

# DEVELOPING INTERACTIVE CONNECTIONS BETWEEN BIM AND FACILITIES INFORMATION SYSTEMS FOR END USER FUNCTIONALITIES

Master Thesis



**Aalto University**  
**School of Engineering**

Xi Liu  
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**Author** Xi Liu

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**Thesis supervisor** Vishal Singh

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**Thesis advisor(s)** Mehmet Yalcinkaya

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**Abstract**

BIM(Building Information Modelling) is becoming commonplace in construction projects and new BIM technologies, processes and people (skills/ roles) continue to emerge in the building industry. With the aim of expanding the potential benefits and uses of BIM in the downstream areas and disciplines within construction and real estate business, this thesis proposes a theoretical framework for an interactive system that connects BIM and facility data for multiple end-user functionalities. Facility managers, building residents and civil engineering students are the target subjects and end-user groups in this thesis. The different user-groups and their requirements are integrated in a centralized data repository via multiple user interfaces and connection systems that suit different user groups. A data synchronization program linking BIM model and data repository is developed, and other technologies and tools such as VisualLynk, augmented reality, and social media are adopted to facilitate the working of the system and the envisioned processes.

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**Keywords** BIM(Building Information Modelling), Facility Management, Visual Programming, Software Development, Building data, Augmented Reality

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## List of Abbreviations

<b>BIM</b>	Building Information Modeling
<b>FM</b>	Facility Management
<b>EDU</b>	Education
<b>COBie</b>	Constructions Operations Building Information Exchange
<b>DB</b>	Database
<b>IFC</b>	Industry Foundation Classes
<b>XML</b>	Extensible Markup Language
<b>JSON</b>	JavaScript Object Notation
<b>AEC</b>	Architecture, Engineering and Construction
<b>PLM</b>	Product Lifecycle Management
<b>GIS</b>	Geographic information system
<b>API</b>	Application Programming Interface
<b>GSA</b>	General Services Administration
<b>LOD</b>	Level of detail
<b>CRUD</b>	Create, Read, Update and Delete
<b>GUID</b>	Globally unique identifier
<b>MEP</b>	Mechanical, electrical, and plumbing
<b>HVAC</b>	Heating, ventilation and air conditioning
<b>AR</b>	Augmented Reality

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# 1. Introduction

## 1.1 Scope of the thesis

This master thesis research explores some of the BIM model uses in downstream, especially end user-related areas that include

- a) Facility management use-case: for facility manager
- b) Asset maintenance use-case: for building residents
- c) Education use-case: for civil engineering students

A theoretical framework is developed and some of the key aspects are implemented as working prototypes and proofs-of-concept to demonstrate the applicability of the proposed approach. As an exploratory technical research, the objective of the thesis is limited to test and demonstrate the applicability of proposed approach in addressing the BIM-usage related problems in the three use-cases listed above. These gaps or lack of adequate BIM-usage in the listed use-cases was identified through related literatures.

The tools adopted in this thesis research are described followed by a description of the implemented system. Finally, the limitations of the current system are outlined and the future improvements and research goals are envisioned.

## 1.2 Research problem:

The research and development in BIM field has been growing at a high rate. Most of this research and development is aimed at design or construction phase, targeting designers and contractors.

However, as a data-rich environment comprising multiple types of information, BIM cannot deliver fully its advantages if many intended downstream end-users cannot benefit from it. A step further, how can we make a more interactive way of communication between BIM and end-users? How can we envision an open interface to allow data input by the end-users, eventually leading to the possibility for continuously enriching the BIM model and BIM database along with the lifecycle of the built facility? Such capabilities that allow end-users to continuously update the BIM model can be used for several other functionalities, opening new possibilities for further research and improvements.

In this thesis, we explore three use-cases and associated functionalities.



Facility managers, building residents and civil engineering students all have a desire to access BIM data according to their specifications as well as make their input and contributions back to the BIM database. Each of these use-cases and associated research problems are described briefly.

## **Facility managers - Facility management (FM)**

### **Understanding the problem**

As also noted by Paul Teicholz, in his edited book titled 'BIM for facility managers / IFMA, IFMA Foundation', we know that one of the best practices proposed in the current way of BIM/FM integration is utilizing Construction Operations Building Information Exchange (COBie) standards. COBie provides a mechanism whereby BIM software and applications export facility data into a COBie-format spreadsheet for facility management use.

For facility managers who choose to use this method with digital facility management system, they are required to enter the facility information from the COBie spreadsheet either by hand or by other import mechanisms into the FM system.

Facility managers also need to take the responsibility of verifying and updating the facility data during its lifecycle. COBie data transfer need to be handled at several stages namely: As-planned, As-designed, As-constructed, As-occupied, As-built and As-maintained during the facility lifecycle. In short, there will be at least six stages of COBie export and import from the building project start to the end. This is still a conservative estimate because in reality factors such as design changes and equipment replacement are not taken into account. Therefore, this process could cause extra amount of time and cost to facility managers, and thus make their work inefficient and even amplify this issue when facing some more complex building projects.

### **Defining requirements**

The problems defined above can be alleviated significantly if we could bridge the gap between BIM Model and FM systems in such a way that we skip the procedure of exporting and importing multiple times, which is the major bottleneck and contributor to the extra time, cost, and workload in the FM field.

Accordingly, one of the ways to address this issue is to implement a direct and interactive link between BIM and FM systems, which is mentioned in the book titled 'BIM for facility managers' as the fourth option in terms of BIM/FM integration method. In addition, this direct link should provide other advantages like:

a) Auto-mapping. BIM contains large amounts of varied types of data, and

there are multiple types of attributes attached to every object. However, only part of all this data is required for facility management purpose. Hence, this direct link should have capability of making auto mapping from BIM-authoring software type of native data schema to facility-purpose data according to the COBie standard.

- b) Synchronization. When facing the fact that facility data is exported multiple times, typically, the direct link should allow data update from time to time.

## **Building residents - Asset maintenance**

### **Understanding the problem**

Buildings, especially residential buildings, will be occupied by its residents for decade of years, which means building residents are the group who keep the longest contact to the building, and the ones to be affected the most by the building facilities. However, the building and its asset information are not easily accessible to them. This limitation leads to extra cost of time, budget or even other negative implications, especially when it comes to any urgent requirement for knowing the building elements information or maintenance manuals. That is, finding the right information about their building at the right time is often not possible for residents and building users.

In addition, currently building residents can report the building issues or errors to building owners by phone or email, which while convenient is neither examined or well-documented nor supporting any degree of self-diagnosis or degree of user autonomy. This is primarily because such media is completely disconnected with the building or FM data.

### **Defining the requirement**

There needs to be greater awareness of the needs of the building residents, because they are the actual users of the building. The building assets should be more user-orientated, accessible and interactive such that lay users, who may have little or nothing to do with BIM and FM tools can still effectively interact with the building data.

According to this problem context, a bidirectional communication system, with the capability of enabling report documentation and instant response, should be adopted for asset maintenance among building residents and facility owners.

Also, as non-professionals, building residents require a user-friendly, no pre-requisite skills interface, to interact with their buildings.

## **Civil Engineering students – Education and learning**

### **Understanding the problem**

As a topic belongs to custom model uses category, educational use of BIM Model needs more attention.

3D-based and information-rich teaching in civil engineering has not been used as yet. Some lecture contents are not always easy to understand, especially when it comes to the courses such as Building Structures, Reinforcement Design, etc. Complementing such teaching with a 3D-based visualization as well as using 3D elements directly for teaching could be more fruitful than use of 2D illustrations and diagrams in textbooks.

### **Defining the requirements**

Currently the teaching of BIM is disconnected with the teaching of domain knowledge in civil engineering, and typically, the theoretical education in civil engineering is not very well connected to the practical day to experience with buildings around us. So the challenge is to address this disconnect!

Thus, an interactive 3D-based learning tool, connecting to the BIM Models needs to be developed for civil engineering students. By doing so, we can expand the scope of significance of BIM Model Uses even down to education aspects, especially connecting theories, textbooks and real world experience with the models.

### **Integration problem and requirement**

The above paragraphs present the research problems for model uses in facility management, asset management and education. Besides utilizing and visualizing the BIM data, every party may also generate and modify the data themselves, wherever applicable. Hence, aiming at inter-communicating and mutual utilization among these entities, a general linked approach is required so that each party can take advantages of the contributions of the other and reach the best significance of BIM Model Uses and multiple user functionalities.

## **1.3 Research goals and objectives**

### **Developing a synchronization link between BIM model and FM system.**

By reviewing related literature, including the 'BIM for Facility Manger' book by Teicholz (2013), we get an overall know-how about BIM/FM integration and related benefits and problems.

This review was followed by extensive brainstorming, preliminary mock-ups, simple web-application demonstrations, and actually system development and improvement. The current working prototype has been tested and debugged, validating a synchronization of the BIM/FM link. The following chapters will describe it in a detail.

### **Exploring a new way of interaction between building residents and BIM via social media.**

This gap was identified through literature as well as reflection of the researcher from day to day experiences. Building occupants, as normal users and non-experts in the domain, may be required to interact with their building just as easy as operating their refrigerators, without professional building management know-how.

As most of people are active in online social media, and may use them frequently in their daily life, an idea of linking building occupants with BIM model just via their social media was conceived. For example, in our research Twitter is taken as one such social media. Therefore, the goal to have the BIM model connected to a Twitter account, and this can allow be streamlined interaction, via a kind of intelligent robot, with the followers of the account, namely the building residents.

### **Bridging BIM model and civil engineering students by the facilitation of Augmented Reality technology.**

With the quick development of BIM and other information technologies, a BIM/Education integration tool, utilizing Augmented Reality, is developed. It will allow students to learn building structures in an immersed 3D environment as well as interact with it.

## **1.4 Research methodology**

The total research began with literature review and discovering current problems and context.

Then I conducted preliminary hands-on work in order to learn practical techniques and thereafter developed the first trial application reflecting the research. I also had the opportunity to develop it further and demonstrate it in AEC Hackathon Helsinki (June 2016), to get preliminary feedback from the attendees. The comments, inputs, and peer review from this event contributed to our later research and understanding of the requirements.

Next, I spent considerable time on proposing a general theoretical framework, and in the meanwhile participating in a university project: AIOLE where we are developing an interactive 3D-based learning platform called InBookMode. I was inspired a lot from this project experience and started to think about BIM/Education integration and related research.

The final part, which is the most time-intensive part, is system development. I spent around one year to complete this phase, which includes development, revision, improvement, test, debug, expert and peer review, validation, etc.

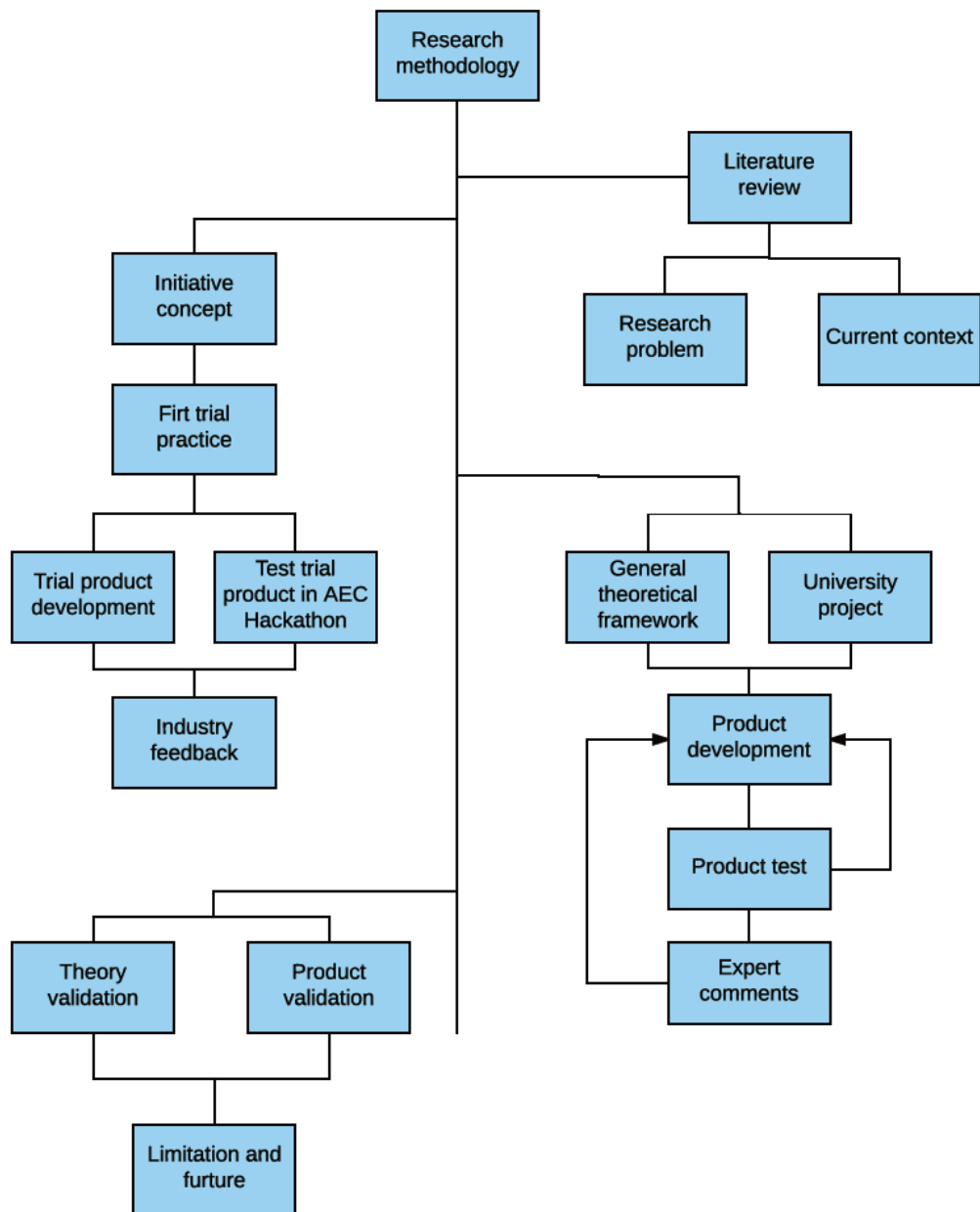


Figure 1: Research methodology

## 1.5 Theoretical framework

### A conceptualized framework of integrating multiple building end-users.

BIM model can be adopted into multiple use cases for multiple end users. This thesis focuses on the integration with BIM and other end-user functionalities such as facility managers, building residents, and civil engineering students.

With the aim of enhancing end-user functionalities, a conceptualized theoretical framework: a centralized repository surrounded by multiple data inputs from multiple end users was proposed. We introduce tailored tools and methods for different target user-groups by analyzing their requirements and situations.

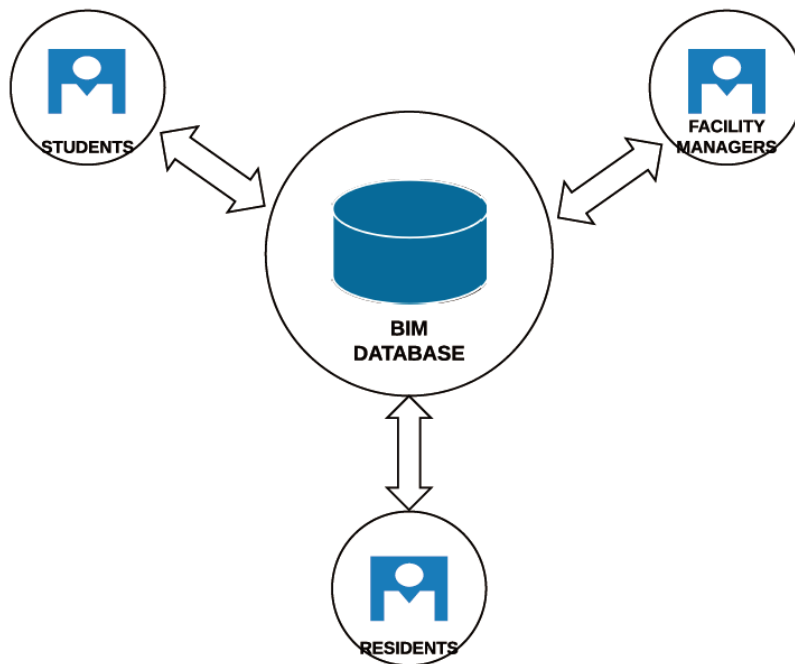


Figure 2: Theoretical framework

### Data requirements of end users

The different data specification of three model use-cases for end users and a shared BIM data structure are proposed.

Based on qualitative feedback and literature review, facility managers, as professional building maintainers, need professional facility attributed data much more than the 3D visualization or graphics.

Building residents also have a stronger desire for facility attribute data more than graphics, however they need an easy-understandable and user-friendly interface to interact with those facility data.

On the other hand, students, in contrast to facility managers and building residents, may require more 3D visualization and graphic support than attribute data, which they already get through textbooks and other academic sources. 3D visualization and graphics provide more virtual than symbolic representation, which makes it explicit. This can enhance comprehension and improve building knowledge. For example, the building skeleton when visualized through the 3D graphical representation, is likely to facilitate greater comprehension than a 2D, non-interactive illustration of the same. Can we connect a BIM model of the building skeleton with the textbook sections and theories that explain the working on the structure?

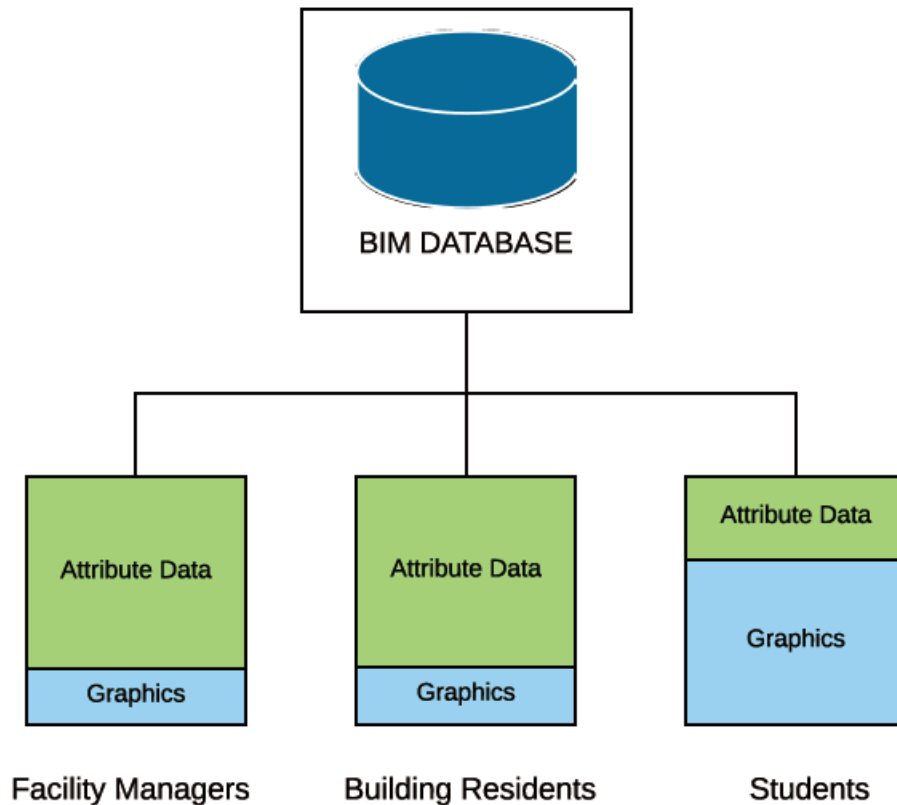


Figure 3: Data specification for multiple end-users

## 2. Background

### 2.1 Literature review

#### **Yalcinkaya M. & Singh V., (2016a). Evaluating the Usability Aspects of Construction Operation Building Information Exchange (COBie) Standard.**

Yalcinkaya & Singh (2016a) present the research on integration between BIM and FM, the background, the pros and cons of COBie, and especially on the research for better visualization of COBie data, namely VisualCOBie.

COBie is a standard for delivering digital facility data. It was developed to overcome the industry problems such as inefficiencies of data transformation among different disciplines in AEC projects, and lower levels of user experience when reviewing and querying the facility data, and so forth.

Currently, COBie information can be exported in any of the three formats, IFC STEP Physical File Format, which is standard for exchange of product model, ifcXML (extensible mark-up language format of IFC), and SpreadsheetML (open XML schema used by spreadsheet application such as MS Excel). Among these three formats for storing and exchanging COBie-based facility data, spreadsheet is the most widely used one, due to its natural advantages such as familiarity, ease-of-use, human-readable, editable, and no special requirement for users. For example, information technologies skills are needed to parse the IFC STEP data, whereas spreadsheets are familiar and easy to use. However, spreadsheet also has some disadvantages when integrating with COBie data. COBie data, due to its speciality, may contain huge amounts of data that leaves users a heavy memory load to navigate the spreadsheet and fetch their required data. Additionally, unlike other normalized type of data, there are lots of dependencies between COBie data so that to some extent it is difficult to understand the whole data structure and their relationships. In a nutshell, these disadvantages may cause inefficiencies and extra work for facility management.

Based on this background research, the author made an investigation upon the user requirements for approaching COBie data. Here are some results:

- a) As a user, I have difficulty to navigate and process COBie data within different tabs in spreadsheet.
- b) As a user, I could not fetch the data I want according to its dependencies.
- c) As a user, I would like to see the COBie data interacting with 3D BIM



Model when I selecting them

Finally the author brings a new concept of processing COBie data, called VisualCOBie. It is directed towards better graphic representation of the facility data, and their dependencies and benefits for end-user functionalities.

**Succar, B. (2015). BIM ThinkSpace episode 24: Understanding Model Uses. Retrieved from BIM Think Space website: <http://www.bimthinkspace.com/>. Accessed, 10.**

This article is a post on bimtinkspace, introducing the concept of model uses and related practical applications.

The intended or expected project deliverables from generating, collaborating-on, and linking models to external databases. A model use represents the interactions between a user and a modelling system to generate model-based deliverables. There are tens of model uses including clash detection, cost estimation, and space management (BIM Dictionary).

The objective of standardizing the model uses is to specify every BIM process and deliverables to simplify the collaboration process and reduce the inefficiencies due to lack of standard communication. A typical model use should defined all the requirements, activities and outputs in a consistent way so that they can be more adaptable and repeatable by similar projects.

The benefits in general of defining model uses are: a) Improving inter-communication among every discipline, teams and organizations. b) Clarifying project requirements, outcomes and deliverables. c) By linking the requirements and outcomes together, we will have clear mind of which methods, tools, approaches need to be adopted and executed. d) Enabling better task distribution and responsibilities assignments, so that to obtain a more powerful team. e) Bridging the semantic gaps between different information systems as model uses are targeting at making information deliverables and communications between multiple parties, for instance BIM and FM, BIM and GIS, and so forth.

The model uses are widely defined with also flexibility to add user defined content as this term is not restricted to AEC industry so can be adopted to a various of fields such as GIS, PLM. Model uses are described more between product and user, between project requirements and project outputs.

Next, the author comes to the discussion about the information structure in the definition of model uses. The author breaks the information along the

building lifecycle down to five layers in terms of their computability. A detailed description of the information categories is described below:



Figure 4 Project Information, from Unstructured to Integrated (Succar, B. 2015)

[0] General background information: Such information does not affect the project, such as the history of the building location.

[1] Unstructured project information: Such information that is not documented with any computability, as well as, the temporary project information such as hand sketches and informal phone calls.

[2] Structured project information: Such information that is computable and documented, including documents, drawings, maps, messages, photos, reports, schedules and visualizations.

[3] Modelled information: Such information that reflect particular model uses, including planning, simulating, quantifying, constructing, fabricating, operating, maintaining, monitoring and controlling information.

[4] Integrated data: Such information that is inter-related and highly-structured, including all types of structured project information.

The actual categories of model uses can be divided to three aspects: General Model Uses, Domain Model Uses and Custom Model Uses.

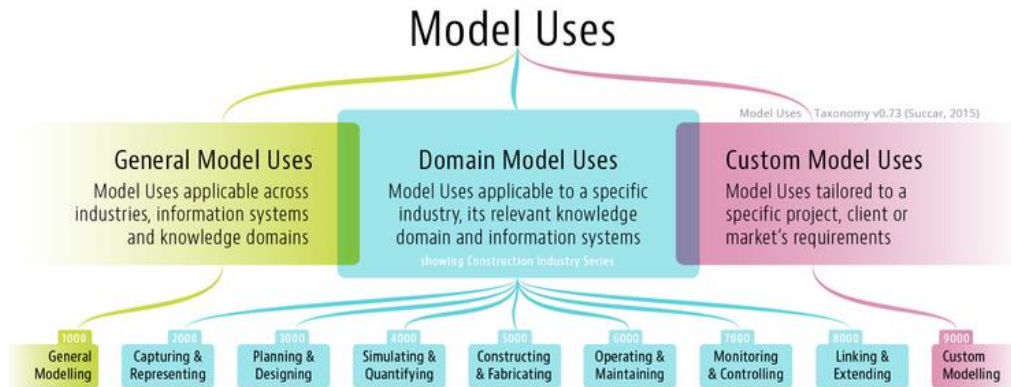


Figure 5: Model Use categories and series (Succar, B. 2015)

General Model Uses are adaptable among industries, information systems and knowledge domains, with the examples of Temporary Structures Modelling, Urban Modelling, and so on.

Domain Model Uses are specific deliverable topics for example: 2D documentation, 3D detailing, clash detection, cost estimation, structural analysis, energy simulation, quantity take-off, asset maintenance, BIM/FM integration, and so forth.

Series 6: Operating and Maintaining (6000-6990), synonyms not listed

Code	Model Uses	Code	Model Uses
6010	<a href="#">Asset Maintenance</a>	6050	<a href="#">Handover and Commissioning</a>
6020	<a href="#">Asset Procurement</a>	6060	<a href="#">Relocation Management</a>
6030	<a href="#">Asset Tracking</a>	6070	<a href="#">Space Management</a>
6040	<a href="#">Building Inspection</a>		

Figure 6: Model Uses in O&M (Succar, B. 2015)

Custom Model Uses are user-defined according to different requirement by end-users.

Teicholz, P. (Ed.). (2013). **BIM for facility managers. John Wiley & Sons.**

### What do owners need?

The process figure below indicates that graphics data reach its peak demand at design stage and thereafter shrink to its minimum at Operate phase. During design phase, lots of graphic objects are created such as windows, doors, structural framings, etc. Then in construction phase, more accurate and more levels of detail (LOD) data are obtained from construction scheduling, cost estimation, quantity take off, etc. Finally, by the completion of installation of building systems, the facility data is ready to be handed over to Operate phase. In Operate phase, owners need BIM data more than graphics.

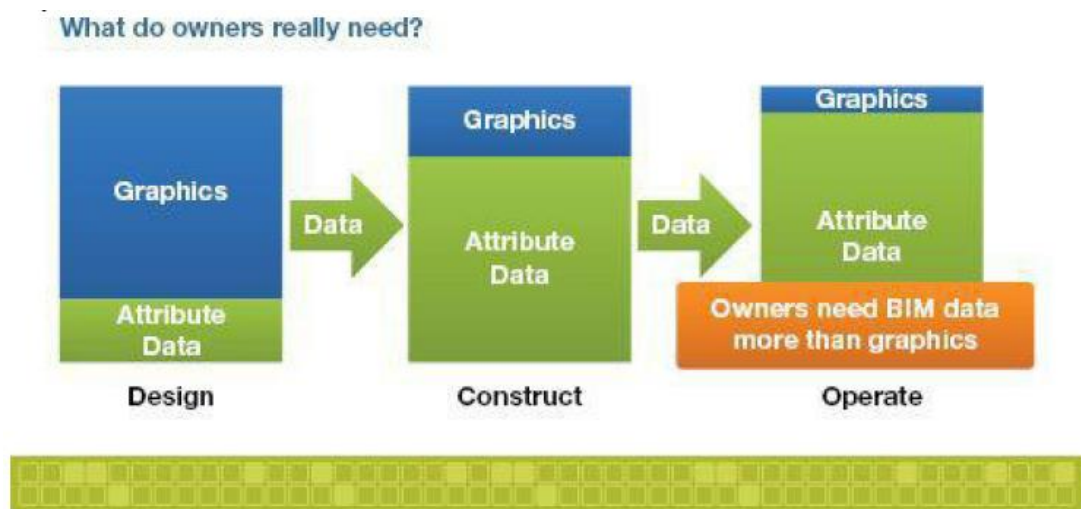


Figure 7: Mix of graphics and data changes over the facility life cycle. (Teicholz, P. (Ed.). 2013)

### BIM/FM Integration benefit

BIM has been adopted in the AEC sector, particularly widely in the design and construction phase of a building project. Whereas, the application of BIM in FM is not that straightforward.

Facility managers have the mission of better managing the whole building along its lifecycle, offering high quality, verified, reliable data to the building maintenance and operation. And the challenges for facility managers are processing the large amount of data on a day to day basis, along with lots of workload to standardize, improve, update the data.

When FM meets BIM, the integration starts to facilitate the FM process. BIM as a rich database container, could arm the facility managers in a better way to process the data, and improve their work efficiency dramatically.

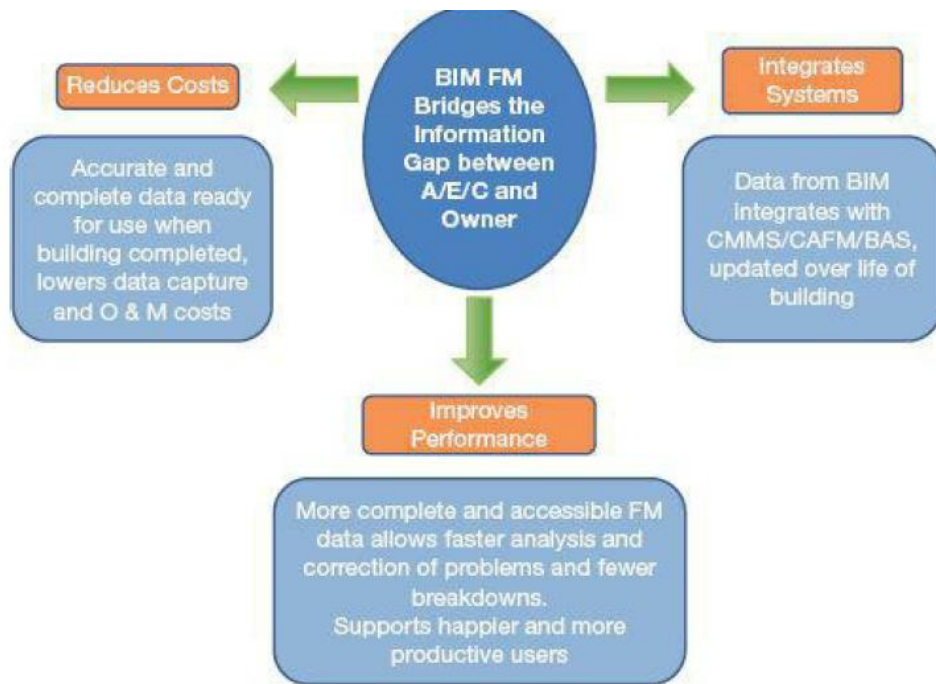


Figure 8: Summary of the main benefits that can be achieved by BIM FM integration. (Teicholz, P. (Ed.). 2013)

In addition to the benefit to FM, the value created by BIM/FM integration will drive the companies to start employing BIM to their schedule, which could potentially formulate an ecosystem, consisting of BIM/FM/AEC.

### The BIM/FM integration method

The book introduces four options for BIM/FM integration.

The first one comes to typing the facility data into a spreadsheet and thereafter importing the data into a certain FM system. This method is easy to use and could be quickly adopted for small projects. However, the drawbacks are explicit that this approach could have high possibilities of error as the data is entered manually without any validation.

The second way goes to using COBie. As COBie specifies the facility data in a given structured form with different workbooks standing for related facility categories.

The third approach leads to utilizing an external link between BIM and FM system.

A fourth option is to directly integrate a FM system with a BIM modeling system using the BIM application programming interface (API). This enables the dynamic and instant connection between BIM and FM so the data

generated in BIM could be transformed and mapped to FM system as COBie/FM form.

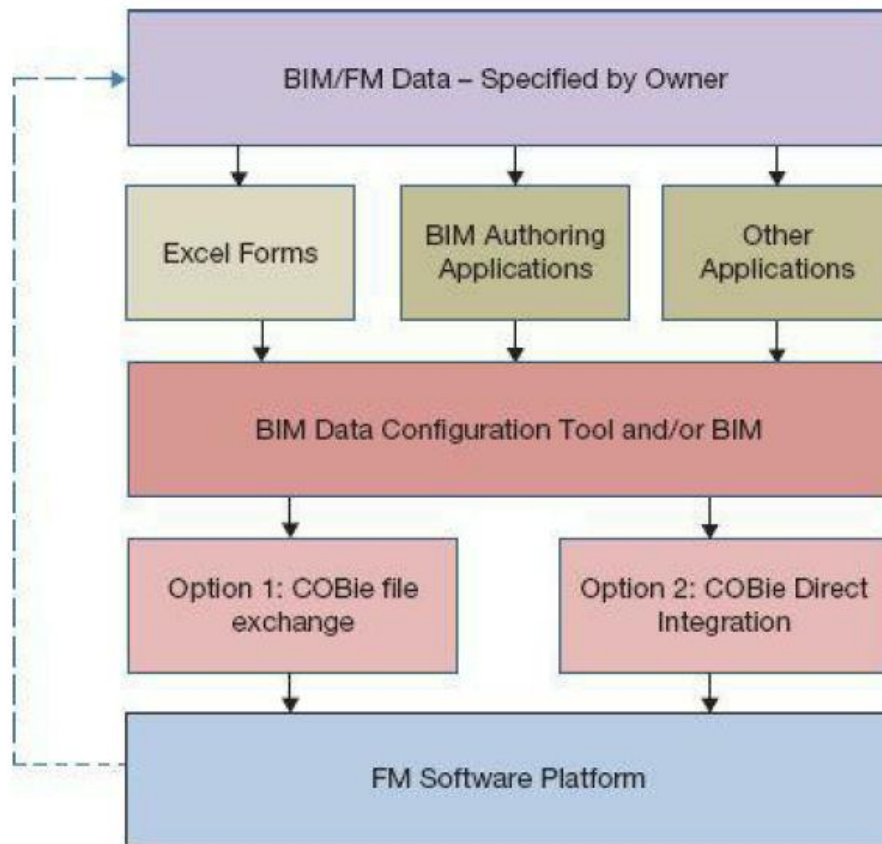


Figure 9: Alternative data paths to integrate BIM with FM. ( Teicholz, P. (Ed.). 2013)

### Overall vision and objectives for BIM/FM integration

A general objective and plan is a critical part when executing BIM/FM integration. The General Services Administration (GSA) describes a guideline introducing linking BIM and FM.

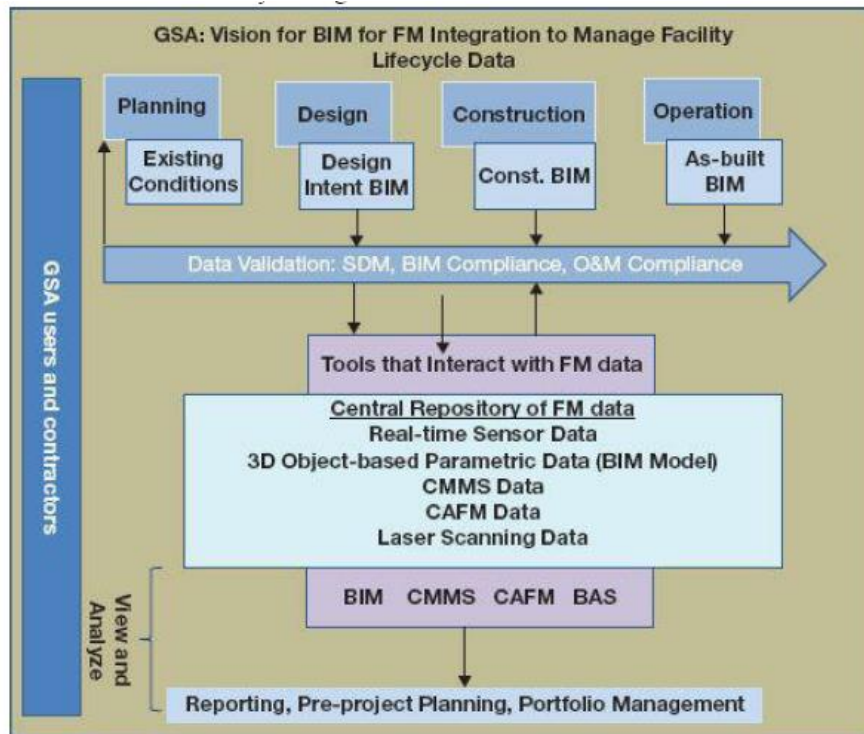


Figure 10: Illustrates their vision of integrating BIM with FM systems to support the life-cycle data needs of a building. (Teicholz, P. (Ed.). 2013)

According to Figure 10 above namely the general vision of BIM/FM integration introduced by GSA, there are some points that need to be emphasized:

- a) The deliverable facility data needs to be executed at several stages throughout the building lifecycle so that the facility data will be dropped to FM database step by step and eventually achieve a completed facility database.
- b) A central repository of FM data needs to be employed which is planned to integrate all the facility data from multiple sources such as building element data, real-time sensor data, laser-scanned data and so on. This central repository will play an important role in BIM/FM integration, because it maintains multiple types of data, and could be applied to multiple kinds of projects.
- c) This BIM/FM integration infrastructure should fulfill the requirements of high-speed data storage, adequate desktop computer processing capacity, adequate numbers of software license, etc.

### **Kiviniemi, A. (2015) BIM in Education – What skills do future professionals need? (University of LIVERPOOL)**

This article discusses some thought of integrating BIM and Education as well as some comparisons to the conventional education in civil engineering field.

The author brings a discussion: Are we teaching issues in the right order? Traditional way of teaching in civil engineering class, for example Engineering drawing course, is 2D based. Students are asked to learn 2D drawings and try to construct a vision of what the 3D looks-like. One reason that students need to learn 2D drawings is that 2D drawings are the outcome of the design work and the compulsory communication media bridging design and construction phase due to the restriction of the current industrial technologies.

However, along with the development of BIM, direct construction is becoming promising which means 3D-based deliverable directly from design to construction is achievable and 2D drawing, as a representative of the backward productivity, may be dropped out in the future.

Thus, as 3D-based deliverable is promising, and today's students are showing their competence in 3D, why do we still force them first into 2D and teach 3D only later? Should not we teach 3D first, and then teach how to generate 2D drawings from the BIM models?



*Figure 11: From 2d to 3d (Kiviniemi, A. 2015)*

The following image could illustrate the appropriation of 3D-based teaching. As we can see, the 2D floor plan in the left image is much more complex and difficult for students to understand and imagine a 3D.

If we first teach students by this 3D model on the right, they could rapidly get to know spatially how this building looks like and gain a graphically understanding of what the floor plan, elevation plan will be.



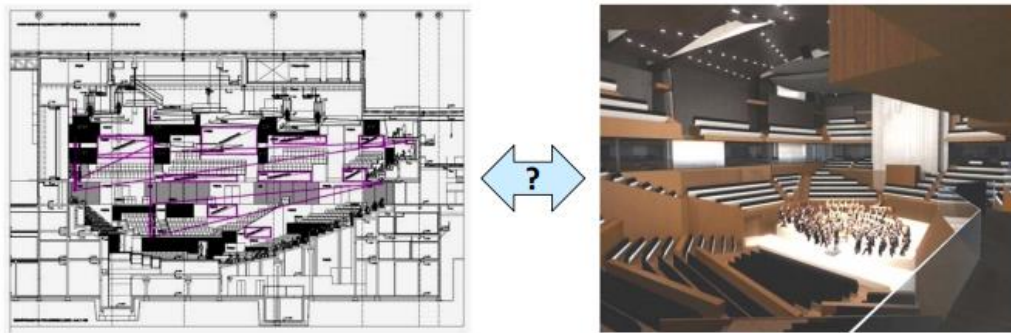
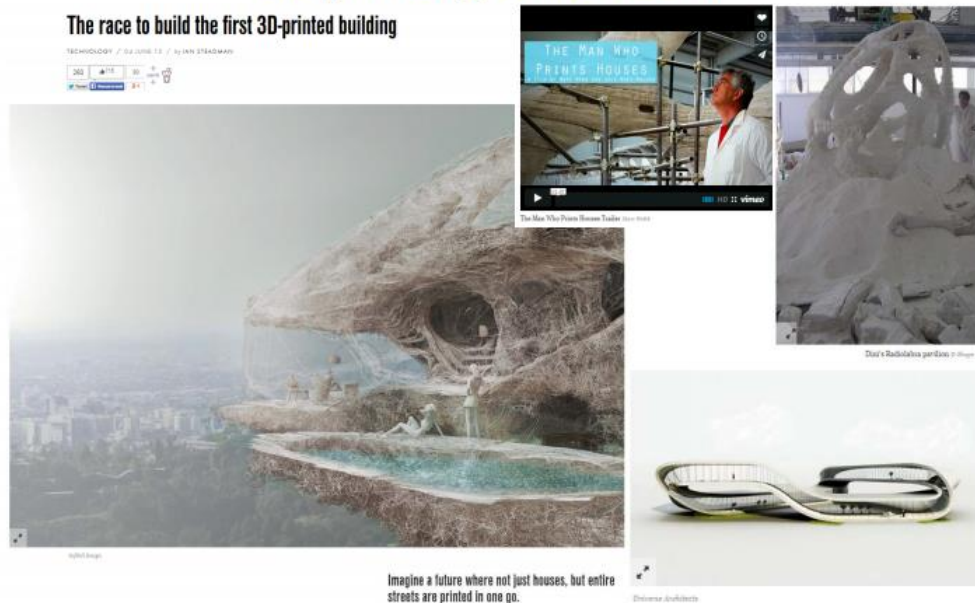


Figure 12: From 2d to 3d in complex building (Kiviniemi, A. 2015)

In addition, a new technology namely 3D printing could strongly support this 3D-based way of teaching. As 3d printing allows 3D models, from designer, to be directly used for construction or manufacture sector without any intermediate transformation, for example, 2d drawing.

### 3D printing of houses...



UNIVERSITY OF LIVERPOOL  
School of Architecture © Prof Arto Kiviniemi 2015

<http://www.wired.co.uk/news/archive/2013-06/04/architecture-and-3d-printing>

Figure 13: 3D printing of houses (Kiviniemi, A. 2015)

Finally, the author introduces other new technologies such as augmented reality and robotics that could be adopted for BIM and educational integration.

## 2.2 Current context

### Building Information Modelling (BIM)

Building Information Modelling (BIM) is a set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct and operate a Facility in virtual space. As a term, BIM has grown tremendously over the years and is now the 'current expression of digital innovation' across the construction industry (BIM DICTIONARY).



Figure 14: BIM definition (What is BIM – Strategy, Process, or Technology? <https://buildinginformationmanagement.wordpress.com/tag/definition-of-bim/>)

BIM is also a container of intelligent relational inventory. For instance, in a BIM model the beam element is connected to a column element. A warning window will pop up in the BIM software if, for example, the beam is not modelled as connecting to the column. This means the objects in the BIM model are no longer just solid geometries, but intelligent components with relationships to each other. This forms a structured data system inside the BIM model, allowing data to be checked, queried, mapped, counted etc. As a consequence, different data could be utilized for different purposes such as clash detection, quantity take off, structural analysis and facility management.

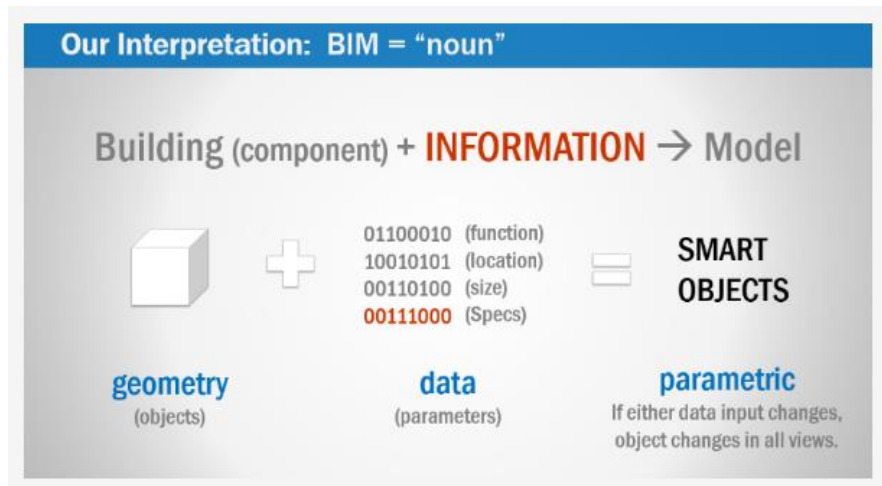


Figure 15: BIM Model (BIM AND VDC DEFINED THE MORTENSON PERSPECTIVE, RICARDO KHAN, 2015, <http://blog.synchro1td.com/bim-and-vdc-defined-the-mortenson-perspective>)

Besides acting as such a data-rich product source, BIM also stands for a new process for the building industry as BIM could change the way of working for each discipline, and the ways of delivery and collaboration between disciplines.

Thus, in order to fully deploy BIM in practice successfully, a healthy ecosystem has to be formed, comprising BIM-authoring software, BIM-enabled working processes, and necessary BIM education.

### Facility Management (FM)

The term Facility Management (FM) refers to the interdisciplinary activities performed during the operation phase of building, space or infrastructure. FM activities typically include operation, leasing occupancy, maintenance, cleaning, etc. (BIM DICTIONARY).



Figure 16: Facility management(<https://www.pinterest.com/explore/facility-management>)

Traditionally the situation of FM is as follows: In December 2004 NIST published a study titled Cost Analysis of Inadequate Interoperability in the U.S.Capital Facilities Industry (NIST GCR 04-867). This report indicated the huge cost due to lack of interoperability among AEC disciplines from architects to owners during the building lifecycle. From the figure 17 below, we can obviously derive that the operation phase takes the most percentage of extra cost due to lack of inter-communication. Thus, it emphasizes the importance of interoperability and information flow from upstream to downstream.

Cost Category	Avoidance Costs	Mitigation Costs	Delay Costs	Total	Pct. of Total
Architects and Engineers	485.3	684.5	—	1,169.8	7.4%
General Contractors	1,095.4	693.3	13.0	1,801.7	11.4%
Special Fabricators and Suppliers	1,908.4	296.1	—	2,204.5	13.9%
Owners and Operators	3,120.0	6,028.2	1,499.8	10,648.0	67.3%
Total	6,609.1	7,702.0	1,512.8	15,824.0	100.0%
Pct. of Total	41.8%	48.7%	9.6%	100.0%	

Note: Sums may not add to totals due to independent rounding.

Figure 17 Cost Analysis of Inadequate Interoperability in the U.S.Capital Facilities Industry

Traditionally, most of the building information is stored in paper documents. The documents could be a chaos and massive, especially for large building projects, which make the building information difficult to search, access or update. Also, the paper documents are delivered to operators after the building is completed. So the operators have to wait for a long time during this process, before they can begin to verify or reform the building data.



*Figure 18: Picture of document storage for FM information after turnover by the contractor. ( Teicholz, P. (Ed.). 2013)*

### **COBie (Construction Operations Building Information Exchange)**

COBie is a specification for the capture and delivery of design/ construction information to Facility Managers. (BIM DICTIONARY).

As we know, BIM model contains rich information, but when integrating with FM phase only COBie-specified attributes needs to be transferred, because COBie describes the the 'necessary and sufficient' information set needed for FM purpose. So in the next paragraphs, the COBie framework is presented.

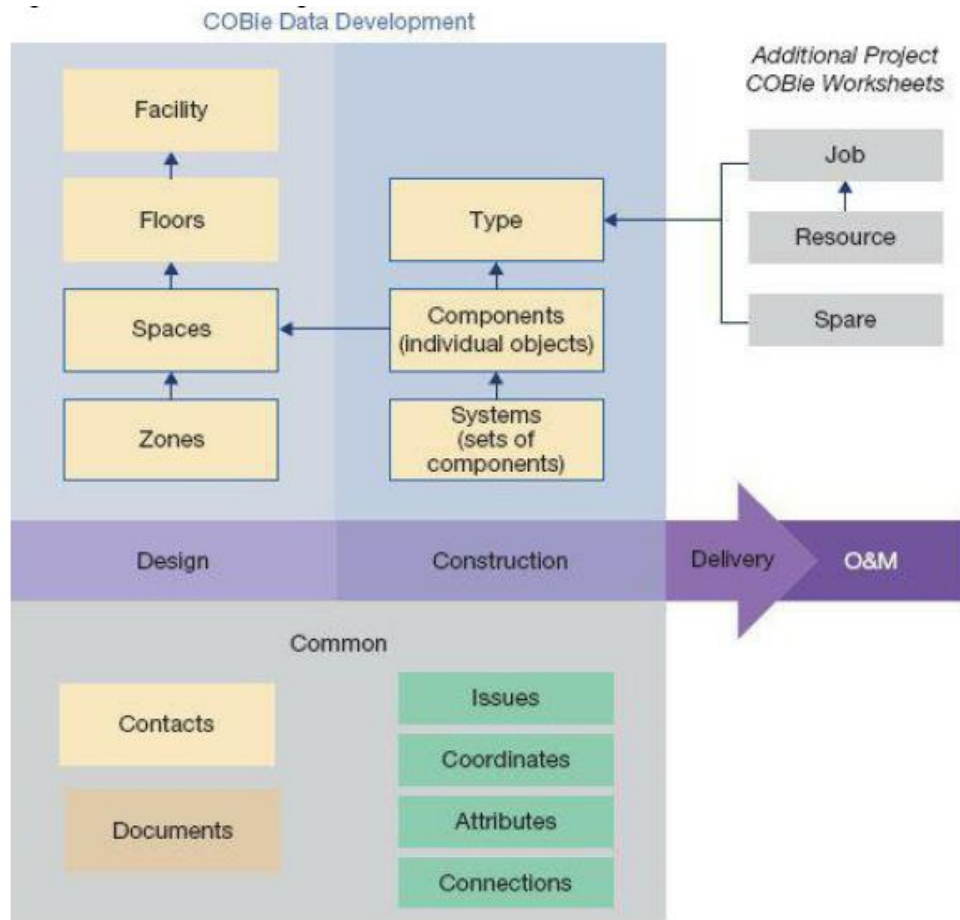


Figure 19: COBie organizational framework. ( Teicholz, P. (Ed.). 2013)

The image above describes the overall structure of COBie standard. It can be separated as two assignments and roles, designers and contractors, in terms of the responsible disciplines involved in COBie. The designers deliver the COBie-formatted design data, including Facility, Floors, Spaces and Zones at the end of the design phase.

The contractors submit the COBie-formatted construction data such as Type, Components, systems, as well as make necessary complementary data onto the design data that designers delivered. Once the building is completed, contractors could decide with product manufacturers to fill in the COBie topic of Job, Resource and Spare.

In terms of the detailed organization structure, COBie standard can be split into two major parts: spatial and equipment facilities.

Regarding spatial assets:

- a) Facility is the general information about the building project.

- b) Floors, connected to Facility, represent the building layers from foundation to roof.
- c) And upon Floors, there are different rooms for residential or other purposes as well as spaces which typically point to HVAC space with function of heating, ventilation, air conditioning purpose. And these two aspects form Space topic in Cobie.
- d) As a summary, Zones are a group of spaces with a central identical use case. Take an example in the figure below, Space 121, 122 and 123 form an Emergency zone while Space 101, 102 and 103 make a Pediatrics zone.

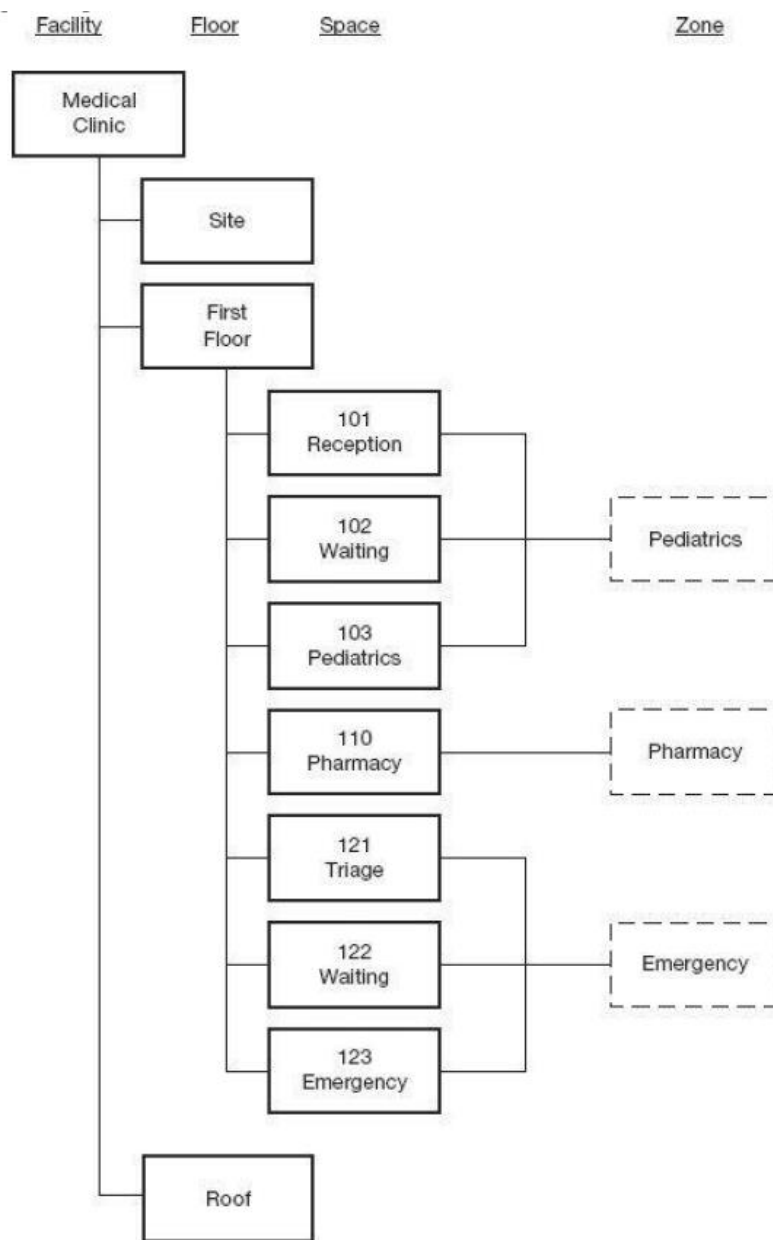


Figure 20: Spatial organization. ( Teicholz, P. (Ed.). 2013)

Next concerning equipment assets:

- Facility stands for the general information about the building project, which is identical to the one in spatial assets.
- Type is the product categories which describing the common and type parameters of the product.
- Component means the instances from the Type, representing almost all the building physical objects such as windows, doors, walls, furniture, HVAC machines and so on.
- As a sum, similar to Zones in spatial assets, Systems behave as a container including multiple Components, which have identical functionalities.

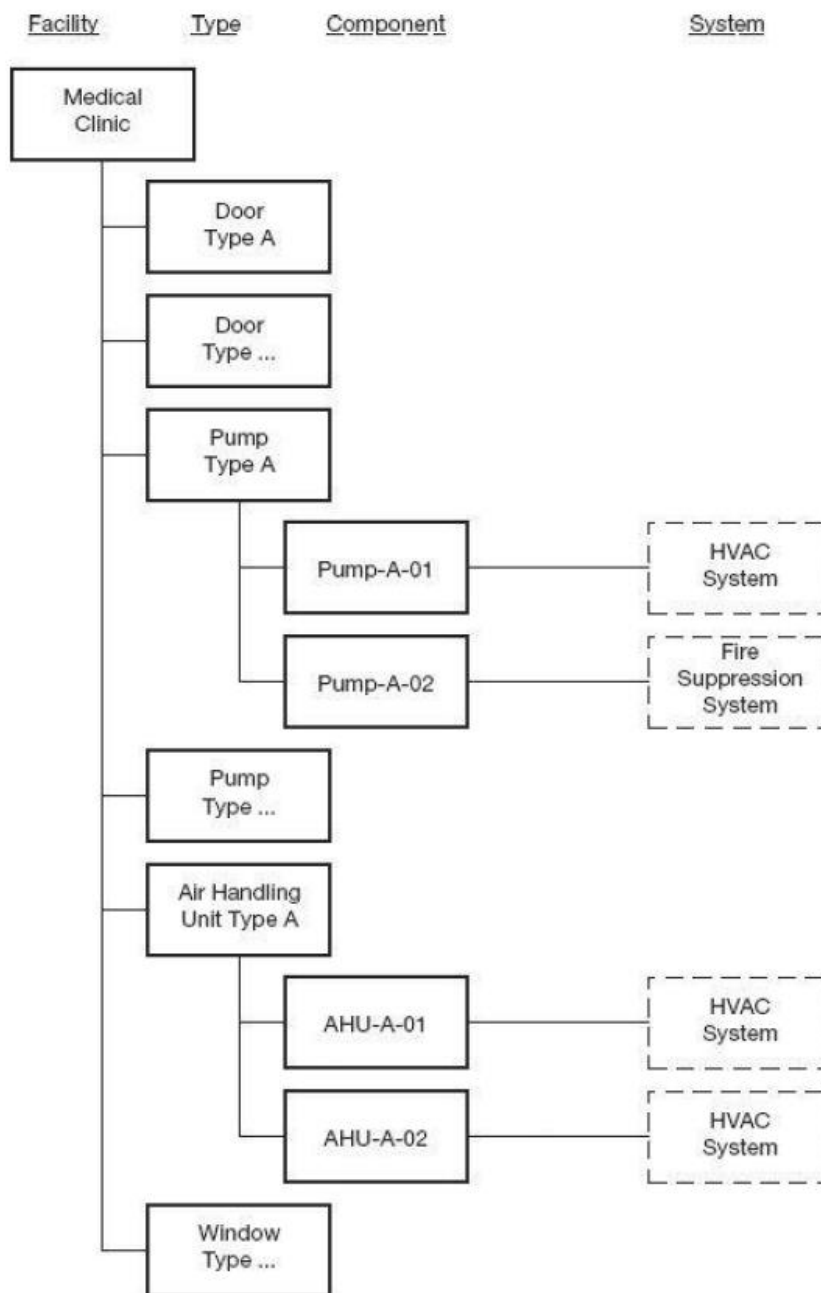
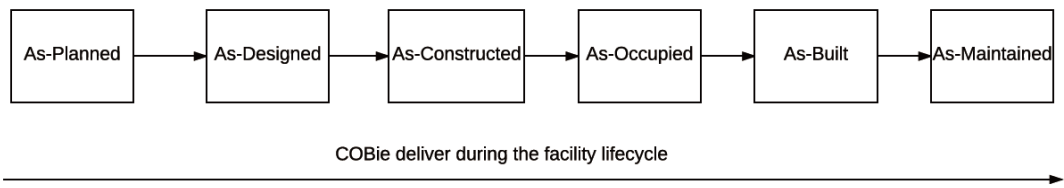


Figure 21: Equipment organization. ( Teicholz, P. (Ed.). 2013)



COBie is organized to deliver the facility information during several stages along facility lifecycle from As-Planned stage to As-Maintained stage.



*Figure 22: COBie deliver along lifecycle*

### 3. System implementation

#### 3.1 System development history

##### Visual programming for querying facility data

As a computing script, visual programming is different from textual programming languages and allows users to create their own scripts by dragging and dropping some pre-defined computable blocks and connect them together as a whole script for a certain functionality.

For most of the cases, visual programming in a BIM software is used for creating complex building shapes or parametric models. Unlike these usages, we use visual programming for querying facility data in term of BIM/FM integration.

Based on this initial idea, I designed a querying logic in visual programming for example: [Building layer]→[Component]→ [Attribute] as a narrowing down sequence.

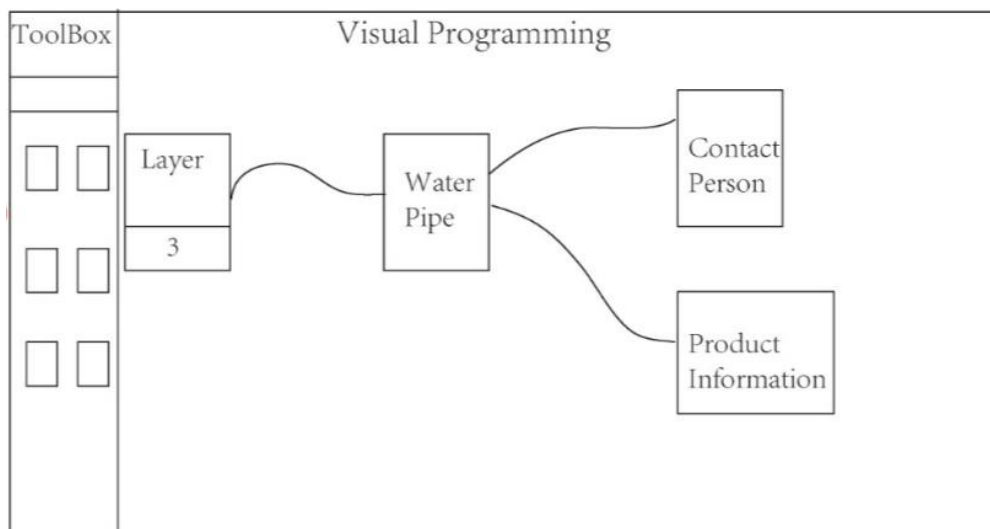


Figure 23: Visual programming interface

With the purpose of better demonstration and testing of the idea, I designed a graphic web-html page of visual programming interface. It allows users to drag and drop to connect the graphical entities as a line and the facility data will be displayed as a result.

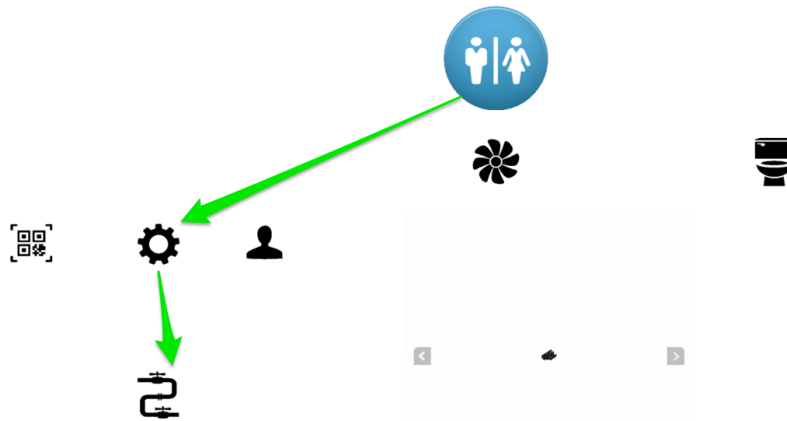


Figure 24: Visual programming interface early design

### Use Twitter as a user-interface for BIM/User interaction.

Since Twitter is an instant messaging system and be widely used, so we thought can we use our own Twitter handle as an application to interact with our own apartment. For example, we tweet a water pipe broken error to the BIM model/Facility managers for an asset maintenance purpose. The message gets linked to the relevant model objects, and can at the same time be linked to other FM systems relevant to the work-order.

So, I made a 3D model of my apartment for testing the idea.



Figure 25: 3D model of my apartment

Next a BIM/Twitter integration picture was proposed as shown in the figure

below. One example use-case scenario is described here: When building occupants find an equipment error in their living apartment, they take a picture, write some textual description add a related Hashtag, and finally press the Tweet button to report this facility error to the BIM model which will be viewed by the facility staff.



Figure 26: BIM/Twitter integration

A step further, we gained opportunity to developed it deeper and had a public demonstration and test in AEC Hackathon Helsinki (June 2016).

As a team, we expanded the initial BIM/Twitter integration idea to more functionalities with the assistance of Dynamo visual programming and Proximi.io, which can provide us the precise location data and has an open API to connect with Twitter.

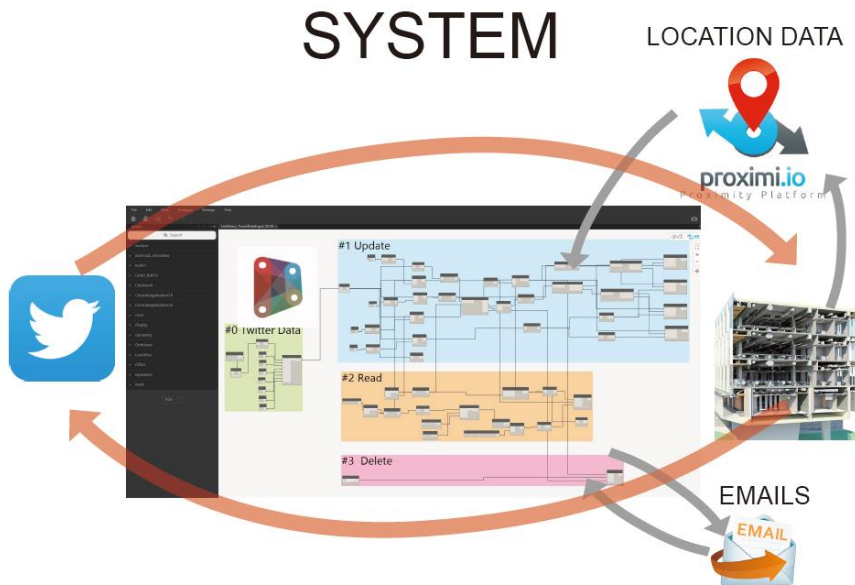


Figure 27: BIM/Twitter system

In terms of functionalities, we made a full Create-read-update-delete (CRUD) command interaction from Twitter to BIM model. We developed a BIM-Twitter text convention for data communication specification. Take Update command as an example, the Twitter text convention is:

[\* Update, !@User's Twitter name, %Element ID, ?Parameter name, +Value ]

Once this Twitter with Update command is sent, the BIM model will react accordingly.

## TWEET COMMANDS

MODIFICATION OF BIM MODEL

**C**REATE - CREATION OF A NEW OBJECT

**R**EAD - READING OBJECT DATA

**U**PDATE - UPDATING OBJECT PARAMETERS

**D**ELETE - DELETING OBJECT

EXAMPLE:

-COMMAND	*update
-USER NAME	!@HarriHumppi
-ELEMENT ID	%141232
-PARAMETER	?Radius
-NEW VALUE	+800
	@FMSYSTEM_TEST

Figure 28: Twitter CRUD command

Fortunately, our product was awarded as Winner of Proximi.io sponsored indoor positioning challenge. (<https://proximi.io/aec-hackathon-helsinki-3-2/>)

### **Mobile learning and quiz application for civil engineering students.**

During the thesis work, I also got involved in a university project: InBookMode (Interactive book and model environment, Learning platform, gaming and augmented reality) which is one of the pilot projects belonging to the AIOLE project (pioneers online/blended learning experiences at the Aalto University with improved learning results).

We explored the learning situation of civil engineering students in a broad view, taking the university campus as a learning environment. Students can go out of the classroom and learn the building structures, equipment facilities according to the actual physical elements, as-built, in the university campus.

Thus, a mobile learning application could leverage this new learning viewpoint. Augmented reality can also play an important role in contributing to this idea, because students may learn from the physical objects together with the digital models.

We designed a draft interface of this mobile learning application, as figure 29 shown below.

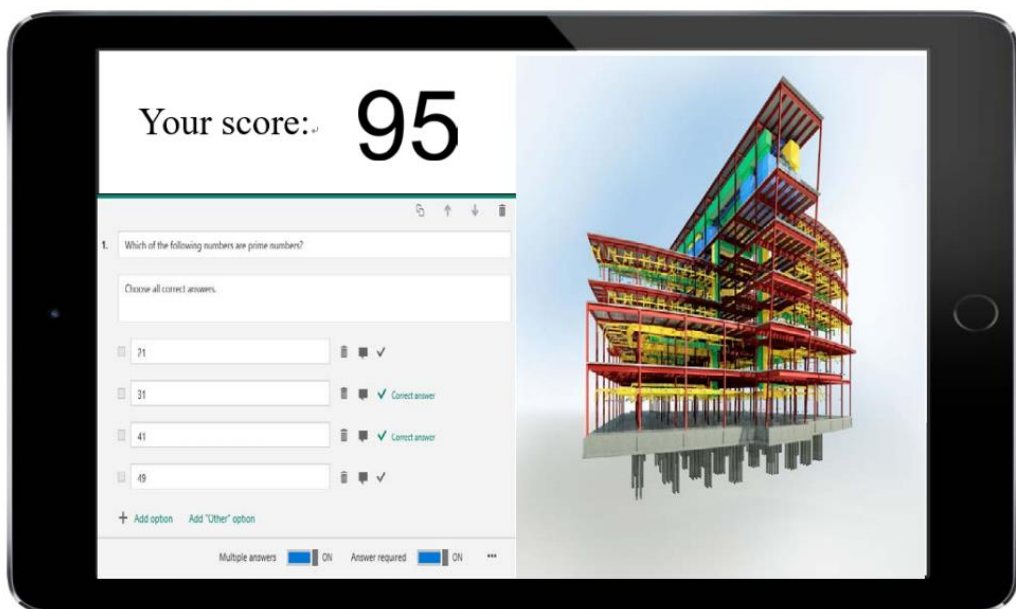


Figure 29: Mobile learning application

## 3.2 Tools description

### Autodesk Revit

Revit software for BIM (Building Information Modeling) includes features for architectural design, MEP and structural engineering, and construction. (<http://www.autodesk.eu>)

### Dynamo

Dynamo is a visual programming application, enhancing the building information modelling performance by data drive and built-in algorithm.

Dynamo is also an open source tool that allows community and users to develop custom package onto it.

Dynamo can be installed as an add-in to Autodesk Revit so can interact with Revit objects. (<http://dynamobim.org/>)

### VisuaLynk

VisuaLynk is a web-based platform that integrates Web of Building Data, Analytics and Visual Management capabilities for intelligent FM solutions. (<http://www.visualynk.com/#/>)

### Neo4j

Neo4j is a highly scalable, graphic and relational database. The query language used by Neo4j is Cypher and Neo4j has open API in order to interact with other applications. (<https://neo4j.com/product/>)

### Nodejs

Node.js is a JavaScript runtime environment built on Chrome's V8 JavaScript engine. Node.js is also a package library and ecosystem. (<https://nodejs.org/en/>)

### Reality Editor

This is a result of three years of MIT (Massachusetts Institute of Technology) research. The Reality Editor is a new kind of tool for empowering users to connect and manipulate the functionality of physical objects. Just point the camera of your smartphone at an object built with the Open Hybrid platform and its invisible capabilities will become visible for you to edit. (<http://www.realityeditor.org/>)

### Open Hybrid

Open Hybrid is a platform for interaction with everyday objects. It combines

physical objects with the benefits of a flexible augmented user interface.

It is Open Source and based on Web-Technology and Arduino.  
 (<http://www.openhybrid.org/>)

We use the combination of Reality Editor and Open Hybrid for augmented reality purpose.

### 3.3 System architecture

#### Overall system organization

The system includes four layers from upstream to downstream:

- a) BIM System layer: It is a dataset layer, where BIM model is linked with an external database. It behaves as a centralized repository to interact with other layers.
- b) Data communication layer: There are some data processing tools situated in between BIM system layer and Interface layer. This layer is used for processing the data input and output.
- c) Interface layer: It is a front-end layer for displaying the facility data and it is manipulated by end-users.
- d) End-user layer: It is where end users are located, including facility managers, building residents and students.

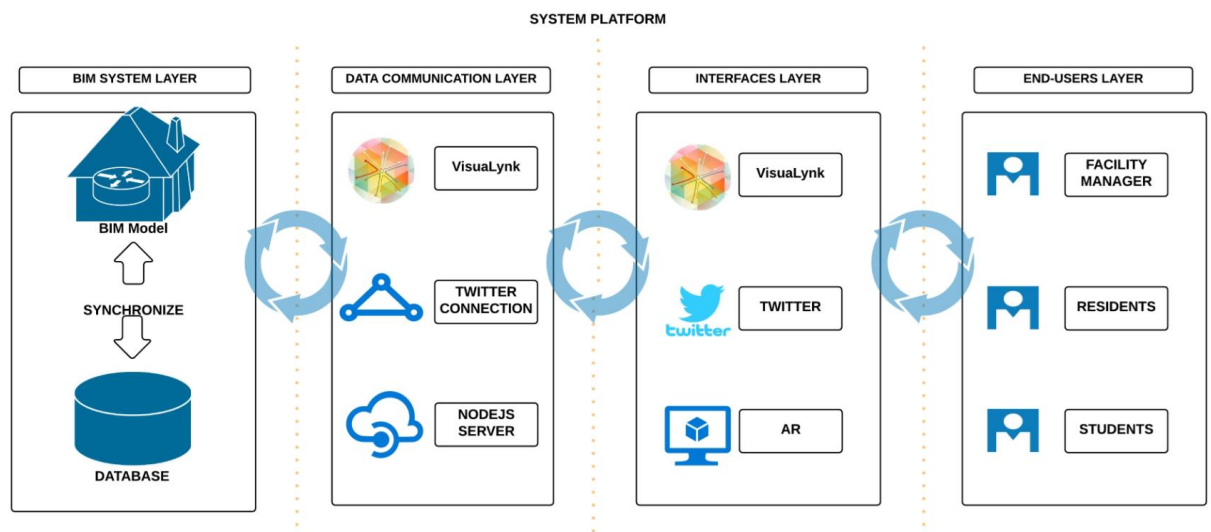


Figure 30: System organization



## BIM Database system architecture

The BIM Database system consists of three items:

- BIM Model:** We use Autodesk Revit as a BIM-authoring software to make building information modelling and acts as a container for BIM Model.
- Data synchronization program:** We developed a computation script with built-in algorithm in Dynamo. It can link the BIM Model with the external database. This program is described followed by in a detail.
- External database:** We use Neo4j as the external database as it is a graphical relational database, which is appropriate for storing COBie-format facility data.

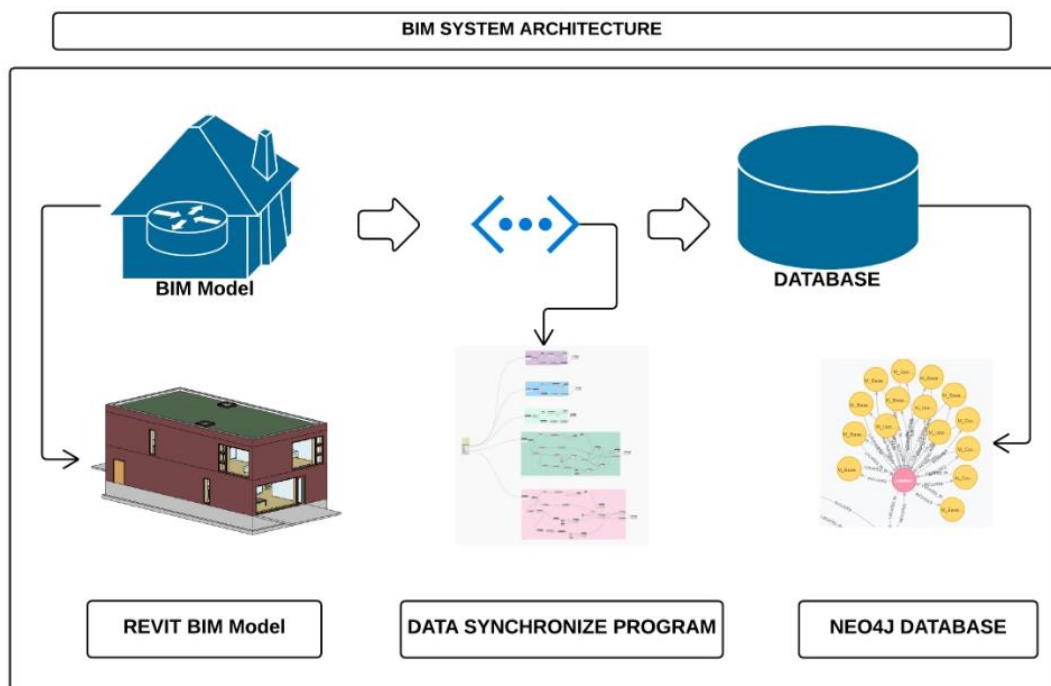


Figure 31: BIM Database system

## Data synchronization program

This synchronization program can link Revit to Neo4j database, and fetch all the facilities information, according to a certain category, from Revit and push them to Neo4j database in format COBie to deliver standard data structure for facility management purposes.

The data mapping from Revit to COBie is developed as built-in algorithm in data synchronization program.

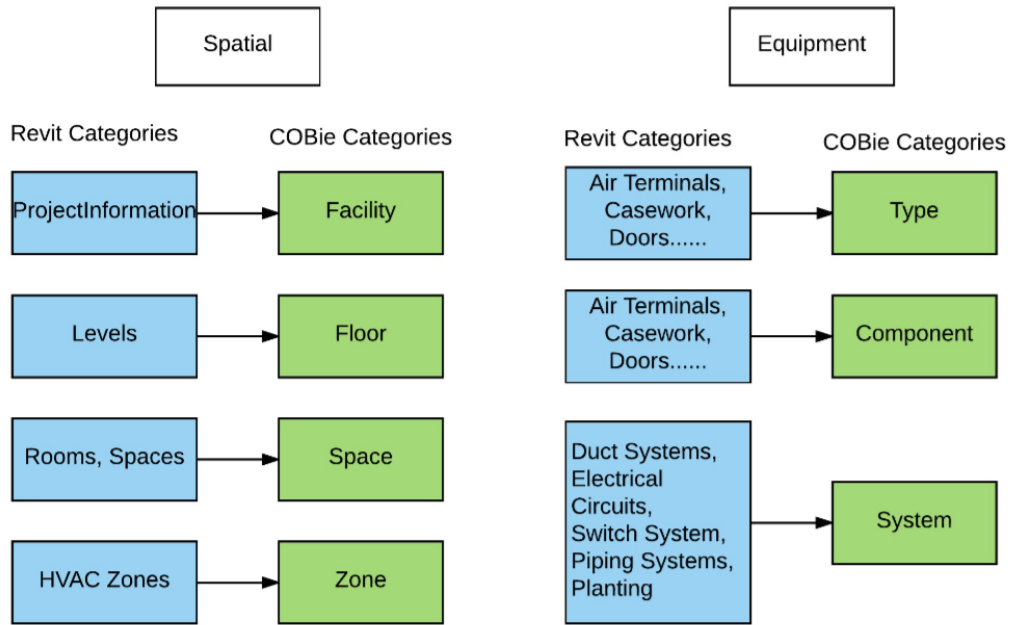


Figure 32: Revit to COBie category mapping

Legend	
	Parameter can be converted from native Revit directly
	Parameter can not be converted from native Revit directly. So require the help of Revit Cobie extension or other data source
	May specified as relationship in Neo4j
	We currently do not need

Data source (N/A or X)			COBie sheet
Revit parameter		Other source	Sheet parameter name
Revit native parameter	Revit COBie extension parameter		
Name	COBie.Space.Name		Name
		X	CreatedBy
		X	CreatedOn
Category	COBie.Space.Category		Category
Level			FloorName
Category Description	COBie.Space.Description		Description
		X	ExtSystem
		X	ExtObject
		X	ExtIdentifier
RoomTag	COBie.Space.RoomTag		RoomTag
Unbounded Height	COBie.Space.UsableHeight		UsableHeight
Area	CCOBie.Space.GrossArea		GrossArea
	COBie.Space.NetArea		NetArea
Number			Number

Figure 33: Revit to COBie parameter mapping (Space).

After creating the facility data in the database, the synchronization function can be activated when needed. Any verified change actions in the BIM model will be captured by the synchronization program, and the database is automatically updated.

A snapshot from this synchronization program is presented below (figure 34). It includes three bases, which are Revit data fetching, internal data processing, and linking with Neo4j database. The program is currently available for Facility, Floor, Space, Component - Furniture and Component - Casework out of the COBie data structure.

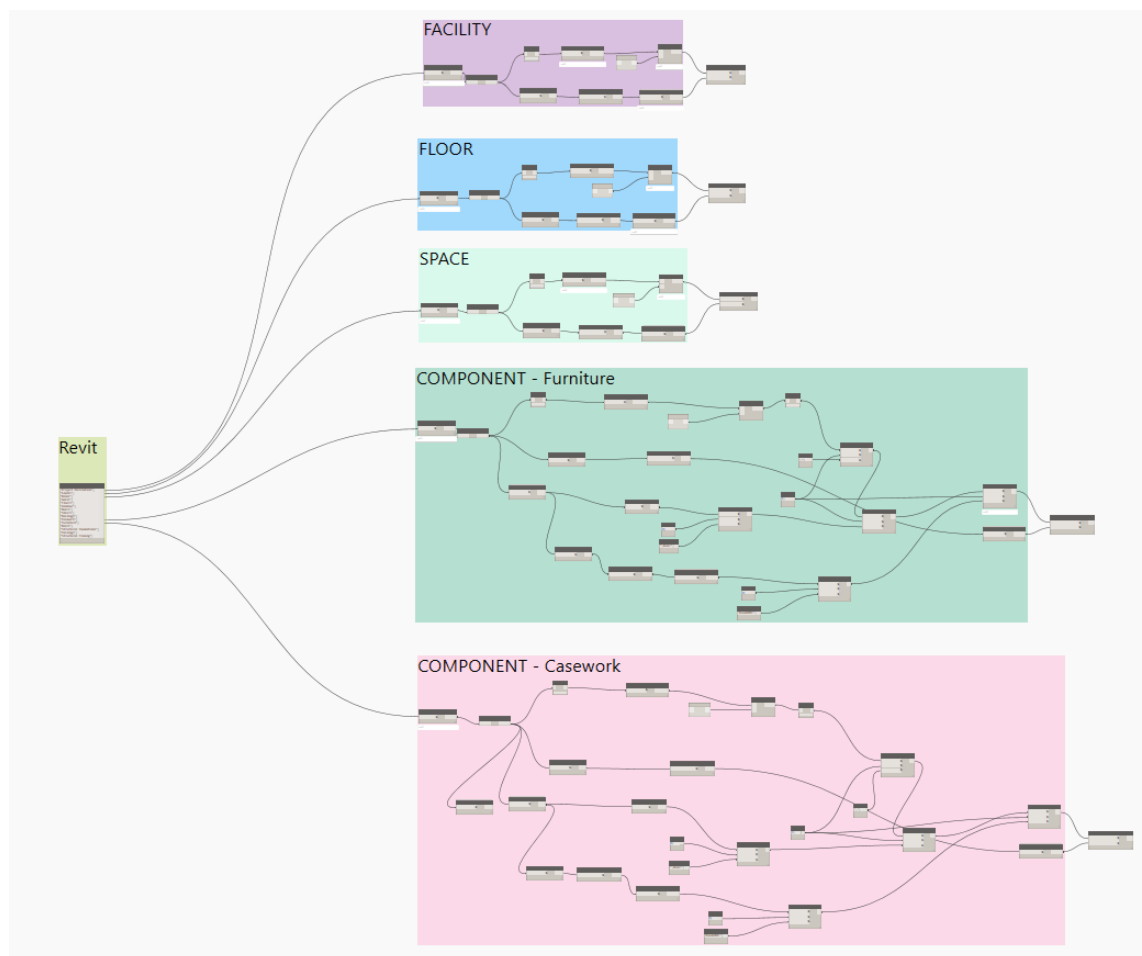


Figure 34: Data synchronization program in Dynamo

Let us take a closer view of COBie – Space data transfer block. The green part represents Revit data fetching, the blue area stands for internal data processing, and the linking with Neo4j database is shown in pink.

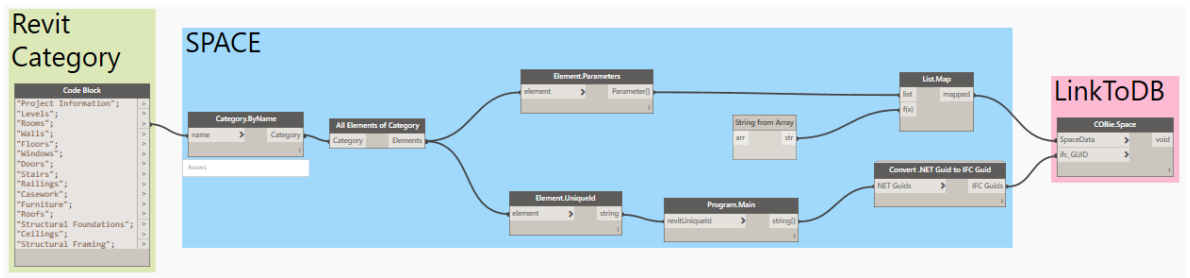


Figure 35: COBie – Space data transfer

The algorithm for data processing part of synchronization program is presented below.

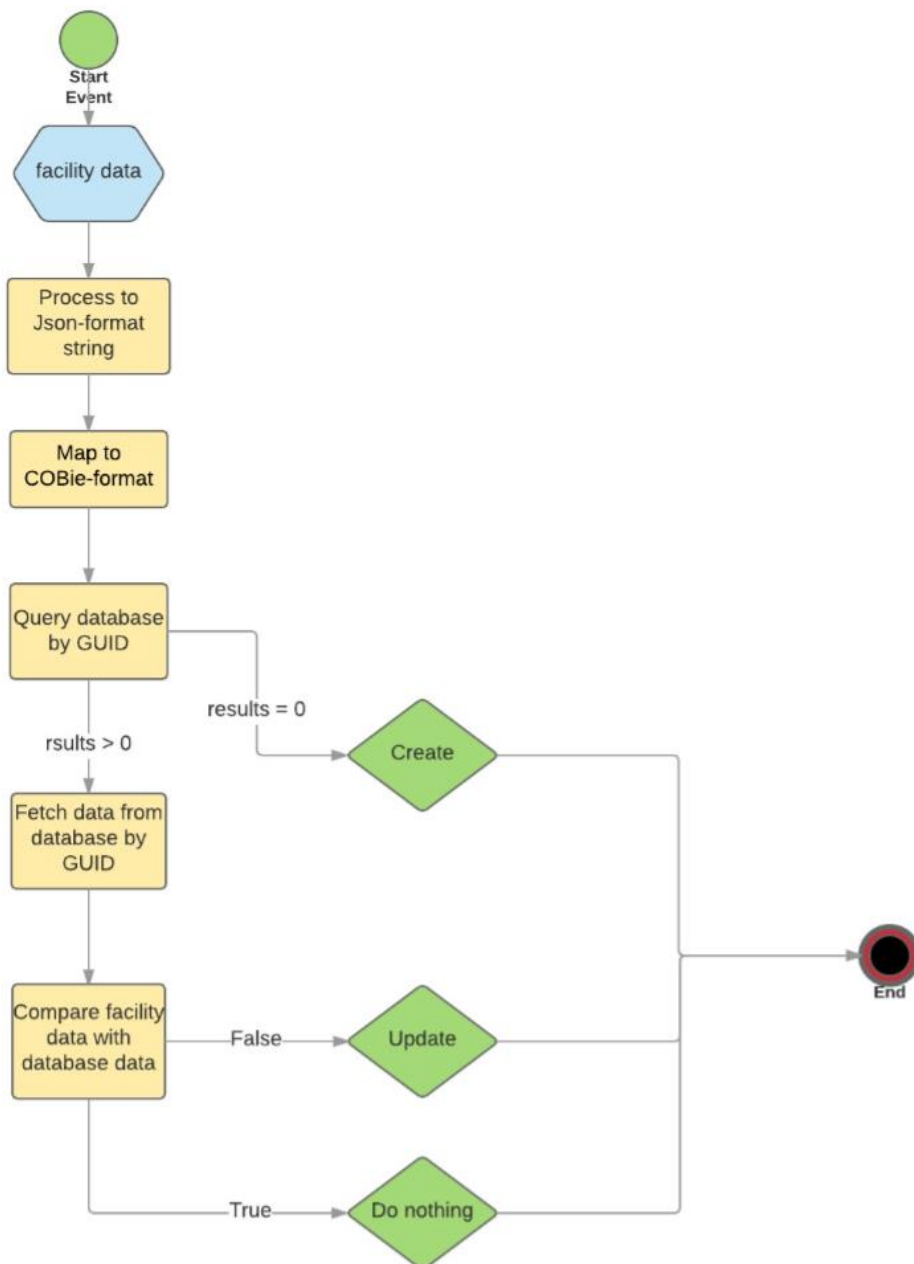


Figure 36: Algorithm in synchronization program

## BIM/FM integration for facility managers

Once we transfer the facility data from BIM Model to Database in a COBie format, it is ready to use for facility management purpose.

We introduce VisuaLynk here in this scenario for data processing as well as a user interface for facility managers. So the facility managers, as end users, are allowed to get access to the BIM database via VisuaLynk platform.

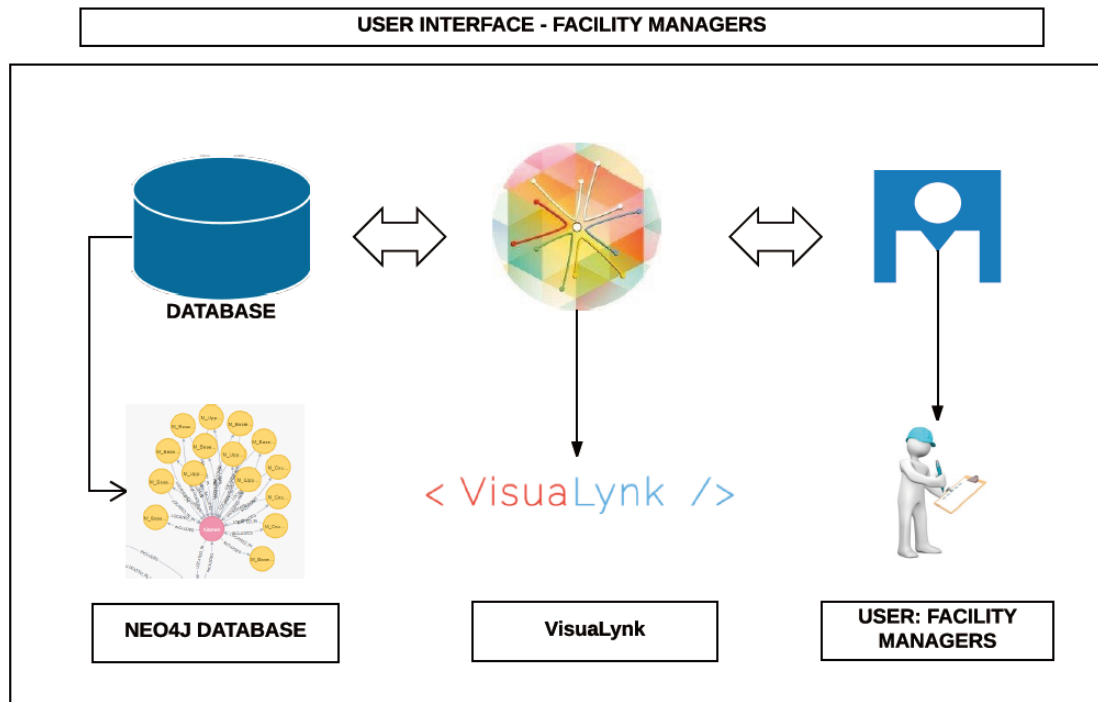


Figure 37: BIM/FM integration for facility managers

The database can be linked with VisuaLynk via its open API. VisuaLynk's state-of-the-art Web of Building Data, intelligent data analytics, and easy-to-use visual management modules combine the fragmented building information and facility data visually and intelligently. This combination of BIM database with VisuaLynk will greatly facilitate the BIM/FM integration.

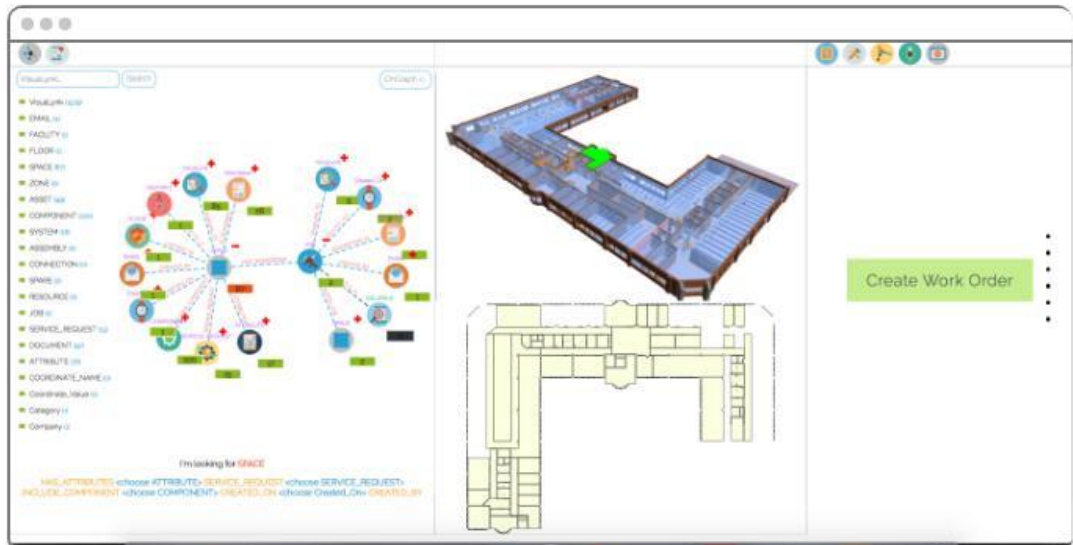


Figure 38: VisualLynk interface

### BIM/Asset maintenance integration for building residents

Once facility data is transferred from BIM model to the database in a COBie format, it is ready for the building residents to use it for asset maintenance purposes.

A Twitter connection, made using Dynamo computation scripts, is developed for connecting the database to the Twitter application.

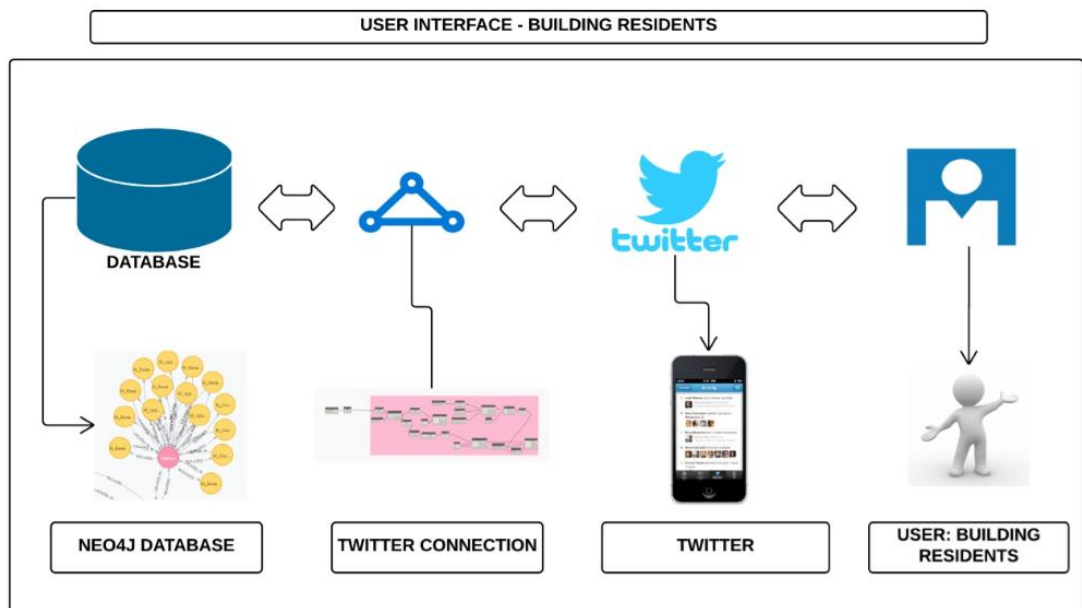


Figure 39: BIM/Asset maintenance integration for building residents

The algorithm of Twitter connection is presented below.

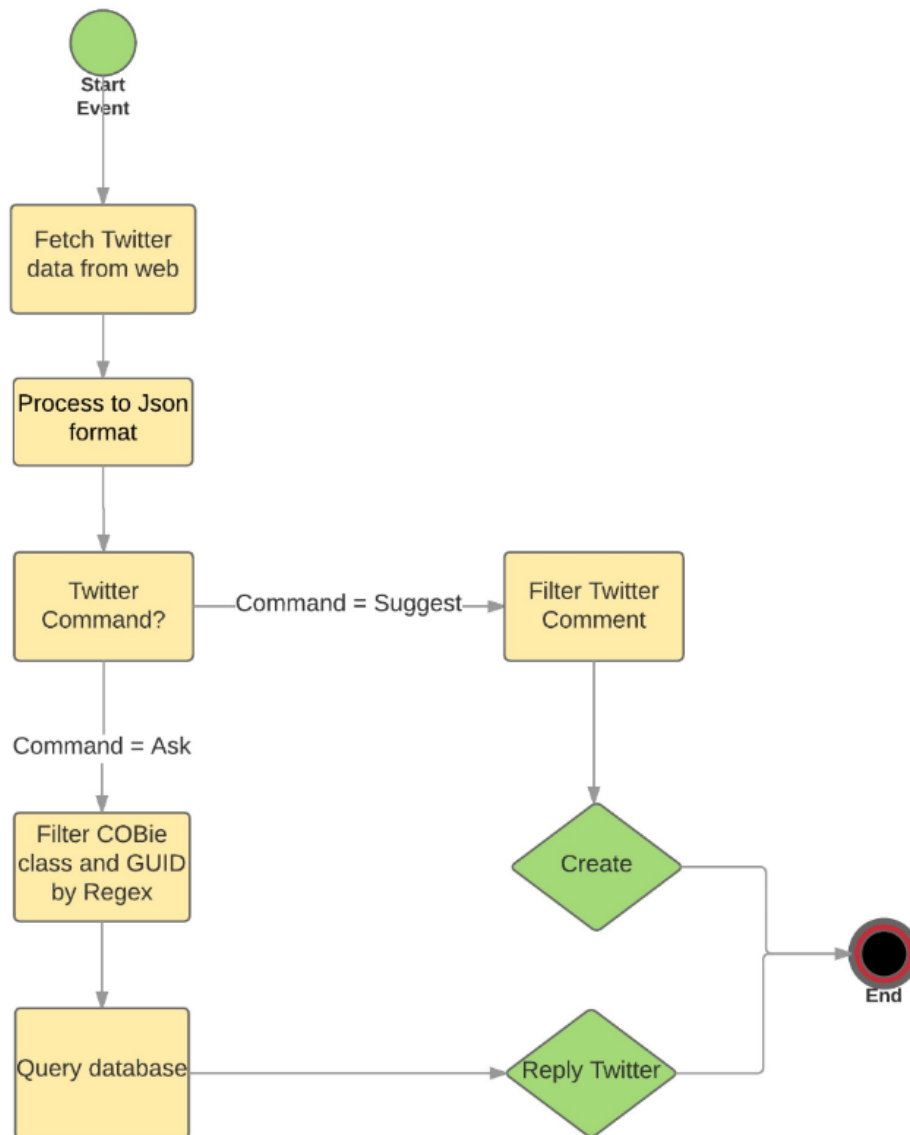


Figure 40: Algorithm in Twitter connection

The Twitter connection currently supports mutual interaction between BIM database and the users, and it requires a standardized Twitter message format. So, we propose a Twitter textual convention where “Ask” is used for querying the facility data from the BIM database and that required facility data will be replied to users as a mentioned Twitter from BIM database’s Twitter account automatically, whereas “Suggest” is used for updating facility data or reporting building asset errors to the BIM database. The details are listed below.

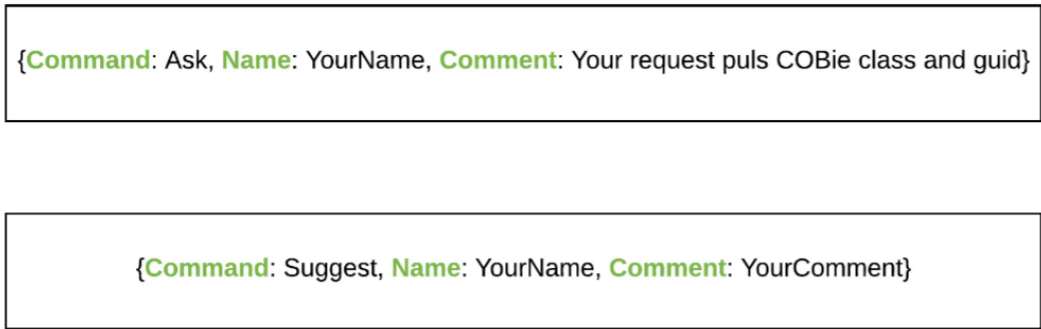


Figure 41: Twitter textual convention

### BIM/Education integration for students

Once facility data is transferred from BIM Model to Database, it is ready for students to use for education purpose.

As discussed earlier, learning and comprehension fo engineering related subject matter can be enhanced via graphics more than attribute data. Incorporating agumented reality can provide students an immerse learning experience and a good way of interactive learning, together with the physical world and the agumented digital 3D model. I developed an agumented reality program based on the open source OpenHybrid platform and Reality Editor. A Nodejs server was developed as well for bridging the agumented reality program and BIM database.

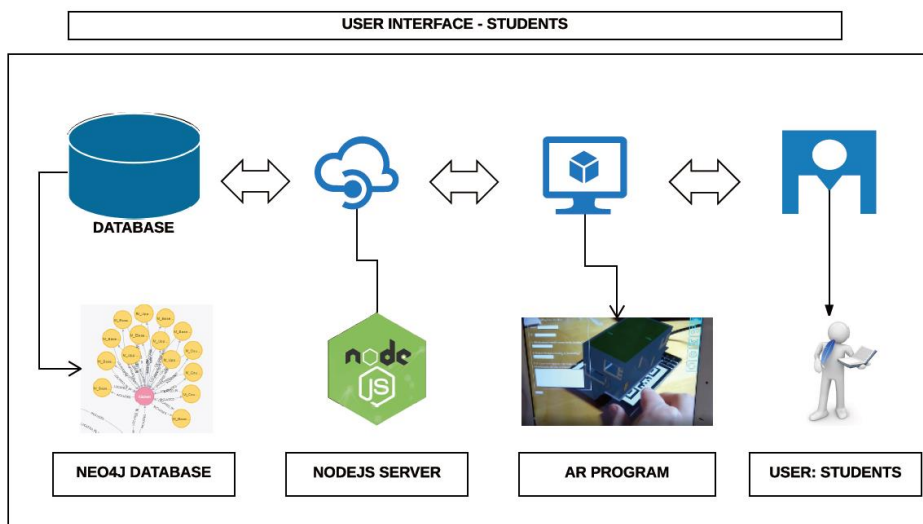


Figure 42: BIM/Education integration for students

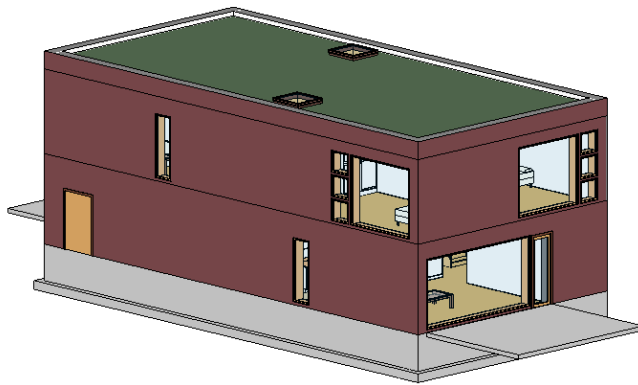


## 4. System test and results

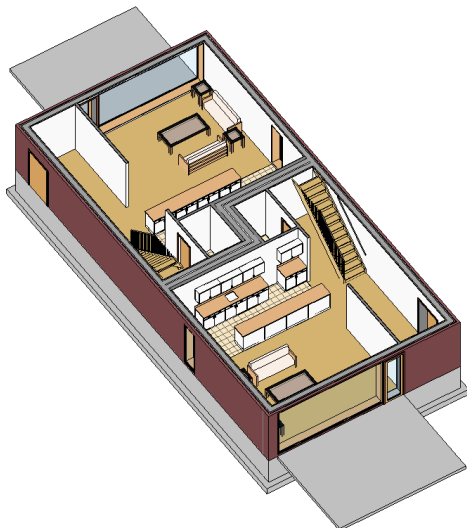
### 4.1 Test BIM model

We use a BIM model called Duplex Apartment in Revit to test the whole system, throughout every connection for consistency purpose.  
( [https://www.nibs.org/?page=bsa\\_commonbimfiles](https://www.nibs.org/?page=bsa_commonbimfiles))

The duplex apartment model was originally created by a student who developed this building as part of a design competition. This model was first used at the Dec 2009 COBie Challenge event.



*Figure 43: 3d view of Duplex Apartment*



*Figure 44: Interior view of Duplex Apartment*

## 4.2 Test Data synchronization program.

In this section, we test the data synchronization program and its functionality of linking BIM Model and the database.

We choose Facility, Floor, Space, Component-Casework, and Component-Furniture from the COBie structure as the test categories. Once we deploy all the system configurations for duplex apartment model, we test the following items.

- a) Spatial categories data transfer.
- b) Overall categories data transfer.
- c) Data synchronization

### Spatial categories data transfer.

The spatial organization of test model is made below.

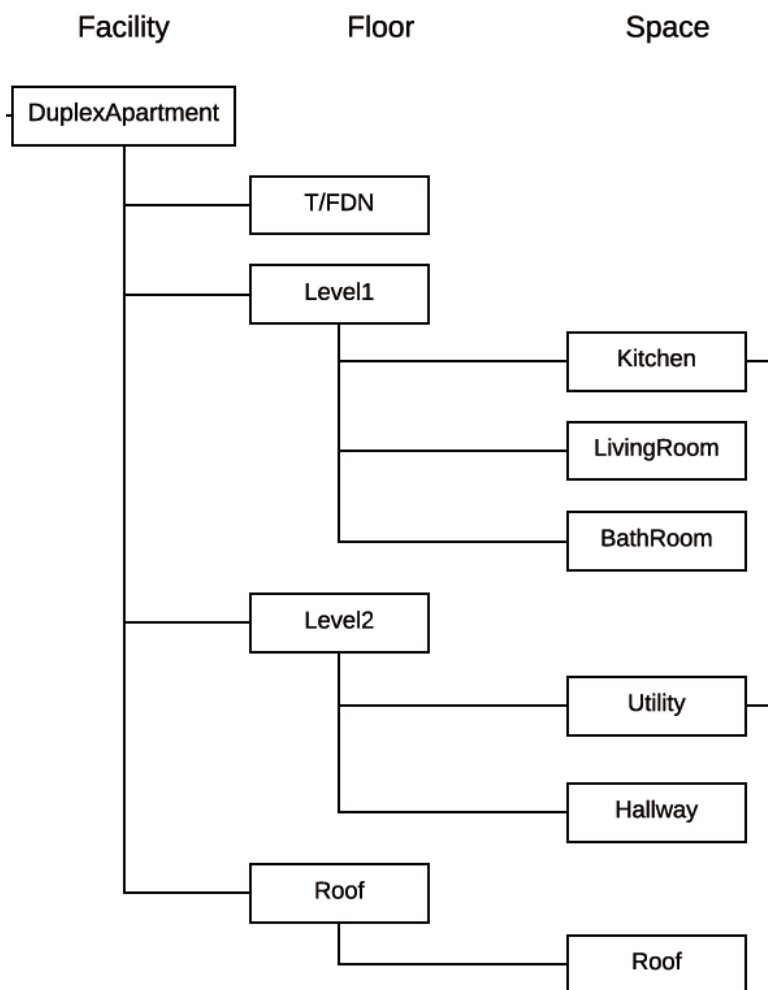


Figure 45: Spatial-COBie organization of test model

After execution of the program, all the spatial data from Revit is transferred into the Neo4j database successfully, in the format specified for COBie.

The figure 46 below shows how the facility data looks graphically. The blue node, located at the center, represents the Facility. The purple nodes represent Floor data, which is connected to the Facility node. The Space data is displayed as the red nodes related to the Floor.

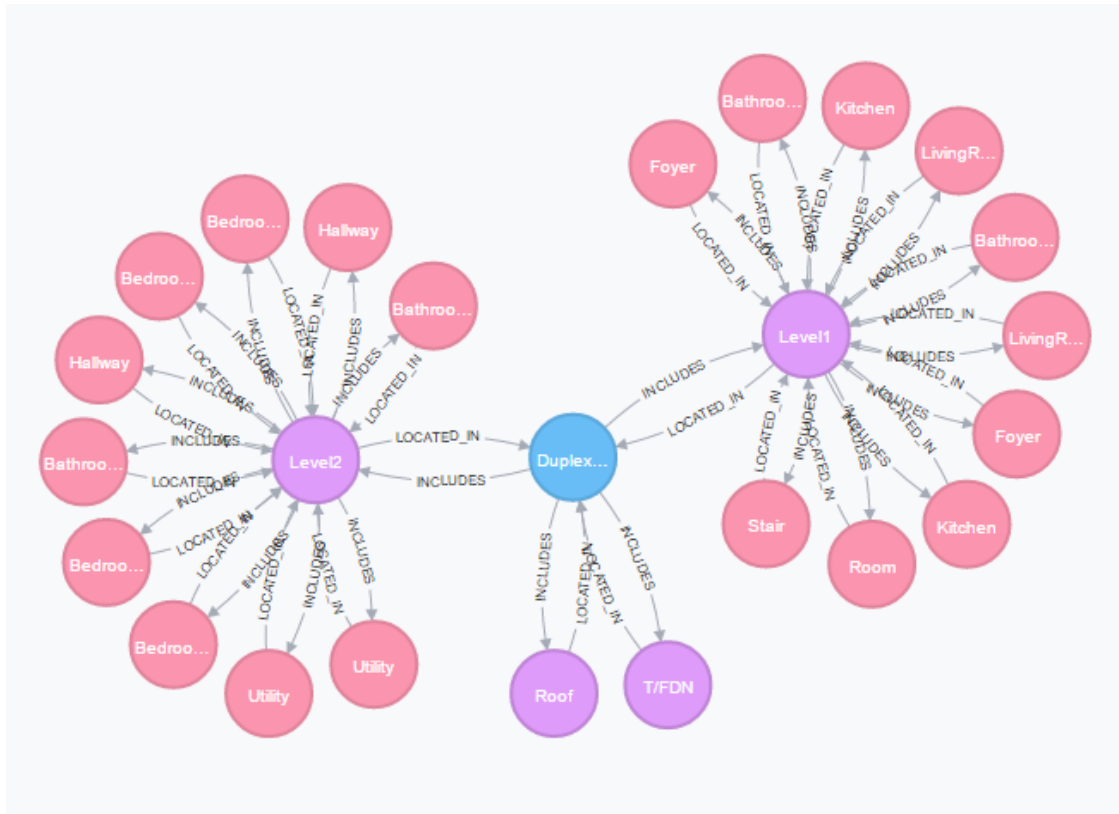


Figure 46: Spatial data in Neo4j database

## Overall categories data transfer.

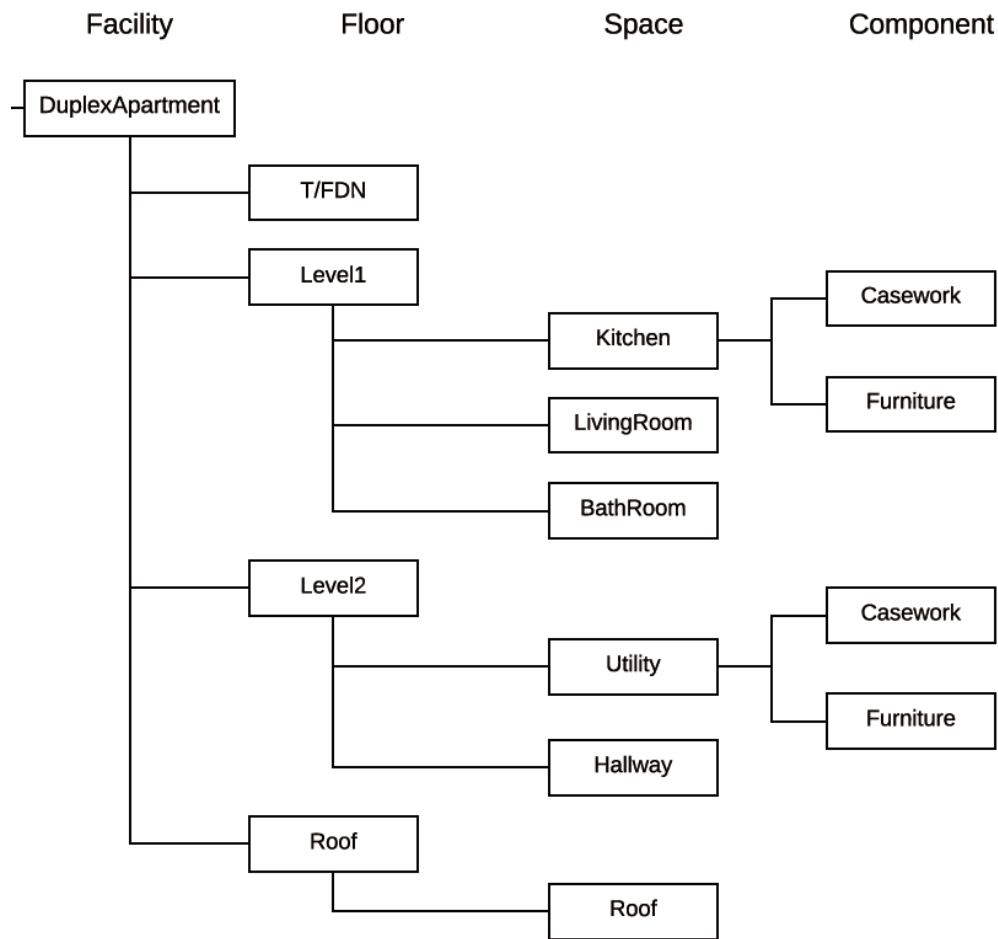


Figure 47: Overall COBie organization of test model

After execution of the program, the overall facility data from Revit is successfully exported into the Neo4j database, in the format specified in COBie.

The figure 48 below shows how the facility data looks graphically. The blue node, located at the center, represents the Facility. The purple nodes represent Floor data, which is connected to the Facility node. The Space data is displayed as the red nodes related to the Floor. And, the yellow nodes represent Component data. All the facility data is connected to its neighbor as a relationship, which reflects the COBie data dependencies and overall structural organization.

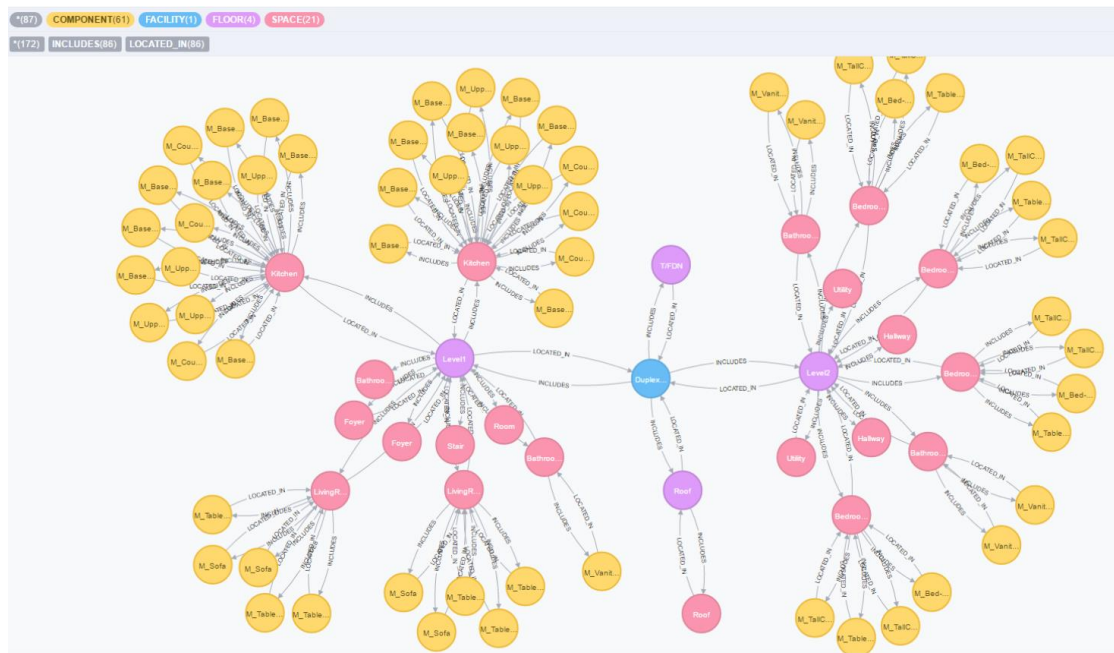


Figure 48: Overall facility data in Neo4j database

## Data synchronization

We choose a spatial data for data synchronization test in the case of changing the room for other functionalities during renovation phase.

In the test BIM model, we change a room from Name: Living Room and Number: B102 to Name: Learning Center and Number: L001. Then we run the data synchronization program in Dynamo. The updated information is captured and BIM Data update its data as well.

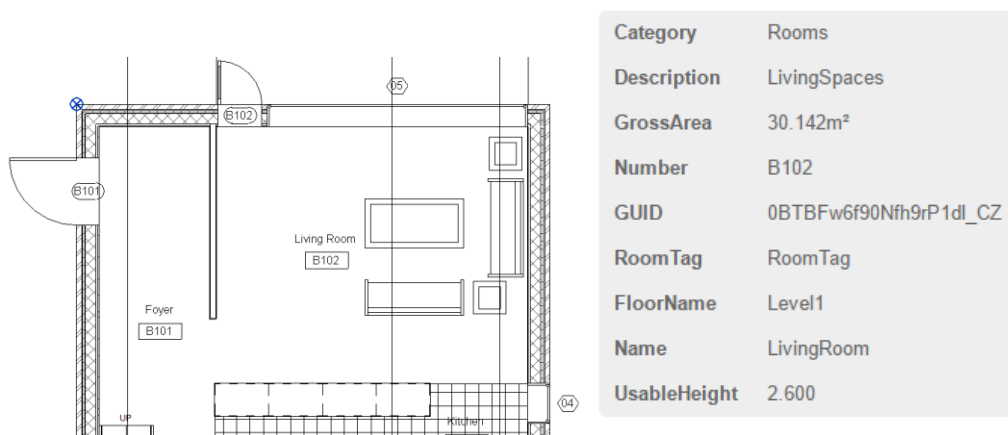


Figure 49: Original room data

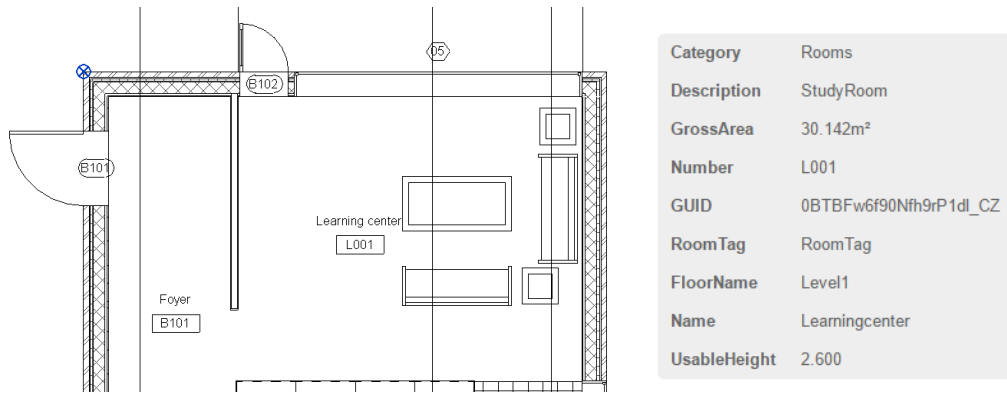


Figure 50: Room data after change

### 4.3 Test BIM/Asset maintenance integration for building residents.

In this section, we test the performance of Twitter connection and its application for linking BIM model and end-user.

We chose two test Twitter accounts, @LIUXI for end-user and @FMSYSTEM\_TEST for BIM database. We make the following test.

- a) From User to BIM database: user reports an asset accident to the BIM database by “Suggest” command.
- b) From BIM database to User: user queries a specific facility data by “Ask” command and BIM database replies user.

#### From user to BIM

As a building resident, LIUXI tweet a message to FMSYSTEM\_TEST(BIM database), reporting a kitchen furniture broken event.

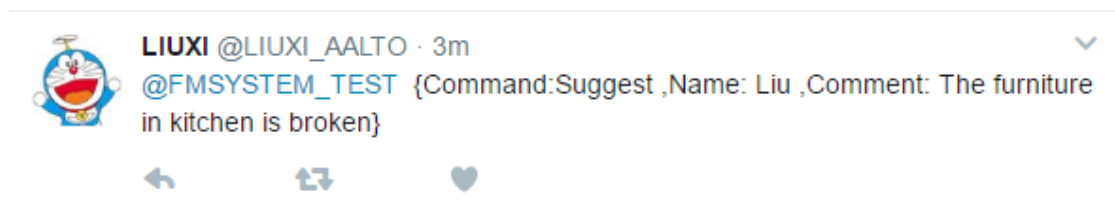


Figure 51: Twitter from building residents

The Twitter connection in Dynamo captures LIUXI's Twitter and transferred into the BIM database.

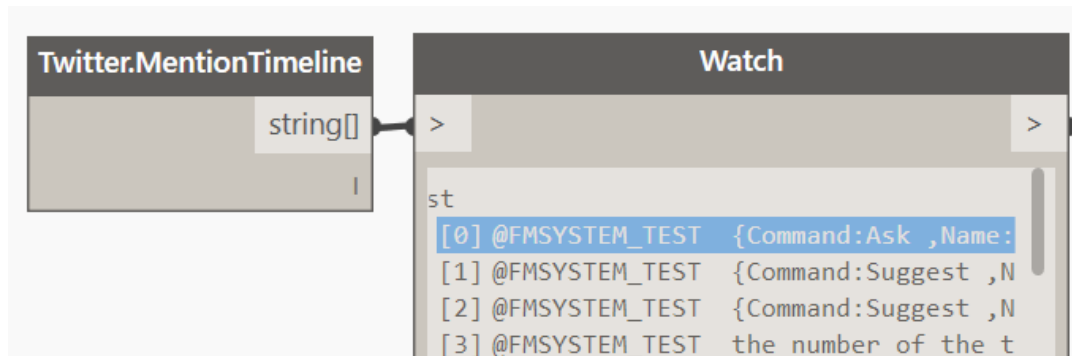


Figure 52: Twitter connection captures Twitters.

The Twitter report data is now created into the database and linked to the existing facility database as a mutual relationship.

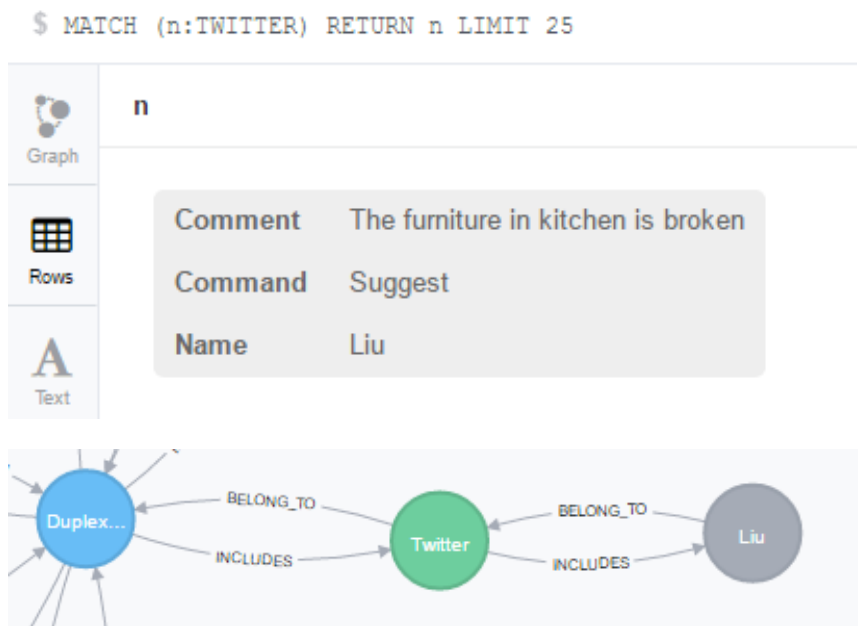


Figure 53: Twitter data in database

## From BIM to user

As a building resident, LIUXI tweet a message to FMSYSTEM\_TEST(BIM database), querying the information of a living room.

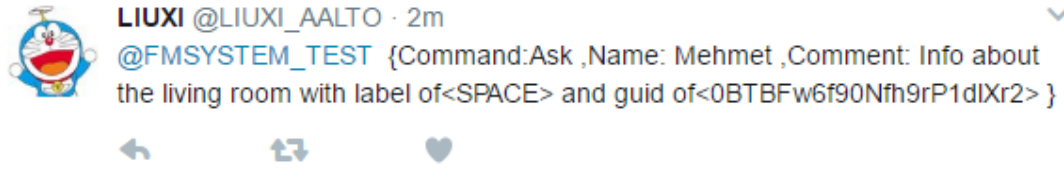


Figure 54: Twitter from building residents

Then the Twitter connection in Dynamo processes the request, and FMSYSTEM\_TEST(BIM Database) responds to LIUXI with the information of about that living room.

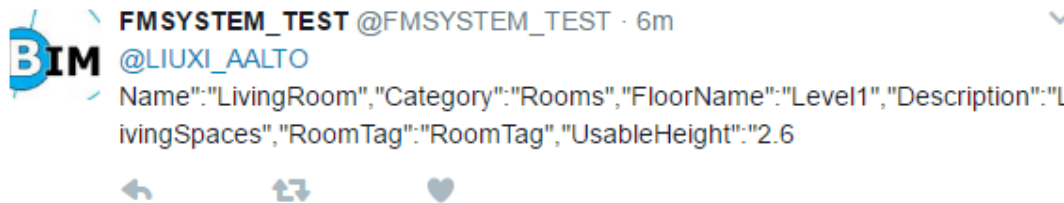


Figure 55: Twitter from BIM Database

This living room information is also presented below for clearer demonstration and comparison.

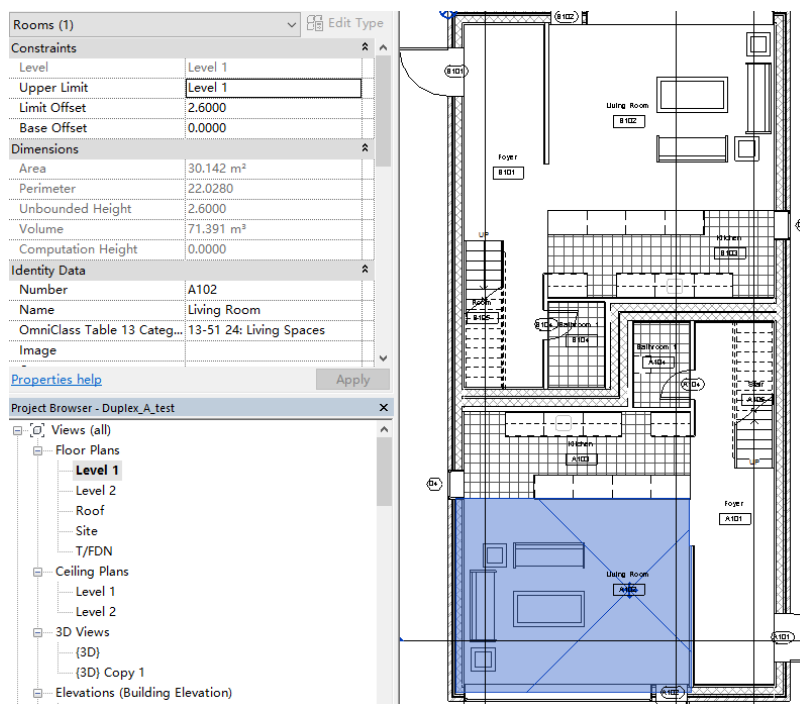


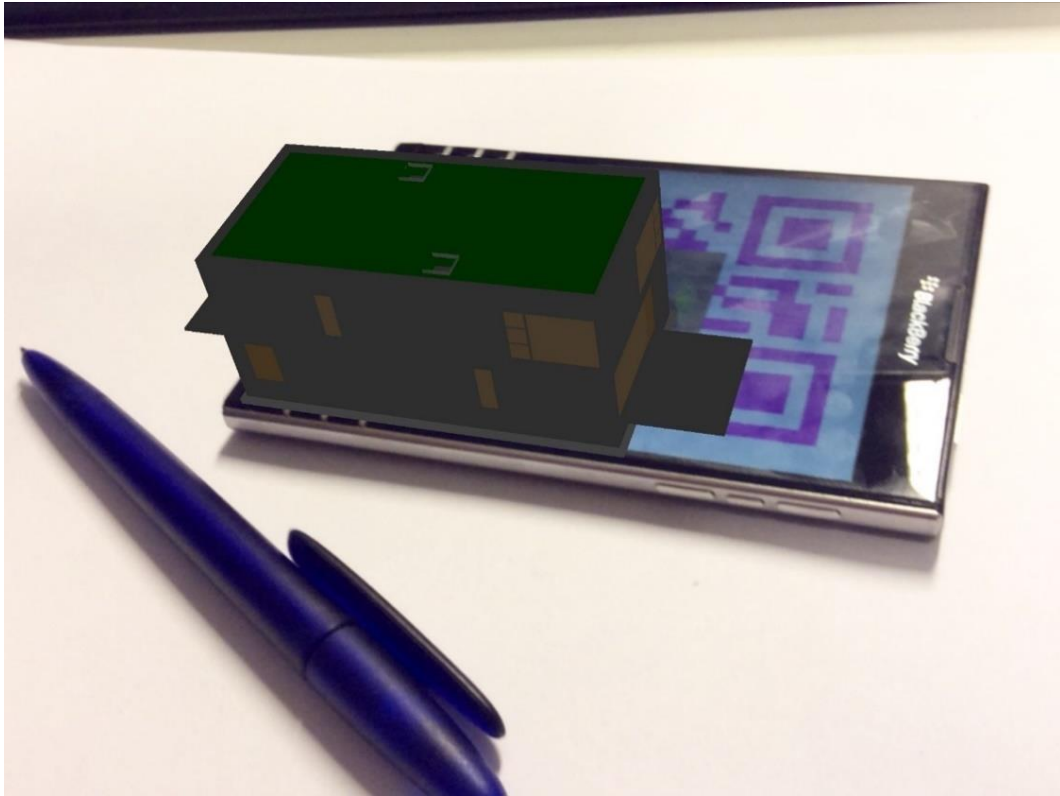
Figure 56: The living room in Revit



#### 4.4 Test BIM/Education integration for students.

In this section, we test how the augmented reality program works for students, and the related connection to the BIM database.

Firstly, we transfer the test model to the OpenHybrid platform and display it with the Reality Editor in an augmented environment.



*Figure 57: test model in augmented reality*

Next, in order to let students have better study options as well as connecting the augmented reality program to the BIM database, we developed a simple quiz about this test model for students to answer, and try to display it together with the test model in the augmented environment.

CIV-1.1 Building Structure Quiz

Name:

ID:

1. Which material would you use for this building?

2. What are the typical loading in this building?

3. As a structural engineer, what would you consider when designing this kind of building?

Figure 58: quiz questions for students

And, we display the quiz and the model together in the augmented reality environment.

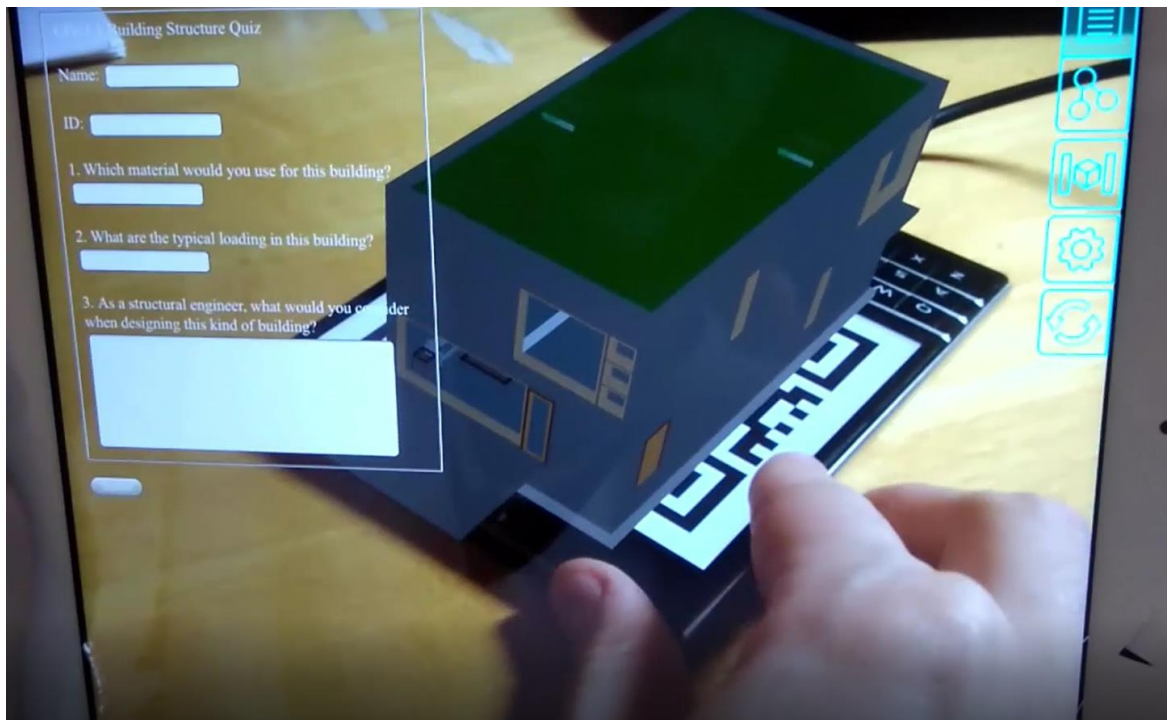


Figure 59: Quiz form and model in augmented reality

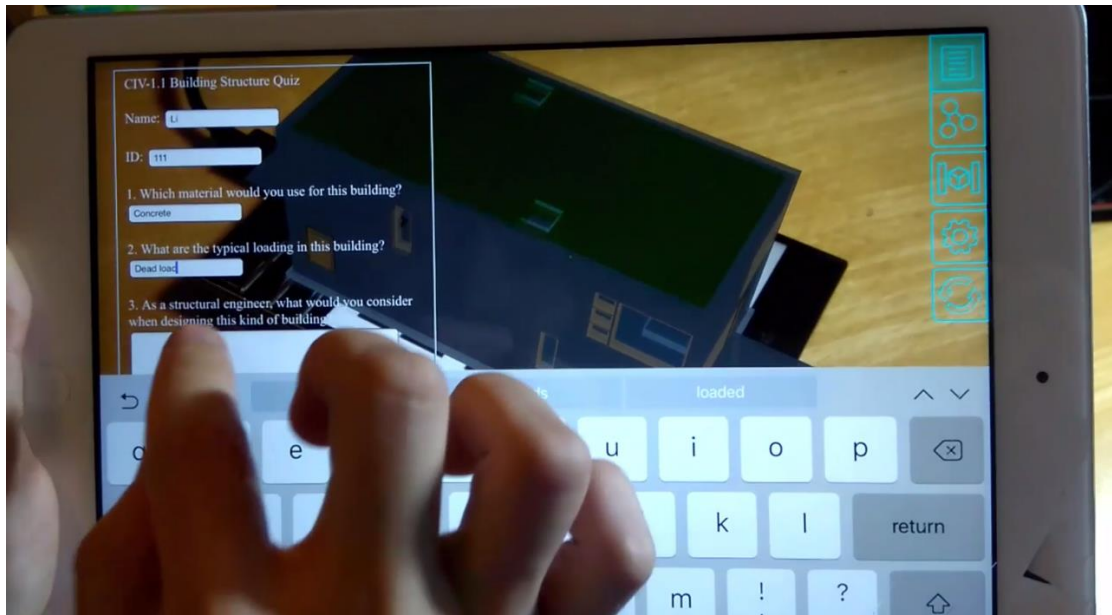


Figure 60: Student is answering the quiz.

With the help of the Nodejs server, the answer from the students is transferred to the BIM Database, linking the new information to the to the existing facility data structure.

<b>Design</b>	Structural stability
<b>Load</b>	Dead load
<b>Material</b>	Concrete
<b>ID</b>	111
<b>Name</b>	Li

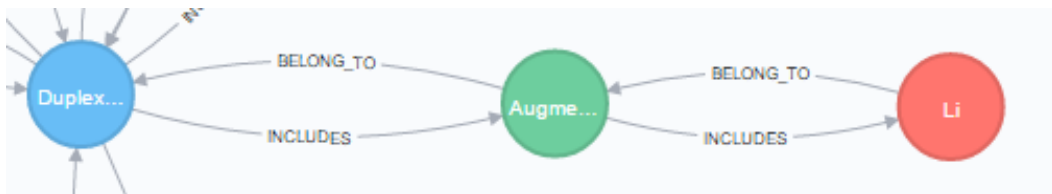


Figure 61: Student's answer in BIM database

### 4.5 Final results

Finally, all the data including facility data from BIM Model, asset maintenance data from building residents and education data from students are gathered together in an integrated data structure.

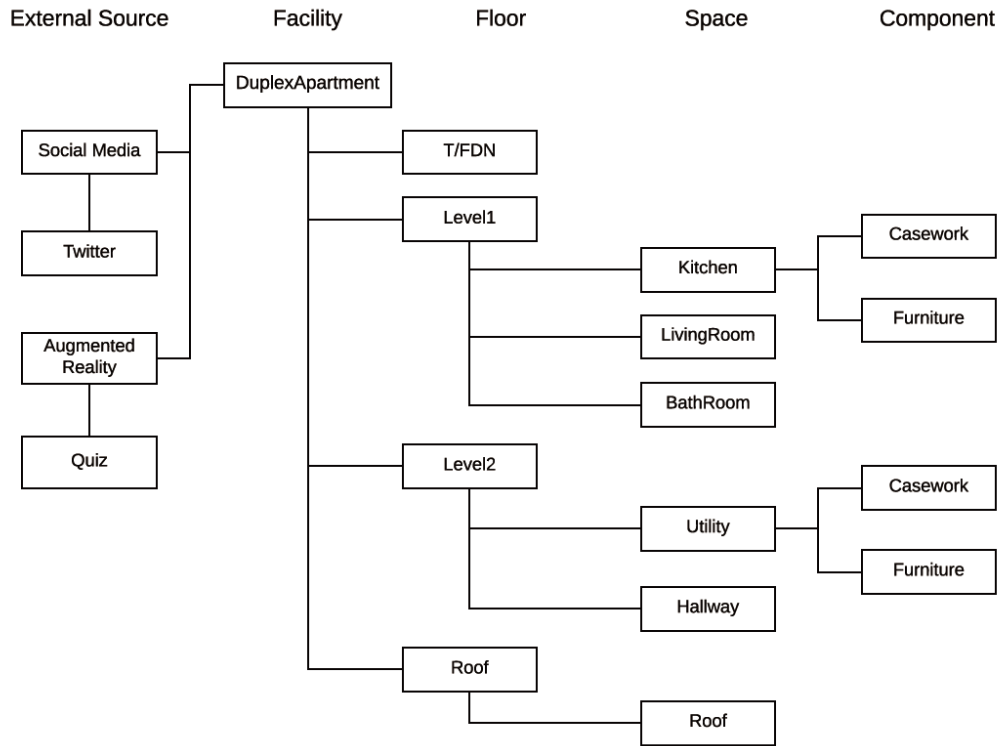


Figure 62: Ultimate data structure from BIM Model, residents and students.

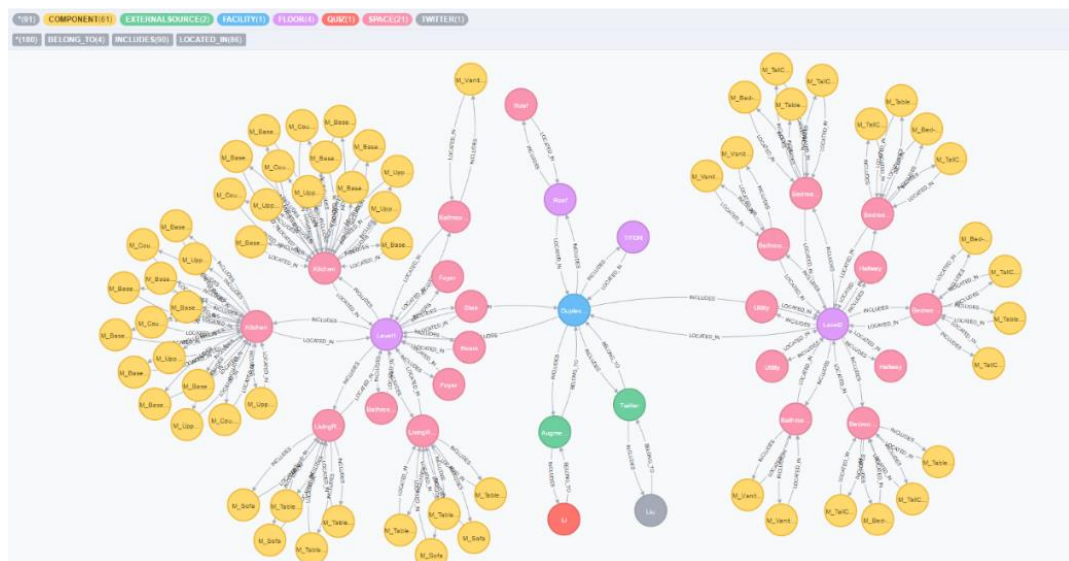


Figure 63: Ultimate data structure from BIM Model, residents and students in Neo4j database.

## 5. Conclusions

### 5.1 Significance of the system product

- a) The developed connection program can directly synchronize the BIM model and the external database, which enables automatic and streamlined COBie data drop. This data drop can happen at anytime, instead of the multiple data drops at each phase, ranging from as-planned to as-maintained stages across the facility lifecycle.

The facility managers does not need to wait for the facility data completion until the finish of the building. So it allows facility mangers to make better and faster operations and maintenance decisions.

Integrated Systems can be used to plan enhancements to the buildings. ( Teicholz, P. (Ed.). 2013). Buildings, as a kind of special products, always have possibilities to change during its working life. Examples are spaces and rooms are changing for different functionalities, HVAC equipment are changing for maintenance, repair or replacement. Our connection program is binding BIM and FM system together, so as to keep the BIM and FM data up-to-date, consistent with the changes as they occur. Therefore, the facility managers does not need to re-enter the new updated data into the FM system. This has the potential to save significant amount of time and money.

A key benefit of integrating BIM with FM is that the key data regarding spaces, equipment types, systems, finishes, zones, and so on, can be captured from BIM, and does not have to be reentered into a downstream FM system. ( Teicholz, P. (Ed.). 2013)

- b) Building residents can query the facility data and report asset maintenance issues at anytime, anywhere. And, they can get an instant reaction from the FM part.
- c) Civil engineering students have opportunities to study building knowledges in a 3D-based augmented environment and do a quiz to test their learning outcomes.
- d) A centralized data repository is formed eventually by multiple data sources, multiple system connections, and multiple end-users. Every end-user has his/her tailored user-interface as well as can benefit from this centralized repository for their use purposes and specific functionalities.

## 5.2 Limitation of the research

- a) The data synchronization program is currently only available for Autodesk Revit and five types of COBie categories. Current implementation is not directly applicable for other BIM-authoring software.
- b) The Twitter connection has risk of data security as currently any Twitter account can query the facility data and add data to the BIM database. The Twitter reply is not 100% automatic like an intelligent robot, it still requires some manual work but just couple of mouse clicks in the Twitter connection program.

## 5.3 Suggestions for further development

- a) As the data synchronization program can sync the BIM model with FM database, so every updated change in the BIM model has possibility to change the FM database. Thus, how to verify the updated data? which updated data is allowed and proofed to change the database storage? How to coordinate a deeper communication between the designers and facility managers? And, exploring a more intelligent algorithm become a further development point.
- b) The augmented reality program can be developed further to be more interactive and has more content to display.
- c) Despite facility managers, building residents and students, we can try to explore more end-users who potential have a desire for building information and more data sources, for example laser scanning data and IOT sensor data, so we can enhance more end user functionalities, increase a richer central repository and expand more Model Uses.
- d) Some technologies such as virtual reality, machine learning and internet of things can be included as a further research.

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