4th Construction Specialty Conference
4e Conférence spécialisée sur la construction

Montréal, Québec
May 29 to June 1, 2013 / *29 mai au 1 juin 2013*

Extending BIM to incorporate information of RFID tags attached to building assets

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Abstract: Building Information Modelling (BIM) is emerging as a method of creating, sharing, exchanging and managing the building information throughout the lifecycle between all stakeholders. Radio Frequency Identification (RFID), on the other hand, has emerged as an automatic data collection and information storage technology, and has been used in different applications in the AECOO (Architecture, Engineering, Construction, Owner and Operator) industry. In our previous research, RFID is proposed to be used to store lifecycle and context aware information taken from a BIM during the lifecycle as a distributed database. Furthermore, RFID tags can be considered as components of the constructed facility. Consequently, there is a need for a standard and formal definition of RFID technology components in BIM. The research goal of this paper is to propose adding the definitions for RFID technology to the BIM standard and to map the data to be stored on RFID memory to associated entries in a BIM database. A requirements' gathering and conceptual design are performed to add new entities, data types, and properties. Furthermore, the paper identifies relationships between RFID tags and building assets. It provides the opportunity to interrelate BIM data and RFID data using predefined relationships. Eventually, the data related to objects that are required to be saved on RFID tags can be automatically selected using defined relationships in a BIM. To explore the technical feasibility of the proposed approach, a case study has been implemented and tested using available BIM software.

1 Introduction

There is an evident need for a standard data model to be used as the basis for computer-aided design, planning, construction and maintenance. Building Information Modeling (BIM) is emerging as a method of creating, sharing, exchanging and managing the information throughout the lifecycle to tackle the problems related to interoperability and information integration. The Industry Foundation Classes (IFC) standard developed by BuildingSMART Alliance (BSA), has matured as a standard BIM in supporting and facilitating interoperability across the various phases of a building lifecycle (Isikdag et al., 2008). IFC is an object-oriented, non-proprietary building data model. However, modelling all possible objects related to the building industry is extremely complex. Therefore, the BSA introduced an incremental development of the IFC model by providing an extensible architecture for extending IFC in various domains.
Motamedi and Hammad (2009) introduced a framework to use RFID memory for facilitating various operations throughout the lifecycle of the building. Similar to barcodes, Radio Frequency Identification (RFID) is a technology for identifying and tracking objects. 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, material management, and quality control (for example, Motamedi et al. 2012;

Jaselskis and El-Misalami, 2003; and Kiziltas et al., 2008). Motamedi and Hammad (2009) suggested permanently attaching RFID tags to assets 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, such as providing the technicians with the maintenance instruction for assets. Moreover, a facility with RFID-equipped assets can potentially provide users with assets' location data (Motamedi et al. 2012).
Based on the assumption that the RFID tags are permanently attached to building components, the tags can be considered as components of the building. Consequently, there is a need to formally define these RFID tags and their associated attributes and properties in the building's data model. The data in the model are essential for tracking and maintaining the RFID components throughout the lifecycle of the building. Moreover, due to the fact that RFID memory is populated with BIM data, defining RFID as an object in the model facilitates the data linkage and management. The data interrelation can be achieved by defining the RFID system components (e.g., tags and readers) as objects in a BIM together with their logical and physical relationships to other objects.
The objectives of the present paper are: (1) to analyze the requirements for adding the definitions, properties, and relationships of RFID tags and readers to a BIM; (2) to integrate the definitions and property sets into the IFC standard by either mapping them into existing IFC definitions or defining new attributes; and (3) to demonstrate the technical feasibility of the proposed approach using a case study.

2 Related research

Froese et al. (1999a, 1999b) analyzed the IFC classes related to project management including project planning and cost estimation. Their implementation and testing confirmed the applicability of the overall approach of the IFC model and provided recommendations for potential improvements. Weise et al. (2000) proposed an extension for the structural engineering domain which was not supported in the IFC standard at the time. The same group further suggested an IFC extension for structural analysis (Weise et al., 2003) that contained the conceptual modelling and the envisaged actors and usage scenarios leading to data exchange views. Fu et al. (2006) presented a holistic architecture of nD modelling tools based on IFC. They have also developed an IFC-viewer as a central interface of nD modelling tools. Ma and Lu (2010) discussed an approach for representing information resources by analyzing available IFC entities and relationships. Ma et al. (2012) presented an IFC-based information model for construction cost estimation for tendering in China. However, there is no research aiming to propose an extension for RFID systems to IFC.

3 RFID data and BIM

Available RFID tags in a facility can be used to store data related to assets. Based on our framework explained in Section 1, these data are dynamic and taken from a standard BIM FileStore/Database. Figure 1 shows how data chunks from the BIM database are copied into the memories of different RFID tags. For example the memory of a tag can contain the maintenance information of the asset such as the condition or the last inspection date. Moreover, the tags memory can contain data related to several assets or spaces. For example, the tag can contain the location coordinates of various assets in a room, or can have the list of occupants in the room. In order to relate the objects' information in a BIM to their associated tags' memory, the relationship between the objects and their associated tags should be identified and modeled. Having these relationship defined in a BIM, the process of selecting data to be stored on tag's memory can be facilitated. For example, in order to copy an asset's last inspection date on the tag's memory, related assets to any chosen tag are identified through the defined relationships and the inspection dates are queried within the model. The selected data are then copied to the tag's memory.

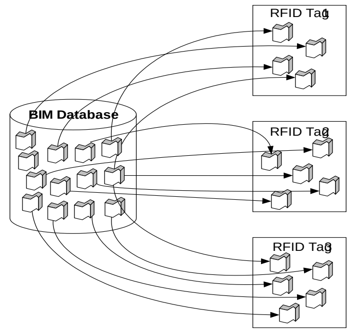

Figure 1 Conceptual BIM-Tag Data Relationship (Motamedi and Hammad, 2009)

Sample scenario: updating the location coordinates of assets on a location tag

An RFID *location tag* is a tag that its memory contains information related to several assets in an area (Motamedi et al. 2012). The list of coordinates for related assets should be stored and updated on the tag. Consequently, when the user is looking for an asset, the location tag's data can be read and the location of the target asset can be queried and shown on the floor plan for localization purpose. Figure 2 shows the flowchart of the process to update the assets' coordinates on the location tag's memory: (1) The tag is scanned and the ID is read by the software; (2) The software queries the ID in the BIM database; (3,4) The software reads the properties of the scanned tag on the IFC file and verifies if the detected tag is a location tag; (5) Using available relationships in the IFC file, the software identifies the related assets; (6) The software reads the location coordinates of each related asset from the IFC file; (7) The software builds the data file containing the queried data; and (8) The data file is merged into the data on the tag.

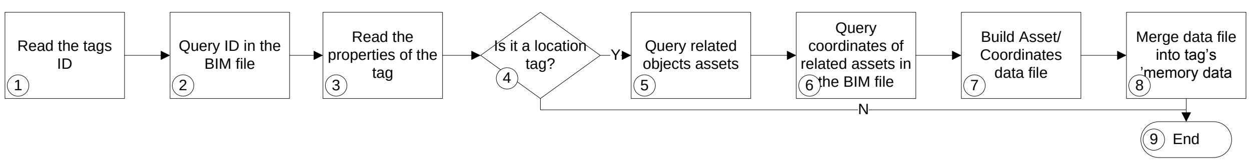

Figure 2 Flowchart of the process to Update Assets' Coordinates on a Location Tag

4 Proposed extension for IFC

Definitions and data structure of the latest version of available IFC standard (i.e., IFC 2x4 RC4) are used as the basis for our proposed extension module. The aim is to define the minimum number of new definitions of objects and relationships. This will avoid the unnecessary expansion of the model. Hence, available relationships and property sets are reused.

4.1 RFID system definitions

In order to add definitions of the RFID components (i.e., tags, readers and antennas) to the IFC model, the elements and their associated attributes are defined based on the properties of the RFID hardware introduced by manufacturers in industry and the captured requirements during field tests. Moreover, the possible relationships between RFID and building components are defined based on our proposed framework in which RFID tags are assigned or attached to building components. The design should be modular and expandable to accommodate newer types of tags, readers and antennas that may be introduced in the future. Hence, the modular approach for defining elements and their properties is used.
RFID hardware can be grouped in three major categories; (1) RFID tag (transponder), (2) RFID reader (Transceiver), and (3) antenna. Each of these entities and their associated properties should be defined. An antenna is defined in IFC as an enumeration of *IfcCommunicationsApplianceType.*

4.2 RFID elements and property sets

The RFID components are defined under the *IFC Electrical Domain* schema which forms a part of the *Domain Layer* of the IFC Model (IFC, 2012). A new type (i.e., *RFIDSystemType*) is proposed with four enumerations: (1) passive tag, (2) active tag, (3) passive reader, and (4) active reader. Other possible types, such as *Semi-Active RFID* that inherits properties of both active and passive tags, can be identified using a combination of properties related to each of the above major types.

4.2.1 RFID system properties definition

Tag properties are defined according to *property set assignment concept* of the IFC. In order to define RFID-specific properties, a property set that contains shared properties for all types are defined (i.e., *RFIDSystemTypeCommon*). Table 1 shows the existing property sets in the IFC that are reused as shared property sets for the RFID system.

Table 1 Shared Property Sets for RFID System

Name of Pset	Description
Pset_ElectricalDeviceCommon	A collection of properties that are commonly used by electrical device types
Pset_Condition	Determines the state or condition of an element at a particular point in time
Pset_EnvironmentalImpactIndicators	Environmental impact indicators are related to a given “functional unit” (ISO 14040 concept)
Pset_ManufacturerOccurrence	Defines properties of individual instances of manufactured products given by the manufacturer
Pset_ManufacturerTypeInformation	Defines characteristics of types (ranges) of manufactured products given by the manufacturer
Pset_PackingInstructions	Packing instructions are specific instructions relating to the packing that is required for an artifact in the event of a move (or transport)
Pset_ServiceLife	Captures the period of time that an artifact will last
Pset_Warranty	An assurance given by the seller or provider of an artifact

Separate property sets are defined to include type-specific information. For example, battery life can be only a property of active tags. *IfcMaterialUse* definition is used to define the material used for the tag and its casing. Identifying the material for casing of the tag has special importance since the radio communication capability of a tag is highly influenced by the type of its casing when attached to metallic objects. Table 2 shows the newly defined property sets for each type of RFID system entities.

4.2.2 Location of the RFID tags and readers

The locations of the RFID system entities are modeled using available methods in IFC for representing the location, orientation and placement of items as follows: (1) **Absolute or relative placements**: *absolute*: by an axis placement, relative to the world coordinate system; *relative*: by an axis placement, relative to the object placement of another product; and *by grid reference*: by the virtual intersection and reference direction given by two axes of a grid. (2) **Containment**: The RFID system entity is located in a space that is part of a building and a floor. The location of the tag can be identified based on the containment relationship to know the spatial level that the tag is located in.

4.3 Relationships with other objects

The RFID tag/reader is either attached to an asset/building element or is part of it (as a subcomponent). These relationships are physical attachment or decomposition type. Figure 3 shows how an RFID tag or reader has one-to-one physical relationship with an element to which it is attached. Although each tag/reader is attached to only one element, several RFID tags/readers can be physically attached to an element.

The *decomposition* relationship between an RFID tag and the associated element (e.g., asset or building component) can be defined using IFC relationship definitions. Entities such as *IfcRelDecomposes* and its subtype *IfcRelAggregates* are used to realize this relationship between tags and their associated elements. Moreover, the reader can be an internal part of a communication device, such as a handheld computer or a cell phone. In this case, a decomposition relationship can be used to identify such setting.

In order to describe the physical connection between an RFID tag/reader and an asset or building component, *IfcRelConnectsElements* together with *IfcConnectionGeometry* are used. *IfcConnectionGeometry* is added to describe the geometric constraints of the physical connection of two objects. The physical connection information is given by specifying exactly where at the relating and related element the connection occurs. Additionally, IFC provides the eccentricity subtypes, to describe the connection when there is a distance between the tag and the element. IFC provides the following connection geometry/topology types: (1) point/vertex point, (2) curve/edge curve, and (3) surface/face surface.

Table 2 Proposed Property Sets

Property set	Description	Example	Active Tag	Passive Tag	Reader
Standard compliance	Communication, memory, ID type, and data type standards	ISO18000	✓	✓	✓
Range	Operating readability range of tag or reader	300 m	✓	✓	✓
Frequency	Communication frequency range for the tag	915 MHz	✓	✓	✓
Operating temperature	Temperature range at which the device operates	-30 C-45 C	✓	✓	✓
Enclosure rating	IP and NEMA Ratings	IP65	✓	✓	✓
Shock	Environmental testing standard	DIN/IEC68-227	✓	✓	✓
Vibration	Environmental testing standard	DIN/IEC68-2-6	✓	✓	✓
Antenna type	Type of internal or attached antenna to the tag	1/4 *wave monopole*	✓	✓	✓
Installation date	Date when the unit is installed	01/01/2012	✓	✓	✓
Transmit power	Maximum transmission power	0.5 mW	✓	✓	✓
Data transmission rate	Data communication rate	128 Kbps	✓	✓	✓
EPC number	Universal identifier as defined in the EPCglobal tag data standard	urn:epc:id:sgtin:0134000.213254.343	✓	✓	
TID	32-bit transponder identification number	2E8E0D4C	✓	✓	
Total memory size	Total size of tags memory	32 KB	✓	✓	
Encryption	Method and possibly keys for encryption of the data	AES	✓	✓	
Shape type	(1) *Label*, (2) *Ticket*, (3) *Card*, (4) *Glass bead*, (5) *Integrated*, (6) *Wristband*, (7) *Button*	Label	✓	✓	
Battery type	Battery type standard	LR AA	✓		
Battery level	Percentage of available battery	40%	✓		
Max. write cycle	Number of cycles that the tag can be written on	100,000	✓	✓	
Write cycle count	Number of the write cycle	1280	✓	✓	
Encoding	Content encoding standard	ASCII	✓	✓	
Markup language	Data presentation standard/ markup language	XML	✓	✓	
Memory content	Reference for the existing content on the tag's memory	ID	✓	✓	
Storage type	Read-write, read-only and WORM (write once, read many)	WORM		✓	
Reader type	*Mobile, Fixed*	Mobile			✓
Number of antennas	Total number of supported or attached antennas	4	✓	✓	✓
Antenna connector	The standard for the RF antenna connector	RP-TNC			✓
Reader buffer	Number of tags that can be read	400			✓

Furthermore, one or many elements or spaces can be logically assigned to a tag in order to keep data related to them on its memory. The following are different alternatives for object-to-tag assignments: (1) A single asset is assigned to a tag (*asset tag*): The tag contains data about one asset. In this scenario, the tag is attached to the same asset; (2) A group of assets is assigned to a tag (*group asset tag)* (for example, the fire extinguisher, fire hose and the first aid box are assigned to a tag); (3) Several spaces and/or assets are assigned to a tag (*location tag*): The tag contains data about the space (e.g., coordinates, room number and occupants) and data about selected assets in that space; (4) A space is assigned to a tag (*area tag*): The tag contains data about the space (e.g., floor plan, occupants); and (5) A group of spaces is assigned to a tag (*zone tag*): The tag contains data about a group of spaces (e.g., contains department name). Figure 3 conceptually shows the relationship of an RFID tag and associated and attached assets and spaces. All of the above-mentioned logical relationships between tags and elements can be described in IFC by using *IfcRelAssignsToProduct* entity.

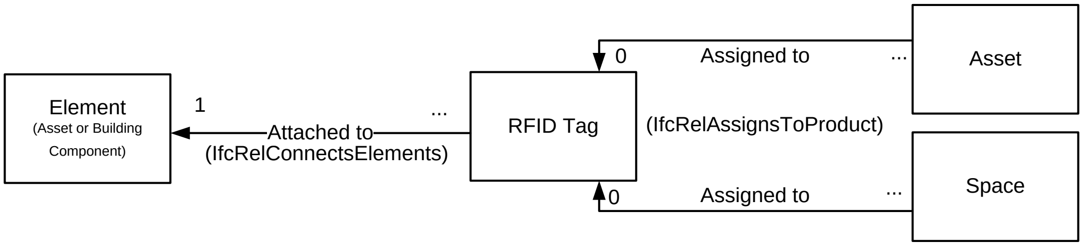

Figure 3 RFID Tag Attachment and Assignment Relationships

5 Case Study

Modeling RFID tags in BIM application

A sample mechanical room has been modeled in Autodesk Revit Architecture 2012. RFID active and passive tags are modeled under the electrical equipment category. The model is then exported to IFC 2x3 and extra code is added to the EXPRESS file in order to define new properties and relationships for tags and assets.

In the case study, passive asset tags are attached to each asset and a long range active location tag is attached to the wall near the entrance of the mechanical room to provide the maximum readability from the corridor. It contains the location data related to the room and selected assets that are located in the room. Figure 4 shows the modeled passive and active tags that are attached to mechanical assets (e.g., pump, boiler) and the wall, respectively. Table 3 shows the types of data that are saved on passive and active tags. As shown in Table 3, passive tags contain only an ID and the last inspection date for the asset. The active tag's memory contains data related to other assets and spaces in addition to its ID.

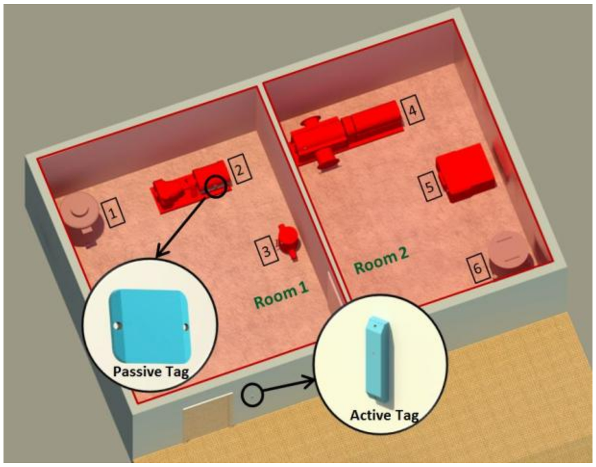

Figure 4 Case Study Setting

Table 3 Data Saved on Tags

Tag type	Data	Example
Asset tag	ID	123
	Related Asset's Last Inspection Date	1/2/13
Location tag	ID	124
	Related Spaces Name	Room_1
	Related Space IDs	123
	Related Spaces Authorized Users	John Smith
	Related Spaces Hazardous Materials	None
	Related Assets Name	M_Pump
	Related Assets ID	321
	Related Assets Coordinates	X,Y

Adding relationships using EXPRESS language

After creating the model objects in the Revit, the various relationships should be defined. The current version of the tool supports only the spatial containment relationship namely *IfcRelContainedInSpatialStructure* amongst types of required relationships. Hence, the model is exported to IFC format and other relationships are manually added using standard EXPRESS format (IFC, 2012). Figure 5 shows the relationships between various elements including the spaces and assets and their attached passive tags. As shown in the figure, four mechanical assets and two rooms are assigned to the location tag (i.e., ActiveTag_LT1). This location tag is attached to Wall_1 and contains the data types presented in Table 3. The figure also identifies various types of relationships to be added to the IFC file in order to realize the required relationships for the case study.

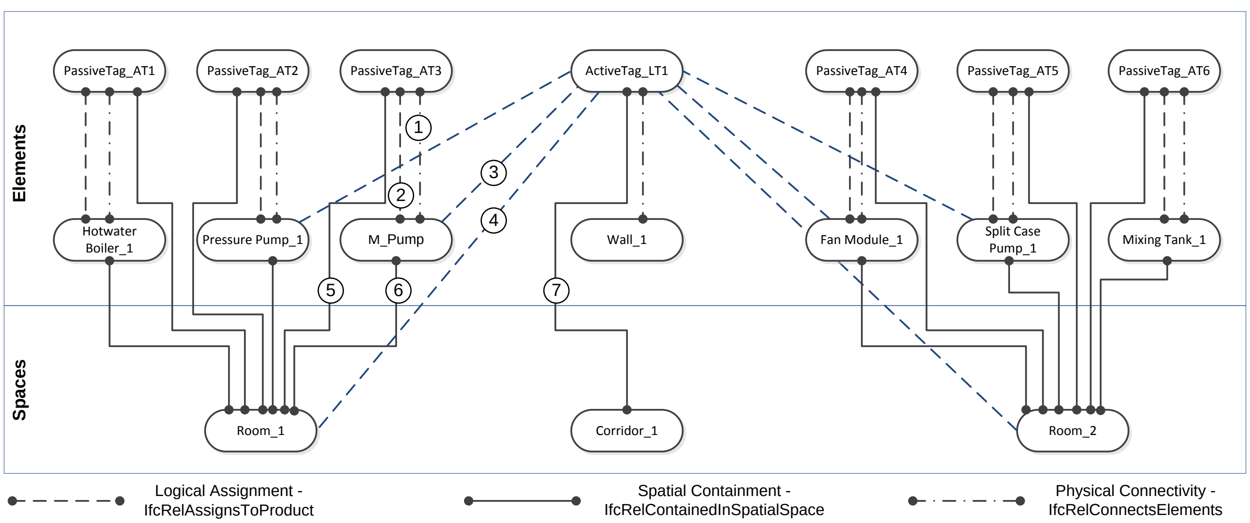

Figure 5 Case Study Entities and Relationships

Table 4 shows parts of the added EXPRESS code to the exported IFC file that describe the relationships between ActiveTag_LT1 and one sample related asset (M_Pump) and sample related space (Room_1). The numbers shown in Figure 5 correspond to the noted numbers in the comment column of Table 4.

6 Conclusions and future work

The paper elaborated on the needs, motivations and benefits of including standard definitions of RFID systems in BIM. A conceptual design and a requirements gathering are performed in order to identify the related attributes and relationships for RFID system components. Furthermore, new entities and property sets are defined for the IFC standard.

Various IFC-compatible tools were utilized and tested to realize the proposed extension of IFC. The results showed that the current tools have several limitations for extending the definitions. Moreover, the exported IFC file of a model that is designed in a certain tool lacks several details of the model when opened by standard IFC viewers. Additionally, the exported IFC file has compatibility issues when opened by other BIM tools. The other major limitation was the inability to utilize existing properties and relationship types of IFC, although the tools claim to be fully compatible with a certain version of IFC implementation. This shows that the current state of practice has major limitations for adding new objects, relationships and properties as well as utilizing existing classes of IFC. In our case study we used the combined approach of utilizing IFC tools as well as manually adding EXPRESS code and finally visualizing the model using standard viewers.

The future research includes proposing the newly defined objects to the Smart Building Alliance to be added in upcoming versions of the IFC standard. Moreover, the same methodology can be used to add the definitions of other types of sensors to BIM.

Table 4 Part of EXPRESS Code for the Model

EXPRESS Code	Comment
/* Definitions */	
#14928=IFCBUILDINGELEMENTPROXY('*GUID*',#33,'M_Pump ',$,'38 LPS - 358 kPa Head',#14927,#14921,'127731',.ELEMENT.);	Definition of "M_Pump"
#31635=IFCBUILDINGELEMENTPROXY(*GUID*',#33,'ActiveTag_LT1',$,'RFID Active Tag',#31634,#31628,'154693',.ELEMENT.);	Definition of "Active Tag_LT1"
#34846=IFCBUILDINGELEMENTPROXY('*GUID*',#33,'Passive Tag_AT3',$,'RFID Passive Tag',#34845,#34839,'170619',.ELEMENT.);	Definition of "Passive Tag_AT3"
#74=IFCSPACE('*GUID*',#33,'1','',$,#61,#73,'Room_1',.ELEMENT.,.INTERNAL.,$);	Definition of "Room_1"
#242=IFCSPACE('*GUID*',#33,'0','',$,#231,#241,'Corridor_1',.ELEMENT.,.INTERNAL.,$);	Definition of "Corridor_1"
/* Coordinates */	
#34843=IFCCARTESIANPOINT((-5659.351757872039,2299.71228107407,431.8754204233143));	Coordinates of “Passive Tag_AT3”
#31632=IFCCARTESIANPOINT((-667.2135581104749,1239.614021979968,1408.456737681661));	Coordinates of “Active Tage_LT1”
#14925=IFCCARTESIANPOINT((-6193.54721173054,1111.194682387459,11.15923613182088));	Coordinates of “M_Pump”
/* Physical Relationships */ #38597=IFCRELCONNECTSELEMENTS('*GUID*',#33,$,$,$,#14928,#34846)	Attachment of “Passive tag_AT3” to the “M_Pump”: Relationship (1)
/* Logical Relationships */ #38598=IFCRELASSIGNSTOPRODUCT('*GUID*',#33,$,$,#14928,$,#34846)	Assigning pump to the passive tag: Relationship (2)
#38599=IFCRELASSIGNSTOPRODUCT('*GUID*',#33,$,$,(#2216,#14928,#23239,#26872,#27053,#30856,#162,#74),$,#31635)	Assigning assets and spaces to the active tag: Relationships(3), (4)
/* Spatial containment Relationships */ #38444=IFCRELCONTAINEDINSPATIALSTRUCTURE(*GUID*',#33,$,$,(#31635,#34063,#34119,#34151),#242);	Containment relationship for assets inside "Corridor_1" including: Relationship (7)
#38442=IFCRELCONTAINEDINSPATIALSTRUCTURE('*GUID*',#33,$,$,(#2216,#4539,#4603,#4635,#4667,#14928,#23239,#34846,#35551,#38367),#74);	Containment relationship for assets inside "Room_1" including: Relationships (5), (6)

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