accurate measurement. Finally, the quantified work items in the QTO are assigned unit prices using the latest construction cost indexes, such as the AIQS BCI or the Rawlinsons Australian Construction Handbook, ensuring that cost estimates reflect current market rates.

### 3.2 Ongoing Lifecycle Management

Once a building is in use, maintenance activities must be systematically recorded and updated to ensure accurate asset management and depreciation estimation. This process is facilitated by CMMS/FMS, which log various maintenance-related data, including preventive and corrective maintenance tasks, work orders, spare parts usage and resource allocation. To effectively integrate this data into the BIM environment, it must be mapped to COBie spreadsheets, updating each component's condition, last service date and other maintenance history.

A key part of this step is establishing a direct and precise link between COBie and the CMMS/FMS. The structured data in CMMS/FMS platforms aligns with three key COBie sheets: Job, Spare and Resource, which specifically capture maintenance activities, inventory and resource allocations. Table 2 presents the structured relationship between CMMS/FMS and COBie data, and Figure 4 illustrates the data flow between CMMS/FMS and COBie, showing how maintenance inspection, request and work order data are mapped to the relevant COBie sheets.

| CMMS or FMS data category | Relevant COBie sheet | Data mapping explanation |
|---|---|---|
| Maintenance work orders | Job | The Job sheet records details of maintenance activities, including task descriptions, responsible personnel, completion dates and associated costs. Work order data from CMMS/FMS (such as work order ID, problem type, emergency level and cost estimates) is transferred here. |
| Preventive and corrective maintenance records | Job | CMMS/FMS logs preventive and reactive maintenance tasks, which are imported into COBie to track component lifecycle history and maintenance interventions. |
| Required resources for maintenance | Resource | CMMS/FMS tracks materials, tools and labor hours needed for maintenance work orders. The Resource sheet in COBie stores this information, ensuring that every job has an associated record of required and used resources. |
| Spare parts and inventory management | Spare | CMMS/FMS maintains an inventory of spare parts, including stock levels, usage history, and procurement details. The Spare sheet in COBie ensures spare parts are documented and available for maintenance activities. |

Table 2. Relationships between CMMS/FMS data categories and COBie sheets.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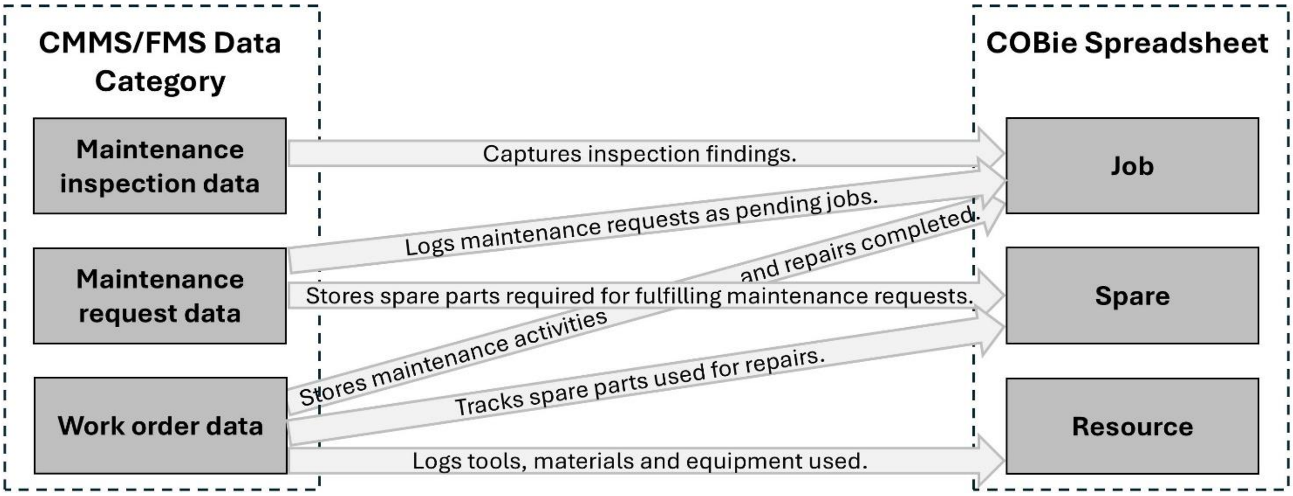


Figure 4. Data flow from CMMS/FMS to COBie.

### 3.3 Useful Life Database for Building Components

Accurate depreciation estimation requires considering the individual useful life of each building component rather than relying solely on the building's overall age. Different building elements have distinct lifespans, influenced by material durability and quality, environmental exposure, usage intensity and maintenance history (InterNACHI, 2024; Ji et al., 2021). For instance, structural elements such as concrete foundations and steel framing may last more than 100 years, while finishes like carpets and sealants require replacement within a decade (InterNACHI, 2024).

To systematically track component lifespans, a useful life database is required. This database records predefined service life values for various materials and components, drawing from industry standards and empirical data. It must be integrated with the "Expected Life" field in COBie, serving as a reference for initial lifespan estimates. As maintenance records from CMMS/FMS are updated, component lifespans are dynamically recalculated to reflect real-world conditions, ensuring that depreciation assessments align with the actual state of building assets.

### 3.4 Integration in a CDE

A CDE serves as the central platform where all relevant data is integrated, allowing updates and access to stakeholders across the asset lifecycle, including:

- The updated COBie data from CMMS/FMS is stored in the CDE, reflecting the latest maintenance history and component conditions.
- The BoQ in the CDE is regularly updated to reflect the latest unit prices for each work item, ensuring cost accuracy.
- Useful life data, dynamically adjusted based on installation records, maintenance activities and replacements.

### 3.5 Depreciation Calculation

Depreciation estimation in the CDE integrates maintenance records, updated BoQ costs and useful life data, ensuring that depreciation accurately reflects the condition and usage of building components. The process follows a three-step approach, incorporating both time-based and condition-based adjustments.

**Step 1 – Initial Depreciation**: At the time of construction, no depreciation is recorded, as all components are in their optimal condition.

**Step 2 – Updating the Remaining Useful Life During O&M:** As the building undergoes O&M, depreciation is updated dynamically based on maintenance activities and component age. The Remaining Useful Life (RUL) of each component is recalculated as follows:

- Without maintenance:

$$RUL = IUL - (CY - YoC), \tag{1}$$

where $RUL$ = Remaining Useful Life
$IUL$ = Initial Useful Life
$CY$ = Current Year
$YoC$ = Year of Construction

Indeed, if no maintenance is performed, the component gradually depreciates according to its original lifespan.

- With maintenance:

$$RUL = IUL - (CY - YoLM), \tag{2}$$

where $YoLM$ = Year of Last Maintenance

Indeed, if maintenance or replacement occurs, the RUL resets, reflecting the most recent servicing date.

**Step 3 – Depreciation Calculation:** Once the RUL is updated, depreciation is calculated for each individual component using the following logic:

- If RUL ≤ 0: The component is considered physically non-functional and in need of full replacement. Hence, its entire replacement cost (from the updated BoQ) is added to depreciation.
- If RUL > 0: The component is partially depreciated, so the depreciation is calculated proportionally based on its usage:

$$Depreciation = \left(1 - \frac{RUL}{IUL}\right) * UCC, \tag{3}$$


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where  *UCC* = Updated Component Cost (from the BoQ)

This approach ensures that only the used portion of the component's value is accounted for as depreciation, aligning with its actual condition. Depreciation calculations are automated in the CDE, ensuring that asset values remain up to date.

These updates occur at:

- Regular intervals (e.g., annually or at predefined periods).
- On-demand, whenever an asset valuation is required.

The framework's components and data flow are illustrated in Figure 5.

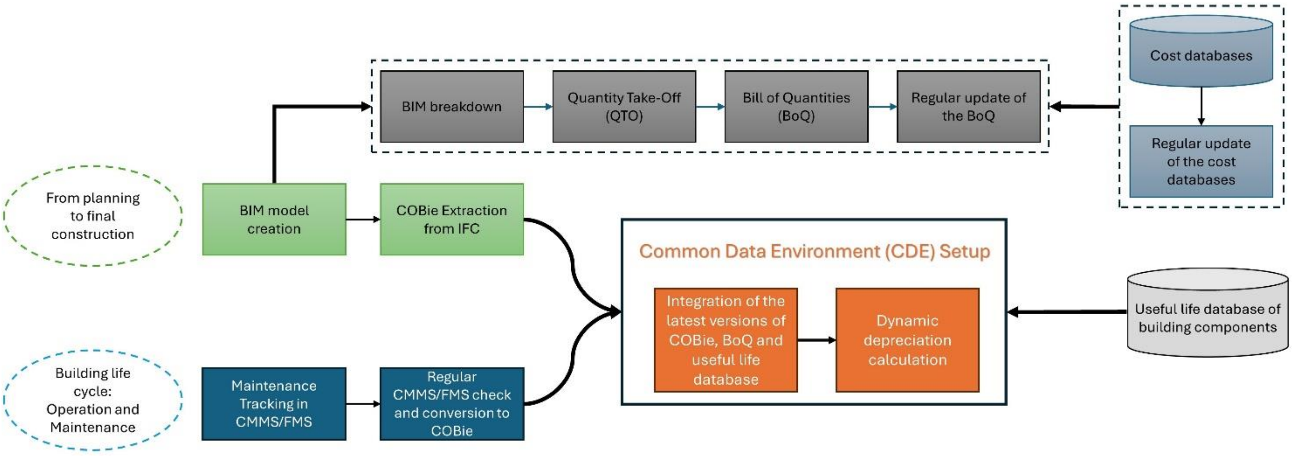


Figure 5. Proposed framework for dynamic depreciation estimation integrating BIM, COBie, BoQ and CMMS/FMS data in a CDE.

## 4. Discussions and Conclusions

The proposed framework for dynamic depreciation estimation integrates BIM, maintenance data from CMMS/FMS, BoQ pricing and useful life tracking within a CDE to improve the accuracy and reliability of real estate asset valuation. By centralizing and synchronizing COBie data, BoQ updates and maintenance records, the CDE ensures that depreciation is continuously adjusted based on actual asset conditions. This approach enhances data transparency and consistency while providing real-time insights that benefit property valuers, facility managers and financial analysts.

One of the key contributions of this framework is the enhanced integration of maintenance data with depreciation estimation, allowing for a condition-based approach rather than the traditional age-based methods. Unlike conventional models, which assume a linear depreciation rate over time, this framework dynamically recalculates depreciation values based on maintenance interventions and updated component lifespans. By leveraging real-time maintenance records and cost updates, depreciation reflects the actual wear, usage and service history of building components.
Additionally, by incorporating depreciation tracking within a CDE, this framework enables different stakeholders to monitor asset performance more effectively and optimize maintenance planning based on real-time component conditions.

However, the primary limitation of this paper is the lack of case study implementation, as access to a building with an existing BIM model and an active CMMS/FMS platform during its O&M phase was not available. A real-world implementation would allow for validating the framework's practicality, assessing interoperability issues and measuring computational efficiency in a dynamic environment. Additionally, the accuracy of depreciation estimation depends heavily on the completeness and reliability of maintenance data, as missing or outdated records may lead to miscalculations. While IFC and COBie facilitate data standardization, integrating BIM with CMMS/FMS and BoQ systems requires further development to ensure seamless interoperability across different software platforms.

Accordingly, future studies should focus on validating the framework through real-world case studies, applying it to various building types, geographical regions and regulatory environments to assess its practical effectiveness and industry adoption potential. Besides, future research could explore several areas to further enhance the framework's capabilities. One promising direction is the integration of Artificial Intelligence (AI) and machine learning for automated condition assessment. Computer vision techniques and deep learning models, especially Convolutional Neural Networks (CNNs), alongside the Internet of Things (IoT)-based monitoring, could be leveraged to detect structural defects, material degradation and environmental wear, allowing for more precise depreciation adjustments.

## Acknowledgements

This research is supported by Building 4.0 CRC. The support of the Commonwealth of Australia through the Cooperative Research Centre Programme is acknowledged.

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