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BIM Distributed Lifecycle Data Storage on RFID Tags

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Abstract
Efficient information sharing and exchange between various players is an evident need for the highly fragmented AECOO (Architecture, Engineering, Construction, Owner and Operator) industry. Managed and easy-to-access information about facility components throughout the lifecycle should be provided for all stakeholders. BIM is emerging as a method of creating, sharing, exchanging and managing the information throughout the lifecycle. RFID, on the other hand, has emerged as an automatic data collection and information storage technology. This research proposes permanently attaching RFID tags to components where the memory of the tags is populated with accumulated lifecycle information taken from a standard BIM database that 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 potential benefits of the proposed approach, an example of location-related data that could be stored on RFID tags is discussed. A case study have been implemented and tested to validate the technical feasibility of the proposed approach.

Keywords
RFID, Lifecycle management, BIM, Construction automation, Location management

1. 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 an 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 in a fragmented fashion. 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.

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 this information with the broader information systems used across diverse organizations is an issue that needs to be investigated.

This paper aims to investigate techniques for managing components' lifecycle information for ETO components as well as other types of engineered components within a constructed facility (i.e., made-to-order and off-the-shelf components). 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. Furthermore, a tag could include information about the surrounding environment of the component to which it is attached in addition to information specific to that component.

2. Review of RFID and BIM

2.1 Radio Frequency Identification

RFID tag is a memory storage device for storing 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. The main usage of RFID is in supply chain management and 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).

2.2 Building Information Model

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).

3. 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 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.

3.1 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. 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.

3.2 Data Capture Methods

The structured data stored on the tags should be read, updated and changed 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.

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 it 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.

3.3 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 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, 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.

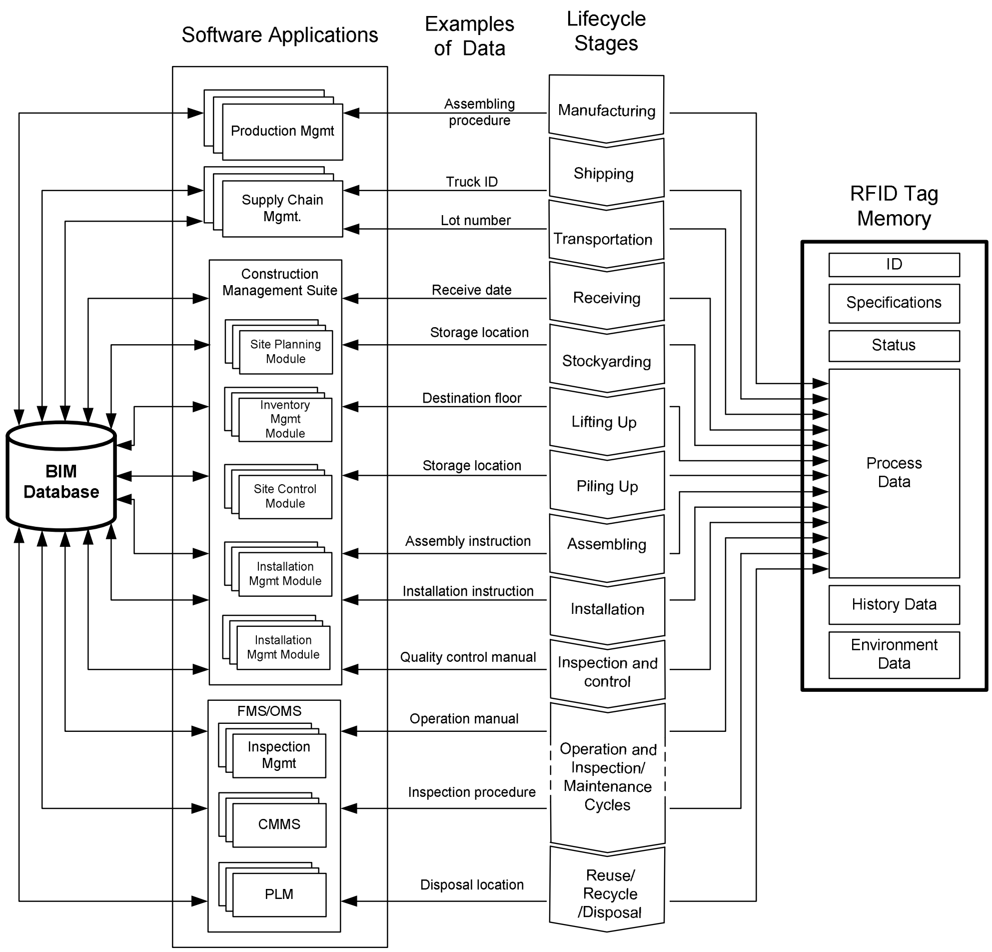

Figure 1: Process Data Update

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.1 shows how different software applications modify the *process data* field. Different applications use the same memory space but at different lifecycle stages.

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.

4. Examples of Lifecycle Location Management Using Tag Data

By storing the information on the tags, real-time data access is provided for a computer system equipped with an RFID reader. Knowing that the location of some components is needed to be tracked at different stages, which is a labour intensive activity, having the location information of the component during the lifecycle would eliminate the search time and increase efficiency.

Several studies propose using the electromagnetic signals received from the tags to calculate their locations (Caron *et al*.,, 2007). However, in this paper we are proposing to write the current location of the components on the attached RFID tags. Based on our proposed approach, components should be scanned and the data on the tags should be updated before each stage or sub-stage. Consequently the location data can be updated during the same data update event. This location information can be obtained by different RTLS technologies (e.g., UWB, GPS) and is written on the tags as they are being updated.

The workers or inspectors can read the RFID data from distance and by retrieving the “current location” information, they would be able to find the component in a storage area or while they are obstructed or hidden in the facility. In addition, we propose to store routing/navigation information or maps on the tags. Consequently, the workers can find the object without having any preloaded maps.

Figure 2 shows some of the possible location related information that could be stored on a tag attached to a generic fixed component. The figure also shows the lifecycle stage where the location data can be used. Different colours show whether the data is stored, read or updated on the tags’ memory at that specific lifecycle stage. The recommended location information to be stored on RFID tags are:

A: “*Final location*” is defined at the design stage for fixed components and recorded on the tags at manufacturing stag. It can be used mainly at installation, operation, inspection, maintenance stages.

B: “*Subcomponents location*” is the information about the parts inside the component, e.g. mechanical parts, controllers and power units. At manufacturing stage, it can be used by robots in the assembly line to do operations, such as welding and part installation. At operation and maintenance stage, the data is useful to detach the faulty part or it could be used to dismantle the component at end-of-life stage.

C: “*Attached parts location*” is the data about how the component should be attached to its adjacent units. This data is most useful at assembling and installation stages and can be used at maintenance stage where the component it detached for repair or maintenance purposes.

D: “*Temporary location*” is one of the main location related information that could be recorded on RFID tags and is useful at various stages to help moving the components. The components are stored at various locations (e.g., storage, yard, shelf, floor, and warehouse) during their supply chain. Temporary location is basically any location that the component may be stored before it reaches its final location in the facility.

E: "*Delivery lot information*" can be used at shipping and transportation stages and managed by supply chain management software. The data can also be used for inspection and quality control purposes.

F: "*Destination site*" is used at transportation and receiving stages where the components are transported and delivered to designated locations. There might be several destination sites during supply chain stream, where their information could be stored and read during transportation.

G: "*Disposal location*" can be recorded on the tag based on environment factors specified in product management software. The data is used to ensure that the component is disposed in the right location.

H: "*Current location*" information recorded on long-range RFID tags can be used to locate components. On the other hand, "current location" data for fixed objects can be used by users equipped with RFID reader to locate themselves in the facility by reading the tags surrounding them.

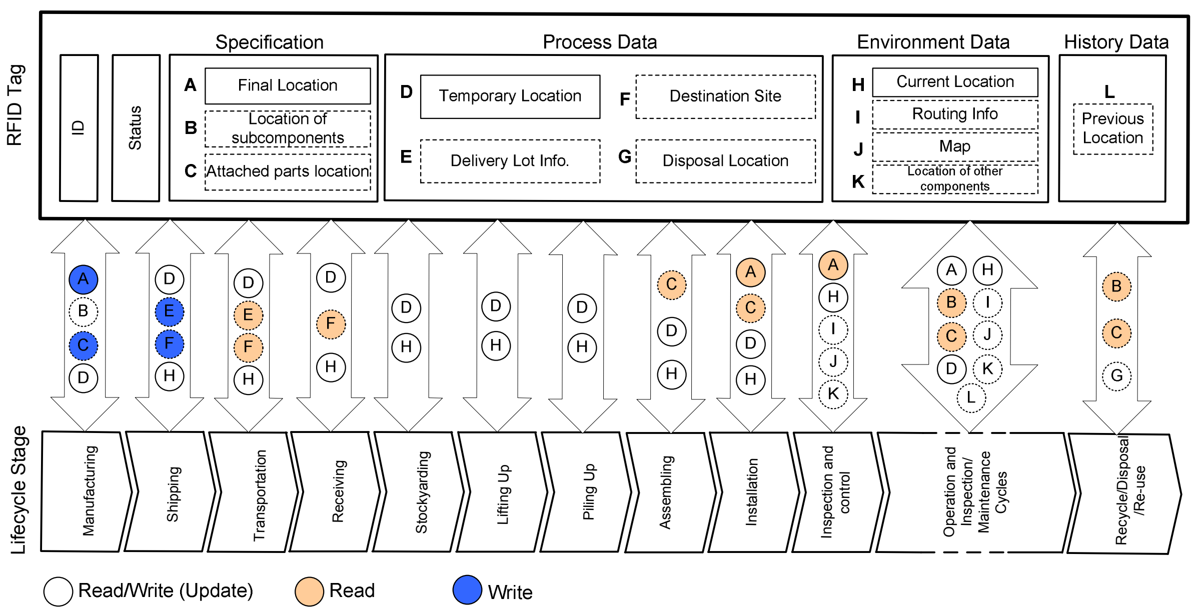

Figure 2: Possible Location-related Information

I and J: "*Routing info*" and "*map*" can be used for navigational purposes. The workers, inspectors, emergency responders or general facility users can use this data to download the map and navigational information. Parts of a map can be stored on adjacent tags that are spread in the facility and the user application can get the map by extracting and combining those parts.

K: "*Location of other components*" includes the relative location of other *components* that do not have tags attached to them or have tags with short readability range.

L: "*Previous locations*" is the history of important previous locations of a component. These locations are managed by the Product Lifecycle Management system based on the type of the component.

5. 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. In addition, the challenges for realizing the proposed approach can be categorized under the following groups:

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; (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 the need of extra efforts and training.

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

6. Case Study: Fire Equipments 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.

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 that 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 1: 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. The user interface provides wizards for the inspectors, which contain 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 (Figure 3). This case study has been done in a pilot scale in EV building of Concordia University where active and passive tags were attached to 9th floor fire valves and extinguishers. The technological feasibility of the system has been tested in a real working environment.

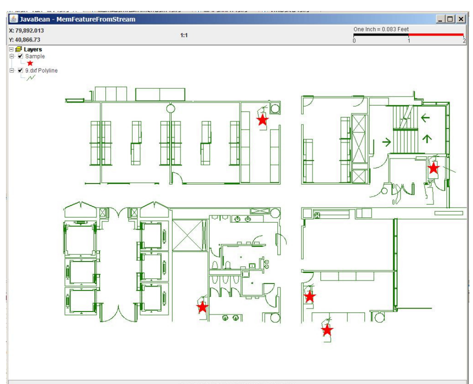

Figure 3: Location of the Detected Extinguishers on the Map

7. 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 study shows 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.

8. Acknowledgement

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