# RFID-Assisted Lifecycle Management of Building Components Using BIM Data

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***Abstract***

The AECOO industry is highly fragmented; therefore, efficient information sharing and exchange between various players are evidently needed. Furthermore, the information about facility components should be managed throughout the lifecycle and be easily accessible for all players in the AECOO industry. BIM is emerging as a method of creating, sharing, exchanging and managing the information throughout the lifecycle between all the stakeholders. RFID, on the other hand, has emerged as an automatic data collection and information storage technology, and has been used in different applications in AECOO. This research proposes permanently attaching RFID tags to facility components where the memory of the tags is populated with accumulated lifecycle information of the components taken from a standard BIM database. This information is used to enhance different processes throughout the lifecycle. A conceptual RFID-based system structure and data storage/retrieval design are elaborated. To explore the technical feasibility of the proposed approach, two case studies have been implemented and tested.

***Keywords***: RFID, Lifecycle Management, BIM, Construction Automation

## Introduction

Radio frequency identification (RFID) is a type of automatic identification technology in which radio frequencies are used to capture and transmit data. It acts as electronic labelling and data-collection system to identify and track items. RFID based systems have been used in different applications in construction and maintenance, such as component tracking and locating, inventory management, equipment monitoring, progress management, facilities and maintenance management, tool tracking and quality control (Motamedi and Hammad, 2009). However, each of the above-mentioned applications is designed for only one specific stage of the facility lifecycle to serve the needs of only one of the stakeholders in a fragmented fashion, i.e., Architects, Engineers, Constructors, Owners and Operators (AECOO). This would increase the cost and the labor for adding and removing different tags at different stages and eliminate the chance of using shared resources among the stakeholders causing duplication of efforts and resources.

This research proposes permanently attaching tags to components in the manufacturing stage as an integrated part of the components. Having the tags permanently attached, where the information on the tags is gradually updated with accumulated lifecycle information, is beneficial for all the stakeholders throughout the stages of the lifecycle, from procurement and supply chain management to maintenance and disposal.

The use of attached RFID tags for lifecycle management has been proposed in the aerospace industry for storing unique ID and important lifecycle information on tags attached to aircraft parts for enhancing inspection and repair processes (Harrison et al., 2006). Ergen et al. (2007) proposed using RFID tags attached to engineered-to-order (ETO) components and explored the technical feasibility of such system by analysing component-related information flow patterns in ETO supply chains. They noted that integration of the data accessed with the broader information systems used across diverse organizations is an issue that needs to be investigated.

This paper aims to propose techniques to manage components' lifecycle data as well as extending the idea of attaching RFID tags to other types of engineered components within a constructed facility (i.e., made-to-order and off-the-shelf components). We also propose to include broader data types on the RFID tags that are attached to building components and are spread in a building. In the proposed approach, the information on the tags represents chunks of the Building Information Model (BIM) as a distributed database. This coupling between the BIM and the RFID information would allow reconstructing the database of the BIM (or part of it) based on the pieces of information distributed in all the attached tags. The proposed approach is further explored in two case studies of a high-rise building by deploying RFID tags on selected components for improving supply chain management, locating items, installation and maintenance activities, as well as progress management and visualization.

## Review of Related Research

### *Radio Frequency Identification*

RFID tag is a memory storage device for storing a certain amount of data. This information can be read wirelessly providing the ability to process large volumes of multiple data sets simultaneously. A basic RFID system consists of three components: an antenna, a transceiver (with decoder) and a transponder (RF tag) electronically programmed with information. The antenna can be packaged with the transceiver and decoder in order to become a reader. The reader can be configured either as a handheld or a fixed-mount device. RFID tags differ in many aspects, such as power source, frequency, readability range data transfer rates, data storage capacity, memory type, size, operational life, and cost (aimglobal.com, 2008).

While RFID technology has significant beneficial applications in manufacturing, retailing, transport and logistics industries, its potential applications in the AECOO industry have only begun to be explored (Song et al., 2006). The main usage of RFID is in supply chain and management and the tracking of materials, components, workers and equipment in construction projects. However, some researchers have proposed using RFID for progress monitoring, visualisation, quality control, and tracking components during inspection and maintenance activities (Motamedi and Hammad, 2009).

### *Building Information Model*

The AECOO industry is highly fragmented in nature. This situation has resulted in significant barriers to communication between the various stakeholders, which in turn has significantly affected the efficiency and performance of the industry. Consequently, there is an evident need for a standard information transfer model between different software applications used in the AECOO industry. The BIM has been developed in order to tackle the problems related to interoperability and information integration by providing effective management, sharing and exchange of a building information through its entire lifecycle. BIM is extensible, open and vendor neutral and BIM data can be stored as a digital file or in a database, and can be shared and exchanged between several applications (Isikdag et al., 2007).

The Industry Foundation Classes (IFC) standard has matured as a standard BIM. IFC is an object-based, non-proprietary building data model and data exchange format. Completion of the IFC model facilitated the development of exchange standards. The Facility Information Council of the National Institute of Building Sciences (NIBS) formed NBIMS group aiming to speed the adoption of an open-standard BIM through the definition of information exchange standards based on the IFC model (East and Brodt, 2007).

Construction industry contracts require the handover of various documents. IFC-mBomb project demonstrated an approach for data capturing during design and construction, and data handover to facility operators (Stephens et al., 2005). Construction Operations Building Information Exchange (COBIE) project was initiated under NBIMS support with the objective of identifying the information exchange needs of facility managers and operators of data available upstream in the facility lifecycle (East and Brodt, 2007). While COBIE is designed to work with the BIM, COBIE data may also be created and exchanged using simple spreadsheets.

## Proposed Approach

The lifecycle of a building can be divided into different stages where each stage is generally managed independently while exchanging partial information with other stages. The information related to each component should be tracked separately throughout the lifecycle. Furthermore, the information should be in a convenient format and stored at a suitable location to enable all the stakeholders to efficiently access throughout the lifecycle. Centrally stored information that is accessible electronically over a computer network is a solution for data access. However, having real-time access to information could be difficult since reliable connections to the central data storage may not be always available.

This research proposes adding structured information taken from BIM database to RFID tags attached to the components. Having the essential data related to the components readily available on the tags provides easy access for whoever needs to access the data regardless of having real-time connection to the central database or having a local copy of the required information.

*System interaction design*

In our proposed approach, every component is a potential target for tagging. Having standard tags attached to components would result in a massive tag cloud in the building. While having tags attached to all components would not happen in the immediate future, in order to benefit from the concept of having identity and memory tags on a mass of items, the subset of components to be tagged can be selected based on the scale of the project, types and values of the components, specific processes applied to these components, and the level of automation and management required by the facility owners.

The system design, including the data structure model and data acquisition method, is general for all components. The target components are tagged during or just after manufacturing and are scanned at several points in time. The scan attempts are both for reading the stored data, or modifying the data based on the system requirements and the stage at which the scan is happening. The scanned data are transferred to different software applications and processed to manage the activities related to the components. Fig. 1 shows the conceptual design for interaction between different system components. The generic software application communicates with RFID tags by using the reader API and stores and retrieves the lifecycle data to/from a central BIM database. The RFID specific information is added to the BIM database in the design phase as part of the product information.

The memory of the tag contains a subset of BIM information. While the BIM database is being populated by information by different software applications throughout the lifecycle, the tag memory space is modified and updated as the component is scanned. Fig. 2 conceptually shows how BIM data chunks are

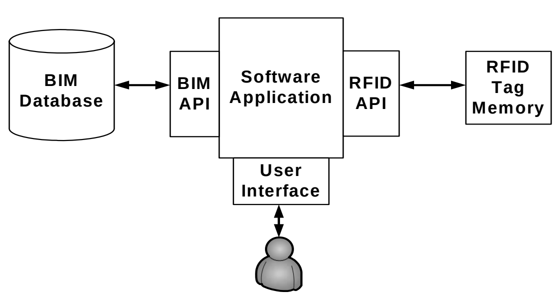



Figure 1 Conceptual system interaction design

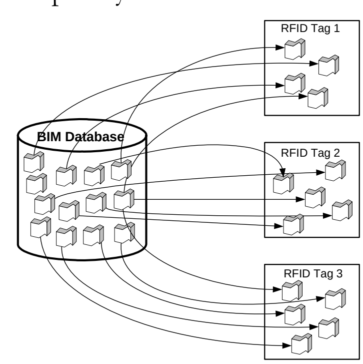



Figure 2 Conceptual BIM-Tag data relationship

stored on tags attached to the building components. While the information is centrally stored in the BIM database, software applications copy the necessary information from the database to the memory space on the tags.

*Data capture methods*

The structured data stored on the tags should be read, updated and changed by several RFID-based systems during the lifecycle. These modifications are executed by different types of RFID readers (stationary or mobile). In order to identify the suitable type of reader for each scan attempts, the detailed process requirements should be captured, such as the readability range, data transfer rate and portability. Moreover, the reader should be selected considering the type of the component (i.e., fixed, movable and temporary).

The data stored on the components can be read from different distances. The maximum readability distance depends on various factors, such as power level of reader, antenna type and size, frequency range and environmental factors. In some applications, it is desirable that the data be read from far distance. Hence, the system can detect the component even if the component is hidden or not visible. Other applications may require shorter readability. For example, if the tags are used to facilitate inspection activities, having short read/write range would guaranty that the inspector was in the required proximity of the component.

In the proposed approach, RFID tags are fixed to components; therefore, tags should be designed to have the maximum possible range and protection from noise and interference. However, it is always possible to control read/write range of the reader based on the process requirements.

*Conceptual data structure*

Considering the limited memory of the tags, the subset of BIM data stored on the tags has to be chosen based on the requirements. While data on a tag are changing during the lifecycle of the component and different software applications use and modify the data with different designated access levels, the memory of the tag should be virtually partitioned in a structured fashion based on predefined data types. `We propose to virtually partition the memory space into the following fields:

**ID:** In order to look up the component in the BIM database, there is a need to have a none-changeable, unique identifier (ID) for each component (e.g., EPCglobal (Electronic Product Code) Tag Data Standards).

**Specifications:** This field is dedicated to specifications of the component derived from the design and manufacturing stage of the lifecycle. Safety related information and hazardous material information are examples of *specifications*.

**Status:** Status field identifies the current main stage (e.g., in service, installed, manufactured, and assembled) and sub-stage (e.g., in service: waiting for inspection) of lifecycle of the component. The *status* information is used to decide which software application can use and modify the data in the *process data* field.

**Process data:** This field is relatively large compared to the other fields and is designed to store the information related to the component's current stage of the lifecycle. The data related to current processes to be stored on the tags are different and should be changed during the lifecycle. For example, assembling instructions are used only in the assembly stage. Therefore, the *process data* field contains only information related to the current lifecycle stage taken from BIM database. Moreover, the ownership (ability to read, modify or change) of the *process data*, should be restricted to one or a group of applications (e.g., inspection management software, installation management software) that are involved in that specific stage. The ownership of the *process data* field is decided based on the s*tatus* field as explained above. Fig. 3 shows how different software applications modify the *process data* field. Different applications use the same memory space but at different lifecycle stage. Fig. 3 demonstrates a sample component that follows a specific lifecycle pattern where BIM information is copied by different software applications on the memory of its RFID tag.

**History data:** This field is designated for storing the history data used during the lifecycle for maintenance and repair purposes. The history records are derived from BIM and accumulated during the lifecycle to be used in forthcoming stages.

**Environment data:** This field is designated for storing environment specific data, such as the location or the functionality and specifications of the space (e.g., floor plan). *Environment data* is also taken from BIM and contains all the information that is not related to the component itself.

*BIM-Tag data exchange method*

The proposed approach suggests using the attached RFID tags as a media for storing the structured information and providing a distributed data storage of BIM information. According to the fact that the media for storing the data is transparent to the efforts to collect, manage and share data, the data can be stored in a central database, RIFD tags, or in printed documents based on a data management method.

Several research projects are undergoing on the subjects of lifecycle information management and identification of information exchange paths, identification of crucial data that should be available during the lifecycle and handover methods between AECOO participants, the results of these researches can be incorporated in our proposed approach.

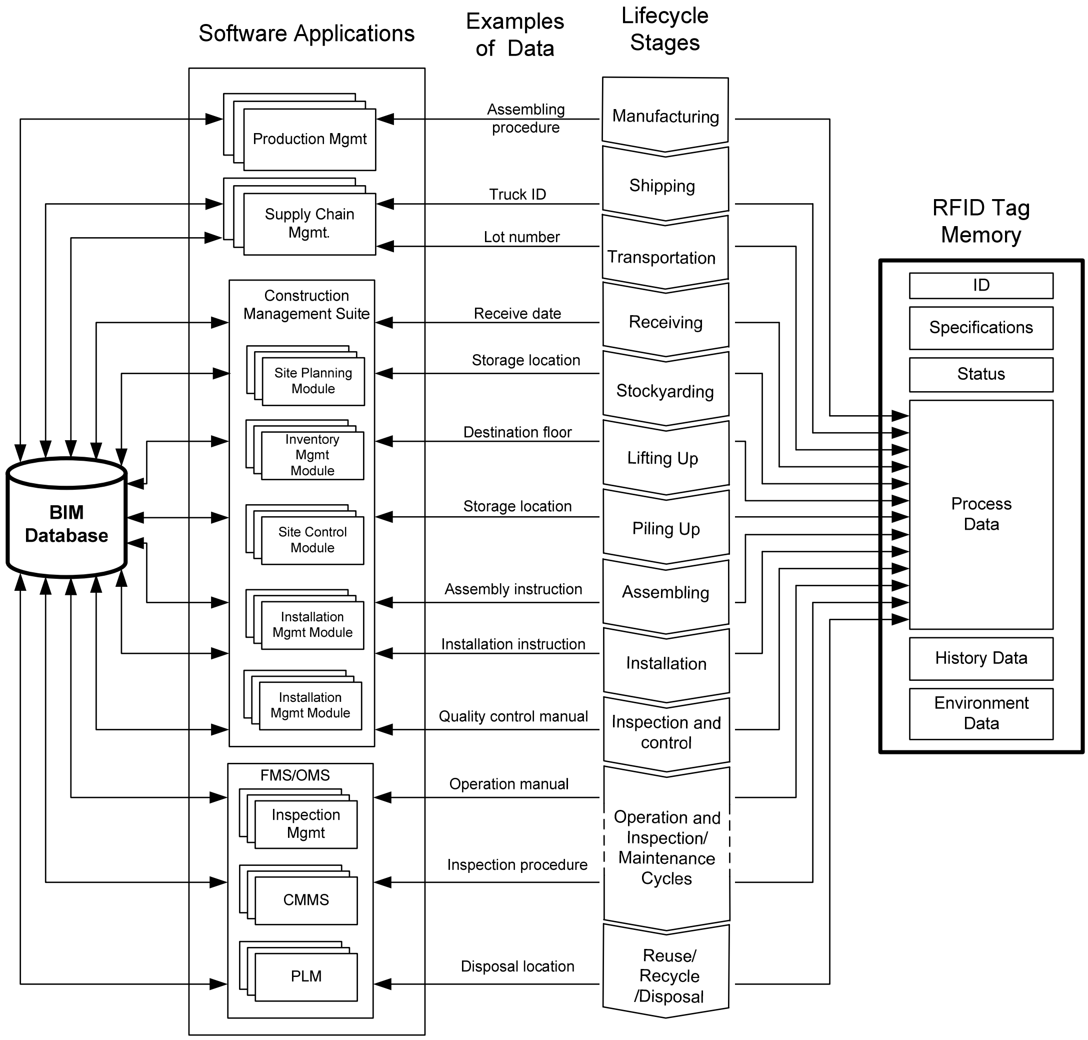



Figure 3 Process data update

## Challenges

Although the proposed approach can be implemented using available hardware, due to high implementation and customization costs, it is not financially feasible at present. The challenges can be categorized under the following main topics:

**Challenges related to adopting RFID technology:** *(1) RF challenges* related to properties of magnetic waves and the effects of materials on them; (2) Lack of complete and international *standards*; (3) *Cost* of tags and infrastructure implementation; (4) *Data security* and privacy; (5) *Ruggedness* of tags that can operate in harsh environments for the construction industry; (6) *Data transfer speed*; (7) *Interoperability:* standards to cover all types of tags and frequencies and multi-protocol tags and readers; (8) *Power:* low power RFID systems to extend the lifetime; and (9) *Environment:* tags made of new materials to facilitate recycling.

**Challenges in extending BIM and its implementation:** The efforts for developing BIM standards are in their early stage and the available standards are not complete and thorough. Moreover, adopting BIM standards has its own challenges and obstacles; issues such as industry acceptance, change management from conventional methods to new BIM, qualified human resources, legal considerations and initial cost to change (hardware, software, training and implementation) have to be tackled for industry-wide implementation of BIM.

**Technology adoption and social challenges:** Wide Implementation of such systems would bring resistance from companies that are using traditional methods because of needed extra efforts and training.

**Process related challenges:** The processes involved in building lifecycle should be reviewed and re-engineered considering new opportunities.

*Case Study 1: Progress management and 4D visualization*

This case study is designed to facilitate the process of progress monitoring of construction projects and to provide visualisation aid for component status tracking. The result of implementing the case study is accurate progress measurement data resulting in accurate 4D model and 3D visualization based on component's status.

The prototype system is composed of six subsystems: (1) the database that store the data extracted from the BIM, which will be updated by RFID reads and other software updates (e.g., inspection data), (2) the 3D modeling software that stores the data in IFCxml format, (3) the scheduling software, (4) the 4D simulation software, (5) the FM software, and (6) the RFID reader interfaces. The communications between the subsystems are based on standard protocols providing scalability and interoperability. The 4D simulation software obtains the geometrical information from the 3D software and the timing and status information from the database to produce different real-time views of the facility using a predefined colouring scheme. These views help project managers and the FM team to better visualize the status of the facility.

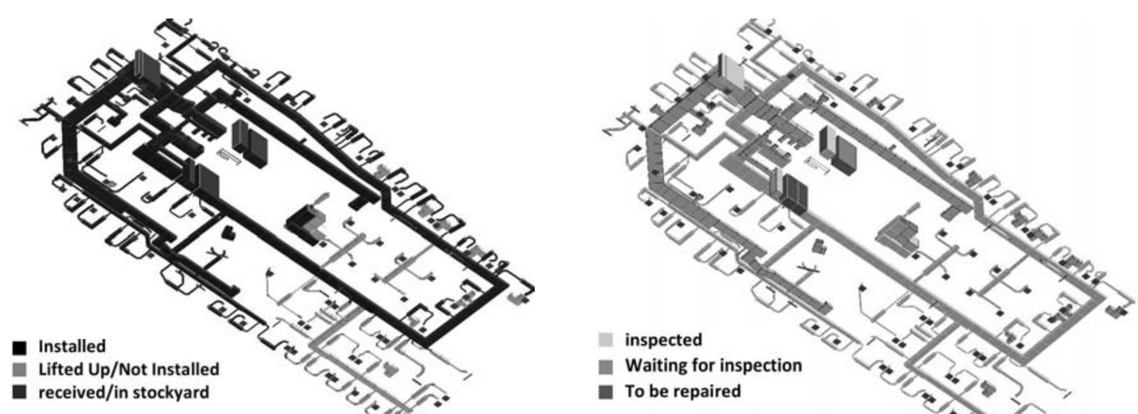
In this study, we focused on the progress monitoring and lifecycle management of the HVAC components in the new building of John Molson School of Business (JMSB) at Concordia University. Various active RFID tags are used that operate in UHF frequency and have 8 or 32 KB of memory. The tags are updated by a mobile reader attached to the inspector's or maintenance worker's hand-held device.

Fig. 4 shows sample snapshots of 4D visualization of the HVAC system on the 14th floor of the building. Fig. 4(a) shows the status of the components during the construction phase. The components that are installed are shown in black. The components that are lifted up but not yet installed are shown in red. The components that are in the stockyard and have not been lifted up are shown in grey. Fig. 4(b) shows the status visualization during the operation phase. The component in green is waiting for inspection and the component in dark brown needs to be repaired.

*Case Study 2: Fire equipment inspection and maintenance*

In this case study, RFID tags are used for storing information about fire safety equipments. Amongst all safety related equipments, fire extinguishers and safety valves are chosen because of their importance and the higher frequency of their maintenance activities.

In our prototype system, crucial information is stored on tags attached to the extinguishers and valves. This would provide the information about the history and the condition of the extinguishers and valves for inspectors and maintenance/repair personnel without access to any central database.




**(a) Construction Phase** **(b) Maintenance Phase**

**Figure 4 HVAC 3D drawings of one floor of the JMSB building**

Two different types of tags have been tested and used in the prototype system: Active tags with 8 or 32 KB of memory and standard passive tags with 96 bits of memory. The active tags are long range but the passive tags have the readability range of few inches for a typical handheld reader.

Short write distance for tags would guaranty that the inspector did the inspection and maintenance activity in close proximity of valves, and the he lifted and displaced the extinguishers in order to update the data. Table 2 shows the data structure for the passive tags attached to fire extinguishers.

Table 3 Tag data structure for fire extinguishers

| ID | | | DATA | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Specs | Status | Maintenance data | | | | | | | | | | | | | | | Environment Data | | | History |
| | | | | | Condition | | | | | | | | Defective part | | | | | | | Location | | | |
| Type | Model | Serial | Manufacturing Date | Status | Obstructed | Pressure High | Pressure Low | Overall | Loose | Dusted | Rusted | Damaged | Missing Pin | Missing Rivet | Missing Paper | Missing Sign | Neck Bended | Plugged Hose | Seal Broken | Building | Floor | Room | Last Inspection Date |

Due to the limited memory of passive tags, the above information is squeezed to binary codes and stored on the tags. The software translates BIM data related to components to codes using lookup tables and store codes in designated memory spaces on the tags.

The information about the defective parts that is written on the tag helps maintenance workers to quickly identify the problem based on the previous inspection and decreases the re-work. The user interface provides wizards for the inspector which contains standard instructions for inspection, alerts that are triggered by data read form the tags and customized data entry dialogue boxes based on the type of component.

The software also provides navigation aid for the inspector to locate the extinguishers and valves in the building using active tags. The software has pre-loaded floor plans as a visualization layer. By surveying the area to detect the tags, the sensed tags are shown on the floor plan based on their location information.

This case study has been done in a pilot scale in EV building of Concordia University where active and passive tags were attached to 9$^{th}$ floor fire valves and extinguishers. The technological feasibility of the system has been tested in a real working environment.

## Conclusions and Future Work

The proposed methodology provides conceptual data structure and implementation approach of a futuristic vision of facilities with RFID tags attached to their components. Although the case studies show the technical feasibility of the proposed framework using available hardware, several challenges should be addressed to make the vision practical and financially feasible.

The following steps are necessary for realizing the proposed approach: (1) identifying most suitable building components for tagging based on cost-benefit analysis considering long-term value adding benefits, (2) re-engineering existing construction and maintenance processes for the selected components, (3) investigating product-specific and detailed tag structure for the selected components, (4) extracting important *process data* to be stored on the tags for each lifecycle stage of selected components, (5) technology selection and field testing for available RFID hardware, and (6) investigating new information to be added to BIM related to RFID.

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