

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

**BUILDING INFORMATION MODELLING
IN FACILITIES MANAGEMENT**



M.Sc. THESIS

Behlül KULA

Department of Civil Engineering

Construction Management Programme

JUNE 2019

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YAPI BİLGİ MODELLEMESİNİN KULLANILMASI**

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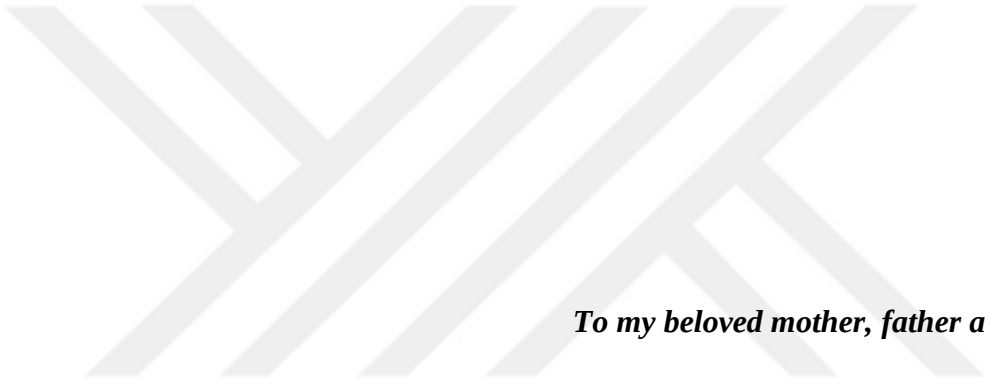
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To my beloved mother, father and brother,



FOREWORD

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TABLE OF CONTENTS

	<u>Page</u>
FOREWORD	ix
TABLE OF CONTENTS	xi
ABBREVIATIONS	xiii
LIST OF TABLES	xv
LIST OF FIGURES	xvii
SUMMARY	xix
ÖZET	xxi
1. INTRODUCTION	1
1.1 Problem Description	2
1.2 Objective	5
1.3 Methodology	5
1.4 Organization of the Thesis	6
2. LITERATURE REVIEW	7
2.1 Facilities Management (FM) Phase in Building Life Cycle	7
2.1.1 Soft and hard facility management	9
2.1.2 FM data types and purposes	9
2.2 Building Information Modeling (BIM)	12
2.3 COBie	13
2.4 Industrial Foundation Classes (IFC)	15
2.5 BIM in FM	17
2.5.1 Requirements of BIM-FM implementation	18
2.5.2 Barriers of BIM-FM implementation	21
2.5.3 Implementation of BIM with FM	21
2.5.4 Representation of FM data	23
2.6 Construction Classification Systems	24
2.6.1 FM requirements for classification system	24
2.6.2 Classification systems for FM usage	26
3. CASE STUDY: IMPLEMENTATION OF BIM-FM INTEGRATION	35
3.1 Using BIM Authoring Tool	38
3.1.1 Defining parameters to elements	38
3.1.2 Filtering elements	39
3.1.3 Using software platform for BIM (i.e. Dynamo)	41
3.1.4 Renovation simulation	42
3.1.5 Using add-ins	43
3.2 Using BIM-FM platform	44
3.3 Using IFC File	50
3.3.1 IFC structure	50
3.3.2 Creating a new class	53
3.3.3 Case scenario	61
4. CASE STUDY: BIM-FM INTEGRATION OF AN INTERNATIONAL AIRPORT	67

4.1 Literature Review	67
4.2 Methodology.....	70
4.3 Project Information.....	72
4.4 Findings and Lessons Learned	77
4.4.1 BIM-FM platform	77
4.4.2 GUID.....	79
4.4.3 Classification systems	79
4.4.4 Equipment tracking	79
4.4.5 Operation phase.....	81
4.4.6 Entering data	82
4.4.7 Document/element tagging	82
4.4.8 Modeling	83
4.4.9 Collaboration of stakeholders.....	84
4.4.10 Room & space definition.....	84
4.4.11 System definition.....	85
5. CONCLUSIONS.....	87
REFERENCES	93
CURRICULUM VITAE	103

ABBREVIATIONS

API	: Application Programming Interfaces
BIM	: Building Information Modeling
CMMS	: Computerized Maintenance Management System
COBie	: Construction Operations Building Information Exchange
FM	: Facility Management
HVAC	: Heating, Ventilation & Air Conditioning
IFC	: Industrial Foundation Classes
IFMA	: International Facility Management Association
NSF	: National Science Foundation
O&M	: Operation & Maintenance
UNSPSC	: United Nations Standard Products and Services Code



LIST OF TABLES

	<u>Page</u>
Table 2.1 : FM data type and purpose.....	11
Table 2.2 : Requirements of BIM-FM integration.....	19
Table 2.3 : Barriers of BIM-FM implementation.....	21
Table 2.4 : Investigated classification systems.	27
Table 2.5 : Coding structure of NL/SfB.....	28
Table 2.6 : Coding structure of CoClass.	29
Table 2.7 : Coding structure of UNSPSC.	29
Table 2.8 : Coding structure of MasterFormat.....	30
Table 2.9 : Coding structure of UniFormat TM	31
Table 2.10 : Coding structure of UNIFORMAT II.	31
Table 2.11 : Coding structure of Uniclass.....	32
Table 2.12 : Coding structure of OmniClass.....	33
Table 2.13 : Comparison of examined classification systems	33
Table 3.1 : Element types inside the model.	37
Table 3.2 : Properties of the new class.....	55
Table 3.3 : Properties of IfcBuildingElementProxy.....	56
Table 3.4 : Attributes of IfcRelContainedInSpatialStructure.....	57
Table 3.5 : Attributes of IfcPropertySingleValue.	57
Table 3.6 : Attributes of IfcPropertySet.....	58
Table 3.7 : Attributes of IfcRelDefinesByProperties.....	58
Table 3.8 : Attributes of IfcRelAssignsToProduct.....	59
Table 3.9 : Attributes of IfcPerson.....	59
Table 3.10 : Attributes of IfcActor.....	60
Table 3.11 : Attributes of IfcRelAssignsToActor.....	60
Table 3.12 : Sample IfcFeedback code.	61
Table 3.13 : Property Values of IfcFeedback.....	62
Table 3.14 : EXPRESS code of the modified IFC file.....	64
Table 4.1 : BIM-FM case studies.....	68
Table 4.2 : Barriers of BIM-FM integration from literature.	69
Table 4.3 : Interview details.....	71
Table 4.4 : Focus group details.	71



LIST OF FIGURES

	<u>Page</u>
Figure 1.1 : Methodology of thesis	6
Figure 2.1 : Phases of the building life cycle.....	8
Figure 2.2 : Role of FM.	8
Figure 2.3 : COBIE process overview.	14
Figure 2.4 : Example of a COBIE Excel Sheet.....	15
Figure 3.1 : Real-world (a-c) and model (b-d) appearance of ARI-3 building and Çekirdek office.....	35
Figure 3.2 : Real situation (left side) and model appearance (right side).	36
Figure 3.3 : Room tags of model.....	37
Figure 3.4 : Supply grille element with parameters.	39
Figure 3.5 : Work order report.	39
Figure 3.6 : Chair renewal parameter.....	40
Figure 3.7 : Visualization of chair renewal.....	40
Figure 3.8 : Temperature parameter.....	41
Figure 3.9 : Dynamo script for uploading temperature data.	42
Figure 3.10 : Visualization of temperature intervals on floor plan.....	42
Figure 3.11 : Render views of different combinations in same room.....	43
Figure 3.12 : Revit model at Unity gaming engine.....	43
Figure 3.13 : Transferring model to EcoDomus via Revit add-in.	44
Figure 3.14 : Saving the model inside the system.	45
Figure 3.15 : Model on EcoDomus viewer.	45
Figure 3.16 : 2D and 3D view together.....	46
Figure 3.17 : Selecting a specific space or zone.	46
Figure 3.18 : Selecting a building element to see the properties.	47
Figure 3.19 : Adding or changing information of building element.....	47
Figure 3.20 : Entering work-order to a building element.	48
Figure 3.21 : Processing the work-orders.	48
Figure 3.22 : Creating hierarchy of work-order procedure.....	49
Figure 3.23 : Creating form document.....	49
Figure 3.24 : Creating control document.	50
Figure 3.25 : Sample model view on Revit (left) and BIM Vision (right).	51
Figure 3.26 : Codes of sample IFC file in Notepad++.....	51
Figure 3.27 : Structure of the IfcDoor entity in the IFC file.....	53
Figure 3.28 : Structure of new entity.	54
Figure 3.29 : IfcFeedback Entity in IFC Hierarchy.	55
Figure 3.30 : Relation Structure of IfcFeedback.....	58
Figure 3.31 : Case study building model and close up of Zone-3.	62
Figure 3.32 : Physical representation of the IfcFeedback in the building model.....	65
Figure 3.33 : Relation diagram.	66
Figure 4.1 : Methodology.....	71

Figure 4.2 : General view of the airport (Sacks et al., 2018).	72
Figure 4.3 : 3D model view of the airport (Sacks et al., 2018).	73
Figure 4.4 : Joint Venture structure.....	73
Figure 4.5 : Project stakeholders of Case Study.	74
Figure 4.6 : System schema of BIM-FM integration.	75
Figure 4.7 : BIM-FM platform.....	76
Figure 4.8 : Findings in BIM-FM process	77



BUILDING INFORMATION MODELLING IN FACILITIES MANAGEMENT

SUMMARY

Facility management (FM) is one of the main stages in the building lifecycle and it covers about 70-80 percent of the entire life cycle of building in terms of both time and cost. Although the facility management phase is three to four times more than the cost of all other stages, project stakeholders focus more on initial investment costs. Building Information Modeling (BIM) is a digital representation of the building and aims to ensure the flow of information in the digital environment and can be used in all phases of the building life cycle. Multiple studies have examined the usage of BIM in the design and construction phases and BIM is commonly used by companies at these stages. However, only a small number of the studies focused on the integration of BIM with facility management. These studies have demonstrated the potential benefits of using BIM at the FM stage. Despite the need to develop an integrated system with BIM for FM is often emphasized in the literature, real-life implementations are scarce. In addition, studies in the literature have not focused on a large-scale complex structure. Existing previous case studies were performed at small scale projects. It was indicated that the scale is important in implementation and large-scale projects where BIM-FM integration is performed may encounter additional problems.

The aim of this thesis is (1) to illustrate how a project can be integrated with BIM in the facilities management phase with advantages and disadvantages and (2) to determine the challenges and lessons-learned of BIM-FM integration in a large-scale complex project by performing case study. To achieve this aim, three pilot studies were conducted for BIM-FM integration by utilizing three main methods: (1) using BIM authoring tool, (2) using BIM-FM platform, and (3) using IFC file format. Each method was evaluated and the advantages and disadvantages were identified for each method. Having learned the advantages and disadvantages various methods used for BIM-FM integration, a case study of a real-life airport project was performed to identify challenges and lessons-learned of a large scale and complex BIM-FM integration case. The case study was performed via expert interviews and document investigation.

The findings of the pilot studies showed that BIM authoring tools have capability of performing most of the basic FM issues. However, the size of the project and the size of the data would affect the process negatively. Besides, since BIM authoring tools is designed mostly for model creation, they are complex software packages and have complex interfaces. The personnel who will use a BIM authoring tool in FM phase should have background and experience on that tool. Finally, BIM authoring tools can be used for basic FM purposes in small or medium scale projects for a short period of time; however, professional software packages for integration of BIM and FM should be used in a continuous FM phase. In the second pilot study, a BIM-FM platform (i.e., EcoDomus) was used for BIM-FM integration. The findings showed that BIM-FM

platforms has many modules that allow the users perform their FM activities according to their purposes. The investigated platform is customized for the project, and the needs can be defined and included in the platform by the platform vendor. However; the project needs should be well defined and necessary modules should be activated by considering cost of the project. The platform combines BIM model by linking building elements with the related activities, and model viewer mode is used to visualize the BIM model. In the third pilot study, the aim was to represent occupant related data by modifying IFC file without using any BIM authoring tool. This file can then be used in any BIM-based software package for FM purposes. This was the most complex method that was used in the pilot studies.

In the second part of the thesis, a case study was conducted at an international airport project to investigate the requirements, challenges and lessons-learned of BIM-FM integration in a large-scale complex structure. Two data collection methods were used in the case study: (1) interviews and (2) document investigation. The challenges and lessons-learned that are specific to project size and complex project structure were identified in the study. For example, room and space definitions are complicated when the project has irregular space shapes with varying floor heights. Another example is that complex MEP systems will require special system definitions in order to track system correctly.

In conclusion, it was aimed to illustrate how a project can be integrated with BIM in the facility management stage and to determine the problems encountered by performing case analysis on a large-scale complex project. Three different BIM-FM integration methods were performed at pilot studies that were conducted at a small size university building. As a large-scale complex project, an international airport project was selected and BIM-FM integration process was examined to identify the encountered challenges. The results highlight that large-scale complex projects encounter with additional challenges related to BIM-FM integration and they develop their unique solutions to overcome those problems. The findings of the study can be used by academicians that would like to work on BIM-FM integration and by the practitioners that would like to implement BIM-FM integration, especially in large-scale projects.

TESİS YÖNETİMİNDE YAPI BİLGİ MODELLEMESİNİN KULLANILMASI

ÖZET

Tesis yönetimi bina yaşam döngüsünün ana aşamalarından biridir ve hem zaman hem de maliyet açısından binanın tüm yaşam döngüsünün yaklaşık yüzde 70-80'ini kapsar. Tesis yönetimi aşaması tüm diğer aşamaların maliyetinden üç ila dört kat fazla olmasına rağmen, proje paydaşları başlangıçtaki yatırım maliyetlerine daha fazla odaklanmaktadır. Yapı Bilgi Modellemesi (BIM), binanın dijital bir temsilidir ve dijital ortamda bilgi akışını sağlamayı amaçlar. Ayrıca bina yaşam döngüsünün tüm aşamalarında kullanılabilir. Birçok çalışma BIM'in tasarım ve inşaat aşamalarında kullanımını incelemiştir ve BIM bu aşamalarda sektördeki şirketler tarafından yaygın olarak kullanılmaktadır. Çalışmaların sadece küçük bir kısmı BIM modelinin tesis yönetimi ile entegrasyonuna odaklanmıştır. Bu çalışmalar, FM aşamasında BIM kullanmanın olası yararlarını göstermiştir. BIM ile entegre bir sistem geliştirme ihtiyacı literatürde sıklıkla vurgulanmasına rağmen, bunlar sadece öneri olarak kalmıştır. Bu durumun en önemli nedeni, BIM ile FM'in nasıl entegre edileceğinin bilinmemesi ve örneklerden elde edilmiş bir bilgi birikiminin olmamasıdır. Ek olarak, literatürdeki çalışmalar büyük ölçekli karmaşık bir yapıya odaklanmamıştır. Böyle bir yapıda, BIM-FM entegrasyonu uygulandığında ne gibi sorunlarla karşılaşılacağı bilinmemektedir.

Bu tezin amacı, bir projenin tesis yönetimi aşamasında BIM ile nasıl entegre edilebileceğini avantajları ve dezavantajlarıyla birlikte göstermek ve büyük ölçekli bir karmaşık projede vaka analizi yaparak BIM ile tesis yönetiminin entegre edilmesi sırasında karşılaşılan sorunları tespit etmektir. Tezin yöntemi olarak literatür taraması yapılmış ve çalışmanın temelini oluşturan konular verilmiştir. Daha sonra 3 farklı yöntem kullanılarak bir BIM modelinin FM amaçları için kullanılması denenmiştir. Bir sonraki adımda, büyük ölçekli karmaşık bir havaalanı projesinde uygulanan BIM-FM entegrasyonu incelenmiştir. Bu projenin vaka analizi sırasında uzmanlarla görüşmeler yapılmış ve ilgili belgeler incelenmiştir.

Literatür taramasında, FM ve BIM'in temelleri tanımlanmıştır. İncelenen makalelerde FM faaliyetlerinin ana veri tipleri sınıflandırılmıştır: (1) sensör verileri, (2) konum verileri, (3) kullanıcı davranış verileri ve (4) kullanıcı geri bildirim verileri. Sensör verileri, çeşitli sensörlerle (örneğin sıcaklık, hareket, gaz) toplanan tesise ilişkin verilerdir. Konum verileri, bir öğenin veya bir kişinin koordinatlarını veya bulunduğu alanı içerir. RFID ve Bluetooth gibi konumlandırma teknolojileri kullanılarak toplanır. Kullanıcı geri bildirim verileri, doğrudan tesisin kullanıcılarından elde edilen bilgilerdir ve kullanıcıların şikayetlerini ve istekleri içerir. Son olarak, kullanıcı davranışları, bir zaman damgasıyla birlikte bir kullanıcının faaliyetlerinin listesi olarak tanımlanabilir. Ayrıca, verilerin nasıl kullanılacağı da önemlidir. Bu nedenle, literatür çalışmasında FM verisinin toplanmasında iki temel amaç olduğunu ortaya konmuştur: (1) enerji analizi ve (2) işletme ve bakım faaliyetleri (O&M). FM faaliyetleri için veri

toplayan çalışmaların ana amacı enerji analizidir. Bu çalışmaların çoğu, binalardaki enerji kullanımını incelemeye ve azaltmaya odaklanmıştır. Toplanan FM verilerinin işlenmesi ve karar alma amacıyla kullanılması için veritabanlarında veya BIM modellerinde gösterilmesi gerekir. İncelenen çalışmalarda FM verilerini transfer etmek ve temsil etmek için üç ana yöntemin kullanıldığı görülmüştür. İlk yöntemde kullanıcıların FM verilerini 3B olarak görselleştirmek için bu verileri doğrudan BIM tabanlı yazılım paketlerine girmelerini gerektirir. İkinci yöntemde, verileri ilgili yazılıma aktarmak ve kendi veri depolama sistemlerinde temsil etmek için API'ler kullanılmaktadır. Araştırmacıların çoğu, toplanan verileri API'leri veya belirli yazılım paketlerinin eklentilerini (örneğin, Autodesk Revit) kullanarak temsil etmiştir. FM verilerini temsil etmek için üçüncü yöntem, IFC formatını kullanmaktır. Üçüncü yöntem ile ilgili bir vaka analizi tez kapsamında gerçekleştirilmiştir. Son olarak, BIM-FM entegrasyonunun gereksinimleri ve zorlukları yapılan literatür çalışması sonucunda listelenmiştir. BIM-FM entegrasyonu için gerekli birer araç olan ve birlikte çalışabilirlik ile verimli veri transferi için kullanılan, COBie ve IFC'nin temelleri bu çalışma sonucunda incelenmiş ve sunulmuştur.

Literatür taramasından sonra üç BIM-FM entegrasyonu yöntemi denenmiştir. Bu yöntemler: (1) BIM modelleme yazılımlarını kullanmak, (2) BIM-FM platformu kullanmak ve (3) IFC dosya formatını kullanmaktır. BIM modelleme araçlarının temel FM konularının çoğunu gerçekleştirme kabiliyetine sahip olduğu görülmüştür. Ancak, projenin büyüklüğü ve verilerin büyüklüğü süreci olumsuz etkileyecektir. Ayrıca, BIM modelleme araçları çoğunlukla model oluşturma için tasarlandığından, karmaşık yazılım paketleridir ve karmaşık arayüzlere sahiptirler. FM aşamasında BIM modelleme yazılımı kullanılacaksa, kullanan kişilerin bu yazılımla ilgili arka planı ve deneyimi olmalıdır. Son olarak, BIM modelleme araçları temel FM amaçları için kullanılabilir, ancak BIM ve FM'in entegrasyonu için profesyonel yazılım paketleri kullanılmalıdır. İkinci yöntem olarak, BIM-FM entegrasyonu için bir BIM-FM platformu (EcoDomus) kullanılmıştır. BIM-FM platformlarında kullanıcıların FM faaliyetlerini kendi amaçları doğrultusunda gerçekleştirmelerine izin veren birçok modül bulunduğu görülmüştür. BIM-FM platformlarında, BIM modelinde bulunan yapı elemanları ilgili faaliyetlerle ilişkilendirilebilir. BIM modelinin görselleştirilmesi, model görüntüleme modülleri yardımıyla platformun içinde kolayca yapılabilir. Genellikle, BIM-FM platformları proje bazlı olarak geliştirilir. Proje genelinde BIM-FM platformunun modüllerinin içinde bulunmayan bir ihtiyaç varsa, BIM-FM platform satıcısı ile iletişim kurularak bunlar platforma eklenebilir. BIM-FM platformları çoğunlukla özelleştirilebilir olduklarından, proje ihtiyaçları iyi tanımlanmalı ve proje maliyetleri dikkate alınarak gerekli modüller etkinleştirilmelidir. Üçüncü method olarak ise IFC dosyasının herhangi bir BIM geliştirme aracı kullanmadan değiştirilebileceğini ve herhangi bir BIM tabanlı yazılım paketinde FM amaçlı kullanılabileceğinin gösterilmesi amaçlanmıştır. Örnek olarak, kullanıcı geri bildiriminin IFC modelinde oluşturulması ve saklanması amaçlanmıştır. Sonuç olarak, tezin bu bölümünde belirtilen 3 yöntem arasında IFC'nin yapısının genişletilmesi en zor yoldur. Ancak, FM verilerini depolamak için en etkili yoldur, çünkü herhangi bir BIM tabanlı yazılım paketi ile uyumlu bir şekilde çalışabilir.

Son olarak, BIM-FM entegrasyonunun gerekliliklerini ve zorluklarını büyük ölçekli bir kompleks yapıda incelemek için uluslararası bir havaalanı projesi seçilmiştir. Önceki vaka çalışmalarının sonuçları küçük ölçekli projeler için faydalı olsa da BIM-FM entegrasyonunun büyük ölçekli bir projede (100.000 m2'den fazla) ortaya çıkacak gereklilikleri ve zorluklarını belirlemek için kapsamlı bir vaka incelemesine ihtiyaç

vardı. Bu vaka analizi çalışmasında iki veri toplama yöntemi kullanılmıştır: (1) röportajlar ve (2) belge incelemesi. Proje büyüklüğü büyümesi ve karmaşık bir yapı olması, bu projelere özgü zorluklar çıkarmaktadır. Örneğin, modelde çok sayıda bina elemanı olduğunda, bu elemanları özgü ve benzersiz olan GUID numaralarında çakışmalar ortaya çıkmıştır. Ekipmanların takibi, küçük ölçekli bir projede BIM modelleme araçları kullanılarak kolayca yapılabilir. Ancak, BIM modelleme araçları, proje büyük ve karmaşık olduğunda yazılım kapasiteleri açısından yeterli olmayacaktır. Proje, farklı kat yüksekliklerine ve düzensiz hacimlere sahip olduğunda oda ve mekan tanımlamaları da karmaşık olacaktır. MEP sistemlerinin doğru takip edilebilmesi ve yararlı verilerin elde edilebilmesi için karmaşık MEP sistemlerine özel sistem tanımlamaları gerekmektedir. Ayrıca, büyük projelerde dünyanın her yerinden birçok paydaşın olması bunların birlikte çalışabilirliğini güçleştirmektedir. Bunun için çözümlerin sunulması gerekmektedir.

Sonuç olarak, bu tezde bir projenin tesis yönetimi aşamasında BIM ile nasıl entegre edilebileceğinin gösterilmesi ve büyük ölçekli karmaşık bir projede vaka analizi yapılarak karşılaşılan sorunların belirlenmesi amaçlanmıştır. Küçük bir üniversite binasında üç farklı BIM-FM entegrasyon yöntemi uygulanarak BIM-FM entegrasyonuna örnekler verilmiştir. Büyük ölçekli bir karmaşık proje olarak, uluslararası bir havaalanı projesi seçilmiş ve karşılaşılan engelleri belirlemek için BIM-FM entegrasyon süreci incelenmiştir. Vaka analizleri ve BIM-FM denemelerinde çıkan sonuçlar listelenmiş ve tartışılmıştır.



1. INTRODUCTION

Facility management (FM) is one of the main stages in the building lifecycle (National Science Foundation (NSF), 2003). It covers about 70-80 percent of the entire life cycle of building in terms of both time and cost (Lewis et al., 2010; Akcamete et al., 2010). Although the facility management phase is three to four times more than the cost of all other stages, project stakeholders focus more on initial investment costs (Becerik-Gerber et al., 2012). Also, all around the world, it is seen that the existing structures (historical buildings, plazas, hospitals, schools, etc.) are 98% and the new ones are 2% (Kassem, et al., 2015). This indicates that almost all structures are in operation phase.

Building Information Modeling (BIM) is a digital representation of the building and aims to ensure the flow of information in the digital environment and can be used in all phases of the building life cycle (Eastman et al., 2011). Many studies have examined the usage of BIM in the design and construction phases and have been widely used by companies in the sector at these stages. Although it is the main approach that the information produced in the previous stages was accessible throughout the entire life cycle, only a small part of the studies were focused on the integration of BIM model with facility management (Akcamete et al., 2010; Becerik-Gerber and Kensek, 2010; Parsanezhad and Dimyadi, 2014; Volk et al., 2014; Korpela et al., 2015). These studies have demonstrated the potential benefits of using BIM at the FM stage; However, when the practices in the sector are examined, it is seen that BIM is applied in design and construction stages rather than the facility management stage (Eastman et al., 2011; Becerik-Gerber et al., 2012; Eadie et al., 2013; Volk et al., 2014). It was observed that the information required for the management of the facility could not be collected effectively and collected information was distributed to many different platforms. Studies stated that BIM's structure and graphic interface based on intelligent building elements could be used to combine this information and to provide easy access from a single point. (Becerik-Gerber et al., 2012; Motawa and Almarshad, 2013; Motamedi et al., 2014; Ilter and Ergen, 2015). BIM, also, is seen as an useful tool for effective transferring of FM data to decision makers. Although the need to

develop an integrated system with BIM is often emphasized in the literature, these are only suggestions (Motawa and Corrigan, 2012; Ozturk et al., 2012; Motawa and Carter, 2013; Hua et al., 2014; Göçer et al., 2015). Becerik-Gerber et al. (2012) described the potential areas where BIM can be used in facility management in a study: (1) Locating building components, (2) facilitating real-time data access, (3) visualization and marketing, (4) checking maintainability, (5) space management, (6) creating and updating digital assets, (7) planning and feasibility studies for noncapital construction, (8) emergency management, (9) personnel training and development, (10) controlling and monitoring energy.

Within the scope of this thesis, the studies on BIM-FM integration were examined and the current challenges of this approach were determined by the literature review. Afterwards, how BIM-FM integration can be done is investigated by utilizing three main methods at small-scale pilot projects: (1) using BIM authoring tool, (2) using BIM-FM platform, and (3) using IFC file format. Each method was evaluated and the advantages and the disadvantages were identified for each method. Having learned the advantages and disadvantages of various methods used for BIM-FM integration, a case study of a real-life airport project was performed to identify challenges and lessons-learned of a large scale and complex BIM-FM integration case. The case study was performed via expert interviews and document investigation. Finally, the results were compared and discussed. The findings of the pilot studies showed that the size of the project and the size of the data would affect the process negatively. The results highlight that large-scale complex projects encounter with additional challenges related to BIM-FM integration and they develop their unique solutions to overcome those problems.

1.1 Problem Description

During the design and construction phases, a huge number of data are created and transferred to FM phase. In addition, a large amount of data are created in the FM phase. However, having vast amount of data does not guarantee efficient operation and maintenance (Singh et al., 2009). This data should be categorized and stored in the operation & maintenance systems according to purposes of use. There are four main data types in the literature: (1) sensor data, (2) location data, (3) occupant behavior data, and (4) occupant feedback data. These data were collected for two main FM

purposes: (1) energy analysis and (2) operation and maintenance (O&M). The studies investigating the requirements of the data at FM phase concluded that these various types of data could not be presented to the decision makers efficiently (Motawa and Almarshad, 2013; Motamedi et al., 2014; Ilter and Ergen, 2015).

Several stakeholders involve during the lifecycle of building and they all use different software packages in purpose of design, engineering and project planning. Because of the lack of interoperability among the software packages, there are some problems. IFC can be used as a solution to solve the interoperability problems among software packages. IFC has an object-oriented structure and it consists of objects representing the components and systems of a building, along with the relationships among those objects. It is an open, international standard for exchanging BIM data (buildingSMART, 2019). It is created by an international organization named buildingSMART for AEC/FM industry and approved as ISO 16739 standard. Since there are many software packages in FM phase, IFC can be used with BIM in that phase as a solution of interoperability problems.

All the phases in the building life cycle have many problems and researchers propose to use Building Information Modeling (BIM) to provide solution for these problems (Hardin, 2011; Eastman et al., 2008). The positive effect of the BIM in the FM phase has not been seen yet, while it is used mostly in the design and construction phases (Teicholz, 2012). According to Becerik-Gerber et al. (2011), even though the FM phase has the biggest portion of the total cost, professionals try to decrease the initial cost of the project by focusing on design and construction phases. Besides, the duration of the FM phase is nearly five times of the sum of the durations of the other phases (Eastman et al. 2011). It shows that the efficiency of the BIM usage can be seen at the FM phase rather than the initial phases. Also, FM teams spent 10-30% of their time on searching the required information (Latham, 1994). According to Eastman et al. (2008), BIM is a useful tool to deliver and use the building information efficiently with reduced time and cost. BIM is an efficient supporting technology for the main role of the FM team, which is integrating people, place and process in purpose of keeping the function of the building (IFMA, 2011). Therefore, the potential of the BIM has been realized by professionals and their interest is grown to use BIM in FM phase (Becerik-Gerber et al., 2011). One of the most important process of using BIM in FM phase is transferring the data from earlier phases. These data should be well organized for an

efficient transfer process. COBie can be used for efficient data transfer from design and construction phases to FM phase.

When a construction stage of a project is completed, contractors are responsible for handover of some type of documents, such as equipment list, warranties, and product data sheets to facility management team. A study shows that during the collection of handed over documents, 30% of the data has errors (East and Nisbet, 2010). Construction Operations Building Information Exchange (COBie) is a tool developed for the transfer the created building data from design and construction phases to FM phase (WBDG, 2016). COBie is a documentation standard to increase the efficiency of building life cycle with reducing the operating costs (WBDG, 2016). It aims to solve interoperability problems of FM related data transfer among the software packages (Young et al., 2008).

Even though, use of BIM in the building lifecycle is seen as an efficient tool in terms of both cost and time savings, many studies have examined the usage of BIM in the design and construction phases and have been widely used by companies in the sector at these stages. The most important reason for this situation is not knowing exactly how to integrate BIM with FM and lack of knowledge gained from real-life examples. Although the need to develop an integrated system with BIM is often emphasized in the literature, these are only suggestions. Most of the studies found the challenges and requirements of BIM-FM integration from opinion-based studies that conducted surveys, interviews and group discussions. Researchears highlighted that these opinion-based findings should be supported with case studies of real-world BIM-FM implementation. There are a few number of case studies that examine overall BIM-FM integration process covering data collection, modeling, integration and usage in FM phase. However, these case studies are conducted at small or medium scale buildings, between 1,000 m² to 30,000 m², such as university buildings and health centers. The scale is a significant factor in BIM-FM integration since a prototype developed for a small facility might not be suitable for a large-scale facility, which has complex requirements and large data sets. To identify the the requirements, barriers and lessons-learned of BIM-FM integration in a large-scale project (i.e., more than 100,000 m²), a case study is needed.

1.2 Objective

The main objectives of this thesis are:

1. To illustrate how a project can be integrated with BIM in the facilities management phase and identify advantages and disadvantages of each approach.
2. To determine the challenges and lessons-learned of BIM-FM integration in a large-scale complex project by performing a case study.

First objective is related to building knowledge on how to integrate BIM with FM in a project. Identified advantages and disadvantages could be used by firms in the sector to select a integration method. Second objective focuses on filling the gap of large-scale BIM-FM integration case study by identifying the requirements, barriers and lessons-learned.

1.3 Methodology

The methodology of the study is provided in Figure 1.1. First of all, a literature review was conducted and BIM-FM integration was performed as a pilot study by utilizing three main methods in small scale projects: (1) using BIM authoring tool, (2) using BIM-FM platform, and (3) using IFC file format. The advantages and disadvantages were identified for each method. These methods are: (1) Using BIM authoring tool, (2) using BIM-FM platform and (3) using IFC file. The advantages and the disadvantages of each method were determined. Having learned the advantages and disadvantages of various methods used for BIM-FM integration, a case study of a real-life airport project was performed to identify challenges and lessons-learned of a large scale and complex BIM-FM integration case. During the case study, interviews were made with the experts that were involved in the project and the related documents were examined for data collection. For validation of the case study results, focus group method was used. Results of interviews and document investigation were discussed with one BIM manager, two BIM consultants and one BIM senior to validate them. The finding of the case study include the challenges and the lessons-learned identified in the case study. The results of the pilot studies and the case study were compared in the end to understand the differences and additional challenges.

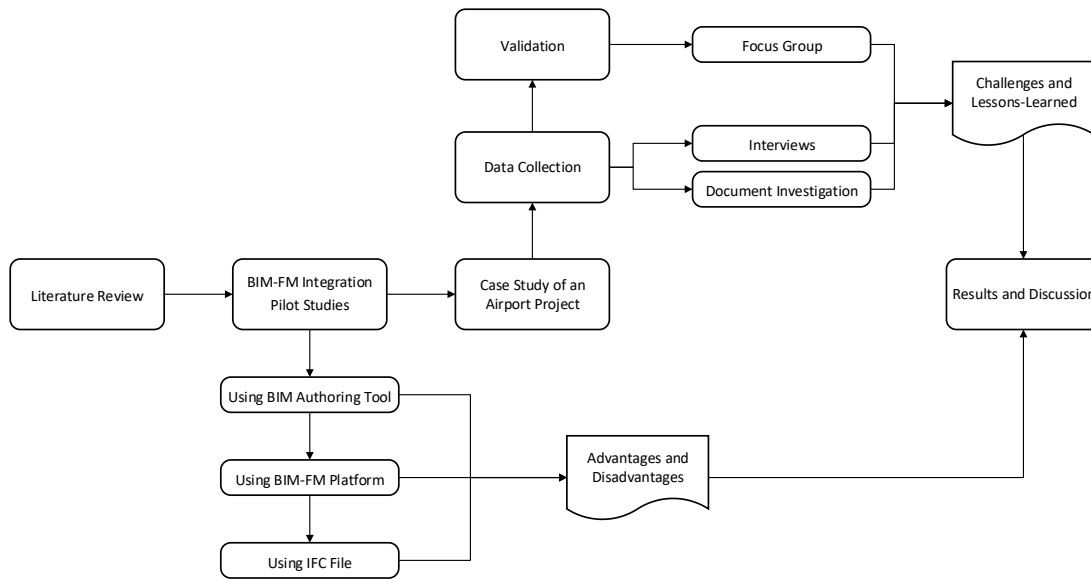


Figure 1.1 : Methodology of thesis.

1.4 Organization of the Thesis

Section 2 is the literature review, which includes definitions related to facility management phase, its data types and usage purposes, and a review of BIM, COBie, IFC concepts. BIM usage in the FM phase is also reviewed with its application areas, requirements, barriers, implementation methods and representation methods. At the end, construction classification systems are evaluated from the perspective of BIM and FM usage. Section 3 includes BIM-FM integration pilot studies, in which three main methods were utilized: (1) Using BIM authoring tool, (2) using BIM-FM platform, and (3) using IFC file format. Section 4 describes the case study of an airport project, where BIM-FM integration is applied. Project is briefly introduced and its implementation details of BIM-FM are given. It also includes methodology of case study and literature review of case studies related with BIM-FM integration. At the end of the chapter, findings of the case study are listed. Conclusion is the final chapter where all the findings are composed and discussed.

2. LITERATURE REVIEW

In this section, literature review of the research is given. After definition of facilities management phase, soft and hard facility management types are listed. Also, FM data types and their collection purposes are examined from literature. After, BIM, COBie and IFC standard are defined and explained. At the fifth part, areas of BIM in FM are given and their requirements, barriers are listed with implementation and representation methods. In the end, construction classification systems are investigated for FM purposes. It is a detail investigation since using BIM for FM has interoperability and data transfer problems without a proper construction classification system.

2.1 Facilities Management (FM) Phase in Building Life Cycle

According to Atkin et al. (2008), in a simplified vision, the building life cycle can be divided as three phases: (1) the design phase, (2) the construction phase and (3) facility management phase (Figure 2.1). The first phase includes all the engineering and architectural design documents and decisions that describes how the construction will be carried out. The second phase is the construction of the structure which is in accordance with the documents coming from design phase. When the construction is completed, the third and the longest phase of the building life cycle starts (Nordstrand, 2000). Facility management phase is the 15 to 25 times longer than the sum of the all other phases (Cotts et al., 2010). It includes operation and maintenance activities of the building. Also, the cost of the facility management phase is much higher than the other phases (Becerik-Gerber et al., 2011). It is nearly 3 times of the other phases (Rundel, 2006).

Operation and maintenance are mostly confused and misunderstood (Sääf and Alvebro, 2008). According to Nordstrand (2000), operation is the activities for the continuity of the functionality of a building, while maintenance is the activities for the conservation of the building's value and function. Operations and maintenance

activities should be managed parallel since an efficient operation depends on a well maintenance of the building (WBDG, 2017).



Figure 2.1 : Phases of the building life cycle.

There are several definitions for Facility Management. According to International Facility Management Association (IFMA), FM is the integration of people, place, process and technology to assure the functionality, comfort, safety and efficiency of the built environment with multiple disciplines (IFMA, 2019). IFMA is founded at 1980 and became the largest and the most widely recognized international association in the world for FM professionals. Atkin & Brooks (2000) states that FM aims to build an environment supporting the main objectives of the organization by operating, maintaining, improving and adapting the building. The common principle of the definitions is that FM is the middle of the interaction among organizational processes, occupants of structure and the place's itself (Sindhu & Gidado, 2014). Figure 2.2 shows the relation between building, occupant, and process with the FM phase which plays an important role to integrate them.

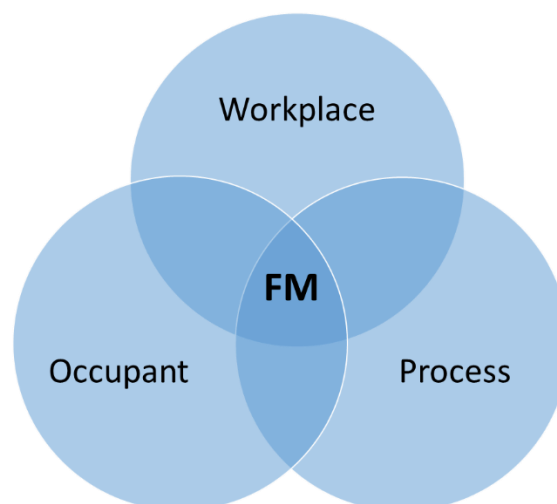


Figure 2.2 : Role of FM.

2.1.1 Soft and hard facility management

In general, FM activities can be divided as Soft and Hard FM services (IFMA, 2019; Arayici, et al., 2012). The FM services are divided for the benefits of the both FM companies and occupants. Basically, it can be said that Hard FM services are the ones which are related with the physical part of the building that is hard to be moved and Soft FM services are the ones which are mostly related with the satisfaction of the occupants. Some of the services are listed below (IFMA, 2019; Arayici, et al., 2012);

Soft FM services: Space management

Reception

Cleaning

Security

Waste disposal

Recycling

Ground maintenance

Internal plants, etc.

Hard FM services: Mechanical and Engineering

Heating, ventilation & air conditioning (HVAC)

Plumbing & drainage

Elevator & escalator, etc.

2.1.2 FM data types and purposes

During the design and construction phases, a huge number of data are created and transferred to FM phase. In addition, lots of data are created in the FM phase. However, having the access of big source of data is not a proof of efficient operation and maintenance (Singh et al., 2009). To categorize the data for FM, a literature review was done and the main types of data collected for FM activities in the reviewed papers are classified as: (1) sensor data, (2) location data, (3) occupant behavior data, and (4) occupant feedback data. Sensor data is the facility-related data that is collected with various sensors (e.g., temperature, motion, gas). Location data either includes the coordinates of an item or a person, or the area at which an item/person is located. It is

collected using localization technologies, such as Radio Frequency Identification (RFID), and Bluetooth. Occupant feedback data is the information obtained directly from users of a facility and this can include complaints and requests. Finally, occupant behavior can be described as the list of activities of an occupant along with a time stamp. Also, it is important that how the data will be used. Therefore, the literature was reviewed and revealed that there were two main purposes in collecting FM data in the reviewed studies: (1) energy analysis and (2) operation and maintenance (O&M). Table 2.1 shows the results of literature review.

Energy analysis is the main purpose of the studies that collected data for FM activities. Most of these studies focused on examining and decreasing the energy use in the buildings (Schott et al., 2012; Cheng et al., 2012; Wang et al., 2013; Ahmadi-Karvigh et al., 2016; Inyim et al., 2016; Wang and Shao, 2017). All of the studies about energy analysis utilized sensors; whereas some of them additionally integrated the sensor data with occupant behavior and location information (Cheng et al., 2012; Jazizadeh et al., 2013; Gupta et al., 2014; Pazhoohesh et al., 2015; Carmenate et al., 2015; Inyim et al., 2016; Gupta et al., 2016; Ahmadi-Karvigh et al., 2016; Wang and Shao, 2017). For example, in one of the studies, the occupant behavior was captured by collecting the times when the occupants enter and exit a room via sensors along with location data to have a better understanding about the energy consumption (Carmenate et al., 2015). Moreover, some studies used occupant feedback for performing energy analysis (Schott et al., 2012; Purdon et al., 2013; Jazizadeh et al., 2013; Gupta et al., 2014; Ghahramani et al., 2015; Gupta et al., 2016; Pritoni et al., 2017; Yang and Becerik-Gerber, 2017). In these studies, data about the occupant's thermal comfort or thermal interval preferences were collected as occupant feedback to find the optimum energy usage for air conditioning system. Temperature data was the main sensor data that was used to determine the optimal room temperature intervals (Schott et al., 2012; Jazizadeh et al., 2013; Purdon et al., 2013; Wang et al., 2013; Chen et al., 2014; Gupta et al., 2014; Riaz et al., 2014; Carmenate et al., 2015; Gupta et al., 2016; Inyim et al., 2016; Ciribini et al., 2017; Pritoni et al., 2017; Yang and Becerik-Gerber, 2017; Cheung et al., 2018; Kim et al., 2018). In addition, the occupant behavior data was combined with sensors or localization systems for energy saving purposes (Cheng et al., 2012; Carmenate et al., 2015; Inyim et al., 2016; Ahmadi-Karvigh et al., 2016). In one of the studies, researchers tracked the user's activities and recorded the usage time

of certain devices (e.g., fridge, TV) to calculate the energy consumption of each device (Cheng et al., 2012).

Table 2.1 : FM data type and purpose.

Data Type	Purpose	
	Energy Analysis	O&M
Sensor data	Cheng et al., 2012; Schott et al., 2012; Jazizadeh et al., 2013; Purdon et al., 2013; Wang et al. 2013; Gupta et al., 2014; Carmenate et al., 2015; Ahmadi-Karvigh et al., 2016; Gupta et al., 2016; Inyim et al., 2016; Ciribini et al. 2017; Pritoni et al., 2017; Wang and Shao, 2017; Yang and Becerik-Gerber, 2017; Kim et al., 2018	Chen et al., 2014; Riaz et al. 2014; Sternal and Dragos, 2016; Ciribini et al. 2017; Arslan et al., 2017; Cheung et al. 2018; Dong et al., 2018; Xu et al., 2018
Occupant feedback data	Schott et al., 2012; Purdon et al., 2013; Jazizadeh et al., 2013; Gupta et al., 2014; Ghahramani et al., 2015; Inyim et al., 2016; Pritoni et al. 2017; Gupta et al., 2016	Shen and Shen, 2011; Konis, 2013; Shalabi and Turkan, 2016; Heydarian and Becerik-Gerber, 2017; Du et al., 2018
Location data	Cheng et al., 2012; Jazizadeh et al., 2013; Wang et al., 2013; Carmenate et al., 2015; Pazhoohesh et al., 2015; Inyim et al., 2016; Ciribini et al., 2017; Wang and Shao, 2017	Ciribini et al., 2017; Dong et al., 2018; Stančík et al., 2018; Cheng et al., 2018; Xu et al., 2018
Occupant behavior data	Cheng et al., 2012; Carmenate et al., 2015; Inyim et al., 2016; Ahmadi-Karvigh et al., 2016; Ciribini et al., 2017; Yang and Becerik-Gerber, 2017	Ciribini et al., 2017; Dong et al., 2018

Second data collection purpose is related to O&M. Some of the studies in this group focused on using sensor data for safety evaluations (Riaz et al., 2014; Cheung et al., 2018; Dong et al., 2018). For instance, Riaz et al. (2014) collected sensor data to be aware of dangerous conditions caused by lack of oxygen in the air. Emergency is another focus of the studies in this category. Two of these studies focused on creating an evacuation plan after a disaster based on the location of the building elements as obtained from the BIM model (Stančík et al., 2018; Cheng et al., 2018). Another study examined the situation of the fire sprinklers after a possible earthquake using the location data of building elements and the data obtained from temperature sensor (Xu et al., 2018). Researchers also used occupant feedback data to make renovation decisions using virtual environments to decorate rooms in a building (Heydarian and Becerik-Gerber, 2017; Du et al., 2018). Also, occupant feedback in the form of questionnaire results were used to make renovation decisions (Shen and Shen, 2011).

In other studies, maintenance requests obtained from sensor data and occupant feedback were used to create work orders (Shalabi and Turkan, 2016; Yang and Ergan, 2017; Chen et al., 2018).

Since the occupants continuously experience building-related problems, occupant feedback is an important data source in FM studies for performing effective O&M activities. When the studies that collected occupant feedback were reviewed, it was determined that all of the studies focused on one particular aspect of occupant feedback data (e.g., thermal comfort) and there were no studies that collected occupant feedback about all building-related issues. In one of the studies, the goal was to determine the types of feedback data that were needed for performing HVAC-related maintenance activities (Yang and Ergan, 2017). Even though there are studies that created work orders using the occupant maintenance requests (Shalabi and Turkan, 2016; Chen et al., 2018), it should be noted that these requests should be enriched with extra information obtained from the occupant, such as the type of complaint and its source.

The studies investigating the requirements of the data at FM phase concluded that these various types of data could not be presented to the decision makers efficiently (Motawa and Almarshad, 2013; Motamedi et al., 2014; Ilter and Ergen, 2015).

2.2 Building Information Modeling (BIM)

Software usage is spread in the building life cycle with the development of the computer technology (Wikforss, 2003). All the phases in the building life cycle have lots of problems and many researchers propose to use Building Information Modeling (BIM) to provide solution for these problems (Hardin, 2011; Eastman et al., 2008). BIM does not mean only software packages for construction industry, but also means a process (Bryde et al., 2013). Definition of the BIM can be divided two parts depending on the meaning of “M” as “Building Information Model” and “Building Information Modeling” (Smith and Tardif, 2012). BIM Alliance Sweden (2019) states that “Building Information Model” refers model of a facility with object-based representation, besides, “Building Information Modeling” refers a process of creating and using building information model at the building life cycle.

According to Eastman et. al. (2011), Building Information Modeling is a digital representation of the building process that is used to facilitate the exchange and

interoperability of information in digital format (Eastman et al., 2011). Another description says that BIM is a digital representation of a facility with physical and functional characteristics of it (American National Institute of Building Sciences, 2007). It can be understood from definitions that building information models are not a basic 3D models. The main point that differs BIM from 3D model is the object-based structure (Smith and Tardif, 2012). In a basic 3D model, there are only geometrical shapes consisting of lines, surfaces and masses, while in a BIM model there are smart objects that know its characteristics as a building component such as window, wall, and door. For example, a door knows that it can only be placed on a wall. When a door is placed on a wall, that wall creates an opening for the door. Besides the geometric information, all the objects can also have non-geometric information. A BIM model can store the whole quantity, cost estimation and project schedule information inside (Azhar, 2011). In general, BIM is a single data model including the whole created information in the building life cycle, while all members of the project can have the direct accessibility to the model and adding/removing information opportunity from it (Smith and Tardif, 2012).

In the beginning, BIM was generally for the architects and engineers who want to do clash detection, visualization and quantification at the design phase (Volk et al., 2014). After development in the sector, the application areas are increased and many areas started to be used such as scheduling, health & safety, energy analysis, operation & maintenance. The purpose is the use the BIM model in the design, construction and facilities management phases by simulating the construction process in a digital environment (Azhar, 2011).

2.3 COBie

When a construction is completed, contractors are responsible to handover some type of documents such as equipment list, warranties, and product data sheets to facility management team. A study shows that during the collection of handed over documents, 30% of the data has errors (East and Nisbet, 2010). Construction Operations Building Information Exchange (COBie) is a tool developed for the transfer the created building data from design and construction phases to FM phase (WBDG, 2016). It aims to solve interoperability problems of FM related data transfer among the software packages (Young et al., 2008). COBie is a documentation standard

to increase the efficiency of building life cycle with reducing the operating costs (WBDG, 2016). It eliminates the not-organized boxes with full of documents at the handover phases.

COBie does not include geometric visual information, it is more likely an excel spreadsheet including text data with relationships (Tarandi, 2012). Project participants at the design, construction and commissioning phases create different type of information (WBDG, 2016). Figure 2.3 shows the process and some of the information types. Delivering the information part on the process is done by COBie (Eastman, 2011).

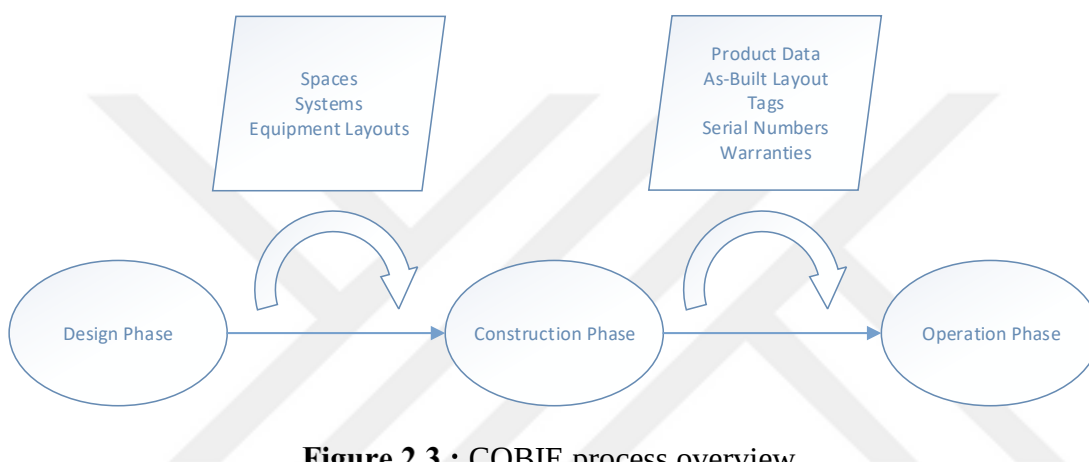


Figure 2.3 : COBIE process overview.

COBie describes the fields to enter the data. As a simply usage, it is an excel spreadsheet consisting 16 different worksheets (WBDG, 2016). These worksheets are named as contact, facility, floor, space, zone, type, component, system, spare, resource, job, document, attribute, coordinate, connection, and issue. An example of a COBie sheet can be seen at the Figure 2.4. At every phase some of the worksheets are filled. For example, facility, floor, space, zones, and systems should be filled during the design phase. At the construction phase, job, resources, and spare worksheets should be filled, while type and components can be filled during both design and construction phases. Lastly, contacts, documents, issues, coordinates, attributes, and connections worksheets are the common fields that can be filled any of the phases (WBDG, 2016).

	Name	ExtentIdentifier	ReplacementCost	ExpectedLife	DurationUnit	WarrantyDescription	NominalLength	NominalWidth	NominalHeight	ModelReference	Shape	Size	Color	Finish	Grade	Material
2	1810 x 2110mm	1CDIQ4E3	n/a	n/a	year	n/a	1810.0	150.0	2110.0	Generic Int DD:1810 x 2110mm	n/a	n/a	n/a	n/a	n/a	Generic
3	790 x 2110mm 3	1uSEcSY8	n/a	n/a	year	n/a	790.0	150.0	2110.0	Generic Int D Cell Door:790 x 2110mm	n/a	n/a	n/a	n/a	n/a	Generic
4	Cell Bed family	0uCr33MT	n/a	n/a	year	n/a	2000.0	700.0	400.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
5	Desk Whitewood	0uCr33MT	n/a	n/a	year	n/a	1360.0	450.0	900.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6	Cell Locker	0uCr33MT	n/a	n/a	year	n/a	500.0	450.0	1000.0	n/a	n/a	n/a	n/a	Whitewo	n/a	Whitewo
7	Safer Seat	0uCr33MT	n/a	n/a	year	n/a	500.0	500.0	500.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
8	1275x1200h	1ZA U6n	n/a	n/a	year	n/a	1275.0	340.0	1200.0	Safer Cell 7 Bay FF:1275x1200h	n/a	n/a	n/a	Generic	n/a	n/a
9	Basic Wall:Generic Ext - 150mm	n/a	n/a	n/a	year	n/a	1000.0	150.0	2700.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
10	Basic Wall:Generic Ext - 340mm	n/a	n/a	n/a	year	n/a	1000.0	340.0	2700.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
11	Basic Wall:Generic Ext - 80mm	n/a	n/a	n/a	year	n/a	1000.0	80.0	2675.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
12	Concrete (Painted)	n/a	n/a	n/a	year	n/a	1000.0	1000.0	1000.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
13	Generic	n/a	n/a	n/a	year	n/a	1000.0	1000.0	1000.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
14	Generic Inserts	n/a	n/a	n/a	year	n/a	1000.0	1000.0	1000.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
15	Material Brickwork	n/a	n/a	n/a	year	n/a	1000.0	1000.0	1000.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
16	TFT Monitor	n/a	n/a	n/a	year	n/a	400.0	75.0	400.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Figure 2.4 : Example of a COBIE Excel Sheet.

2.4 Industrial Foundation Classes (IFC)

IFC is an open, international standard for exchanging BIM data (buildingSMART, 2019). It is created by an international organization named buildingSMART for AEC/FM industry and approved as ISO 16739 standard. Several stakeholders involve during the lifecycle of building and they all use different software packages in purpose of design, engineering and project planning. Because of the lack of interoperability among the software packages there are some problems. Therefore, IFC is an emerging solution. IFC has an object-oriented structure and it consists of objects representing the components and systems of a building, along with the relationships among those objects. An IFC model can have the physical building components such as wall, window and door, while having non-physical objects such as schedule, activity, etc. Data created over the lifecycle of a project can be stored and exchanged using the IFC schema. When the data is represented in IFC format, it can be viewed and processed by using IFC viewers or any BIM-based software packages. There are many free IFC viewers developed to visualize the geometry of model with properties of elements. Even though, IFC has some limitations, it is the most neutral standard which is in accordance with wide range of software packages in the AEC/FM industry (Froese, 2003; Wang, et al., 2013).

The current IFC schema does not cover all the information created and exchanged throughout the life-cycle of a building. Therefore, the researchers have been working

on developing new definitions by extending the IFC format based on the AEC/FM industry needs. Examples of those studies include extensions proposed for project estimating and scheduling, construction project management, structural analysis, nD modeling applications, cost estimation, modeling precast facades and precast concrete elements, road structure elements and as-damaged building components (Froese et al., 1999a; 1999b; Weise et al., 2003; Fu et al., 2006; Sacks et al., 2010; Ma et al., 2011; Li and Kim, 2011; Ma et al., 2015).

To extend the IFC standard, three methods can be used (Motamedi et al., 2016): (1) using property sets or types, (2) utilizing proxy elements, (3) defining new entities or types. First method is to add extra information in text format under the `IfcPropertySet` class in the entities defined in the IFC standard (Sternal and Dragos, 2016; Shalabi and Turkan, 2016). This method was used by most of the studies in the literature. For example, sensor data is represented in the `IfcSensor` class as an `IfcPropertySet` for FM purposes (Sternal and Dragos, 2016; Andriamamonjy et al., 2015; Chen et al., 2014). This method is preferred when there is an existing IFC class that serves a similar purpose to that of the new class. Since all the relations are already defined inside the existing class, the only necessity is the adding additional text information by using `IfcPropertySet` class according to purpose of usage. The second method is to create a new class by using proxy elements, such as `IfcBuildingElementProxy` (Motamedi et al., 2016). Proxy element allows for adding new entities that can be related with other entities, spaces, actors, and property sets. Therefore, this method is preferred when the current IFC standard does not include an entity that serves a similar purpose that can be used to represent the required element and the related information. When this method is used, the required relations of the new class with other elements and spaces need to be defined. The related text data is still represented by utilizing the first method, which is using `IfcPropertySet`. To apply the second method, IFC file that is created in EXPRESS language format needs to be modified manually by using a text editor. Finally, the third method is defining new entities or types; however, these should be formally approved by buildingSmart, which can take at least two years (Weise et al., 2009). Thus, this third method is not a practical approach to extend IFC (Motamedi et al., 2016).

2.5 BIM in FM

As stated in the previous sections, the positive effect of the BIM in the FM phase has not been seen yet, while it is used mostly in the design and construction phases (Teicholz, 2012). According to Becerik-Gerber et al. (2011), even though the FM phase has the biggest portion of the total cost, professionals try to decrease the initial cost of the project by focusing on design and construction phases. Besides, the duration of the FM phase is nearly 5 times of the sum of the durations of the other phases (Eastman et al. 2011). It shows that the efficiency of the BIM usage can be seen at the FM phase rather than the initial phases. Also, FM teams spent 10-30% of their time on searching the required information (Latham, 1994). According to Eastman et al. (2008), BIM is a useful tool to deliver and use the building information efficiently with reduced time and cost. BIM is an efficient supporting technology for the main role of the FM team, which is integrating people, place and process in purpose of keeping the function of the building (IFMA, 2011). Therefore, the potential of the BIM has been realized by professionals and their interest is grown to use BIM in FM phase (Becerik-Gerber et al., 2011). In a study of Becerik-Gerber et al. (2011), the current and possible 10 application areas of BIM in the FM phase are determined:

- (1) *Locating building components:* Rather than blueprints, using 3D model enriched with equipment information is more efficient and faster to locate the needed component if there is a new personnel who does not know the building or in case of emergency situation.
- (2) *Facilitating real-time data access:* FM personnel can easily store and reach the data related with the specific building component. Also saved data history can be used for decision making.
- (3) *Visualization and marketing:* 3D BIM model can represent the building itself and environment to make analyses and decision supporting for renovation. Besides, it can be used for the marketing such as renting the stores by showing the interior spaces with furniture.
- (4) *Checking maintainability:* A BIM model can provide the information about the maintainability works such as accessibility, sustainability of materials, and preventive maintenance.

(5) *Space management*: Rather than the CAD drawings, a BIM model provides more visualization features. With the help of boundaries, volume, areas, space status, etc., it is possible to forecast the space requirements, plan moving processes, assign spaces to the people or groups, and see underutilized spaces.

(6) *Creating and updating digital assets*: In traditional methods, it is hard to collect, organize and transfer the data coming from early phases of the building life cycle to FM system. Since BIM model can store the information of different disciplines, and transferring of these information can be digitally automated, BIM usage is more efficient and faster than traditional methods.

(7) *Planning and feasibility studies for noncapital construction*: In the activities of planning, designing, analyzing, and simulation of renovation or demolishing, BIM model can be used as a decision supporting tool. Besides, the data including historical records of material usage, labor hour, and cost of a specific activity can be used for the future renovation works.

(8) *Emergency management*: Especially the 3D visualization tool of BIM model can be used to understand the emergency problems and locate the hazardous locations. Also, it can simulate the evacuation plans in case of an emergency situation.

(9) *Personnel training and development*: A visual BIM model can be used to train the new personnel by allowing them to walk around the model and investigate the building components. Also, when the existing working space is changed, it can be used for same purposes for the existing personnel.

(10) *Controlling and monitoring energy*: Building components inside the BIM model can be linked with sensors. It allows to both monitor the energy consumption of the building and control the components by such as shutting down or decreasing the power. Besides, historical energy consumption data can be used for decision-making.

2.5.1 Requirements of BIM-FM implementation

There are some requirements to use BIM in FM phase for implementation and increasing the efficiency. These requirements are found from literature and shown at the Table 2.2.

- (1) *FM team should involve the project from the design phase*: To proceed the facility management phase by using BIM, the required information for FM phase should

be determined before the handover. However, required information for FM activities are not fully listed or clearly defined in the literature (Clayton et al., 1999). Eventhough there are some studies about the created information during the FM phase, it is not clear that which information created before the FM phase should be stored (Yang and Ergan, 2017). Some standards define the procedures of collection of the information and storing data, though, they only define the method not the information itself (BSI, 2014). Since design and construction teams do not know the which information is needed for the FM phase, some of the FM members who will facilitate the building should be involved the project from the initial phases of the building life cycle (Liu and Issa, 2016). According to Mohammed and Hassanain (2010), involving the FM team into design phase will decrease the big size of changings at the project. Also, Arditi and Nawakorawi (1999) stated that early detection of the mistakes at the design phase with the help pf the FM members will decrease the problems of FM phase nearly 50%.

Table 2.2 : Requirements of BIM-FM integration.

Requirements	References
FM team should involve the project from the design phase	(Liu and Issa, 2016)
FM team should include members who has the modeling skills	(Korpela et al., 2015)
A correct as-built model should be created for the FM phase	(Eastman et al., 2011) (Huber et al., 2011)
Software packages used during the FM phase should be compatible with BIM	(Becerik-Gerber et al., 2012)
Collected data before the FM phase should be transferred to BIM-FM platform in a correct way	(Becerik-Gerber et al., 2012)
Indoor localization systems should be used	(Becerik-Gerber et al., 2012)
A proper construction classification system should be used in accordance with FM requirements	(Akcamete et al., 2010)

(2) *FM team should include members who has the modeling skills:* During the FM activities, BIM model should be updated periodically. Therefore, some of the FM team members should have the modeling skills, besides all the team should have knowledge of BIM process (Korpela et al., 2015).

(3) *A correct as-built model should be created for the FM phase:* To integrate the BIM and FM phase, BIM model should be created according to up-to-date situation of the

building, since differences between the model and real building could generate some problems (Korpela et al., 2015). Instead of the model created at the design and construction phases, an as-built model should be used at the FM phase (Eastman et al., 2011; Huber et al., 2011). Laser scanning and photogrammetry technologies can be used to create the correct as-built FM model (Kempter et al., 2015).

(4) *Software packages used during the FM phase should be compatible with BIM:* There are several FM software packages in accordance with BIM, though, most of the FM software packages which are currently used at the existing buildings are not in accordance with BIM (Kiviniemi and Codinhoto, 2014). The potential of the using created data with BIM for the FM activities such as space management, energy analysis, and tracking work-order is high, however, software packages used for these activities should be well integrated with BIM (Becerik-Gerber et al., 2012).

(5) *Collected data before the FM phase should be transferred to BIM-FM platform in a correct way:* During the building life cycle, lots of data are created to use for different purposes (Yang and Ergan, 2017). It is possible to collect and store all the created information thanks to BIM (Liu and Issa, 2016). Stored FM information inside the BIM model should be transferred to FM phase automatically to prevent the data losing at the traditional manual method (Becerik-Gerber et al., 2012). Construction Operations Building Information Exchange (COBie) standard, which is generated specifically for this purpose, can be used to build a link between BIM and FM (East, 2007). COBie will be explained in detail at the next sections.

(6) *Indoor localization systems should be used:* To complete the FM activities efficiently, required building components should be correctly located and location information should be stored (Becerik-Gerber et al., 2012). Building equipment can be tracked by using the systems like barcode or QR-Code, while real-time location information can be reached remotely by using indoor localization systems such as Wi-Fi and Bluetooth.

(7) *A proper construction classification system should be used in accordance with FM requirements:* A construction classification system is needed to track and control the data created during the building life cycle (Becerik-Gerber et al., 2012). Especially for the efficient FM activities, a standard classification is required (Akçamete et al., 2010). A detailed result will be given at the next sections.

2.5.2 Barriers of BIM-FM implementation

Table 2.3 shows the list of barriers encountered during the integration of BIM and FM. It can be seen that the biggest problem is the data transfer among the software packages used for the FM activities and BIM process. Another mostly encountered barrier is the lack of BIM knowledge and experience of FM members, since BIM is a new approach for the FM phase. In addition, there is no proof that shows the positive results of a real BIM-FM implementation.

Table 2.3 : Barriers of BIM-FM implementation.

Barriers	References
Interoperability problems between BIM authoring tools and FM software packages	(Becerik-Gerber et al., 2012) (Kiviniemi and Codinhoto, 2014) (Migilinskas et al., 2013) (Kassem et al., 2015) (Terreno et al., 2016) (Korpela et al., 2015)
Unclear roles and responsibilities of uploading information and checking model in FM phase	(Becerik-Gerber et al., 2012) (Kassem et al., 2015) (Nguyen et al., 2017)
Cultural resistance of accepting new technology	(Becerik-Gerber et al., 2012) (Motamedi and Hammad, 2009)
Not proven positive returns with real-world cases	(Becerik-Gerber et al., 2012) (Migilinskas et al., 2013) (Kassem et al., 2015)
Resistance in firm for requirements (i.e. investment of infrastructure, new software packages and training)	(Becerik-Gerber et al., 2012) (Migilinskas et al., 2013)
Inefficient collaboration among project stakeholders	(Becerik-Gerber et al., 2012) (Migilinskas et al., 2013) (Kiviniemi and Codinhoto, 2014) (Kassem et al., 2015)
Unclear capabilities of BIM in FM phase	(Nguyen et al., 2017) (Migilinskas et al., 2013) (Kassem et al., 2015)
Lack of BIM experience of FM members	(Motamedi and Hammad, 2009) (Korpela et al., 2015)
High initial investment cost	(Motamedi and Hammad, 2009)
Unknown required data transfer from design and construction phase to FM phase	(Nguyen et al., 2017)

2.5.3 Implementation of BIM with FM

As mentioned at the previous sections, BIM provides many application areas with many benefits at the FM phase. It is important to consider every BIM-FM implementation as a unique, since every organization is different than others (Smith

and Tardif, 2012). Therefore, implementation processes should be evaluated after the FM organization is investigated to understand the characteristics organization, proper application areas and required building data. The general BIM-FM implementation example according to specific organization will be given at the case study section. At the following of this section, some BIM usage examples at the FM activities from the literature will be given.

Most of the examples for BIM-FM integration are related with operation & maintenance (O&M) activities. In a study, work orders are managed by using 3D BIM model (Akçamete et al., 2010). Performed O&M works are saved on the related building components as a text information such as “installed” or “replaced”. After giving some specific geometrical shapes according to their status, work orders are tracked on the 3D model. In other study, Kassem et al. (2015) created models of some buildings inside the Northumbria City University Campus by following the existing blueprints to use the visualization of the models for some FM activities. For example, building components are given colors according to their specific properties to follow them on the model. Also, interior furniture renovations are simulated on the model to make a decision. Another study focused on tracking fire equipment with the help of RFID system (Motamedi and Hammad, 2009). O&M works of fire equipment are tracked with RFID system. Besides, they have easily located in the model with RFID tags. Kim et al. (2018) used the common data file format, IFC, to follow the work orders by relating O&M works with the building equipment. They have export the BIM data from the IFC file with their algorithm and link them with FM activities. Another study aimed to sort work orders in an optimum order for an effective O&M process (Chen et al., 2018). The work orders are related with building components with their emergency and process duration data. After, system used the components location data to arrange the order of the work orders. Davtalab (2017) tried to establish the profit of the BIM usage at O&M activities compared with traditional methods. He used the BIM-FM platform EcoDomus for the O&M works. Same maintenance works are simulated by using both traditional method and BIM approach. The study shows that using the EcoDomus platform, which is in accordance with BIM, saves the time nearly 80% when compared with traditional method. In a health facility, Lucas et al. (2013) aimed to develop a prototype which includes several O&M scenarios to help the technicians solve the problem. Occupants use the system to send the problems they

have encountered to the FM team by linking the related building component. The problems are solved and tracked by technicians with the help of previously saved scenarios and BIM model.

There are also studies aside from operation and maintenance purposes. For instance, Ploennigs et al. (2011) aimed to show sensor data on the BIM model. The temperature sensors inside the rooms send the real time data to the BIM model. The colors of the rooms inside the model are changed according to their temperature interval and it is easily established if any of the room is out of the determined temperature interval. Some of the studies are focused on simulating emergency and disaster situations to analyze. In Germany, a model of fire training house was created and send to game engine to simulate several fire disaster situations (Rüppel and Schatz, 2011). By using virtual reality technology, firemen are trained inside the 3D model. Another study aimed to see the possible effects of a flood disaster by integrating geographic information system (GIS) and BIM (Amirebrahimi et al., 2015). Building data coming from BIM is combined with flood data coming from GIS and it is determined that which buildings will be effected in which level by simulating the flood. Bruno et al. (2018) defined the methodology of BIM usage for the sustainability of historical building. The defined methodology explains the processes from collecting the data of historical building to renovation of the building.

2.5.4 Representation of FM data

The collected FM data needs to be represented in databases or BIM models to be processed and used for decision-making purposes. It was observed that three main methods were used to transfer and represent FM data in the reviewed studies. The first method has a simplified approach and requires users to enter O&M related data directly to BIM-based software packages for visualization of the FM data in 3D (Cheung et al., 2018; Arslan et al., 2017; Shalabi and Turkan, 2016; Pazhoohesh et al., 2015; Riaz et al., 2014; Wang et al., 2013; Shen and Shen, 2011). The second method is to use Application Programming Interfaces (API) to transfer the data to the related software and represent it in its own data storage system. This software can either be a BIM-based software or not. Most of the researchers represented the collected data using APIs or add-ins of certain software packages (e.g., Autodesk Revit), and transferred it to the related software package to be stored and processed (Schott et al,

2012; Purdon et al, 2013; Chen et al, 2014; Riaz et al., 2014; Pazhoohesh et al., 2015; Inyim et al, 2016; Pritoni et al, 2017; Cheung et al., 2018; Du et al., 2018). In some studies, APIs were used to transfer data to software packages (e.g., Navizon) that visualize the location of occupant (Shen and Shen, 2011; Wang and Shao, 2017; Cheung et al, 2018). A major disadvantage of this method is not being flexible. When the software package that is used is replaced by another one or even when the version of the software package changes; data representation schema needs to be modified based on the new API of the software. Some studies developed add-ins using APIs for Autodesk Revit or Navisworks software packages to view the collected sensor data (Chen et al, 2014; Riaz et al., 2014; Cheung et al., 2018), use the model as a virtual reality environment (Du et al., 2018) and check the LEED analysis of the building (Pazhoohesh et al., 2015).

The third method to represent the FM data is to use IFC format. Extending IFC file for FM purposes is mentioned at Section 2.4.

2.6 Construction Classification Systems

At the construction life cycle, large sets of data are created at every phase of the cycle (Yang and Ergun, 2017). An effective construction classification system is needed to control, follow and use this data through different phases (Becerik-Gerber et al., 2012). Moreover, standardization of the classification system is necessary to enable effective data transfer among different disciplines. The need for a standardized classification is even more prominent for facilities management (FM) phase, since supporting a facility's operation, maintenance and repair activities requires well-organized information (Akçamete, 2011). Most of the classification systems in the construction sector are suitable for design and construction phases of life cycle, but there are different requirements that should be considered for the FM phase. For instance, the type of a pump is important for the FM members, however, the purpose of the pump is more important for the construction engineer. Therefore, the classification systems should also consider the FM requirements for the sustainability of the life cycle.

2.6.1 FM requirements for classification system

With the literature review, the requirements of the construction classification system, especially from the perspective of FM, were determined. The most important need that

was identified is related to the categorization structure. Grouping the elements according to their functions is more suitable for FM purposes. For a facility manager, the purpose of the pump (e.g., waste pump) is not a critical information but type of the pump is important (e.g., centrifuged or air-pressured (Keady, 2013). Another example is that a fan motor can be classified as supply fan motor (SFAN) and return fan motor (RFAN). Actually, they are same fan motors but just its orientation is different: it is turned 180 degrees. Giving different names for these fan motors is not an effective classification for a facility manager. There should be object-oriented classification for the fan motors and they should associate to the systems after the classification of the fan motors' itself. The identified requirements are listed below. The requirements that are of critical importance are categorized under primary requirements and the requirements that are preferable are listed under secondary requirements (Keady, 2013; NATSPEC, 2008).

Primary requirements:

- (P1) To have a categorization system that focuses on function of the object rather than other properties of the object, such as the system that it belongs to or the material of the object.
- (P2) To have an open-standard that can be updated upon formal request of the users.
- (P3) To have an extensible and flexible structure that enables adding new elements to the structure.
- (P4) To be in accordance with international standards.

Secondary requirements:

- (S1) To be international classification system
- (S2) To be commonly used in the construction sector.
- (S3) To be used by different disciplines to enable effective data transfer among different disciplines.
- (S4) To be compatible with Building Information Modelling (BIM) for enabling integration with BIM models.

For FM usage, primary requirements should be provided by classification system. P1 is explained above. P2 and P3 is important, since any new or unique element should be coded easily when there is a need. In addition, P4 should also be provided for the interoperability. Providing secondary requirements could strengthen the usage of classification system at FM phase, though they are not mandatory requirements. To be used for all the projects in different countries, S1 and S2 should be matched with the classification system. In addition, S3 is important for the interdisciplinary working. Also, S4 is preferable for the compatibility with BIM.

2.6.2 Classification systems for FM usage

In general, two categorization principles are used when developing classification systems: (1) hierarchical (direct) categorization and (2) faceted (combinatory) categorization (Afsari and Eastman, 2016). If hierarchical categorization is used, the elements are grouped according to a property, such as functions or construction systems, and new elements cannot be added without official revision (Cann, 1997). In a faceted categorization, the attributes are grouped under facets and an element can be described as combination of these facets. For example, in a hierarchical system, a water distribution pipe should be under water distribution system according to system-based grouping; but, in a faceted system, water distribution pipe can be created as a combination of pipe under product facet and water distribution system under building systems facet. Also, if there are new elements that contains the same pipe at the roof system, it can be represented by using existing facets as the combination of pipe and roof system; however, this cannot be represented in the hierarchical system since it is a new element (Ekholm, 1996).

Table 2.4 provides the list of main construction classification systems in the literature. Most of the information about the classification systems were gathered at the official websites of classification systems or organizations. For some classification systems, there is very limited information, especially for the national ones that are in other languages.

Table 2.4 : Investigated classification systems.

Classification Systems	References
NATSPEC	(NATSPEC, 2008)
Masterspec	(NATSPEC, 2008) (Masterspec, 2017)
DBK	(NATSPEC, 2008) (Jorgensen, 2011)
Building 90	(NATSPEC, 2008) (Rakennustieto, 1999)
NL/SfB	(NATSPEC, 2008) (BNA, 2005)
CoClass	(NATSPEC, 2008) (CoClass, 2018)
UNSPSC	(Keady, 2013) (Turner, 2006)
MasterFormat	(Keady, 2013) (Afsari and Eastman, 2016)
UniFormat TM	(CSI, 2013) (Lou and Goulding, 2008)
UNIFORMAT II	(Afsari and Eastman, 2016) (CSI and CSC, 2010)
Uniclass	(Keady, 2013) (Charette and Marshall, 1999)
OmniClass	(NATSPEC, 2008) (Afsari and Eastman, 2016) (Lou and Goulding, 2008) (NBS, 2017)
	(Keady, 2013) (NATSPEC, 2008) (Lou and Goulding, 2008) (OmniClass, 2006)

(1) *NATSPEC*: In Australia, NATSPEC is the first national unified construction classification system that was developed in 1989 (NATSPEC, 2008). The first revision was performed in 2005 when it is decided that NATSPEC will be a similar structure as Masterspec, which was developed at New Zealand. Another revision was done in 2007 and large number of new work groups were included in NATSPEC. It is a hierarchical system and consists of 4-digit coding (e.g. 02 Site > 024 Landscape > 0240 Gardening). The coding structure of NATSPEC is not intuitive and it only provides one of the primary requirements.

(2) *Masterspec*: Masterpec is a national construction classification system of New Zealand managed by Construction Information Limited (NATSPEC, 2008). It contains seven libraries with more than 880 sections (Masterspec, 2017). It has the same structure as NATSPEC with 4-digit notation and hierarchical structure. Masterspec has a very similar structure as NATSPEC, and have the same limitations to be used for FM purposes.

(3) *Dansk Bygge Klassifikation (DBK)*: DBK system was developed under “Digital Convergence” program for the standardization of the activities of construction sector (NATSPEC, 2008). It has been developed at Denmark in 2006. Its structure is hierarchical and based on the building systems such as wall system, roof system, etc. (Jorgensen, 2011). It divides the elements of a building as a subclass of building

systems (e.g. Wall System > Window > Window Glass). The information about this classification is limited since it is not in English.

(4) *Talo 90 (Building 90)*: Talo 90, which is used commonly by “Finnish Engineering Community”, has been developed at Finland in 1999 (NATSPEC, 2008). It is the last version of Talo 70 and Talo 80. It has a faceted structure, which is one of the primary requirements that were identified, and it is based on ISO/TR 14177 standard (Rakennustieto, 1999). Its coding system is maximum 3-digit with numbers and letters (e.g. J Information System Services > J1 Telephone Systems > J11 Public Telephone Network Systems). Even though it has a faceted system, the drawback of this system is that it is not an international system, and the classification system was developed for cost estimation and process control during construction (Rakennustieto, 1999).

(5) *Elementenmethode (NL/SfB)*: Elementenmethode is a construction classification system that was developed in the Netherlands based on Swedish classification system, Samarbetskommitten for Byggnadsfragor (SfB), and in accordance with ISO 12006-2 standard (NATSPEC, 2008). It has five tables with elements represented with combinations of numbers and letters, and this combination structure varies at every table (BNA, 2005). For example, coding includes only numbers at the “Functional Building Elements”; and lowercase letter and number are included at the coding of “Construction Resources” (Table 2.5). Although it has a faceted structure, the limitation of NL/SfB is that it is a national classification system and it is not in English.

Table 2.5 : Coding structure of NL/SfB.

Code	Name
Table 1	FUNCTIONAL BUILDING ELEMENTS
3	Dismantling
34	Balustrade and Handrail
34.1	Balustrade
Table 3	CONSTRUCTION RESOURCES
e	Natural Stone
e2	Marble

(6) *CoClass*: CoClass has its roots in another classification system called Byggandets Samordning AB (BSAB). BSAB was developed in 1972 at Sweden (NATSPEC, 2008). Over time, the BSAB has been modified and at the end of the BSAB 2.0 project, CoClass was released (CoClass, 2018). It is a faceted system and contains seven main tables and two additional tables with elements coded as the combination of letters and

numbers. Since it is a faceted classification system, an element can be described as a combination of these tables. For example, a light fixture can be described with its related building system as seen at Table 2.6. CoClass is still being updated and some portion of the classification system has not been translated to English yet. It can be suitable as a classification system to be used for FM purposes when the translation and revision is completed because it is faceted, open-standard, object-oriented and in accordance with ISO 12006-2.

Table 2.6 : Coding structure of CoClass.

+CAB10=K.HH.UAA011%HH07	
Code	Name
CAB10	Transport tunnel no 10
K	Electrical system
HH	Lighting system
UAA011	Light fixture no 011
HH07	Emergency and backup lighting system

(7) *United Nations Standard Products and Services Code (UNSPSC)*: UNSPC is an international product and service classification system that allows classifying wide range of elements from animals to check valve (Keady, 2013). It is an open-standard and its structure is hierarchical with eight-number element codes (Turner, 2006). The coding structure starts with segment and continues with family, class and commodity (Table 2.7). The limitations of this classification system are (1) it does not include all of the equipment that used in facilities, and (2) it is not widely used at international area (Keady, 2013).

Table 2.7 : Coding structure of UNSPSC.

Code	Name
44101501	Photocopiers
Segment 44	Office equipment and accessories and supplies
Family 10	Office machines and their supplies and accessories
Class 15	Duplicating machines
Commodity 01	Photocopiers

(8) *MasterFormat*: MasterFormat has been developed by The Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC) and it is mostly used at North America for organizing the construction specifications and cost estimation (Keady, 2013). Its main structure is based on work results, a galvanized

pipe can be categorized both as a type of handrail and water pipe (Afsari and Eastman, 2016). Element coding system has four degrees and mostly six digits with hierarchical structure (Table 2.8) (Afsari and Eastman, 2016; CSI, 2013). In some elements, the fifth degree, that could be both digit and letter, can be used for more detail (Lou and Goulding, 2008). Since MasterFormat is based on work results, it contains mounted equipment and materials (Keady, 2013). The work-breakdown structure of MasterFormat is not based on functionality, and it is only based on mounted elements and systems (Keady, 2013). For instance, a centrifugal pump can be found under both fire protection system and water distribution system but it is not classified as a centrifugal pump, as required for the FM purposes. It is an international classification system but other FM requirements are not met.

Table 2.8 : Coding structure of MasterFormat.

Code	Name
08	Openings
08 30	Specialty Doors and Frames
08 31	Access Doors and Panels
08 31 13	Access Doors and Frames
08 31 13.53	Security Access Doors and Panels

(9) *UniFormatTM*: Similar to UniFormatTM, MasterFormat has been developed by CSI and CSC. The difference is that its classification is based on functional elements, which describes the elements only by their functions without considering their materials or systems (Afsari and Eastman, 2016). Its structure is hierarchical with 5-level coding and UniFormatTM is in accordance with ISO 12006-2 (CSI and CSC, 2010). Also, it can be extended with codes coming from MasterFormat. For example, a continuous footing can be described with its material by adding the element code of cast-in-place concrete from MasterFormat (Table 2.9). Even though UniFormatTM can be extended with MasterFormat codes similar to faceted systems, it is hierarchical and not object-oriented. It is more suitable than MasterFormat for FM purposes; because, the grouping is according to functions of elements and it is in accordance with an international standard.

Table 2.9 : Coding structure of UniFormat™.

Code	Name
A1010.10.CF.033000	Continuous Footing with Cast-In-Place Concrete
A1010.10.CF 033000	Continuous Footings (from UniFormat™) Cast-In-Place Concrete (from MasterFormat)

(10) *UNIFORMAT II*: UNIFORMAT II has been developed by American Society for Testing and Materials (ASTM) and it is in accordance with ASTM E1557-97 standard (Keady, 2013). Even though the names are similar, UNIFORMAT II and UniFormat™ are different classification systems. Its structure is hierarchical and has four levels with 7-digit (Charette and Marshall, 1999). It has similar structure with MasterFormat (Table 2.10). Similar to MasterFormat, some difficulties could be faced with when it is used for FM purposes (Keady, 2013). It is in accordance with an international standard, but it is hierarchical and categorization is based on construction systems. Besides, the maximum number of element coding with an iteration up to 4-level is 825 at UNIFORMAT II (Keady, 2013). It is limited when compared with OmniClass and Uniclass that have more than 6000 elements. Since the number of elements that were defined in this classification system is low, it results in high customization of the system by adding new elements that were required by the companies for their own purposes. This approach hinders the data exchange among different disciplines and parties at different phases.

Table 2.10 : Coding structure of UNIFORMAT II.

Code	Name
D	Services
D30	HVAC
D3030	Cooling Generating Systems
D303001	Chilled Water Systems

(11) *Unified Classification for the Construction Industry (Uniclass)*: Uniclass is an international classification system, which was developed at England at 1997, for organizing the construction life cycle phases (NATSPEC, 2008). It was in accordance with ISO TR 14177 at first, then it has been adapted to ISO 12006-2 after a revision (Afsari and Eastman, 2016). It is a faceted classification system and with the last revision, the number tables decreased from 15 to 11 (Afsari and Eastman, 2016; Lou and Goulding, 2008). The coding system is mostly 4-level and sometimes 5-level with 2-digit for representing every level. Uniclass tables were designed for asset

management and facility management (NBS, n.d.). When the product table is investigated for the FM purposes, it can be seen that there are plenty of elements (i.e., more than 6500) defined and they can be associated with proper systems according to their functions (NBS, 2017). For example, a copper pipework, coded as Pr_65_52_63_17 (Table 2.11), can be used at both gas supply system and hot/cold water supply system. In addition, it is faceted and in accordance with an international standard. Therefore, it is a proper classification system for facilities management phase.

Table 2.11 : Coding structure of Uniclass.

Code	Name
Pr	Products
Pr_65	Services distribution products
Pr_65_52	Pipe, tube and fitting products
Pr_65_52_63	Pipes and fittings
Pr_65_52_63_17	Copper pipelines

(12) *OmniClass*: OmniClass is a classification system designed for the whole life cycle of a structure starting from idea to demolition (Lou and Goulding, 2008). Most of the OmniClass was completed at 2006 with 15 tables (NATSPEC, 2008). It is in accordance with ISO 12006-2 and suitable for object-oriented classification (Keady, 2013; OmniClass, 2006). Tables of OmniClass can be used individually to identify an element or they can be combined (Keady, 2013). Its development is continuous and will not be totally completed because every organization can apply for adding new element for the next revision (Keady, 2013; Lou and Goulding, 2008). Its coding system starts with table number and has five or six levels with two digits for every level (Table 2.12). Some of the OmniClass tables are based on different classification systems: Table 21 – Elements is from UniFormat™; Table 22 - Work Results is from MasterFormat; and Table 23 – Products is from EPIC (OmniClass, 2006). Especially, products table is suitable for facilities management and it is organized similar to a product catalog (Keady, 2013). For example, in a product catalog, water pump can be found under the plumbing section, not under the water distribution system section. Also, OmniClass is the base classification system for the National Building Information Standard (NBIMS) developed by buildingSMART (Keady, 2013). In addition, it is in accordance with the classification system used in Construction

Operations Building Information Exchange (COBie) Thus, it is compatible with BIM systems.

Table 2.12 : Coding structure of OmniClass.

Code	Name
Table 41	Materials
41-30	Solid Compounds
41-30 10	Mineral Compounds
41-30 10 15	Metamorphic Rocks
41-30 10 15 13	Marble
41-30 10 15 13 15	Limestone Marble

Table 2.13 shows the investigated classification systems and their suitability with the identified FM requirements listed at previous section. Twelve classification systems are evaluated against the determined FM requirements firstly considering the primary requirements. Generally, the official websites and guidelines of the classification systems are used to understand the suitability of them with determined requirements. Almost all of the classification systems are open-standard and most of them are in accordance with an international standard; however, only three of them meets all the primary requirements. Even though, CoClass can be used at FM phase, it does not meet with the secondary requirements and is not fully translated to English yet. Therefore, OmniClass and Uniclass are the only classification systems that meet both the primary and secondary requirements.

Table 2.13 : Comparison of examined classification systems

Classification Systems	Primary Requirements				Secondary Requirements			
	(P1)	(P2)	(P3)	(P4)	(S1)	(S2)	(S3)	(S4)
NATSPEC		✓					✓	
Masterpec		✓					✓	
DBK								
Building 90		✓	✓	✓				
NL/SfB		✓	✓	✓			✓	
CoClass	✓	✓	✓	✓			✓	✓
UNSPSC		✓			✓		✓	
MasterFormat		✓			✓	✓	✓	✓
UniFormat TM	✓	✓		✓	✓	✓	✓	✓
UNIFORMA								
T II		✓		✓	✓	✓	✓	
Uniclass	✓	✓	✓	✓	✓	✓	✓	✓
OmniClass	✓	✓	✓	✓	✓	✓	✓	✓



3. CASE STUDY: IMPLEMENTATION OF BIM-FM INTEGRATION

In this section, three methods of BIM-FM integration are investigated. These methods are: (1) using BIM authoring tool, (2) using BIM-FM platform, and (3) using IFC file format. They were not used to compare their capabilities for same purposes but used to show their capabilities on different purposes. In the first method, capabilities of BIM authoring tools (i.e. Autodesk Revit, Navisworks, Dynamo) were used for some FM related purposes (e.g. using parameters and colors to filter). In the second method, BIM-FM platform (i.e. EcoDomus) was used for some FM activities such as creation of work-orders and inspection forms. In the last method, BIM model was exported as IFC file and its code was modified to store the FM data.

For the trials, a university office was used. The office is named as “İTÜ Çekirdek” which is located inside the Istanbul Technical University, Ayazağa Campus, Turkey. It is an office to support the start-ups inside ARI-3 building which includes Research & Development (R&D) departments of technology companies. Figure 3.1 shows both real-world and model appearance of the ARI-3 building and İTÜ Çekirdek office.

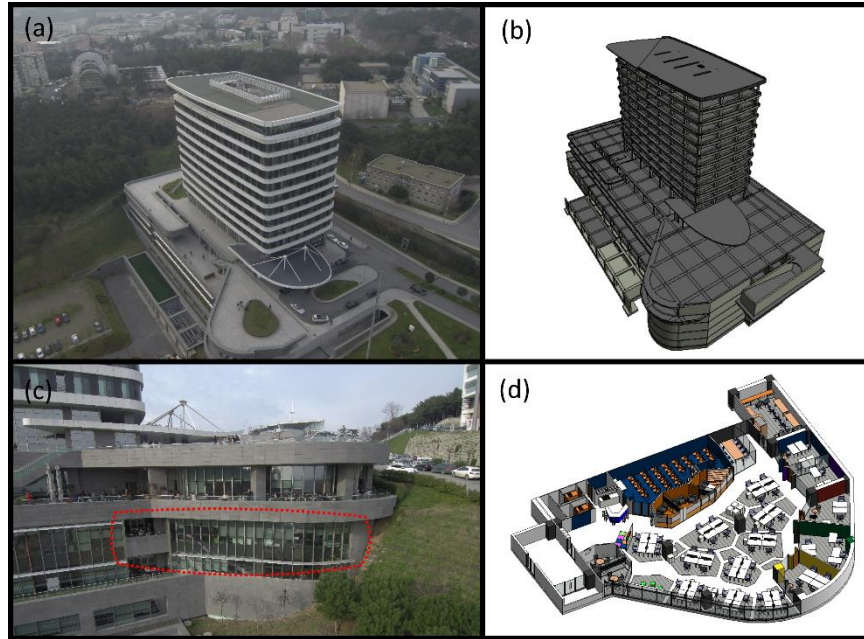


Figure 3.1 : Real-world (a-c) and model (b-d) appearance of ARI-3 building and Çekirdek office.

Autodesk Revit 2019 was used to model the office. While modeling, as-built construction drawings, photos and on-site measurements were used as reference data. Since the model will be used for FM purposes, architectural details were mostly considered rather than structural details. It was aimed to be have nearly same interior appearance of real situation of the office in the BIM model (Figure 3.2).

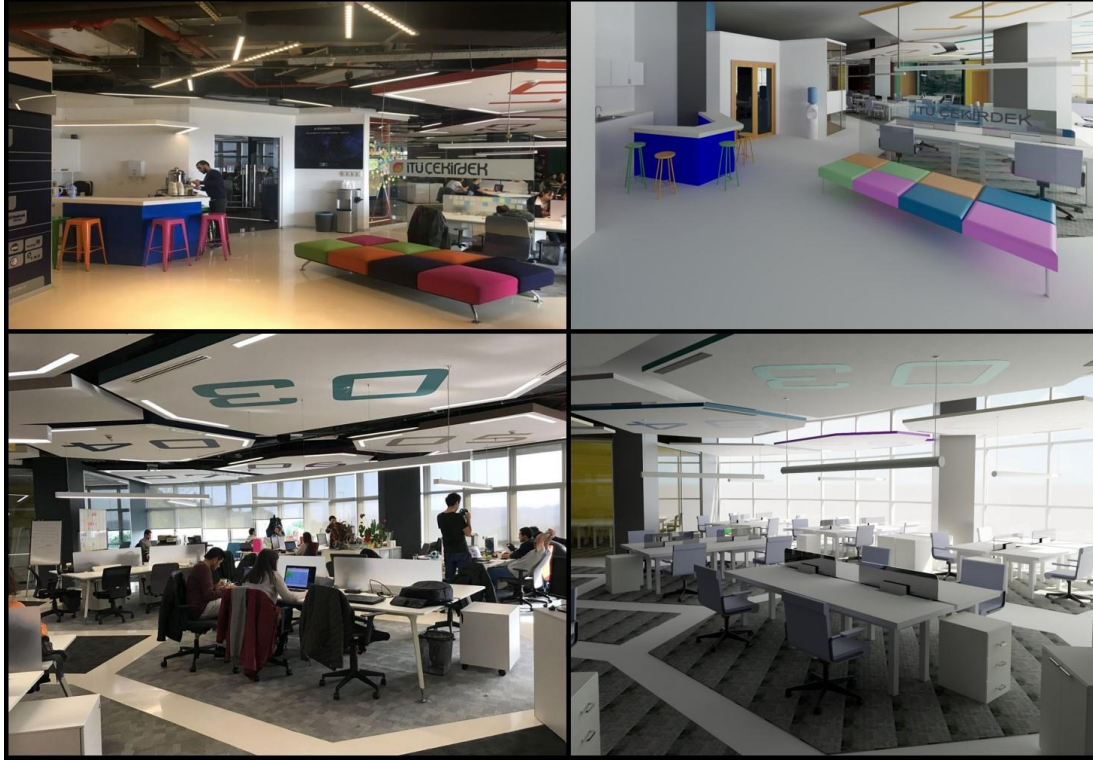


Figure 3.2 : Real situation (left side) and model appearance (right side).

There are 897 elements in the model. Most of the elements are architectural elements (Table 3.1). Mostly, furniture families of Revit were used by changing their size. For some elements, families were created in accordance with real ones. For example, a colorful seat was created near the entrance. Also, kitchen table was created after measurements. Mechanical systems were not modeled, only the visible mechanical elements were modeled (i.e. air diffuser and lighting). Inside the model, there are totally 31 rooms and spaces (Figure 3.3).

Table 3.1 : Element types inside the model.

Element Type	Element
Structural Elements	Column
	Shear wall
	Floor
	Wall
Architectural Elements	Glass curtain wall
	Ceiling
	Door
	Window
Electrical & Mechanical Elements	Lighting
	Air diffuser
	Floor covering
	Desk
Office Equipment and Furnishing Elements	Chair
	Cabinet
	Water dispenser
	Toilet
	Sink



Figure 3.3 : Room tags of model.

3.1 Using BIM Authoring Tool

BIM authoring tools can be used for the basic FM purposes. In this study, Autodesk Revit 2019 was used. Revit has the capability of filtering elements according to defined rules and giving them visual differences such as color and transparency. Also, defining parameters to the building elements would be effective to follow the FM information. These parameters can be enriched by using software platforms for computational design and BIM (i.e. Dynamo). Since it is a 3D model, renovations can be simulated on the model to support the decision-making. In addition, add-ins can be used for several FM purpose such as exporting the model to gaming engine to walk inside the model.

Aim of this section is to show what could be performed by using BIM authoring tool (i.e. Revit) for FM purposes. It was tested in 5 categories: (1) Defining parameters to elements, (2) filtering elements, (3) using software platforms for BIM (i.e. Dynamo), (4) renovation simulation, and (5) using add-ins. Firstly, parameters will be defined to building elements to create work order. Then, building elements will be filtered according to parameters for understand the differences. In the third section, a software platform for Revit (i.e. Dynamo) will be used to transfer the live data from database to parameters of building elements in Revit. Fourth section shows how Revit can be used to design simulations by rendering the image. Lastly, an add-in will be used to export model to gaming engine (i.e. Unity) for using it in virtual reality environment.

3.1.1 Defining parameters to elements

Most of the FM related information can be stored inside the model as a value of parameter. For example, work orders related with a certain building element can be tracked from its parameters. To track the work order, a supply grille mechanical element was selected (Figure 3.4). Firstly, “User Manuel” parameter was defined to link the user manual of supply grille element to the model object. It is defined as type parameter, since it defines all of the similar type of supply grille. Its value type was selected as “URL” to link the file path of PDF file. Related PDF file of user manual is linked into this parameter. For the work order information, three different parameters were defined. They were created as instance parameters, since each supply grille element, even if they are same type, should be given values individually. Parameters

were named as “WO Number” – text type, “Status” – text type, and “Picture” – image type.

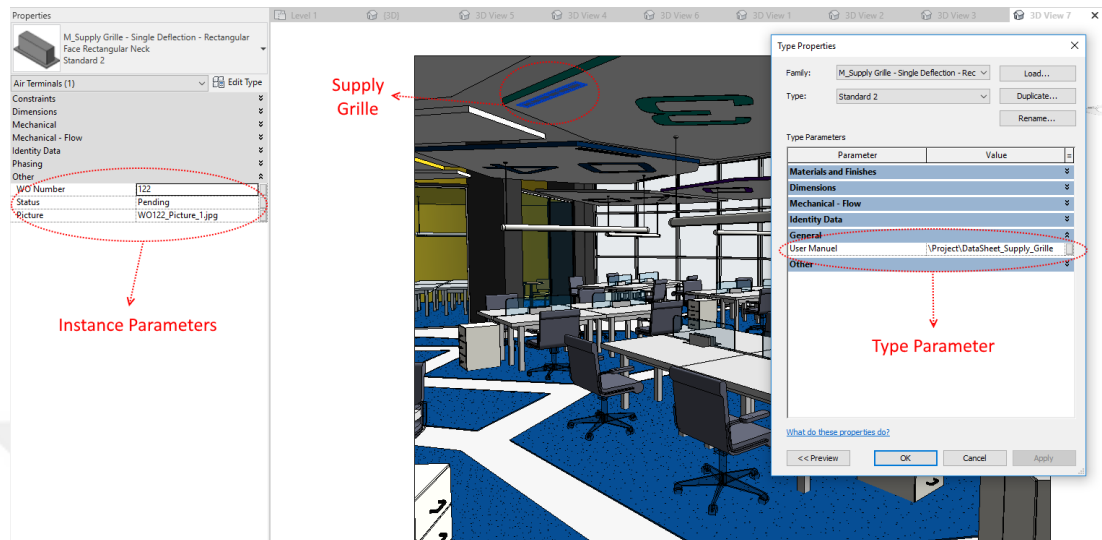


Figure 3.4 : Supply grille element with parameters.

Work orders can be tracked by using BIM model and related user manual of building elements can be reached easily from parameter. Also, work order reports can be created from “Schedules/Quantities” of Revit (Figure 3.5).

<Work Order Report>				
A	B	C	D	E
Family and Type	WO Number	Status	Picture	User Manual
M_Supply Grille - Sin	122	Pending	WO122_Picture	\\Project\\DataShe

Figure 3.5 : Work order report.

3.1.2 Filtering elements

Highlighting the desired elements on the 3D model can be helpful to understand the situation of the specific area easily. For instance, all the chairs inside the open office zones and office rooms were planned to be changed. An instance parameter, named as “Changed?”, was defined and its value type was selected as boolean which its value can be only “Yes” or “No” (Figure 3.6). Since it is an instance parameter, it defines each element individually. Some of the chairs entered as “Yes” and others remained as “No”.

<Chair Renewal Issue>		
A	B	C
Family and Type	Manufacturer	Changed?
Chair-Task (Arms): Sa X Firm		☒
Chair-Task (Arms): Sa X Firm		☒
Chair-Task (Arms): Sa X Firm		☐
Chair-Task (Arms): Sa X Firm		☐
Chair-Task (Arms): Sa X Firm		☒
Chair-Task (Arms): Sa X Firm		☐
Chair-Task (Arms): Sa X Firm		☐
Chair-Task (Arms): Sa X Firm		☒
Chair-Task (Arms): Sa X Firm		☐
Chair-Task (Arms): Sa X Firm		☐
Chair-Task (Arms): Sa X Firm		☒
Chair-Task (Arms): Sa X Firm		☐
Chair-Task (Arms): Sa X Firm		☒
Chair-Task (Arms): Sa X Firm		☒
Chair-Task (Arms): Sa X Firm		☐
Chair-Task (Arms): Sa X Firm		☐

Figure 3.6 : Chair renewal parameter.

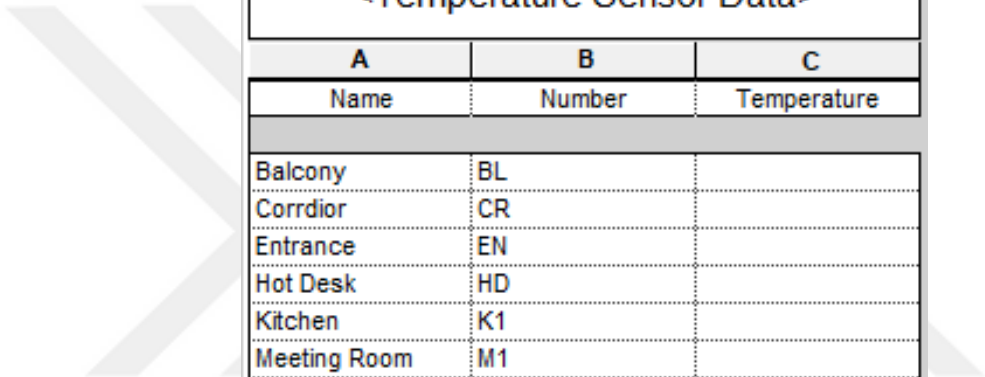
To visualize the situation of chair renewal activity, rule-based filters were created. It is defined that changed chairs will be green and others red. These filters were applied from “Visibility/Graphics” options (Figure 3.7). It can be easily seen which chair was changed or not.



Figure 3.7 : Visualization of chair renewal.

3.1.3 Using software platform for BIM (i.e. Dynamo)

Some of the commands can be done in less time and effort with the support of using software platforms (i.e. Dynamo). For example, temperature sensor data calculated by devices inside the rooms and zones can be automatically uploaded in the model. For instance, “Temperature” parameter was assigned to rooms and zones as instance parameter (Figure 3.8). Besides, rule-based filters were created for the temperature intervals: (1) If temperature is less than 22, rooms or zones will be blue, (2) if it is between 22 and 25, they will be green, and (3) if it is higher than 25, they will be red.



<Temperature Sensor Data>		
A	B	C
Name	Number	Temperature
Balcony	BL	
Corrdior	CR	
Entrance	EN	
Hot Desk	HD	
Kitchen	K1	
Meeting Room	M1	
Meeting Room	M2	
Meeting Room	M3	
Meeting Room	M4	
Meeting Room	M5	
Meeting Room	M6	
Men Toilet	T1	
Office	O1	

Figure 3.8 : Temperature parameter.

Dynamo was used to write a script for uploading temperature data inside the BIM model. It is a platform that uses smart nodes to create algorithm for desired work in BIM authoring tools (i.e. Revit). Basically, collected temperature data was stored inside an excel sheet. Then, it was transferred from excel sheet to “Temperature” parameter of rooms by using Dynamo script (Figure 3.9). Room numbers were used to match the temperature value with correct room and zone.

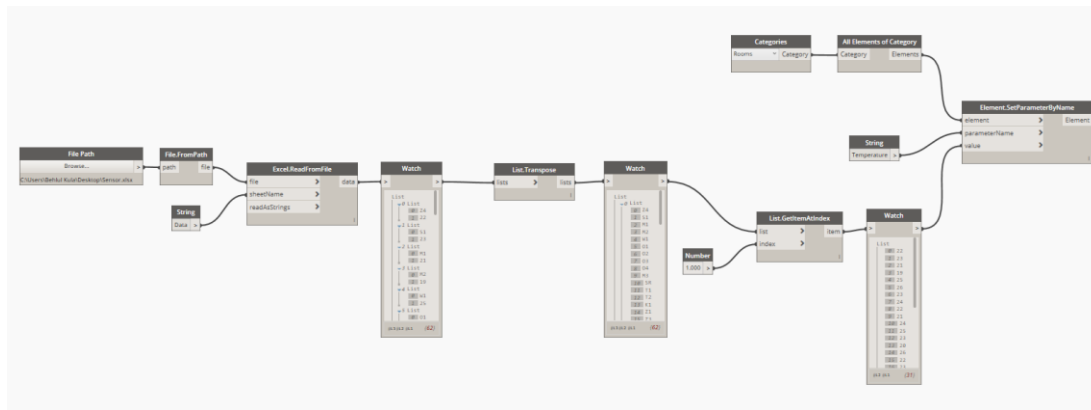


Figure 3.9 : Dynamo script for uploading temperature data.

When the script was run, it can be seen if there is any room with high or low temperature (red or blue color) in accordance with created filter rules (Figure 3.10).



Figure 3.10 : Visualization of temperature intervals on floor plan.

3.1.4 Renovation simulation

Since visualization is one of advantages of BIM models, they are very useful for decision making of design issues. For example, an office room was designed with different paint color and different combination of furniture (Figure 3.11). It allows the

decision-maker to see the possible design alternatives in the model. Captured screens can also be rendered for a realistic view.



Figure 3.11 : Render views of different combinations in same room.

3.1.5 Using add-ins

There are lots of add-ins for BIM authoring tools to make easier the process of varies purposes. For example, “Walk-Through-3D” add-in for Revit can export the BIM model as a first-person view game by using Unity gaming engine (Figure 3.12). When the model extracted to a gaming engine, there are numerous options to perform. Models can be used for understand the building or train the new workers by allowing them to walk inside the model. It can also be used with virtual reality devices.



Figure 3.12 : Revit model at Unity gaming engine.

In conclusion, BIM authoring tools have capability of performing most of the basic FM issues. However, size of the project and size of the data would affect the process

negatively. Besides, since BIM authoring tools is designed mostly for model creation, they are complex software packages and have complex interfaces. The one who will use a BIM authoring tool in FM phase should has background and experience on that tool. Finally, BIM authoring tools can be used for basic FM purposes for a short time, however, professional software packages for integration of BIM and FM should be used in a continuous FM phase.

3.2 Using BIM-FM platform

In this section, ITU Çekirdek model was uploaded to a BIM-FM platform (i.e. EcoDomus) to understand the capabilities for FM purposes. EcoDomus software is a platform that provides a common data environment, which can be integrated with 3D BIM model of the buildings, for operational phase. For integration, BIM model of structure is uploaded to platform and building elements inside the model are saved into database with its parameters. In order to carry out the examination, a user account was created on EcoDomus platform. The results are listed below.

Firstly, BIM model should be uploaded to the system. There are two options. One is using IFC file of the model. Other is using Revit add-in of EcoDomus. Second method is more effective and easier. To transfer the whole model, geometric data and information data should be transferred, separately (Figure 3.13). Geometry and information will be matched by using Revit ID automatically inside the platform.

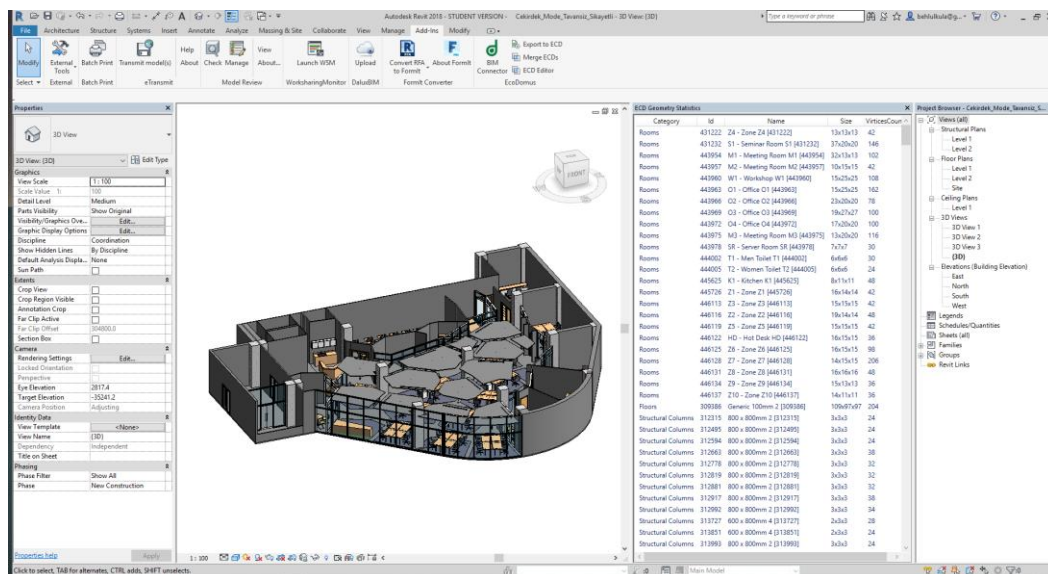


Figure 3.13 : Transferring model to EcoDomus via Revit add-in.

Transferred model should be saved inside the model with the necessary information (Figure 3.14). Location of the building can be saved by placing a pin on Google Maps. Other information such as name, description, units can be entered manually. Also, OmniClass code of the building can be saved.

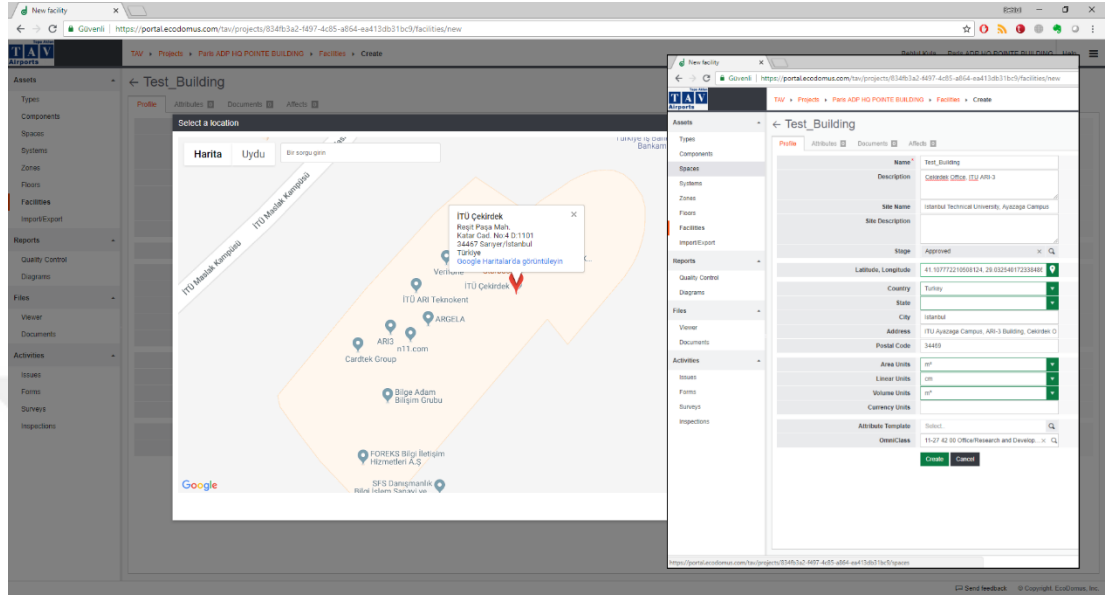


Figure 3.14 : Saving the model inside the system.

EcoDomus platform has a viewer that allows the user to walk around the 3D model and select a building element (Figure 3.15). Users can combine both 2D and 3D view to understand the exact location inside the model (Figure 3.16). On 2D plan, a location can be selected and system automatically will open the 3D view on that location.

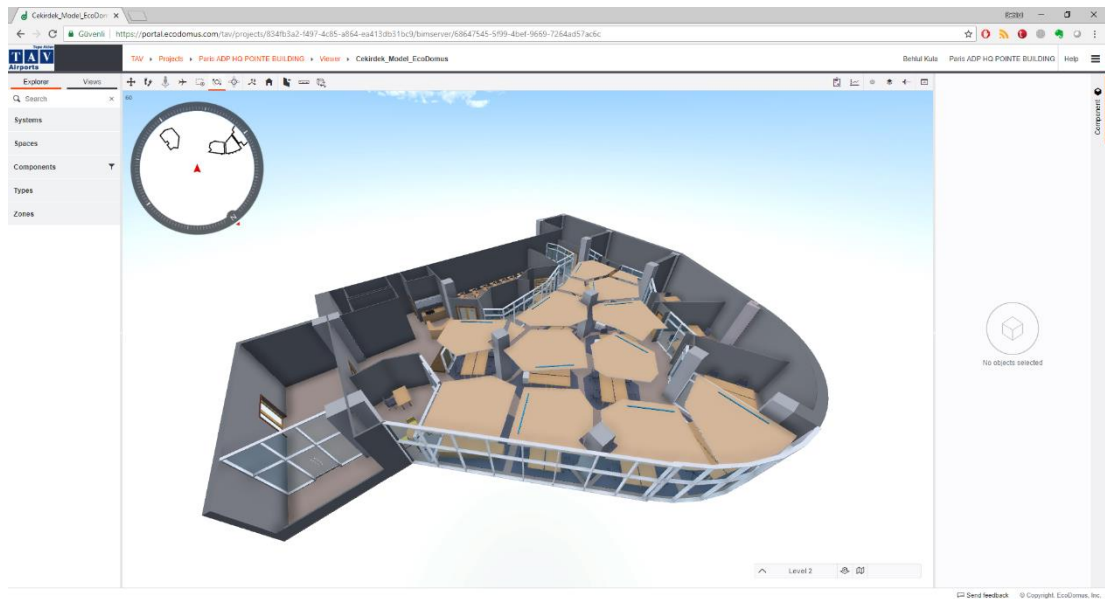


Figure 3.15 : Model on EcoDomus viewer.

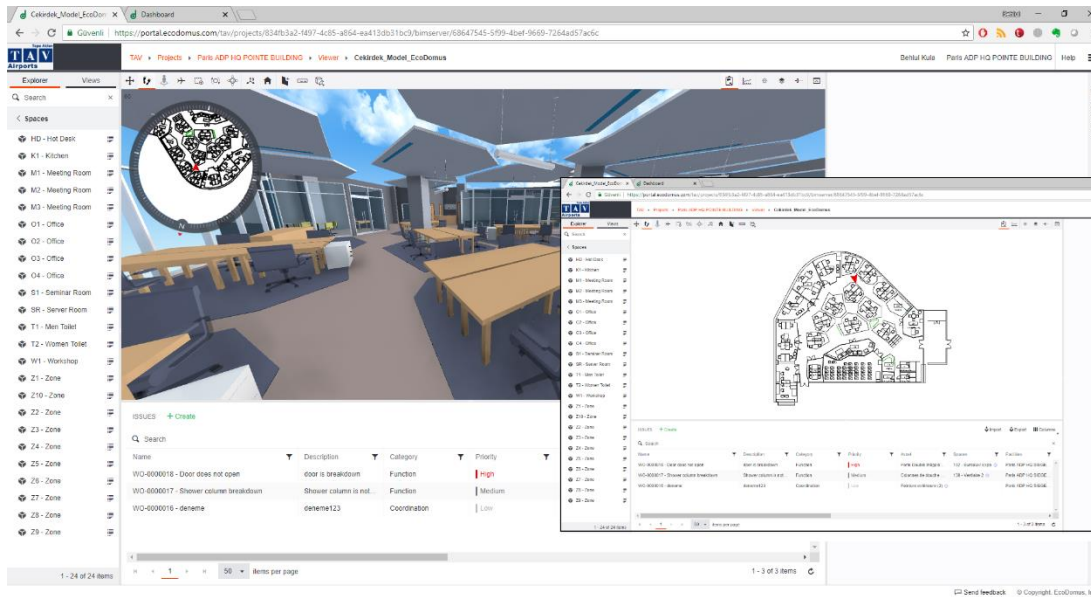


Figure 3.16 : 2D and 3D view together.

By selecting a space or zone of the model from the list, desired area can be easily isolated inside the model (Figure 3.17). Only the building elements inside the selected space or zone will be active and others will be deactive with transparent pattern.

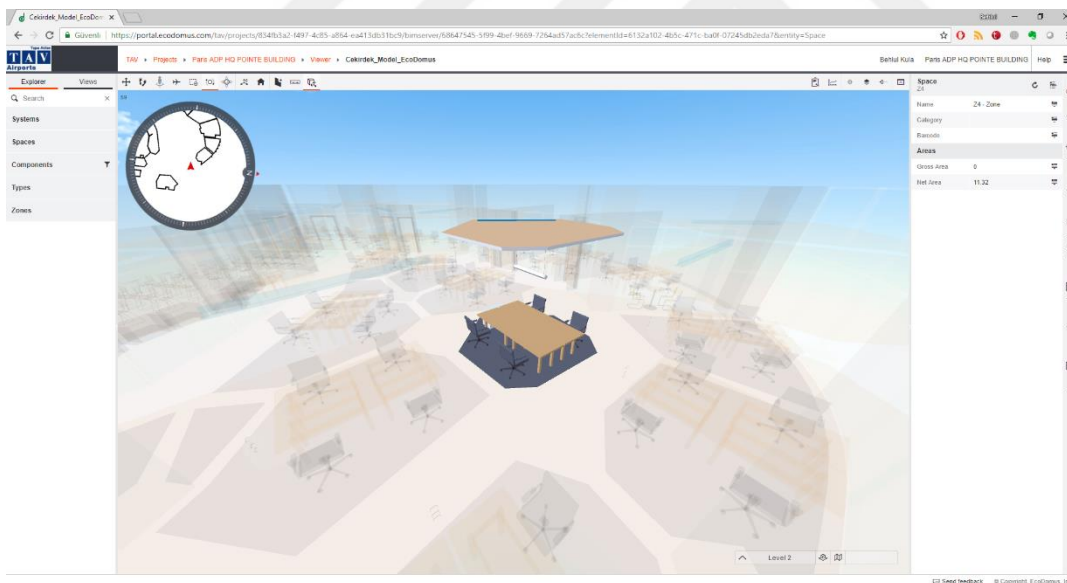


Figure 3.17 : Selecting a specific space or zone.

When a building element is selected, properties of that element will be listed on the right side of screen (Figure 3.18). On the properties panel, there are 5 tabs related with selected element: (1) Component, (2) Attributes, (3) Documents, (4) Issues and (5) Affects.

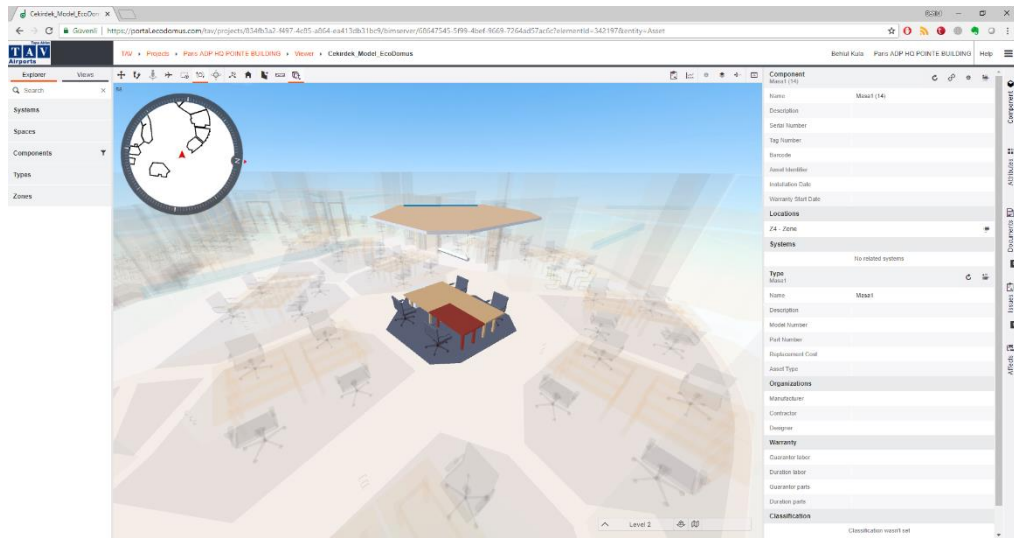


Figure 3.18 : Selecting a building element to see the properties.

Properties of the building element can be changed or new information can be added to the element (Figure 3.19). The attributes coming from Revit model can be changed and this renewal can be sent back to the BIM model from EcoDomus. Also, documents such as photo and PDF file can be uploaded to the system and linked with the building elements.

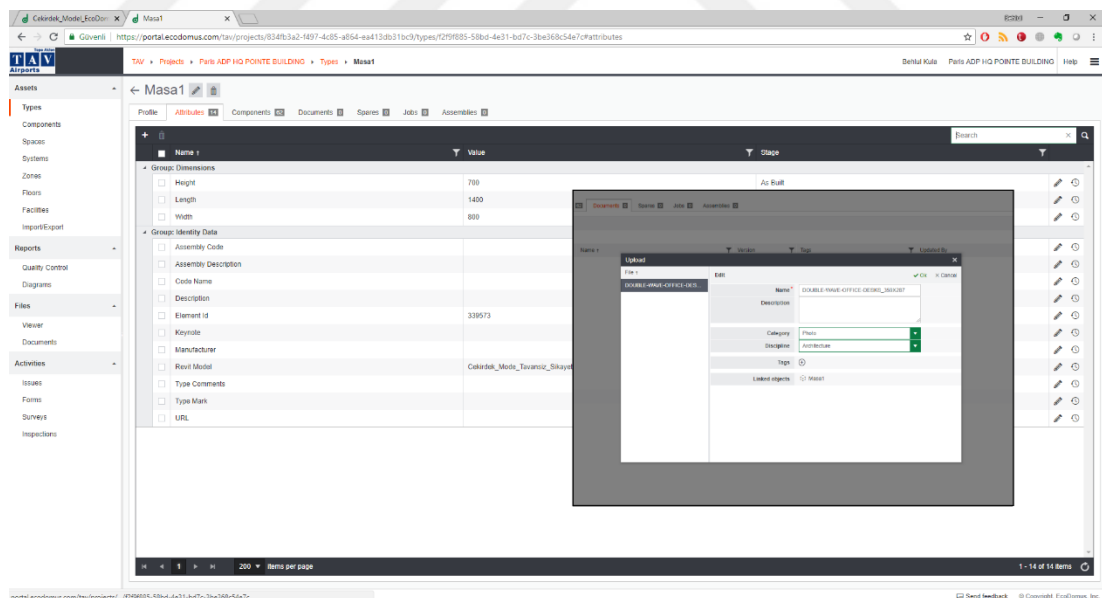


Figure 3.19 : Adding or changing information of building element.

By using Issues tab, a work-order can be created for a specific element (Figure 3.20). While creating the work-order, related component and space must be selected. Also, it can be assigned to a person.

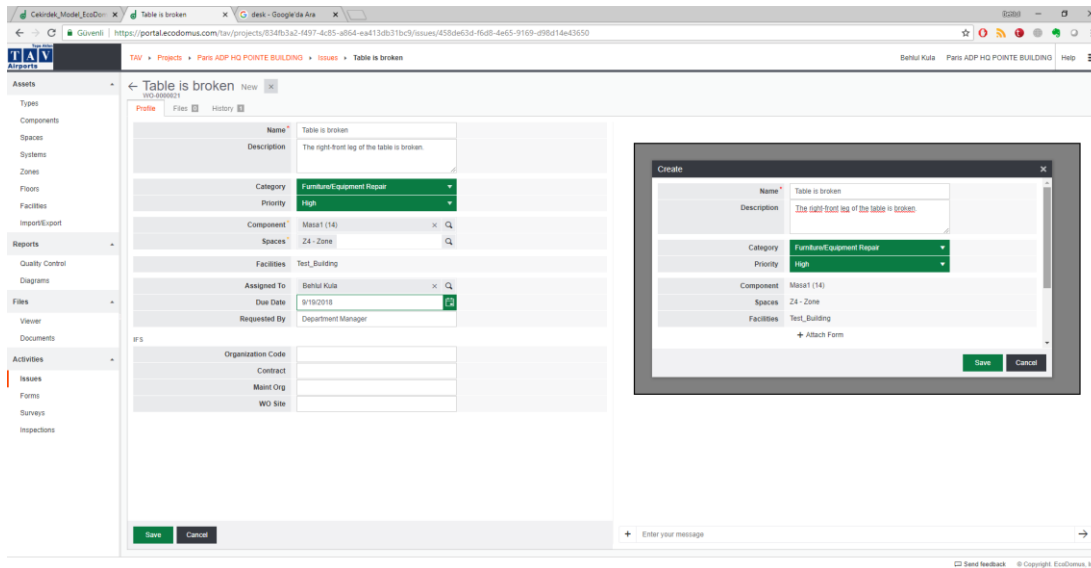


Figure 3.20 : Entering work-order to a building element.

When a work-order assigned to someone, an email will be sent to that person (Figure 3.21). By clicking on the link in the email, assigned work-order can be opened. On the screen, status of the work-order can be changed and additional information can be added. Besides, there is a messaging screen for communication among FM team members.

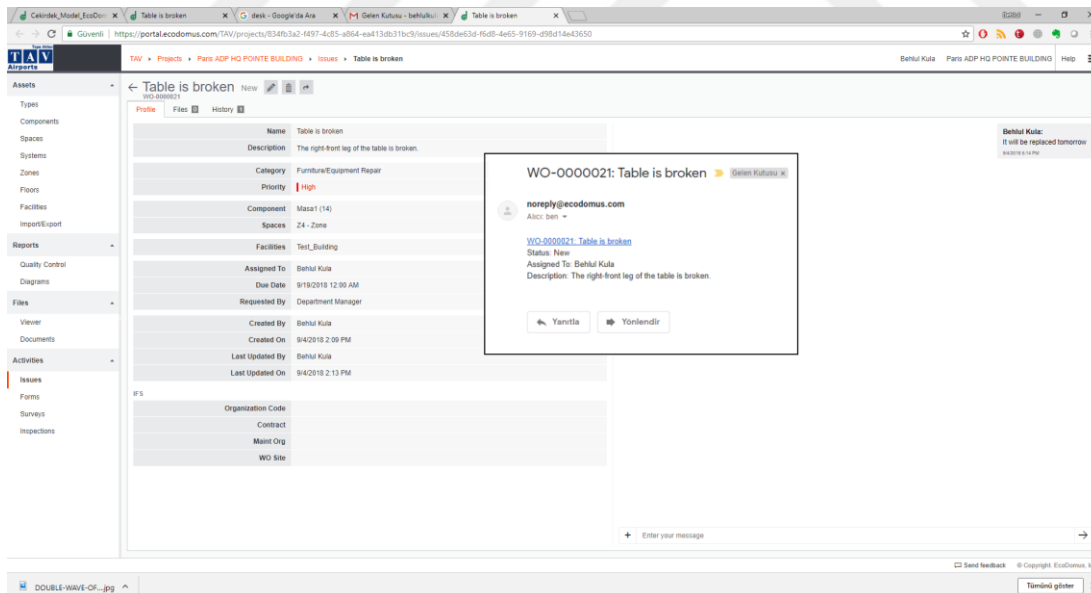


Figure 3.21 : Processing the work-orders.

Before creating the work-orders, a work-order process hierarchy should be structured (Figure 3.22). It defines the status of the work-orders with determined order. For example, when a work-order is created its status will be “New”. Its status can be

changed to “Canceled” or “Open” by FM manager. After, it can be turned to “Completed”, “On-Hold” or “Rejected”.

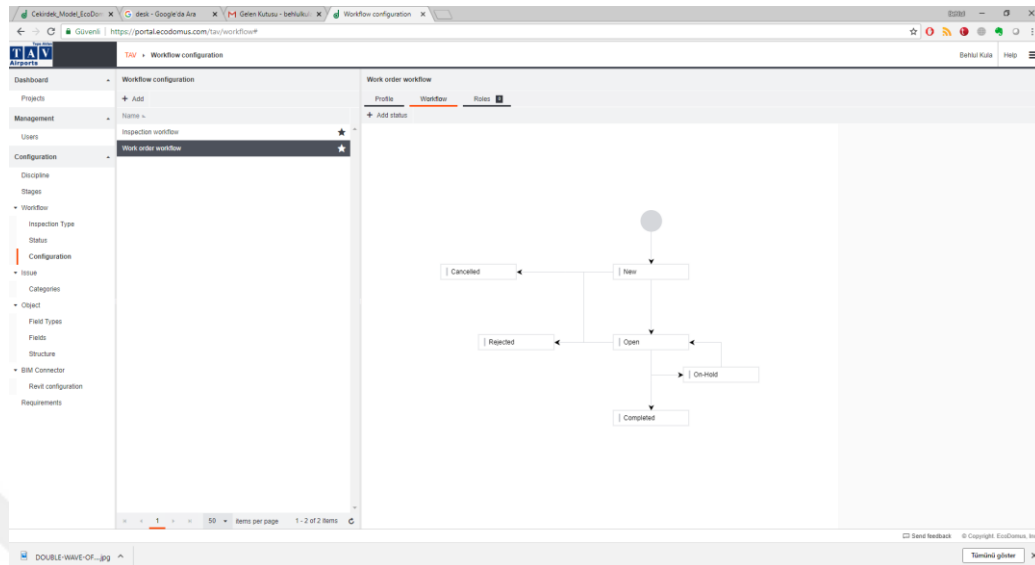


Figure 3.22 : Creating hierarchy of work-order procedure.

For inspections, forms can be created (Figure 3.23). Inside the form, questions can be added. The type of the answer of questions can be text format or check boxes according to purpose.

The screenshot shows the 'Daily Restroom Control' form creation page. The form has a title 'Daily Restroom Control' and a description. Below the title, there is a table for 'QUESTIONS'. The table has two columns: 'Name' and 'Question Type'. The questions listed are: 'Any other problem?' (Text), 'It is clean' (Checkboxes), and 'Papers are available' (Checkboxes). The interface includes a top navigation bar with 'Home', 'Projects', 'Forms', and 'Daily Restroom Control' tabs, and a bottom status bar with 'DOUBLE-WAVE-OF...jpg' and 'Standard glider'.

Figure 3.23 : Creating form document.

Created forms can be assigned to a control document (Figure 3.24). For example, daily restroom control form was created and it was assigned to inspection document.

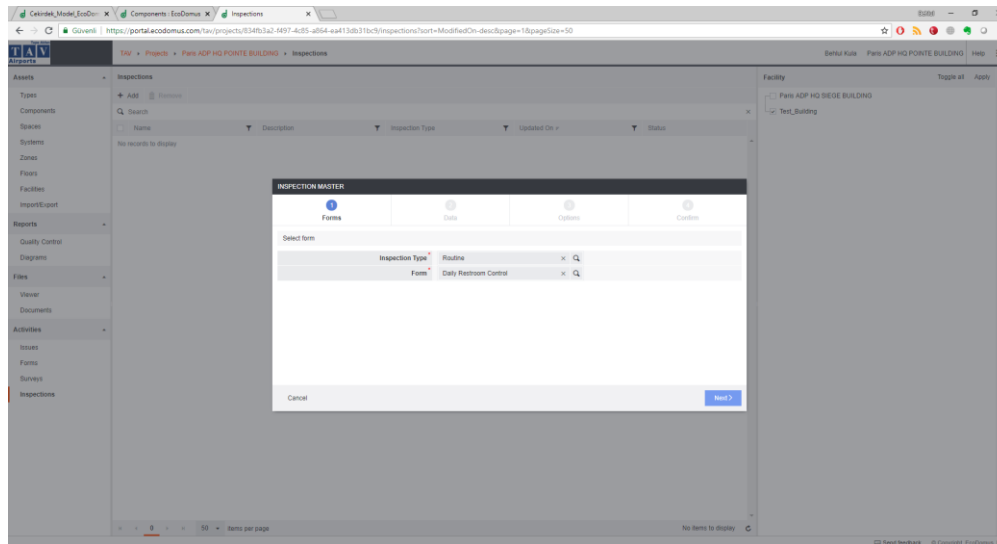


Figure 3.24 : Creating control document.

In conclusion, BIM-FM platforms has many modules that allow the users perform their FM activities according to their purposes. It also combines BIM model by linking building elements with related activities. The visualization of BIM model can also be used inside the platform with the help of model viewer mode. Generally, BIM-FM platforms are specialized with the project. If there is a need that is not included inside the modules of BIM-FM platform, it can be added by communicating with BIM-FM platform vendor. Since they are mostly customizable, project needs should be well defined and necessary modules should be activated by considering cost of the project.

3.3 Using IFC File

IFC is an open, international standard for exchanging BIM data over the lifecycle of a project, which mentioned in Section 2.4. The proxy element method will be used in this example. It is aimed to show that IFC file can be modified without using any BIM authoring tool and it can be used in any BIM-based software package.

As an example, it is aimed to store the occupant feedback and the location of the feedback in the IFC model and to obtain the information of the related building element from the IFC model. Thus, this section focuses on extending IFC for representing the occupant feedback.

3.3.1 IFC structure

To be able to extend the IFC by creating a new class, firstly the structure of the IFC should be understood. The main source to understand the IFC structure is webpage of

BuildingSMART (BuildingSMART, 2018a). The file format is .ifc and its coding is based on STEP format which is defined at ISO-10303-21 (International Organization for Standardization, 2016). An IFC file can be opened by any text editor to change the code. In this research “Notepad++” was used as a text editor (Notepad++, 2016). To create the IFC file, “Revit 2019” was used. A sample model, ITU Çekirdek Office, was created and extracted as IFC file in “IFC 2x3 Coordination View 2.0” format (Figure 3.25). To open the IFC file, “BIM Vision 2.19” is used as an IFC viewer (BIM Vision, 2018).

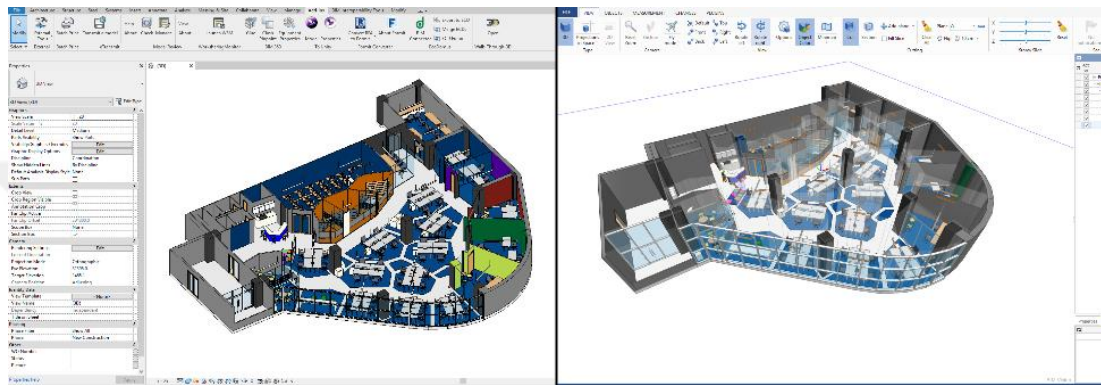


Figure 3.25 : Sample model view on Revit (left) and BIM Vision (right).

When the IFC file is opened in Notepad++, there are two sections: (1) HEADER and (2) DATA (Figure 3.26). First section includes the information about the file and second section includes the entities which define every asset, information and relation about the created model.

```

File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window ?
Colunus_Model_v3.ifc [2]
1 ISO-10303-21:
2 HEADER:
3
4 *****
5 * STEP Physical File produced by: The EXPRESS Data Manager Version 5.02.0100.07 : 28 Aug 2019
6 * Module: EDMstepFileFactory/EDMstandAlone
7 * Creation date: Tue Mar 26 21:39:51 2019
8 * Host: DESKTOP-157GVSP
9 * Database: C:\Users\BEHLUL-1\AppData\Local\Temp\{AFA0D198-43EB-4126-8EC1-A35E50E7C015}\lifo
10 * Database version: 5507
11 * Database creation date: Tue Mar 26 21:39:43 2019
12 * Schema: IFC2X3
13 * Model: DataRepository.Ifc
14 * Model creation date: Tue Mar 26 21:39:43 2019
15 * Header model: DataRepository.Ifc_HeaderModel
16 * Header model creation date: Tue Mar 26 21:39:43 2019
17 * EDUser: sda1-user
18 * EDGroup: sda1-group
19 * License ID and type: 5605 : Permanent license. Expiry date:
20 * EDMstepFileFactory options: 020000
21 *****
22 FILE_DESCRIPTION('ViewDefinition [CoordinationView_V2.0]', '2.1')
23 FILE_NAME('0001', '2019-03-26T21:39:51', (''), (''), 'The EXPRESS Data Manager Version 5.02.0100.07 : 28 Aug 2019', '20181217_1515(x64) - Exporter 19.2.0.65 - Alternate UI 19.2.0.65', '')
24 FILE_SCHEMA('IFC2X3')
25 ENDSEC;
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27 DATA:
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29 #2= IFCAPPLICATION(0, '2019', 'Autodesk Revit 2019 (ENR)', 'Revit');
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31 #4= IFCCARTESIANPOINT(0, 0, 0);
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496 #469= IFCDIRECTION(0, 0, 0);
497 #470= IFCDIRECTION(0, 0, 0);
498 #471= IFCDIRECTION(0, 0, 0);
499 #472= IFCDIRECTION(0, 0, 0);
500 #473= IFCDIRECTION(0, 0, 0);
501 #474= IFCDIRECTION(0, 0, 0);
502 #475= IFCDIRECTION(0, 0, 0);
503 #476= IFCDIRECTION(0, 0, 0);
504 #477= IFCDIRECTION(0, 0, 0);
505 #478= IFCDIRECTION(0, 0, 0);
506 #479= IFCDIRECTION(0, 0, 0);
507 #480= IFCDIRECTION(0, 0, 0);
508 #481= IFCDIRECTION(0, 0, 0);
509 #482= IFCDIRECTION(0, 0, 0);
510 #483= IFCDIRECTION(0, 0, 0);
511 #484= IFCDIRECTION(0, 0, 0);
512 #485= IFCDIRECTION(0, 0, 0);
513 #486= IFCDIRECTION(0, 0, 0);
514 #487= IFCDIRECTION(0, 0, 0);
515 #488= IFCDIRECTION(0, 0, 0);
516 #489= IFCDIRECTION(0, 0, 0);
517 #490= IFCDIRECTION(0, 0, 0);
518 #491= IFCDIRECTION(0, 0, 0);
519 #492= IFCDIRECTION(0, 0, 0);
520 #493= IFCDIRECTION(0, 0, 0);
521 #494= IFCDIRECTION(0, 0, 0);
522 #495= IFCDIRECTION(0, 0, 0);
523 #496= IFCDIRECTION(0, 0, 0);
524 #497= IFCDIRECTION(0, 0, 0);
525 #498= IFCDIRECTION(0, 0, 0);
526 #499= IFCDIRECTION(0, 0, 0);
527 #500= IFCDIRECTION(0, 0, 0);
528 #501= IFCDIRECTION(0, 0, 0);
529 #502= IFCDIRECTION(0, 0, 0);
530 #503= IFCDIRECTION(0, 0, 0);
531 #504= IFCDIRECTION(0, 0, 0);
532 #505= IFCDIRECTION(0, 0, 0);
533 #506= IFCDIRECTION(0, 0, 0);
534 #507= IFCDIRECTION(0, 0, 0);
535 #508= IFCDIRECTION(0, 0, 0);
536 #509= IFCDIRECTION(0, 0, 0);
537 #510= IFCDIRECTION(0, 0, 0);
538 #511= IFCDIRECTION(0, 0, 0);
539 #512= IFCDIRECTION(0, 0, 0);
540 #513= IFCDIRECTION(0, 0, 0);
541 #514= IFCDIRECTION(0, 0, 0);
542 #515= IFCDIRECTION(0, 0, 0);
543 #516= IFCDIRECTION(0, 0, 0);
544 #517= IFCDIRECTION(0, 0, 0);
545 #518= IFCDIRECTION(0, 0, 0);
546 #519= IFCDIRECTION(0, 0, 0);
547 #520= IFCDIRECTION(0, 0, 0);
548 #521= IFCDIRECTION(0, 0, 0);
549 #522= IFCDIRECTION(0, 0, 0);
550 #523= IFCDIRECTION(0, 0, 0);
551 #524= IFCDIRECTION(0, 0, 0);
552 #525= IFCDIRECTION(0, 0, 0);
553 #526= IFCDIRECTION(0, 0, 0);
554 #527= IFCDIRECTION(0, 0, 0);
555 #528= IFCDIRECTION(0, 0, 0);
556 #529= IFCDIRECTION(0, 0, 0);
557 #530= IFCDIRECTION(0, 0, 0);
558 #531= IFCDIRECTION(0, 0, 0);
559 #532= IFCDIRECTION(0, 0, 0);
560 #533= IFCDIRECTION(0, 0, 0);
561 #534= IFCDIRECTION(0, 0, 0);
562 #535= IFCDIRECTION(0, 0, 0);
563 #536= IFCDIRECTION(0, 0, 0);
564 #537= IFCDIRECTION(0, 0, 0);
565 #538= IFCDIRECTION(0, 0, 0);
566 #539= IFCDIRECTION(0, 0, 0);
567 #540= IFCDIRECTION(0, 0, 0);
568 #541= IFCDIRECTION(0, 0, 0);
569 #542= IFCDIRECTION(0, 0, 0);
570 #543= IFCDIRECTION(0, 0, 0);
571 #544= IFCDIRECTION(0, 0, 0);
572 #545= IFCDIRECTION(0, 0,
```

In data section, each row has a reference number (e.g. #16) and they will be used to refer that row in the IFC file when required. The row numbers do not have to be in ascending or descending order, but they must be unique in the file. Each row number includes an IFC entity with its attributes that are separated with commas inside the parenthesis. The properties and attributes of each IFC entity are defined and they can be found at the webpage of BuildingSMART (BuildingSMART, 2018a). Some of the attributes can be entered directly inside the entity as string data (e.g. Global ID: '1Fk9CvWJP0ffx6dLDk5sF1'). Some of them should be written as reference row number to refer to related IFC entity (e.g. OwnerHistory: #42). Some of the attributes are optional and can be left blank by putting dollar (\$) sign. Also, there are inverse attributes which define the relation of that entity with other IFC entities. Inverse attributes create the structure of related data and provide referential integrity. An attribute can be type of String, Integer, Real, Boolean, Logical, Binary, Enumeration, Select or Entity as defined in ISO 10303-11. String, Integer, Real, Boolean, Logical and Binary should be entered in text format. In Enumeration type, value should be selected from multiple predefined values. In Select type, it should be selected from multiple types or entities. In addition, most of the IFC entities include the Globally Unique Identifier (GUID) number which gives them a unique code. It is mostly used to create a bond between entity and related object or activity or action. It can be manually created by using IFC-GUID rules or “GUID Compressor” can be used to automatically create them (BuildingSMART, 2018b). In this study, GUID numbers are created manually in accordance with rules.

For example, Figure 3.27 shows a sample entity structure. In the figure, the first line presents the code of the IFCDOOR. Every value that is separated by commas inside the parenthesis represents the attributes. For example, first value is the Global ID and second value is the OwnerHistory of the entity. The value of OwnerHistory is written as “#42” which refers it to the line of 42 and the line 42 describes IfcOwnerHistory entity. The Description attribute of IfcDoor is optional attribute and it is leaved blank by putting a dollar (\$) sign. Attribute of PredefinedType is an enum type of attribute and its value must be selected from predefined list which includes door, gate, trapdoor, userdefined, notdefined. IFCDOOR also has two inverse attributes which are IsDefinedBy and FillsVoids. While IsDefinedBy connects the related property sets and IfcDoor, FillsVoids describes the opening on the wall when the door is placed. The

line number of IfcDoor (#1460) can be found inside the entity which defines the inverse attribute.

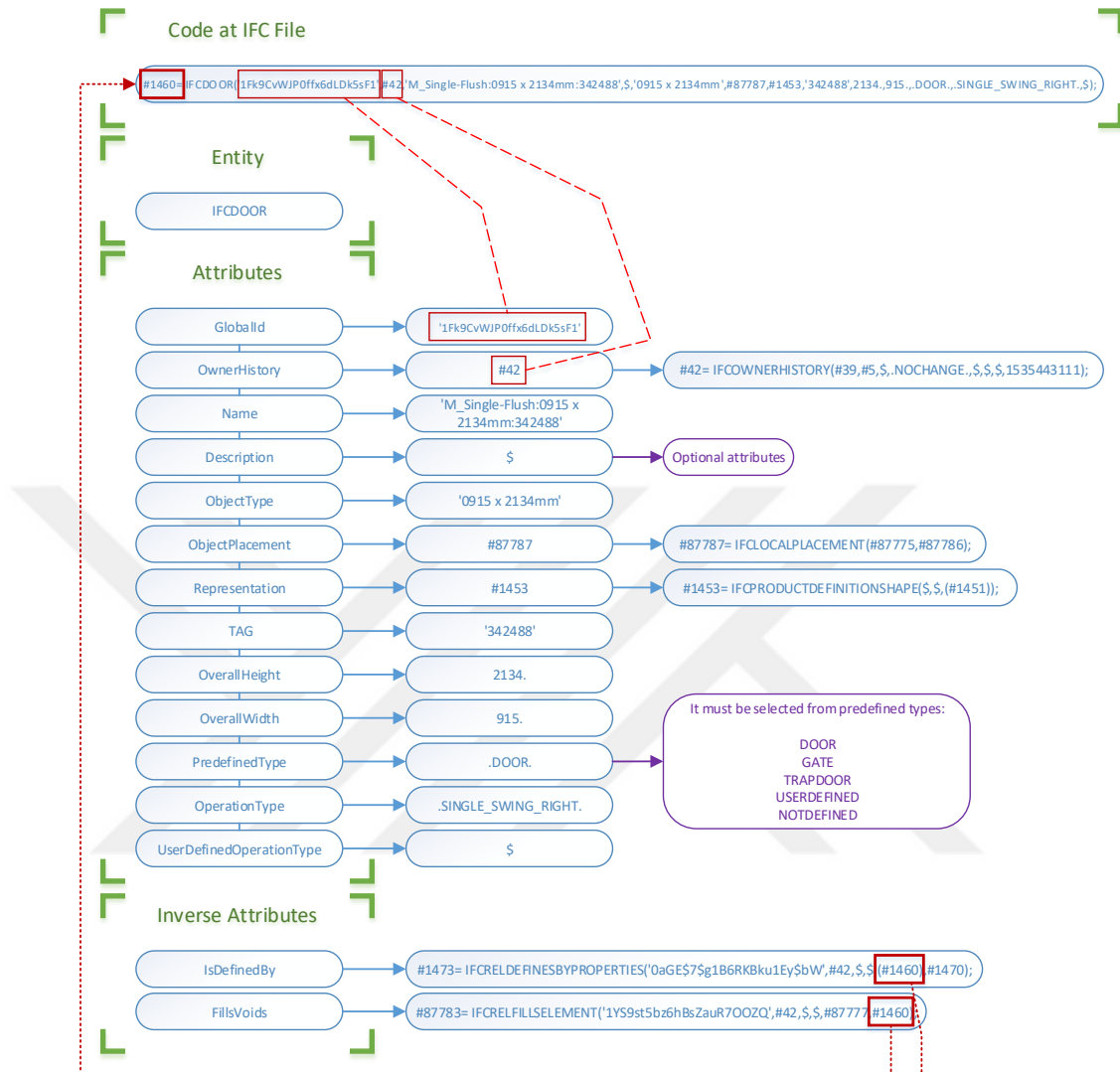


Figure 3.27 : Structure of the IfcDoor entity in the IFC file.

In the next section, new IfcFeedback class will be created by adding new code rows to IFC file.

3.3.2 Creating a new class

As an example, a new class will be created for the purpose of feedback collection from occupants. It will be named as IfcFeedback. Creation of IfcFeedback class is explained under five sections. First section positions IfcFeedback class in the hierarchy of IFC structure. Second section presents the required properties of IfcFeedback class. In the third section, IfcFeedback entity is defined with its attributes by using IfcBuildingElementProxy. In the next section, required text data of IfcFeedback is

created and linked to created entity. Last section defines how to create relations between IfcFeedback and related elements, person and space. Figure 3.28 shows the structure of created entity, IfcFeedback.

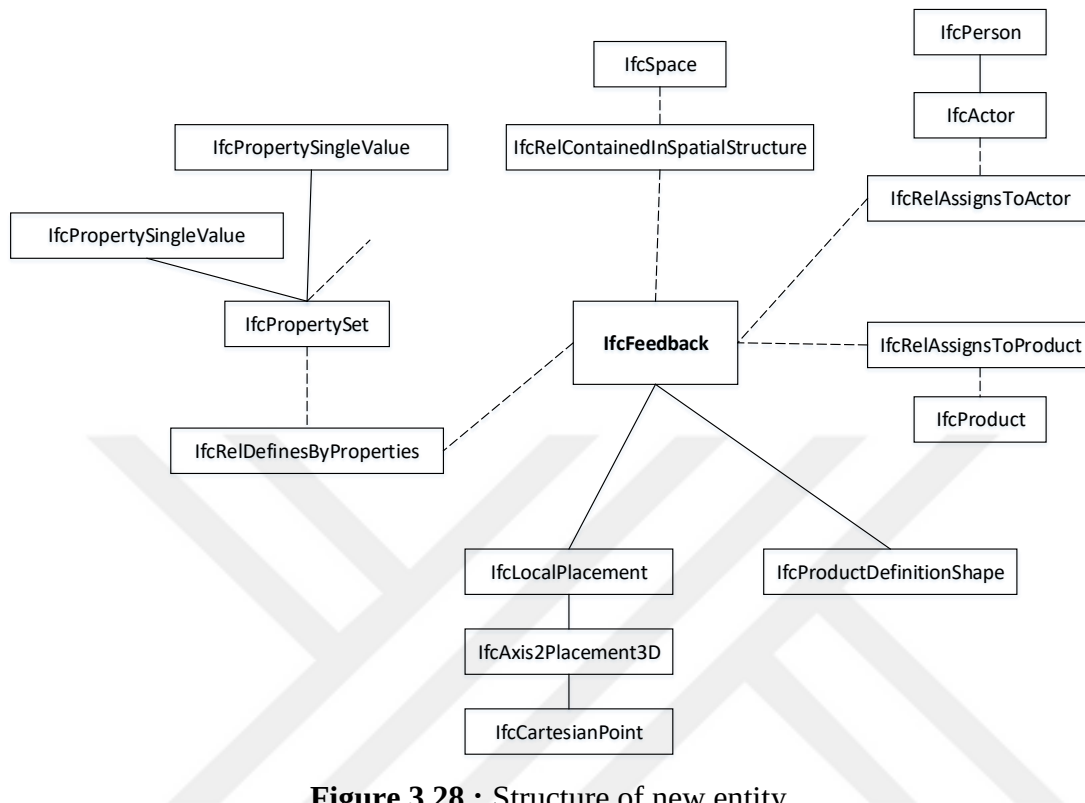


Figure 3.28 : Structure of new entity.

3.3.2.1 IFC hierarchy

After examination of current IFC structure, it was decided that the IfcFeedback class, which is used to represent the collected occupant feedbacks, will be at same level with IfcSensor. It was assumed that the occupants are like sensor devices and they send feedback data similar to sensors sending sensed data. The superclass of the IfcFeedback class is IfcDistributionControlElement (Figure 3.29).

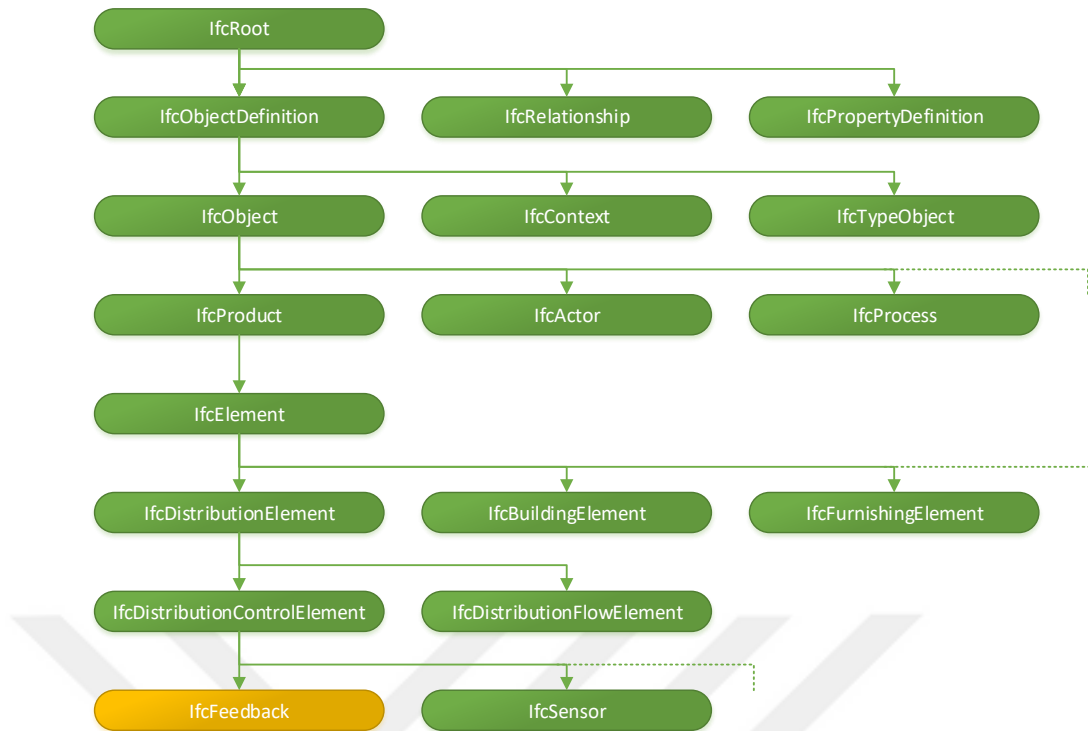


Figure 3.29 : IfcFeedback Entity in IFC Hierarchy.

3.3.2.2 Properties of the new class

The required information and properties of new class were identified at Table 3.2. Five main information data were defined to store in the new class. They are: (1) Feedback number, (2) feedback, (3) occupant name, (4) date and time, and (5) situation of feedback. Since most of the information is text data, the new class should store text data inside. To understand the relevant elements of given feedback, the new class can be related with building elements. In addition, it should be linked with rooms and/or spaces. The location and identity of the person who gave the feedback should be included inside the new class.

Table 3.2 : Properties of the new class.

#	Property
P1	Should include text data
P2	Can be related with building elements
P3	Can be related with spaces and/or rooms
P4	Can be related with person of feedback
P5	Should include the location of person or feedback

3.3.2.3 Defining IfcFeedback

If a new entity will be created in the IFC file without an official release, it can be created as a proxy element. Details of IFC extension methods are mentioned in the

previous sections. IfcBuildingElementProxy was used to create the IfcFeedback class. The properties of this class is given in Table 3.3. To create the class, a GUID must be given as a 22-character string. It was created manually according to GUID rules. All the other attributes were optional and can be left blank. Since the name of the new class was determined as IfcFeedback, the name attribute should be entered as 'IfcFeedback'. To represent the feedback in the model as a physical object, Representation attribute should be linked with related IfcProductRepresentation. Since it is complicated to manual creation of a shape in the IFC file, desired shape of created class can be modeled in the family editor of a BIM authoring tool. Then it can be exported as an IFC file and IfcProductRepresentation entity can be copied. For the Predefined Type attribute, there are six predefined values (i.e. complex, element, partial, provisionforvoid, userdefined, and notdefined) in the list. While it is manually created, “.USERDEFINED.” can be used from the enumeration list. To store the location of the feedback, object placement should be linked with IfcLocalPlacement. Below code lines can be created. The object placement property of IfcBuildingElementProxy should be linked with line #101 which refers to line #102. Finally, IfcAxisPlacement3D refers to line #103 which specifies the coordinate of IfcFeedback as x-y-z format. They are coming from coordinate system of BIM model.

```
#101= IFCLOCALPLACEMENT($,#102);
```

```
#102= IFCAXIS2PLACEMENT3D(#103,$,$);
```

```
#103= IFCCARTESIANPOINT((221,2653,0));
```

Table 3.3 : Properties of IfcBuildingElementProxy.

Attribute	Type	Entity	Value
Global ID	String	IfcGloballyUniqueId	'2B10...'
Owner History	Entity	IfcOwnerHistory	#41
Name	String	IfcLabel	'IfcFeed...'
Description	String	IfcText	\$
Object Type	String	IfcLabel	\$
Object Placement	Entity	IfcObjectPlacement	#101
Representation	Entity	IfcProductRepresentation	#104
TAG	String	IfcIdentifier	'100'
Predefined Type	Enum	IfcBuildingElementProxyTypeEnum	\$

Code of Entity

```
#100=IFCBUILDINGELEMENTPROXY('2B10rBGgrFhhBOm1200001',#41,'IfcFeedback',$,$,#101,#104,'100',$);
```

Beside the x-y-z coordinate, the space or room that contains feedback location can be represented by using IfcRelContainedInSpatialStructure (Table 3.4). The space or room must be entered as a Relating Structure attribute with line number and line number of IfcFeedback must be added to existing elements of Related Elements attribute in parenthesis.

Table 3.4 : Attributes of IfcRelContainedInSpatialStructure.

Attribute	Type	IFC Class	Value
Global ID	String	IfcGloballyUniqueId	'2XzW...'
Owner History	Entity	IfcOwnerHistory	#41
Name	String	IfcLabel	\$
Description	String	IfcText	\$
Related Elements	Entity	IfcProduct	(#91,#92...)
Relating Structure	Entity	IfcSpatialElement	#74

Code of Entity

#105=IFCRELCONTAINEDINSPATIALSTRUCTURE('2XzW4yP4z4nP3rFMrGGoOo',#41,\$,\$,(#91,#92,#93,#130,#100),#74);

3.3.2.4 Defining the text data of IfcFeedback

Text data can be related with the IfcFeedback by using IfcPropertySingleValue (Table 3.5). The name must be defined and if needed, a description can be entered. Since it is a text data, nominal value should be entered as IfcText('value') and unit attribute should be left blank.

These created IfcPropertySingleValue classes should be related with IfcFeedback. Firstly, all necessary text data should be grouped by using IfcPropertySet (Table 3.6). A GUID must be given and 'Feedback' can be entered as a Name attribute that will be used to group property values under that name. Related line numbers of IfcPropertySingleValue classes must be written in parenthesis.

Table 3.5 : Attributes of IfcPropertySingleValue.

Attribute	Type	IFC Class	Value
Name	String	IfcIdentifier	'Feedback'
Description	String	IfcText	\$
Nominal Value	Select	IfcValue	IFCTEXT('Nois...')
Unit	Select	IfcUnit	\$

Code of Entity

#111=IFCPROPERTYSINGLEVALUE('Feedback',\$,IFCTEXT('Noise coming from air diffuser'),\$);

Table 3.6 : Attributes of IfcPropertySet.

Attribute	Type	IFC Class	Value
Global ID	String	IfcGloballyUniqueId	'2B10rBGgr...'
Owner History	Entity	IfcOwnerHistory	#41
Name	String	IfcLabel	'IfcFeedback'
Description	String	IfcText	\$
Has properties	Entity	IfcProperty	(#110,#111...)

Code of Entity

#121=IFCPROPERTYSET('2B10rBGgrFhhBOM0330001',#41,'IfcFeedback',\$, (#110,#111,#112,#113,#114));

After grouping, IfcPropertySet should be related with IfcFeedback by using IfcRelDefinesByProperties (Table 3.7). After giving the GUID, related object attribute must be linked with IfcFeedback by writing line number of it in parenthesis. The line number of IfcPropertySet must be written at relating property definition attribute.

Table 3.7 : Attributes of IfcRelDefinesByProperties.

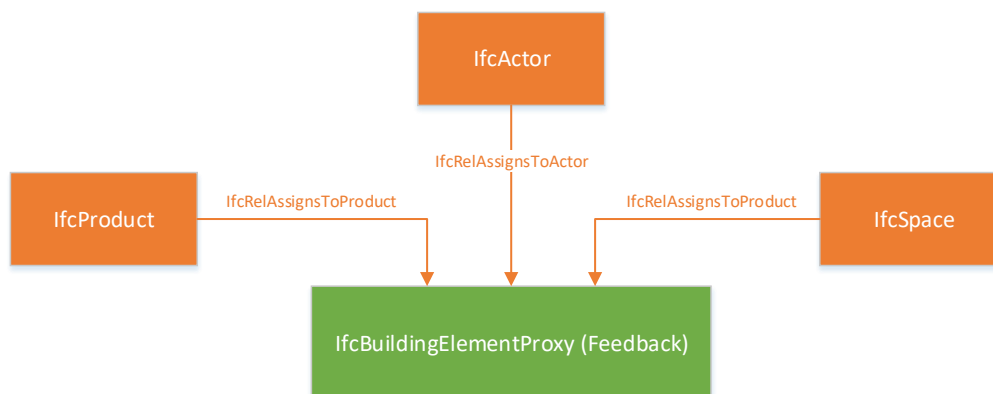
Attribute	Type	IFC Class	Value
Global ID	String	IfcGloballyUniqueId	'2B10rBGgr...'
Owner History	Entity	IfcOwnerHistory	#41
Name	String	IfcLabel	\$
Description	String	IfcText	\$
Related Objects	Entity	IfcObjectDefinition	(#100)
Relating Property Definition	Select	IfcPropertySetDefinitionSelect	#121

Code of Entity

#122= IFCRELDEFINESBYPROPERTIES('2B10rBGgrFhhBOM0330002',#41, \$, \$,(#100),#121);

3.3.2.5 Defining the relations of IfcFeedback

The IfcFeedback can be related with element(s) and/or space(s) and/or person(s) (Figure 3.30).

**Figure 3.30 :** Relation Structure of IfcFeedback.

For the relation of element(s) and/or space(s) with IfcFeedback, IfcRelAssignsToProduct should be used (Table 3.8). The relevant element(s) and/or space(s) must be referred as a Relating Product attribute. The line number of IfcFeedback must be entered as Relating Product attribute.

Table 3.8 : Attributes of IfcRelAssignsToProduct.

Attribute	Type	IFC Class	Value
Global ID	String	IfcGloballyUniqueId	'2B10rBG...'
Owner History	Entity	IfcOwnerHistory	#41
Name	String	IfcLabel	\$
Description	String	IfcText	\$
Related Objects	Entity	IfcObjectDefinition	#100
Related Object	Enum	IfcObjectTypeEnum	\$
Type	Enum	IfcObjectTypeEnum	\$
Relating Product	Select	IfcProductSelect	#130
Code of Entity			
#125=IFCRELASSIGNSTOPRODUCT('2B10rBGgrFhhBOM0340000',#41,\$,\$,#100,\$,#130);			

The information of occupant who gave the feedback was stored inside the IFC structure as IfcPerson entity which will be defined as an actor who creates the feedback (Table 3.9). The necessary information of occupant can be entered as value of relevant attributes in IfcPerson entity.

Table 3.9 : Attributes of IfcPerson.

Attribute	Type	IFC Class	Value
Identification	String	IfcIdentifier	'0221115'
Family Name	String	IfcLabel	'Smith'
Given Name	String	IfcLabel	'John'
Middle Names	String	IfcLabel	\$
Prefix Titles	String	IfcLabel	'Mr.'
Suffix Titles	String	IfcLabel	\$
Roles	Entity	IfcActorRole	\$
Addresses	Entity	IfcAddress	\$
Code of Entity			
#135=IFCPERSON('0221115','Smith','John',\$,'Mr.',,\$,\$,\$);			

Next step is to define IfcActor entity, that is associated with the created IfcPerson, and relate it with IfcFeedback (Table 3.10). The line number of IfcPerson must be entered as The Actor attribute of the IfcActor.

To relate the IfcActor and IfcFeedback IfcRelAssignsToActor should be use (Table 3.11). IfcRelAssignsToActor is similar to IfcRelAssignsToProduct.

Table 3.10 : Attributes of IfcActor.

Attribute	Type	IFC Class	Value
Global ID	String	IfcGloballyUniqueId	'2B10rBG...'
Owner History	Entity	IfcOwnerHistory	#41
Name	String	IfcLabel	\$
Description	String	IfcText	\$
Object Type	String	IfcLabel	\$
The Actor	Select	IfcActorSelect	#135

Code of Entity

#136=IFCACTOR('2B10rBGgrFhhBOM0350001',#41,\$,\$,\$,#135);

Table 3.11 : Attributes of IfcRelAssignsToActor.

Attribute	Type	IFC Class	Value
Global ID	String	IfcGloballyUniqueId	'2B10rBG...'
Owner History	Entity	IfcOwnerHistory	#41
Name	String	IfcLabel	\$
Description	String	IfcText	\$
Related Objects	Entity	IfcObjectDefinition	(#100)
Relating Object Type	Enum	IfcObjectTypeEnum	\$
Related Actor	Entity	IfcActor	#136
Acting Role	Entity	IfcActorRole	\$

Code of Entity

#137=IFCRELASSIGNSTOACTOR('2B10rBGgrFhhBOM0350002',#41,\$,\$,(#100),\$,#136,\$);

3.3.2.6 IfcFeedback code in EXPRESS in a BIM model

To create a feedback element, the IFC file of a BIM model needs to be retrieved and manually edited. The IFC file can be modified using a text editor (e.g. NotePad++). The Table 3.12 presents the IFC file that was modified to represent the sample IfcFeedback given in this section. The row numbers highlighted by purple lines of code are existing and the row numbers in red are created to represent the IfcFeedback. The rows in green color show the GUID numbers which should be created according to GUID rules mentioned previously.

Table 3.12 : Sample IfcFeedback code.

```
#X1=IFCBUILDINGELEMENTPROXY('GUID',#41,'IfcFeedback',$,$,#X2,#X5,'100',$);

#X2=IFCLOCALPLACEMENT(#52,#X3);
#X3=IFCAXIS2PLACEMENT3D(#X4,$,$);
#X4=IFCCARTESIANPOINT((39040.0905849641,-24116.8361267889,10.));

#74=IFCSPACE('1a1gCyFS5ABeQw8xRuxiAi',#41,'Z3',$,$,#1005,#1031,'Zone',ELEMENT.,INTERNAL.,$);
#105=IFCRELCONTAINEDINSPATIALSTRUCTURE('2XzW4yP4z4nP3rFMrGGoOo',#41,$,$,(#91,#92,#93,#130,#X1),#74);

#X5=IFCPRODUCTDEFINITIONSHAPE($,$,(#63));

#Y1=IFCPROPERTYSINGLEVALUE('Feedback Number',$,IFCTEXT('F0234'),$);
#Y2=IFCPROPERTYSINGLEVALUE('Feedback',$,IFCTEXT('Noise coming from air diffuser'),$);
#Y3=IFCPROPERTYSINGLEVALUE('Person',$,IFCTEXT('John Smith'),$);
#Y4=IFCPROPERTYSINGLEVALUE('Date / Time',$,IFCTEXT('26.02.2019 / 14:22'),$);
#Y5=IFCPROPERTYSINGLEVALUE('Situation',$,IFCTEXT('Requested'),$);
#Y6=IFCCOMPLEXPROPERTY('F0234',IFCTEXT('IfcFeedback'),$,(#Y1,#Y2,#Y3,#Y4,#Y5));
#Y7=IFCPROPERTYSET('GUID',#41,'IfcFeedback'),$,(#Y1,#Y2,#Y3,#Y4,#Y5));
#Y8=IFCRELDEFINESBYPROPERTIES('GUID',#41,$,$,(#X1),#Y7);

#Z1=IFCRELASSIGNSTOPRODUCT('GUID',#41,$,$,#X1,#130);
#130=IFCFLOWTERMINAL('2eyAOQE618xgAZkqrwFq1x',#41,'M_Supply_Grille-AirDiffuser:102',$,'Standard 2',#311,#325,'AD102');

#W1=IFCPERSON('0221115','Smith','John',$,'Mr.',,$,$,$);
#W2=IFCACTOR('GUID',#41,$,$,$,#W1);
#W3=IFCRELASSIGNSTOACTOR('GUID',#41,$,$,(#X1),$,#W2,$);
```

3.3.3 Case scenario

The proposed IFC entities were validated at the “ITU Çekirdek Office” (Figure 3.31). In the case scenario, an occupant in Zone 3 is disturbed by a loud noise coming from the air diffuser attached to the ceiling above his desk (Figure 3.31). He wants to report a feedback related to this issue and pointed out the related building element (i.e., air diffuser) along with the feedback. The next paragraph describes how the IFC file was modified to represent the information about the feedback. Table 3.13 shows which information will be entered in which format. All properties are string type except Situation. Since its values are predefined as requested, on progress, and finished, it is a enum type property.

The building model was exported to the IFC format by using IFC 2x3 Coordination View 2.0 and the EXPRESS file was modified using a text editor (Notepad++ (2016)). Table 3.14 shows how the EXPRESS code of the IFC model was modified to create and store the occupant's feedback in the case study building model. This process has six main steps: (1) creating the feedback and assigning a GUID, (2) storing the feedback location, (3) representing the feedback physically, (4) entering the feedback properties, (5) connecting the related elements with the feedback, and (6) connecting the occupant with the feedback.

Table 3.13 : Property Values of IfcFeedback.

Property Name	Type	Property Value
Feedback Number	String	F0234
Feedback	String	Noise coming from air diffuser
Person	String	John Smith
Date / Time	String	23.02.2019 / 14:22
Situation	Enum	Requested

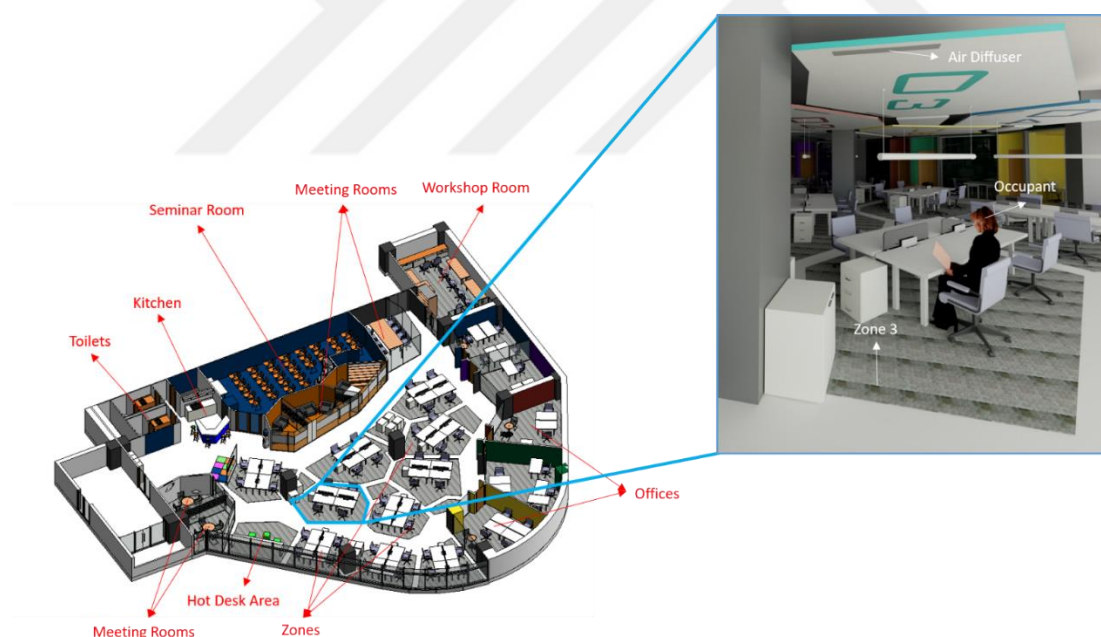


Figure 3.31 : Case study building model and close up of Zone-3.

When the user in the case study enters a feedback about his disturbance by the air diffuser, IfcBuildingElementProxy (i.e., #100) entity was created to store the IfcFeedback. This entity includes a GUID that is a 22-character string (i.e., '2B10rBGgrFhhBOMl200001'). In the case study, location of the feedback was identified in terms of coordinates. Therefore, the feedback location was stored in

IfcCartesianPoint (i.e., #103) and related with the IfcFeedback entity by using IfcLocalPlacement (i.e., #101). To connect this feedback location with the IfcFeedback, IfcRelContainedInSpatialStructure (i.e. #105) was used and the zone at which the occupant and the building element that is related to the feedback (i.e., #74) was connected with the IfcFeedback. The feedback needs to be viewed in the model as a physical object, for example to pin-point the complaint in a future query. Thus, the feedback was represented with a red cone in the building model, as can be seen in Figure 3.32. The cone was created in Autodesk Revit's Family Editor and it was represented using IfcProductDefinitionShape (i.e., #104) and linked with the IfcFeedback.

After creating the feedback and defining the location, information related to the feedback was stored in the IFC file. The related text information was entered in multiple IfcPropertySingleValue entities of the IfcFeedback entity. Since this data should be IfcText entity, they were entered as IfcText('value'). A feedback number was assigned (i.e., #110). The occupant's feedback was written as "noise coming from air diffuser" (i.e., #111). Occupant's identity was stored, as well (i.e., #112). The current time and date were also saved in the building model (i.e., #113). The condition of the feedback was saved as "requested" (i.e., #114).

To create relation with all the IfcPropertySingleValue entities, all necessary text data was first grouped by using IfcPropertySet (i.e., #121), and then IfcPropertySet was related with IfcFeedback by using IfcRelDefinesByProperties (i.e., #122). To relate the feedback with the building element that is the problem source, a relation in between the feedback and the air terminal was created by using IfcRelAssignsToProduct (i.e., #115).

Figure 3.33 shows the relations among the classes that are mentioned in the case. In the figure, all entities and relations are shown along with the row numbers of entities and relations next to each one of them to explain the EXPRESS code in Table 3.14. IfcFeedback is at the center of the structure and it is related with IfcPropertySet, IfcProduct, IfcActor, IfcProductDefinitionShape and IfcLocalPlacement. While the attributes were shown with lines in the figure, relations were shown with dashed lines. When the IFC file modified in accordance with IFC standard, it can be opened in any BIM-based software (e.g. Revit, IFC-Viewer, Navisworks).

Table 3.14 : EXPRESS code of the modified IFC file.

/ 1- Creating the feedback */*

#100=IFCBUILDINGELEMENTPROXY('2B10rBGgrFhhBOm1200001',#41,'IfcFeedback',,\$,\$,#101,#104,'100',\$);

/ 2- Storing the location */*

**#101=IFCLOCALPLACEMENT(#52,#102);
#102=IFCAXIS2PLACEMENT3D(#103,\$,\$);
#103=IFCCARTESIANPOINT((39040.0905849641,-24116.8361267889,10.));

#74=IFCSPACE('1a1gCyFS5ABeQw8xRuxiAi',#41,'Z3',,\$,\$,#1005,#1031,'Zone',
.ELEMENT.,.INTERNAL.,\$);
#105=IFCRELCONTAINEDINSPATIALSTRUCTURE('2XzW4yP4z4nP3rFMr
GGoOo',#41,\$,\$,(#91,#92,#93,#130,#100),#74);**

/ 3- Physical representation of the feedback */*

#104=IFCPRODUCTDEFINITIONSHAPE(\$,\$,(#63));

/ 4- Entering the properties of the feedback */*

**#110=IFCPROPERTYSINGLEVALUE('Feedback
Number',\$,IFCTEXT('F0234'),\$);
#111=IFCPROPERTYSINGLEVALUE('Feedback',\$,IFCTEXT('Noise coming
from air diffuser'),\$);
#112=IFCPROPERTYSINGLEVALUE('Person',\$,IFCTEXT('John Smith'),\$);
#113=IFCPROPERTYSINGLEVALUE('Date / Time',\$,IFCTEXT('26.02.2019 /
14:22'),\$);
#114=IFCPROPERTYSINGLEVALUE('Situation',\$,IFCTEXT('Requested'),\$);
#121=IFCPROPERTYSET('2B10rBGgrFhhBOm0330001',#41,'IfcFeedback',\$(#
110,#111,#112,#113,#114));
#122=
IFCRELDEFINESBYPROPERTIES('2B10rBGgrFhhBOm0330002',#41,\$,\$,(#10
0),#121);**

/ 5- Connecting the related elements with the feedback */*

**#125=IFCRELASSIGNSTOPRODUCT('2B10rBGgrFhhBOm0340000',#
41,\$,\$,#100,#130);
#130=IFCFLOWTERMINAL('2eyAQOE618xgAZkqrwFq1x',#41,'M_Supply_Gr
ille-AirDiffuser:102',\$,
'Standard 2',#311,#325,'AD102');**

/ 6- Connecting the occupant with the feedback */*

**#135=IFCPERSON('0221115','Smith','John',\$','Mr.',,\$,\$,\$);
#136=IFCACTOR('2B10rBGgrFhhBOm0350001',#41,\$,\$,\$,#135);
#137=IFCRELASSIGNSTOACTOR('2B10rBGgrFhhBOm0350002',#41,\$,\$,(#10
0),\$,#136,\$);**

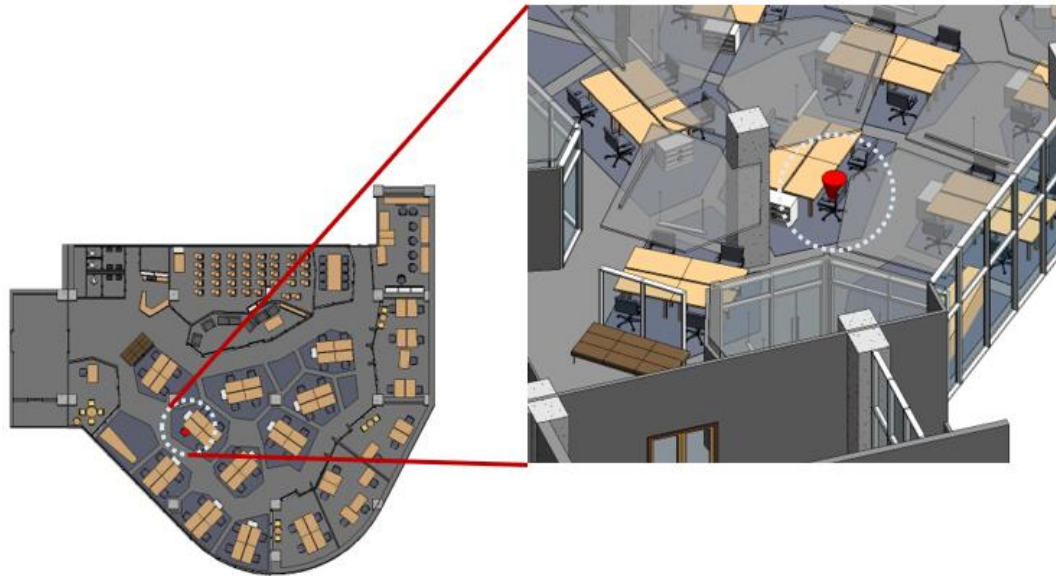
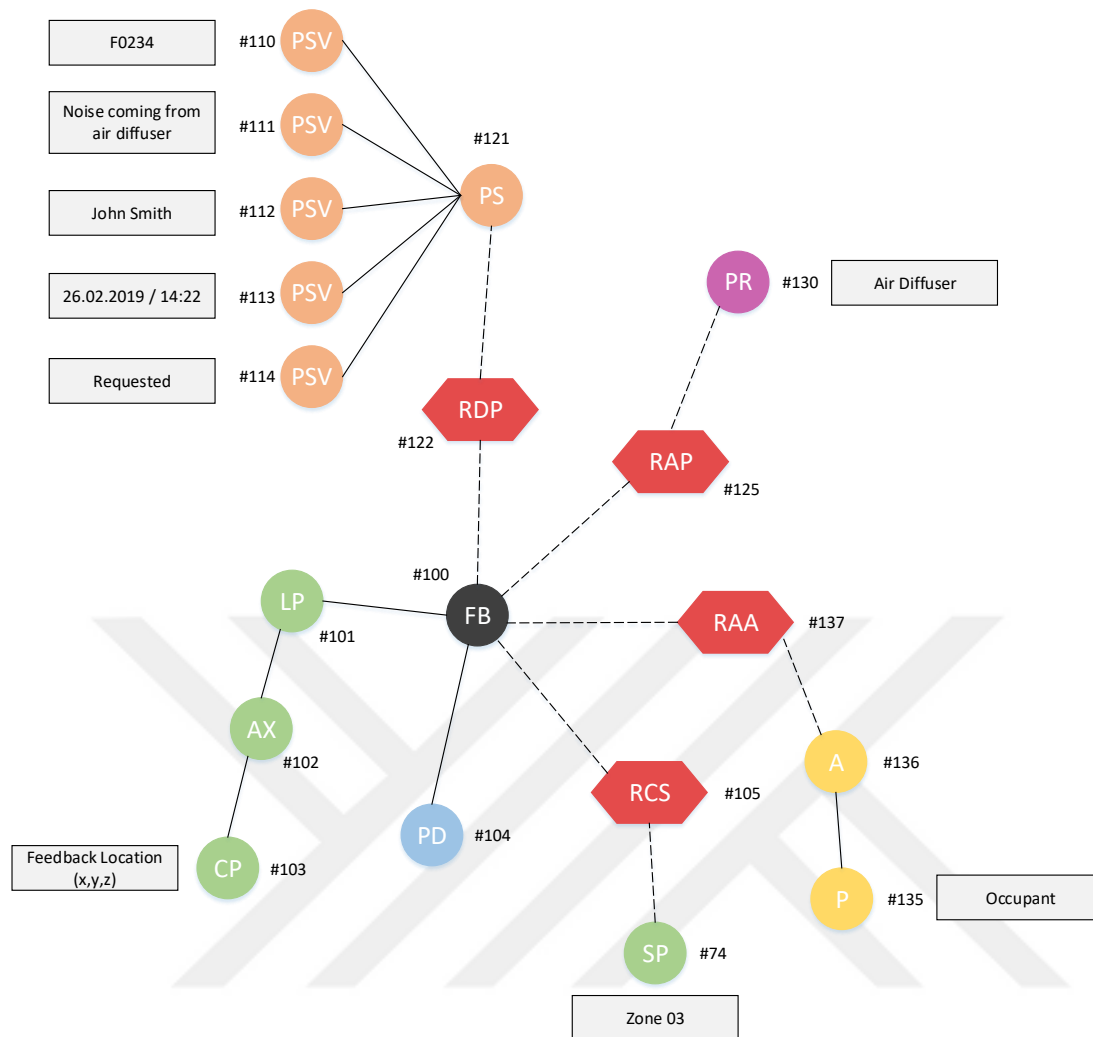


Figure 3.32 : Physical representation of the IfcFeedback in the building model.

In conclusion, extension of IFC is the most difficult way among the mentioned 3 methods in this part of thesis. However, it is the most effective way to store the FM data since it can be shared to any BIM-based software package. Also, modification of IFC file can be automated by writing APIs or software packages.

To sum up, three different methods were used for different FM purposes. Since they have variable capabilities, they were not compared with same FM activity. It has seen that BIM authoring tools could be a quick and easy way to perform some basic FM activities. However, it is only effective when the project size is small and it is not used for a continuous project. The best way to integrate the BIM in FM phase is using BIM-FM platform which is specially created for this purpose. The important point is that project needs should be well defined to decide the suitable software platform. Besides, extension of IFC file is an effective way. Manual modification in the IFC file could be acceptable but it will not be practical for a long term implementation. The modification process should be structured and developed into a software package or API in a BIM-based tool.

In this chapter, the advantages and the disadvantages of the main methods that are used in BIM-FM integration was discussed. In the light of this information, a detailed real-life case study was performed, as given in the next section.



ENTITIES

Creating the feedback

FB IFCFEEDBACK

Storing the location

LP IFCLOCALPLACEMENT

AX IFCAXIS2PLACEMENT3D

CP IFCARTESIANPOINT

SP IFCSPACE

Physical representation of the feedback

PD IFCPRODUCTDEFINITIONSHAPE

Entering the properties of the feedback

PSV IFCPROPERTYSINGLEVALUE

PS IFCPROPERTYSET

Connecting the related elements with the feedback

PR IFCPRODUCT

Connecting the occupant with the feedback

A IFCACTOR

P IFCPERSON

RELATIONS

RDP IFCRELDEFINESBYPROPERTIES

RAP IFCRELASSIGNSTOPRODUCT

RAA IFCRELASSIGNSTOACTOR

RCS IFCRELCONTAINEDINSPATIALSTRUCTURE

—— Attribute

----- Relation

Figure 3.33 : Relation diagram.

4. CASE STUDY: BIM-FM INTEGRATION OF AN INTERNATIONAL AIRPORT

Having learned the advantages and disadvantages of various methods used for BIM-FM integration, a case study of a real-life airport project was performed to identify challenges and lessons-learned of a large scale and complex BIM-FM integration case. In this section, an international airport project is investigated to examine the requirements, barriers and lessons-learned of BIM-FM integration in a large-scale complex structure. Findings are discussed at the end of the section.

4.1 Literature Review

The studies on the area of BIM usage in FM phase can be grouped into two categories according to their data collection methods: (1) Opinion-based studies that conducted surveys, interviews and group discussions, and (2) case studies. In the previous studies, researchers mostly used the first method (Becerik-Gerber et al., 2011; Liu and Issa, 2015; Sattenini et al., 2011; Mayo and Issa, 2015; Tian and Liu, 2014; Orr et al., 2014). Pishdad-Bozorgi et al. (2018) highlighted that these opinion-based findings should be supported with case studies of real-world BIM-FM implementation. Some of the case studies in the literature focused on one aspect of BIM-FM integration, such as handover phase (Hosseini et al., 2018). There are a number of case studies that examine overall BIM-FM integration process covering data collection, modeling, integration and usage in FM phase (Table 4.1). However, these case studies are conducted at small or medium scale buildings, between 1,000 m² to 30,000 m², such as university buildings and health centers. The scale is a significant factor in BIM-FM integration since a prototype developed for a small facility might not be suitable for a large-scale facility, which has complex requirements and large data sets. Teicholz (2013) highlighted this issue stating that integration of BIM with FM could have different methods and needs according to aim of organization and requirements of the facility. To identify the the requirements, barriers and lessons-learned of BIM-FM

integration in a large-scale project (i.e., more than 100,000 m²), a comprehensive case study is needed.

Table 4.1 : BIM-FM case studies.

Reference	Case Study Building	Gross Area m ²
Pishdad-Bozorgi et al., 2018	A university research facility	18,500
Thabet and Lucas, 2017	A university building	6,040
Lin et al., 2016	A new building	Unknown
McArthur, 2015	A university building	11,200
Wang et al., 2015	An institutional building	930
Kassem et al., 2015	University complex with 32 non-residential buildings	120,000 (32 Buildings)
Korpela et al., 2015	A library	26,500
Lavy and Jawadekar, 2014	A university building	8,400
	A health facility	26,000
	A health facility	12,000
Kiviniemi and Codinhoto, 2014	A city council complex	Unknown
Arayici et al., 2012	A university building	9,300
Sattenini et al., 2011	A university building	3,260
Akcamete et al., 2010	A university building	Unknown

Most of the previous studies implemented BIM-FM integration at one building in the case study (Table 4.1). Among the investigated studies, there is only one study that performed more than one case study (Lavy and Jawadekar, 2014). In this study, the researchers conducted three case studies where BIM and COBie were used for facility management and identified the encountered problems. Although Kassem et al. (2015) performed the case study at a university campus with approximately 120,000 m² area, 32 non-residential buildings were covered and the same method was replicated at each building. In this study, only a BIM authoring tool (Revit) was used for BIM-FM integration and there were no other BIM-FM platforms.

The most commonly used case study techniques was interview and document investigation in the literature. Interviews were performed online or face-to-face (Miettinen et al., 2018; Pishdad-Bozorgi et al., 2018; Kassem et al., 2015; Korpela et al., 2015; Kiviniemi and Codinhoto, 2014; Lavy and Jawadekar, 2014; Arayici et al., 2012; Sattenini et al., 2011). Besides, document investigation (e.g., e-mails and project drawings) was used to extract the problems (Pishdad-Bozorgi et al., 2018; Kassem et

al., 2015; Korpela et al., 2015; McArthur, 2015; Kiviniemi and Codinhoto, 2014; Lavy and Jawadekar, 2014; Akcamete et al., 2010).

Table 4.2 lists the challenges of BIM-FM integration found in the literature. These challenges can be divided in two categories: (1) general challenges which are not specific to BIM-FM integration but related to BIM adoption (e.g., cultural resistance and lack of knowledge), (2) challenges related specifically to BIM-FM integration (e.g., interoperability and having no proof of positive return).

Table 4.2 : Barriers of BIM-FM integration from literature.

Type	Challenges	References
General	Cultural resistance to accept the new technology	Becerik-Gerber et al., 2012; Motamedi and Hammad, 2009
General	Resistance to the new investment of necessary infrastructure such as software packages and training inside the firm	Becerik-Gerber et al., 2012; Migilinskas et al., 2013
General	Not collaborative and effective working among the project stakeholders	Becerik-Gerber et al., 2012; Migilinskas et al., 2013
General	Lack of BIM knowledge in the FM team members	Migilinskas et al., 2013; Kassem et al., 2015; Motamedi and Hammad, 2009; Korpela et al., 2015
General	High cost of initial investment	Motamedi and Hammad, 2009
BIM-FM related	No proof of positive returns from real cases of BIM-FM integration	Becerik-Gerber et al., 2012; Migilinskas et al., 2013; Kassem et al., 2015
BIM-FM related	Unclear capacities of BIM in the FM phase	Kiviniemi and Codinhoto, 2014; Kassem et al., 2015; Nguyen et al., 2017
BIM-FM related	Unclear roles and responsibilities during the process of uploading data to BIM model for FM phase and checking this model	Becerik-Gerber et al., 2012; Kassem et al., 2015; Nguyen et al., 2017
BIM-FM related	Interoperability problems between BIM models and FM software packages.	Becerik-Gerber et al., 2012; Kiviniemi and Codinhoto, 2014; Migilinskas et al., 2013; Kassem et al., 2015; Terreno et al., 2016; Korpela et al., 2015
BIM-FM related	Undefined data created on the design and construction phases to be transferred to the FM phase	Nguyen et al., 2017

Besides challenges of BIM-FM integration, lessons-learned identified from the case studies are contributing to the body-of-knowledge. They can be used to define the frameworks and helps to understand how to implement BIM and FM efficiently.

According to Pishdad-Bozorgi et al. (2018), there is a need for a real-world project that examines the overall BIM-FM integration. In their study, they have examined a research facility at a university to define the challenges and lessons learned for FM-enabled BIM (Pishdad-Bozorgi et al., 2018). They also proposed a research framework for implementation of BIM-FM. However, the area of the building used at the case study was nearly 18,500 m² and it is not a complex structure when compared with industrial facilities and airports.

To conclude, there is no real-life large-scale complex structure case in literature. Since there is limited cases and lack of large-scale complex structure case, this study aims to contribute the body-of-knowledge by conducting a case study in a large-scale complex structure (i.e. international airport project) to identify requirements and challenges.

4.2 Methodology

BIM-FM integration in a large-scale international airport was investigated in this study. An airport was selected since it has different floor plans with complex MEP systems in both vertical and horizontal layouts. The case study method is selected as a research method for this study, since it is the suggested method for a holistic in-depth investigation (Tellis, 1997). According to Yin (2011), real-life contexts should be evaluated to find the in-depth knowledge of lessons-learned and challenges, as it cannot be find from general questionnaires. To find the challenges and lessons-learned of BIM-FM integration in a large-scale complex structure, an international airport was selected. The BIM model of the airport was developed at the end of the construction phase to be used in the FM phase.

Two data collection methods were used in the case study: (1) interviews and (2) document investigation (Figure 4.1). Several semi-structured interviews were carried out with the members of the BIM team in the project (e.g. BIM manager and BIM engineer). Some of the interviews were online and some of them were in person (Table 4.3). Some of the interviews were done with same person multiple times. Duration of the interviews was spread over 9 months. Document investigation was performed on

project-related documents, BIM models and BIM-FM platform (i.e. EcoDomus). To discuss the results of document investigation, interviews and investigation processes were carried out concurrently. Data collection performed over a six-month period. In the end, a triangulation was performed to combine the results of document investigation and interviews (Bryman, 2016).

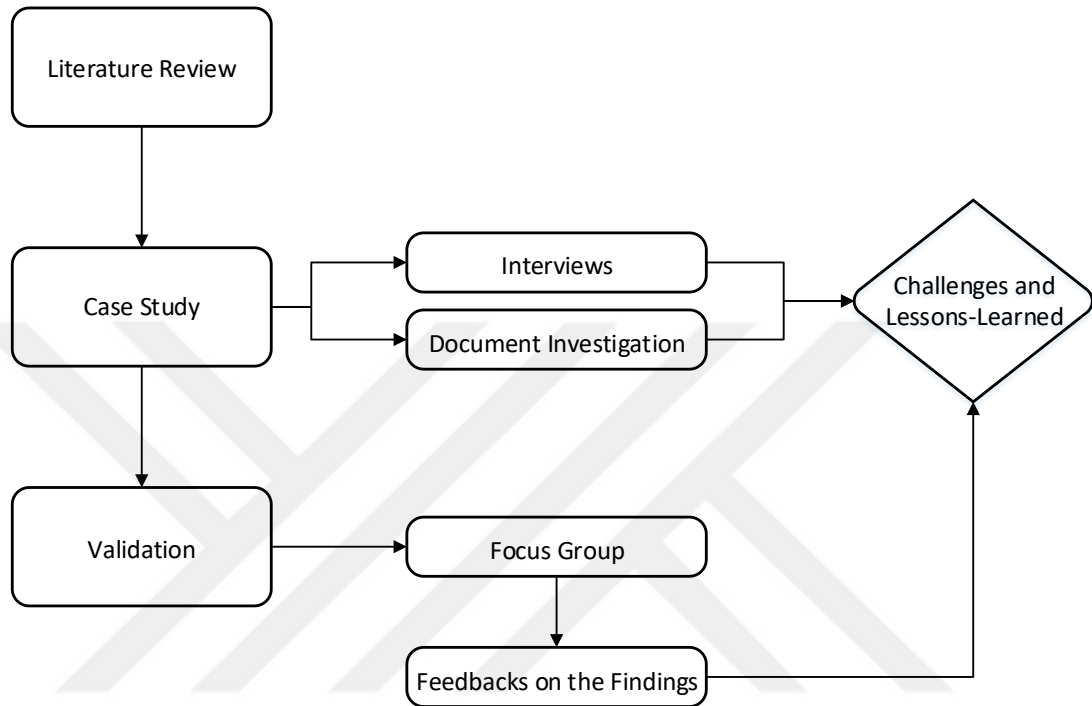


Figure 4.1 : Methodology.

Table 4.3 : Interview details.

No	Participant	Duration	Type
1	BIM Manager	60 min	Face-to-face
2	BIM Senior, BIM Engineer	120 min	Face-to-face
3	BIM Senior, BIM Engineer	120 min	Face-to-face
4	BIM Manager	90 min	Face-to-face
5	BIM Engineer	30 min	Telephone

To validate the results, the findings were presented to group of experts (Table 4.4) in a focus group meeting. The feedback from the focus group are integrated with the results.

Table 4.4 : Focus group details.

Participant	Firm
BIM Manager	Large-Scale Construction Company
BIM Consultant	BIM Consultancy Firm
BIM Consultant	BIM Consultancy Firm
BIM Senior	Large-Scale Construction Company

The case study findings were compared with the findings in the literature. Also, the differences of the implementation barriers when the project is large-scale complex structure were defined. Also, challenges related to implementation in large-scale projects were highlighted and discussed.

There are two limitations in this study. Since BIM-FM integration is decided at the end of the construction phase, the possible problems in the design and construction phases could not be identified. However, potential problems that can be experienced in these phases discussed with experts. Therefore, the findings are mostly related to the integration of BIM-FM for the existing buildings. The other limitation is that a commercial BIM-FM platform is used in the project. Even though different BIM-FM platforms and integration methods (i.e. GIS) are tried in selection process, the other options were not fully applied to the real project. The results can be used for the selection of BIM-FM platform.

4.3 Project Information

An international airport, which is a large-scale infrastructure project located in a Gulf country, is selected in this study (Figure 4.2). The total area of the whole project is 1.5 million m² including runway, taxiway and apron area. Only the terminal building and concourses, which cover 156,940 m², are modeled for FM phase (Figure 4.3). The capacity of the airport is 8 million passengers per year. The project is the first LEED Gold certified airport project in the Middle East and North Africa region. It also has the award of ENR's Global Best Projects in the airports/ports category in 2015.

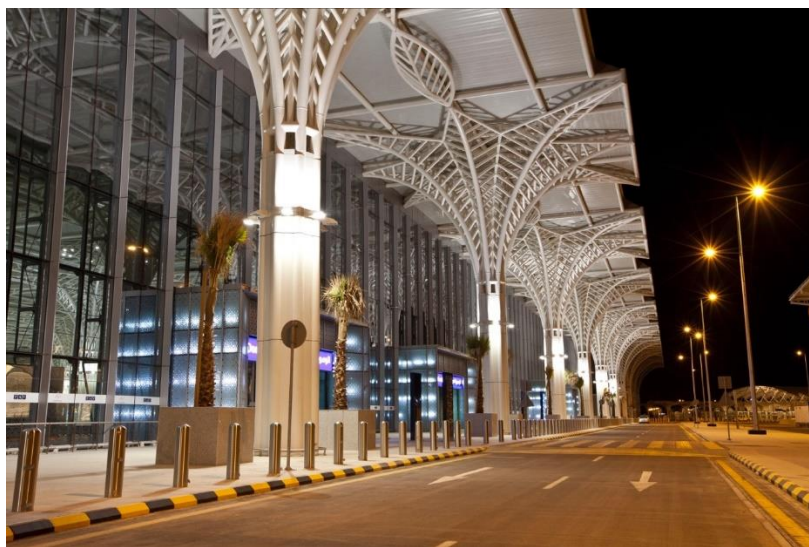


Figure 4.2 : General view of the airport (Sacks et al., 2018).

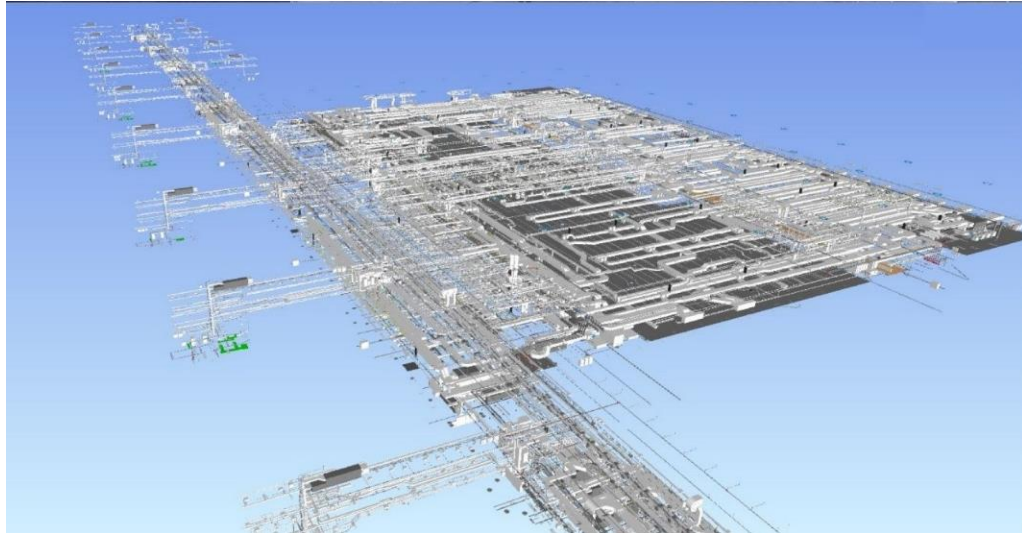


Figure 4.3 : 3D model view of the airport (Sacks et al., 2018).

The project is Build-Transfer-Operate (BTO) project and main contractor is a Joint Venture (JV) of one company from Turkey and two companies from Saudi Arabia (Figure 4.4). The JV is responsible of both construction and management of airport including both airside and landside. BIM usage was not planned for the project, however, it was considered as a useful tool to comply with the Employer's Information Requirements (EIR). BIM implementation is founded by JV and managed by BIM department of the main contractor from Turkey. It has also an FM team within the company. This team helped to BIM department to consider the project needs of operation phase. This main contractor will be called as BIM contractor and JV will be called as FM company in the following sections of this paper.

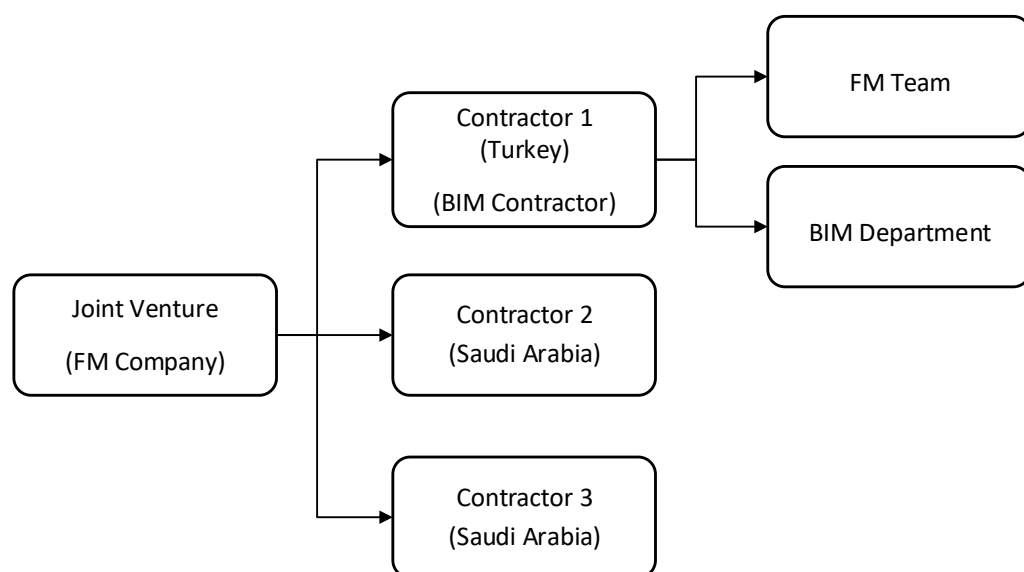


Figure 4.4 : Joint Venture structure.

For the entire BIM-FM integration process, there were participants from seven countries and four different continents (Figure 4.5). To work with all stakeholders efficiently, a web-based project management platform was used for communication, and an enterprise hybrid cloud file sharing platform was used for file sharing. It is aimed to create model in LOD 500 for achieving FM integration in twelve months. Some changes and updates on the project extended this duration to 18 months. Entire FM model of airport includes eleven BIM models which are authored in Autodesk Revit with more than 580,000 components. The files were divided according to the disciplines and floor levels. A Computerized Maintenance Management System (CMMS) is also integrated with the BIM-FM platform. Figure 4.6 shows the system schema. More information about the airport project can be found at Sacks et al. (2018).

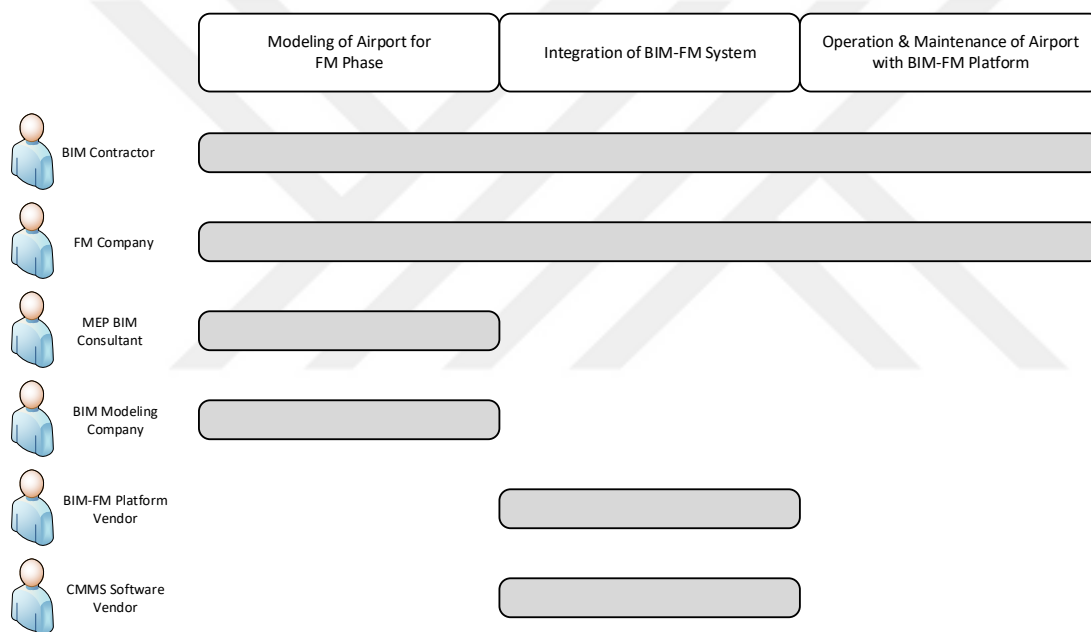


Figure 4.5 : Project stakeholders of Case Study.

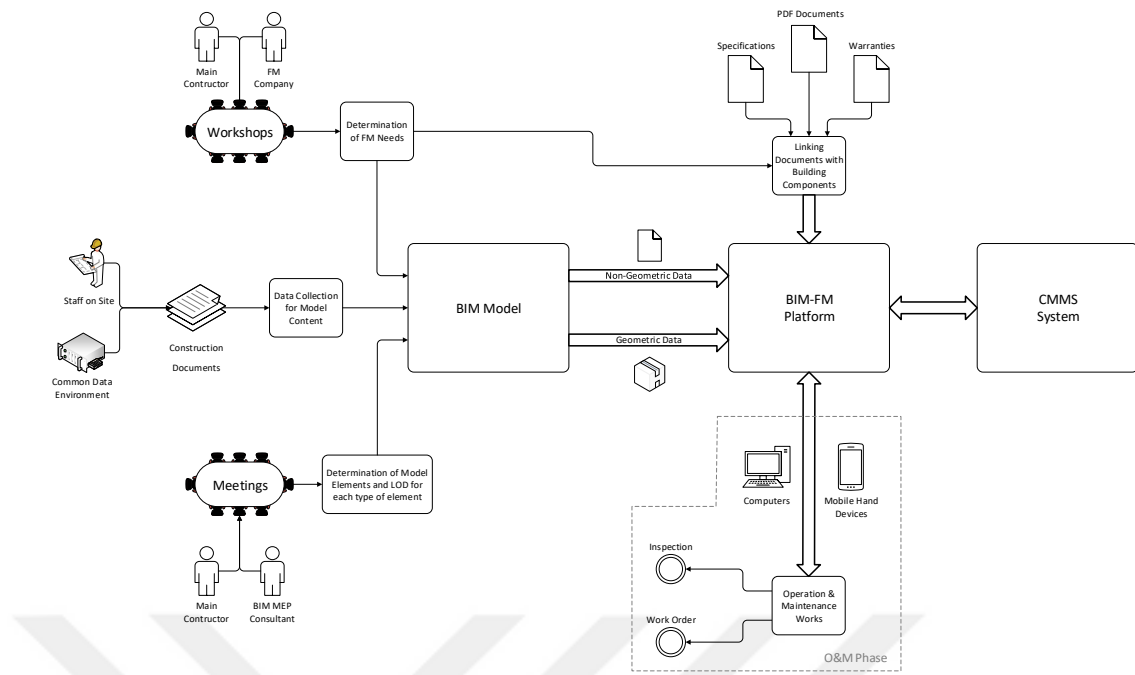


Figure 4.6 : System schema of BIM-FM integration.

The entire process of BIM-FM integration in this case can be divided as 3 stages: (1) Modeling, (2) integration of BIM model with BIM-FM platform, and (3) integration of CMMS system with BIM-FM platform.

Since the BIM-FM integration is started at the end of the construction phase, there was no BIM model; only the 2D drawings were available. In the first stage, the main goal was to determine model elements and the data to be included in the model. Workshops and meetings were set up to determine the requirements of BIM model in the FM phase. In the workshops in attendance with FM experts of BIM contractor and FM company, end-user needs are discussed. Important building elements, systems and asset information for the FM staff are determined to define the scope of the BIM model. BIM contractor and MEP BIM consultant scheduled meetings for determining the model contents. MEP BIM consultant focused on especially for the solving and modeling of the complex MEP systems. Drawings are retrieved from the common data environment (CDE) system (i.e. Aconex). The as-built information is gathered from site staff of main contractor. For a proper tagging, an Object ID scheme is developed for the assets of airport. Object IDs were assigned to each element as a parameter value in the BIM model. Rooms and spaces are also defined and modeled without any overlapping with a naming system. MEP systems and their subsystems were created and related with proper MEP elements. Modeling the airport from the gathered as-built

drawings and data is done by BIM contractor and MEP BIM consultant with the support of a BIM modeling company. As BIM authoring tool, Autodesk Revit software package was used for modeling.

The second stage includes transferring of the model to BIM-FM platform (EcoDomus) and linking documents with building components. There are two types of data that were transferred in BIM model. The first one is geometric data which contains 3D geometric information of building components. The second one is non-geometric data including user-defined parameters (e.g. Object ID). Geometric data and non-geometric data were matched using Revit ID numbers. In this case, model can be transferred to BIM-FM platform via an add-in in the BIM authoring software or IFC file can be uploaded to system. It is a unidirectional activity; thus, changes made at the BIM-FM platform were not transferred to the BIM model. The documents, that are required in the FM phase (e.g. photos, warranties, specifications), were related with the building components in the BIM-FM platform. Figure 4.7 shows a model view in the BIM-FM platform.

As a third stage, a CMMS platform (IFS) is selected and its database was synchronized with BIM-FM platform via APIs. FM team is used to operate airport with CMMS platform and CMMS platform is used when the airport is in operation. In this phase, BIM-FM platform vendor and CMMS system vendor worked together to determine the interoperability protocols between the systems. Data is stored in COBie format inside both CMMS and BIM-FM platforms.

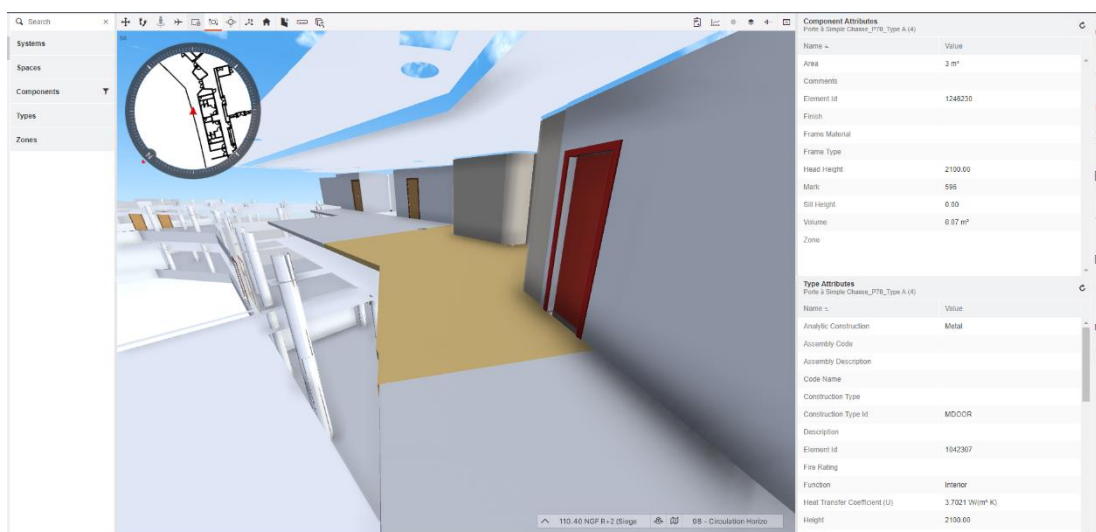


Figure 4.7 : BIM-FM platform.

Integrated BIM-FM system can be used via mobile hand devices such as mobile phone and tablet at site or computers at office. Work orders and inspections can be created and followed inside the BIM-FM platform. Asset data and work orders are stored inside the CMMS database linked to BIM-FM platform. O&M activities are managed by FM company, while updates and authoring of BIM model is the responsibility of main contractor. It is periodically updated once a month if there is no emergency. Data that should be updated are gathered by FM company and sent to BIM contractor.

4.4 Findings and Lessons Learned

In this section, the findings and lessons learned are provided. Figure 4.8 shows the phases where each topic belongs in the BIM-FM process.

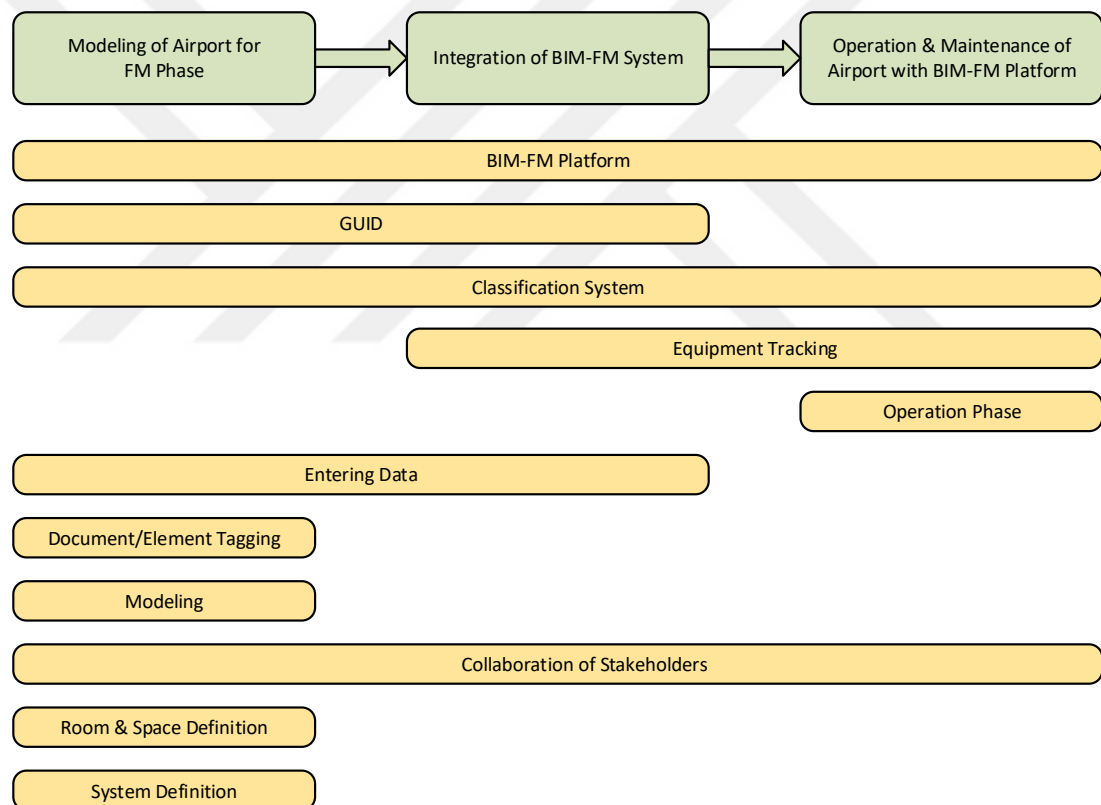


Figure 4.8 : Findings in BIM-FM process.

4.4.1 BIM-FM platform

File size: When the project is large-scale and complex, size and number of the BIM model files are larger. In this project, there were 11 BIM models and their size are approximately 300 megabytes. BIM-FM platform allows to upload model file only less than 1 GB because of its server system. Since total size of the geometric data of federated BIM model is more than 1 GB in this project, system does not allow to

upload data to the platform by users. As a basic solution, main contractor sends all the files to the BIM-FM platform vendor to upload them to their system. BIM-FM platform vendor arranges files to be able to upload into system and updates the model. Since this update procedure should be repeated for every update, it is not an efficient solution. As a permanent solution, BIM-FM vendor updated its server system to be able to allow users to upload large files.

While modeling the airport, it is divided into 11 models according to levels, systems and zones. When there is an update in one of the models, all the models must be linked and combined (federated BIM model) by using BIM-FM platform add-in in Revit. Since the size of the files are heavy, it takes time to update model inside the platform.

Another problem related to the file size is the poor performance of the model viewer in the BIM-FM platform. The size of the model file makes it hard to navigate in the model because of the lags. BIM-FM platform vendor has changed its rendering engine and they are now using Unity gaming engine for rendering the model. Stability and speed of the model viewer is better after renewal of the system.

Categorization of building elements: In the platform, breakdown structure of the building elements are categorized according to IFC format. However, for the facilities management purposes, data needs to be organized based on breakdown structure. As a result of request of BIM contractor, BIM-FM vendor has added a categorization option in the platform. So that users could define the element breakdown structure for their FM purposes.

Factors to be considered when selection of BIM-FM platform software: Firstly, financial decision should be done based on pricing of software. Some BIM-FM platforms are priced by number of users and some of them one priced by the size of the project with unlimited users. Secondly, system infrastructure has an important role on the selection phase. Some platforms are on a server and some of them are on cloud. While cloud systems are more accessible and have more option to reach the file (e.g. mobile hand devices), the speed of server systems are higher since they do not depend on internet connection. Lastly, data transferring method is another factor. Some platforms divide the data transfer as geometry and information. After transferring, they are matched by using Element ID numbers. Dividing this process could be effective if the geometry will not be changed and information will be updated from outside.

However, there could be geometry and data matching problems when an element is deleted or changed which creating new Element ID. The BIM-FM platform should be selected by considering the project conditions. Also, even some platforms have extraordinary properties in their systems, it should be well decided that if they are suitable on FM phase of the structure.

4.4.2 GUID

For interoperability of the software packages, IFC files are used in the project including BIM-FM platform. When the model file is exported into an IFC file from Revit, Globally Unique Identifier (GUID) number of the building elements are regenerated automatically. Sometimes, this process can be resulted in overlapping GUIDs of different elements. For example, when the IFC file, which is generated at Revit 2017, was checked, it was seen that there were nearly 100 out of 3000 IfcDoors missing. In some cases, four different doors had the same GUID. To identify the overlapping IDs, pivot tables including element types and counts should be created. It can be checked via schedules created in Revit or schedules can be extracted to Excel spreadsheets to compare. If number of elements in a Revit file does not match with that of IFC file, relevant building elements should be cross-checked individually.

4.4.3 Classification systems

Although classification standards such as OmniClass and Unifomat were used in the project, they are not sufficient for a complex structure like an airport. These complex structures includes many different mechanical equipments and building elements. In addition to the classification codes, it is necessary a hybrid tagging system by adding extra information to the classification code. For example, diameter of a pipe can be added to pipe tag, if it is necessary for FM phase. OmniClass, which is one of the most commonly used classification system, defines 600 breakdowns in Table 23 (Products), while Revit model of the airport has about 3000 families. It shows that some of the elements should be tagged with same OmniClass code. In return, some of the building elements could not be found in the classification table.

4.4.4 Equipment tracking

In the case study, most of the maintenance and operation works (e.g. luggage system, ventilation) is done by subcontractors. Therefore, element-based tracking is not done

by FM firm and subcontractors are responsible for these elements. Only some special equipments are being monitored. For example, if an elevator fails in a certain period of time (e.g. 30 minutes), a penalty is cut. In an airport nearly 30-40 important building equipments are tracked.

Equipment-based tracking is performed only for large and/or special elements (e.g. cooling unit) in the CMMS database. Location-based tracking is performed for most of the elements. In other words, most of the elements are tracked as bulk material in each space or room and only total numbers of elements are known. For example, a specific bulb change is not tracked. The only information that is stored is the number of bulbs that was replaced in each room. It is not seen the specific tag of the replaced bulb in the reports. When location-based tracking is performed, only reactive maintenance is done and maintenance and repair works of them are charged as lump-sum. The O&M history of the elements are not available. There is no predictive or preventive maintenance record. In room-based tracking, when the filter of an air conditioner in a specific room was changed, it is not clear which air conditioner it is. Since not all the elements are tracked in the FM phase, Revit model of airport has about 2 million elements and this number drops to 6-7 thousand in the CMMS database.

The spare parts and spare parts of the components are kept in the warehouse and these are saved in CMMS data. However, this data is not modeled in BIM model. Therefore, it is not possible to track these elements in the model. The warehouse data should be saved in COBie format for easy integration with the CMMS database and FM systems if needed.

Location of the some elements can be changed through FM phase. For example, furniture can be moved to another space. In addition, elements can be replaced by a new one to perform maintain or to repair the component. When maintenance/repair is completed, it can be used elsewhere. In such cases, the locations of the elements can be updated on the CMMS database as text data, but it needs to be updated in the Revit model and uploaded to the BIM-FM platform for object-based tracking. In some cases, only data-based tracking can be considered as a quick solution. For example, during the pilgrimage time, the tents are installed outdoor of the airport and mobile air conditioners are transported inside the tents from the warehouse. Tracking of these equipment is difficult to in 3D on the BIM-FM platform.

Three different methods can be used for equipment-based tracking:

- (1) Using a database without model: In this method, it is hard to follow equipments individually, since it is hard for technician to determine which equipment is the relevant one among the others inside a room.
- (2) Using barcode system to identify the equipments on site: However, due to the positions of some elements, it may not be possible to reach the elements and read the barcode. For example, security cameras can be found at 8 meters above the ground level at airports. A solution for this problem is that the barcodes can be installed on any reachable point of the room and this barcode can include list of equipment in the room. However, it is still not easy to identify the related equipment, if there are more than one in the same room or space.
- (3) Identifying the equipment from the model: This is the most effective solution since it allows for identification of the equipment from the model. Therefore, it is suggested that a BIM model needs to be created even for existing buildings.

4.4.5 Operation phase

Field teams are not interested in using hand-held devices such as tablets or smartphones for data entry. They are relevant to use these kind of devices since most of the times their hands are full and/or dirty because of site conditions . In addition, field teams are usually not technology-friendly. Therefore, more user-friendly technologies (e.g. artificial and mixed reality) are suggested to be used at site by the technical field personnel. Such devices would alter the working conditions minimally and the menus can be designed for easy-access at site.

Currently, the BIM-FM integration is still in progress at this airport. Since there is no previous experience on such an integration at a large scale, there are still some vague points. In addition, workers are not interested with the system, since it records everything that allows the errors be seen easily.

Only the technical team is working with the BIM-FM platform. Three people from FM firm are involved in this process. The continuity of the model is currently provided by the main contractor. After a certain period of time it is planned to be completely transferred to FM firm. However it is still not possible since suitable environment has not been occurred for the time being. The FM team should gain more experience.

For effective FM, it is suggested that the FM team have two separate teams. While one of the teams deals with maintenance and repair, the other team should only deal with maintenance of the BIM-FM platform. This team should be capable of updating the model and recognizing the fluctuations (e.g. missing elements) in the system for taking necessary actions.

4.4.6 Entering data

Parameters and the value should be determined by the FM team before modeling. For example, if the FM platform needs to include mobile phone number of the technician who will change the bulb in the model, this information should be available when the model is being created. However, this information might not be available at the modeling phase since the technician is not hired at that time. In this case, this information should be later entered by the FM team or transferred to the BIM team by the FM team.

4.4.7 Document/element tagging

While starting a project with BIM for the first time, most of the companies prefer to leave their standard document numbering system and create a new system. They think that their system must be renewed for BIM usage. This approach generally results in data compatibility problems in the future, especially on the FM phase, when data from previous project needed to be merged with the data that was created using the new system. Therefore, a system should be created in accordance with the existing numbering and tagging system of firm. Even though the project is delivered with COBie format, it might not be useful since tagging and numbering used in COBie format does not match with the company's system. Usually when the project is modeled in the architectural office, the project office is used their numbering and tagging system. After the model has been delivered, numbers and tags of the documents and building elements have to re-entered in their format by FM team for compatibility with the FM systems. Sometimes, the owner wants to see links of the related documents in the parameters of elements. However, usually the file path and file naming is not certain, yet. Therefore, entered links are not worked when model delivered to FM team. Either file structure and naming should be determined at the beginning or file paths should be given to designer before entering the URL links. In

case study, assets in the BIM model and CMMS database are suitable for both system. Each data can be transferred to the other system easily, if needed.

If there are more than one element in same type in a room, a number is added at the end of their naming tags. For example, if there are three air terminal in the same room, their naming tags are: (1) XXX_YY_01, (2) XXX_YY_02 and (3) XXX_YY_03. While assigning codes to the elements, the numbers of the same elements are usually reset in each room. However, FM team wants to see the total number of elements in the facility, when they look at the element list. Therefore, they do not want element tagging numbers to be reset in the rooms. These numbering can cause some problems. For example, when an element is disassembled and taken to the warehouse for repair, it is not clear what will be the number of element that added instead of the removed element. Besides, if the removed element is installed somewhere else, it is not clear that if the number will remain the same or it will be changed according to the order in the room. It is more useful to not reset the numbers in the tagging of elements of same types, since the number will be unique for each element.

4.4.8 Modeling

In the project, LOD500 model was aimed but geometry of the model should not have to be LOD500. If it is modeled in LOD500, all of the elements and their details must be included in the model, which makes the model be extra heavy. For the FM phase, important detail is level of information. It is suggested to divide model detail level in two categories: (1) Level of geometry (LOG) and (2) level of information (LOI). Combination of these two details will be called as level of development (LOD). Besides, level of information need (LOIN) can be used to define the detail of request of owner. According to LOIN, LOG and LOI levels should be determined for the project.

Generally, the families created by suppliers have lots of geometric and non-geometric data. In the case study, this type of families were also used. Some elements that has big file size and too much detail have been simplified or removed to reduce their size. Each element was not created at the same geometric detail level. For example, pipe hangers were never modeled, since they will not be used in the FM phase and there are huge number of pipe hanger element which causes big size of data in the model file. In addition, some geometric and non-geometric (e.g. view angle parameter) details of

supplier family of the security cameras were simplified. Security cameras have view angle parameters and these were removed to simplify the elements.

While the geometry of the elements is kept simple, some important points in view of FM team should be taken into consideration. For example, if the element has cable or pipe inlet and outlet, they should be modeled in the right place. It is not has to be exactly same element with every detail. However, there should not be symbolic elements like cube, but generic elements can be used. For example, there are 85.000 sprinklers in the model and basic generic sprinkler elements were used to not make the model heavy.

4.4.9 Collaboration of stakeholders

Airport project involves stakeholders from seven countries all around world including four different continents. It was even challenging to arrange meetings for collaboration and communication among stakeholders. Each country has different holidays and different time zones. Only method for meetings was conducting web meetings and it also had some disadvantages such as internet connection quality. To solve this problem, a common communication and file sharing platform was used and all web meetings were recorded and shared with other participants. In addition, a web-based project management platform was used inside of sending email among stakeholders.

4.4.10 Room & space definition

In the case study, tags of the elements include room or space codes. In order to include location information in the tag of all elements, the spaces in room must be defined for all areas in the model. To ensure that the equipment tags are unique for each unit of equipment, a unique room space that is not overlapping is required to be defined. Many places in the terminal have high ceiling gaps and irregular elevated slabs. It is an important challenge to define each room at an airport terminal with different room heights, ceiling gaps, shafts and technical chambers.

A difficulty in room naming is that some defined rooms and spaces at design phase might be redefined when operations start. Due to this problem, the airport project required a lot of manual modification of BIM models. Room volumes must be defined to include all elements in the specific room area. They must be unique and cannot overlap to ensure that the associated tagging is unique. Visual inspections were

performed on Revit and Navisworks to ensure that all equipment is captured in a room volume.

4.4.11 System definition

Connecting all MEP systems within BIM models to provide consistent visual and text information of connected pipe and duct networks was a fundamental requirement and challenge. In the model, some elements are part of more than one system. This situation can cause difficulties because of limitations of BIM authoring tool and filtering purposes of equipments and systems. To solve the problem, shared parameters were created and added to elements to be able to filter the systems by using parameter values.

To summarize, it is found that most of the findings of case study are related with only large scale complex projects. Some of them are similar with the findings of pilot study, however additional barriers and challenges were found that can fill the gap in the literature. For example, the file size was not a problem in the pilot study, however there were difficulties of uploading/updating the model and viewing the model in the case study because of the big file size. In addition, GUIDs were overlapped since there were lots of building element in the BIM model. The standard classification systems could not be enough for categorization of the building elements because of the high number of building element type. For the element tagging a hybrid system was developed. GUIDs and element tagging was not a problem for a small size project in the pilot study. Room definitions and MEP system definitions were also a problem, since the project is complex in terms of floor layout and MEP system.

When the case study results compared with the barriers found in the literature (Table 4.2), it is seen that nearly all of the barriers were solved. For example, cultural resistance and lack of BIM knowledge in the FM team members are two general barriers from the literature, that matches with the case study. However, there were no resistance to the new investment since BIM integration in FM phase has seen as a necessary tool to comply the employer's information requirements. In addition, the barrier of not collaborative and effective working among the project stakeholders were solved by using a common communication and file sharing platform. BIM-FM integration was funded by JV for an effective operation & maintenance, therefore the high initial cost barrier was not a problem for the project. Besides the general

challengess, there are challenges which are directly related with BIM-FM integration. For example, interoperability problems between BIM models and FM software packages were solved by using add-in of platform and IFC files. All data were defined before the project with meetings and transferred to FM phase. The roles and responsibilites of uploading data to BIM model for FM phase and checking the model were decided at the beginning. The capacities of BIM were investigated with experts and known before the implementation.

Also, all of the requirements of BIM-FM integration (Table 2.2) in the literature were needed for this project and applied. It is suggested that an FM team should be divided in two parts and one part should include members who has the modeling skills to manage the BIM-FM platform. In the begining of the project, end-users were involved the project with meetings and workshops. It is highligted that a correct as-built model is important for equipment tracking and room/space definitions. For the compatibility issues, special APIs were developed by both BIM-FM platform vendor and CMMS vendor. Some of the collected FM data were transfered to the system inside the Revit model while some of the data entered inside the BIM-FM platform. In addition, some data were stored inside the CMMS database. Lastly, a hybrid classification system developed for a proper element tagging.

5. CONCLUSIONS

The aim of this thesis was (1) to illustrate how a project can be integrated with BIM in the facilities management phase with advantages and disadvantages and (2) to determine the challenges and lessons-learned of BIM-FM integration in a large-scale complex project by performing case study. To achieve the first aim, three pilot studies were conducted for BIM-FM integration by utilizing three main methods: (1) using BIM authoring tool, (2) using BIM-FM platform, and (3) using IFC file format. Each method was evaluated and the advantages and disadvantages were identified for each method. For the second aim, a case study of a real-life airport project was performed to identify challenges and lessons-learned of a large scale and complex BIM-FM integration case. The case study was performed via expert interviews and document investigation.

In the literature review, main data types for FM purposes, their representation methods, IFC, COBie, current requirements and barriers of BIM-FM integration, and requirements of a proper classification system in BIM-FM integration were investigated.

To categorize the data for FM, a literature review was done and the main types of data collected for FM activities in the reviewed papers are classified as: (1) sensor data, (2) location data, (3) occupant behavior data, and (4) occupant feedback data. Sensor data is the facility-related data that is collected with various sensors (e.g., temperature, motion, gas). Location data either includes the coordinates of an item or a person, or the area at which an item/person is located. It is collected using localization technologies, such as Radio Frequency Identification (RFID), and Bluetooth. Occupant feedback data is the information obtained directly from users of a facility and this can include complaints and requests. Finally, occupant behavior can be described as the list of activities of an occupant along with a time stamp. Also, it is important that how the data will be used. Therefore, the literature was reviewed and revealed that there were two main purposes in collecting FM data in the reviewed studies: (1) energy analysis and (2) operation and maintenance (O&M). Energy

analysis is the main purpose of the studies that collected data for FM activities. Most of these studies focused on examining and decreasing the energy use in the buildings.

The collected FM data needs to be represented in databases or BIM models to be processed and used for decision-making purposes. It was observed that three main methods were used to transfer and represent FM data in the reviewed studies. The first method has a simplified approach and requires users to enter O&M related data directly to BIM-based software packages for visualization of the FM data in 3D. The second method is to use Application Programming Interfaces (API) to transfer the data to the related software and represent it in its own data storage system. This software can either be a BIM-based software or not. Most of the researchers represented the collected data using APIs or add-ins of certain software packages (e.g., Autodesk Revit), and transferred it to the related software package to be stored and processed. The third method to represent the FM data is to use IFC format.

For interoperability and efficient data transfer in BIM-FM integration, Construction Operations Building Information Exchange (COBie) and Industrial Foundation Classes (IFC) are helpful tools. COBie is a tool developed for the transfer the created building data from design and construction phases to FM phase. It is a documentation standard to increase the efficiency of building life cycle with reducing the operating costs. IFC is an open, international standard for exchanging BIM data. Several stakeholders involve during the lifecycle of building and they all use different software packages in purpose of design, engineering and project planning. Because of the lack of interoperability among the software packages there are some problems. Therefore, IFC is an emerging solution. IFC has an object-oriented structure and it consists of objects representing the components and systems of a building, along with the relationships among those objects. The current IFC schema does not cover all the information created and exchanged throughout the life-cycle of a building. Therefore, the researchers have been working on developing new definitions by extending the IFC format based on the AEC/FM industry needs. To extend the IFC standard, three methods can be used: (1) using property sets or types, (2) utilizing proxy elements, (3) defining new entities or types.

Requirements and barriers of BIM-FM integration were listed in result of literature review.

Requirements:

- FM team should involve the project from the design phase.
- FM team should include members who has the modeling skills.
- A correct as-built model should be created for the FM phase.
- Software packages used during the FM phase should be compatible with BIM.
- Collected data before the FM phase should be transfered to BIM-FM platform in a correct way.
- Indoor localization systems should be used.
- A proper construction classification system should be used in accordance with FM requirements

Barriers:

- Interoperability problems between BIM authoring tools and FM software packages.
- Unclear roles and responsibilities of uploading information and checking model in FM phase.
- Cultural resistance of accepting new technology.
- Not proven positive returns with real-world cases.
- Resistance in firm for requirements (i.e. investment of infrastructure, new software packages and training).
- Inefficient collaboration among project stakeholders.
- Unclear capabilities of BIM in FM phase.
- Lack of BIM experience of FM members.
- High initial investment cost.
- Unknown required data transfer from design and construction phase to FM phase.

As a requirement of BIM-FM integration, an effective construction classification system was needed to control, follow and use this data through different phases.

Moreover, standardization of the classification system is necessary to enable effective data transfer among different disciplines. The need for a standardized classification is even more prominent for facilities management (FM) phase, since supporting a facility's operation, maintenance and repair activities requires well-organized information. Requirements of a proper classification system in BIM-FM integration were found in the literature and identified as follows:

- To have a categorization system that focuses on function of the object rather than other properties of the object, such as the system that it belongs to or the material of the object.
- To have an open-standard that can be updated upon formal request of the users.
- To have an extensible and flexible structure that enables adding new elements to the structure.
- To be in accordance with international standards.
- To be international classification system
- To be commonly used in the construction sector.
- To be used by different disciplines to enable effective data transfer among different disciplines.
- To be compatible with Building Information Modelling (BIM) for enabling integration with BIM models.

After literature review, three different BIM-FM integration methods were performed at pilot studies that were conducted at a small size university building. These methods were: (1) using BIM authoring tool, (2) using BIM-FM platform, and (3) using IFC file format.

It was observed that BIM authoring tools have capability of performing most of the basic FM issues. However, size of the project and size of the data would affect the process negatively. Besides, since BIM authoring tools is designed mostly for model creation, they are complex software packages and have complex interfaces. The one who will use a BIM authoring tool in FM phase should has background and experience on that tool. Finally, BIM authoring tools can be used for basic FM purposes for a short time, however, professional software packages for integration of BIM and FM

should be used in a continuous FM phase. In the second case, a BIM-FM platform (i.e. EcoDomus) was used for BIM-FM integration. It was seen that BIM-FM platforms has many modules that allow the users perform their FM activities according to their purposes. It also combines BIM model by linking building elements with related activities. The visualization of BIM model can also be used inside the platform with the help of model viewer mode. Generally, BIM-FM platforms are specialized with the project. If there is a need that is not included inside the modules of BIM-FM platform, it can be added by communicating with BIM-FM platform vendor. Since they are mostly customizable, project needs should be well defined and necessary modules should be activated by considering cost of the project.

In the third case, it was aimed to show that IFC file can be modified without using any BIM authoring tool and it can be used in any BIM-based software package for FM purposes. As an example, it was aimed to store the occupant feedback and the location of the feedback in the IFC model and to obtain the information of the related building element from the IFC model. In conclusion, extension of IFC is the most difficult way among the mentioned 3 methods in this part of thesis. However, it is the most effective way to store the FM data since it can be shared to any BIM-based software package.

After identifying the advantages and disadvantages various methods used for BIM-FM integration via pilot studies, a case study of a real-life airport project was performed to identify challenges and lessons-learned of a large scale and complex BIM-FM integration case. Previous case studies were useful for small scale projects, however to identify the requirements, barriers and lessons-learned of BIM-FM integration in a large-scale project (i.e., more than 100,000 m²), a comprehensive case study was needed. An international airport, which is a large-scale infrastructure project located in a Gulf country, was selected in this study. The total area of the whole project is 1.5 million m² including runway, taxiway and apron area. Only the terminal building and concourses, which cover 156,940 m², are modeled for FM phase.

Two data collection methods were used in the case study: (1) interviews and (2) document investigation. Findings were categorized in 11 topics:

- BIM-FM platform
- GUID
- Classification system

- Equipment tracking
- Operation phase
- Entering data
- Document/element tagging
- Modeling
- Collaboration of stakeholders
- Room & space definition
- System definition

The results highlight that large-scale complex projects encounter with additional challenges related to BIM-FM integration and they develop their unique solutions to overcome those problems. For example, it is possible to match GUID numbers when there are huge number of building elements. Tracking the equipments could be easily done in a small size project by using BIM authoring tools. However, BIM authoring tools will not be enough in terms of software capabilities when the project is large-scale and complex. Room & space definitions will be complicated when the project has irregular space shapes with different floor heights. Complex MEP systems will require special system definitions in order to track system correctly. In the large projects, there are many stakeholders from all around the world and collaboration of them needs to be solved. The findings of the study can be used by academicians that would like to work on BIM-FM integration and by the practitioners that would like to implement BIM-FM integration, especially in large-scale projects.

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