QATAR UNIVERSITY

COLLEGE OF ENGINEERING

DIGITAL FACILITIES: A BIM CAPTURING REALITY FRAMEWORK AND INTEGRATION WITH BUILDING MANAGEMENT SYSTEM

BY

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ABSTRACT

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Qatar University (QU) had been sharing the vision of the country in developing various technological aspects and approaches in order to achieve global standard qualities and accomplishments. In this research, from the construction management perspective, referring to QU digitalization initiative objectives and considering global market processes, computerized capturing framework of campus existing building will be executed, discussed and analyzed in-depth, through Building Information Modeling (BIM). Current worldwide capturing techniques, such as as-built drawings, laser scanning and UAV will be implemented and illustrated along with their cost, time and quality analysis. The study will also discuss the novel approach of integrating BIM Model with present Building Management System (BMS) of QU; and its contribution towards Facility Management (FM). This integrative activity between BMS real-time values readings and BIM data representation will add-value to Facility Management (FM) workflow efficiency and performance of the university or any other applicable party with the same environment. Concluding the best practice of reality digital capturing towards a successful integration prior to achieving study objectives, with diverse recommendations, discussions and future works.

DEDICATION

"Personal achievements are the best parental dedications, in return to their life-time sacrifice, support and love."

I am dedicating this thesis to my beloved Mother and Father who sacrificed in order to teach and raise me and my sister to work hard with self-belief, values, integrity, honor and respect. Also, my Sister for showing continuous caring, friendship and love.

This thesis is also dedicated to my dear Wife who has been the source and center of inspiration, motivation, encouragement and support; she is my life precious jewel that gives her time and effort to her beloveds. Her parents and sister were always behind and contributive at all time.

I also dedicated this thesis to my friends, and everyone showed helpful and useful actions or ideas with care and appreciation throughout the work.

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CHAPTER 1: INTRODUCTION

Overview

Problem Statement

Research Objectives/Benefits

Aims and Objectives

This research is aiming creation and development of an intuitive framework towards the digital capturing of Building Information Modelling (BIM); to be used also in-benefit of Qatar University already existing buildings in relation with its digitalization initiative. This framework shall be used in-depth to plan and implement all necessary activities in direction to gain a complete digital model of any existing building or campus (BIM enabled). Integration between BIM and Building Management System (BMS) towards Facility Management (FM) use will be fully designed and implemented. Thus, in order to accomplish these aims, the following objectives shall be demonstrated and described:

- Define the cruciality and outcomes of BIM with respect to the global perspective
- Define the latest BIM processes and tools used to accomplish similar goal
- Define in detail the methods and techniques held to enable an existing building of privileging BIM benefits
- Develop an integration method between BIM and Building Management System (BMS) in favor of Facility Management
- Develop ideas to benefit from this framework academically within and beyond Qatar University community
- Illustrate the difficulties and challenges shall be faced during framework accomplishment

- Verify and assess the research outcomes by driving it to future recommendations and conclusion

Research Scope

This research contributes to the breakthrough BIM – BMS integration, also validate the process of BIM digital capturing for multi-purposes, not only Facility Management and academic uses but also framework of the latest capturing reality to BIM techniques. Through this research, university requirements shall be validated in a way that consider all challenges and constraints would be faced. Moreover, identifying the resources allocation plan for the future projects in order to reach the final end-goal of digitalization. The framework shall be illustrated as a project with its full life cycle activities for multiple uses. Furthermore, one of the main scopes is to give an add value and benefits to Qatar University facilities to gain more efficiency. Facility Management had proven that it would advance dramatically the performance and efficiency of buildings and personnel.

Research Methodology

Research Processes

The processes shall be flowed to attain the research aims and objectives. This will happen through extensive development of each process activity to include all needed requirements. These processes will be categorized as phases, and they'll be shown as following:

- Phase 1: developing the proper literature review to support the research execution process, and that to evaluate the upcoming phases requirements and expectations. Also showing an initial relationship between the tools will be used to reach our goal

- Phase 2: illustration of all research required needs and outcomes through various methods with identification of the starting points for each objective. Further linking literature review results to the milestones of the analysis and exploration
- Phase 3: demonstrating the data collection channels and techniques through all reliable sources. And this phase will start regulating the initiative into visible theory in-process to conduct. Along with configuring the BIM model on the integration with BMS platform.
- Phase 4: delivering practices and techniques of the research objectives through implementation tools, which were pre-described in the literature review. Validating the data and product generated by showing real examples and samples of the theory overtaken. Additionally, finalizing the main structure of the research framework and showing BIM-BMS integration benefits.
- Phase 5: concluding the results of the research with recommending the next possible phases to the recent current status of the study.

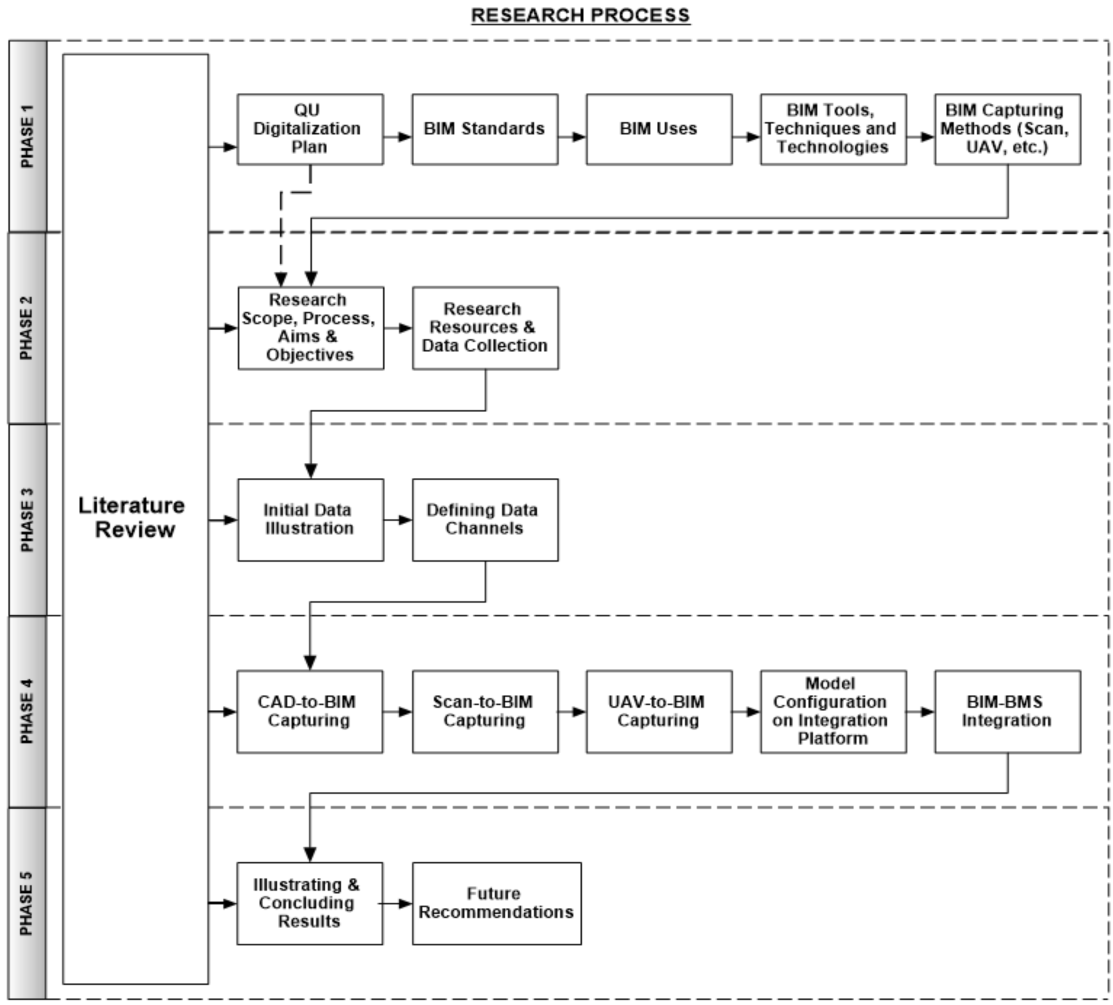


Figure 1. Research Process Flowchart

Thesis Organization

This thesis will pass through few logical sequential stages in order to express the solution of the problem stated. The organization will be as follows:

Figure 2. Thesis Organization Structure

CHAPTER 2: LITERATURE REVIEW

BIM Overview

Digitalization is an attribute of data technology growth and positive results, since conversion of data and information into digital format for further usage had been presenting frequent favorable outcomes. Recent digitalization achievements were the representation of building information into a computerized model with all required features towards constructional and facility management success; named as Building Information Modeling.

Building Information Modeling (BIM) is development and management of data in digital illustrations of visible and useful features with respect to location. BIMs are electronic information directory that shall be obtained, replaced or shared to help directing and managing a building or alternative designed entity. Recent BIM software, private and public organizations who organize, develop, execute, manage and sustain different groundwork, such as water, electricity, gas, network utilities, streets, railways, ports, and tunnels. (Wikipedia, 2019)

BIM Origins and Elements

The BIM originated through a certain lifecycle started since the seventies up till now. In the 80s the term Building Model was first introduced to the public as a defined illustration of an entity without any further sub-entity in-depth details. The following representation will show the sequence of main events associated with BIM development. In the late time of the same decade, GMW Computers worked on further development of the Building Model concept. In the nineties, BIM was explained with few differences of the recent known. Reaching the 20s century, Building Information Modelling extensive features was shown by Autodesk and other software solution providers (Wikipedia, 2019).

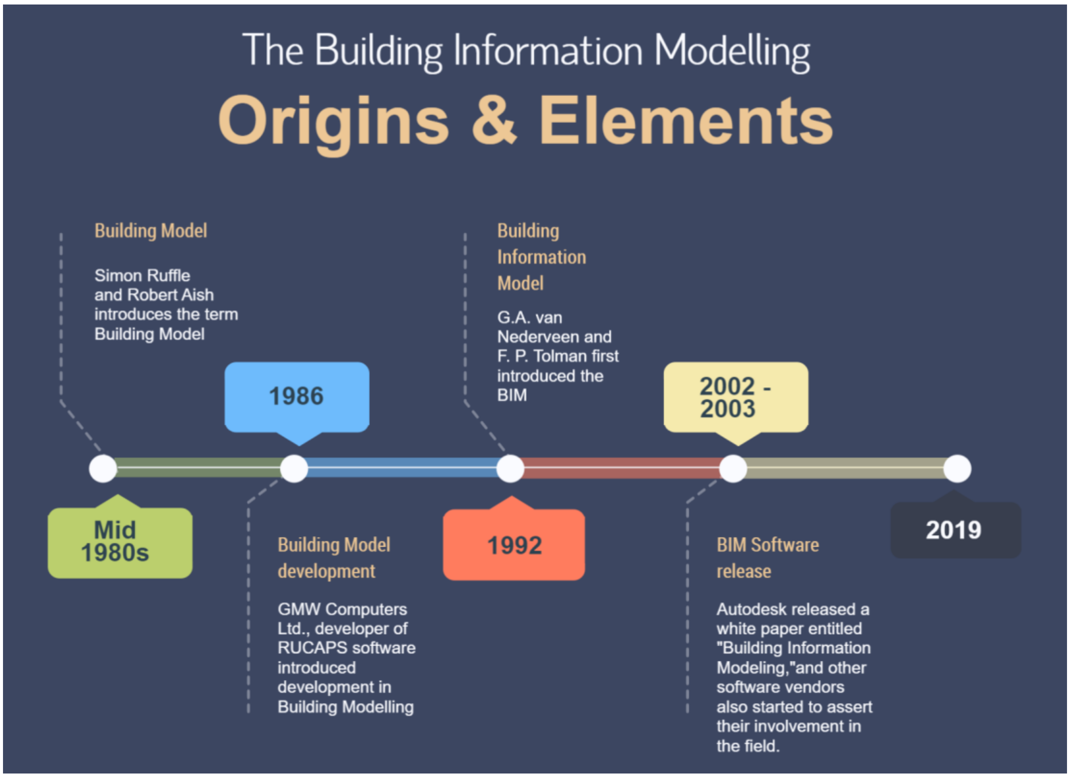


Figure 3. Building Information Modelling origins and elements (Wikipedia, 2019)

Definition

BIM (Building Information Modeling) is smart three-dimensional representation method of building and infrastructure which benefit all construction, design, and consultant professionals the possibility to efficiently schedule, plan, develop and simulate. BIM technology is a developed technique that professionals in construction and facility management are utilizing nowadays, because of its wide positive outcomes. Shall also be considered as a decision-making technique to raise efficiency across projects lifecycles. (Autodesk, 2019)

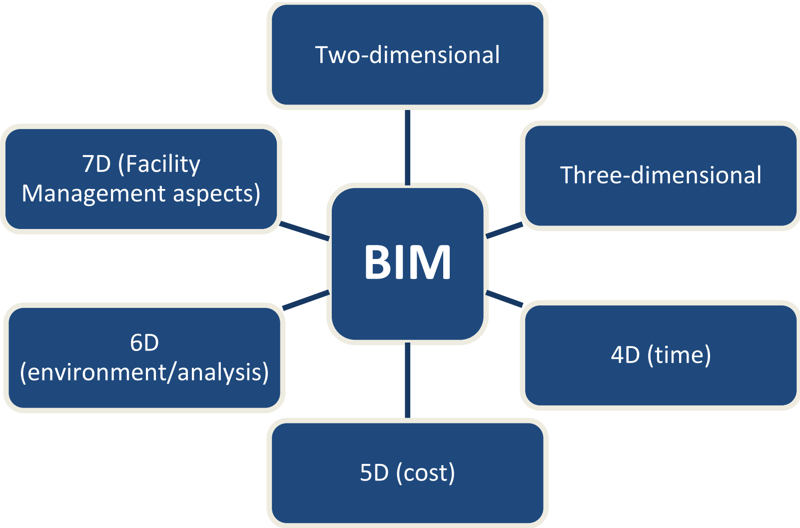


Figure 4. BIM representation types (Wikipedia, 2019)

BIM Standards

BIM various standards are widely spread all over the globe with few differences that impact the applicable markets. In this section will illustrate the different BIM standards institutions those are commonly used.

Table 1. BIM Commonly Used Global Standards as National BIM (2019), ISO (2019), Standards Australia, Singapore BIM Guide (2013) and HKIBIM (2018)

S.N.	BIM Institution Name	Country	Logo
1	National Institute of Building Sciences	United States of America	National Institute of BUILDING SCIENCES
2	International Organization for Standardization ISO 19650	United Kingdom	ISO 19650 International Organization for Standardization
3	Australasian Procurement and Construction Council (APCC)	Australia	Australasian Procurement and Construction Council

4	Singapore BIM Guide Version 2	Singapore	
5	The Hong Kong Institute of Building Information Modelling	Hong Kong	

BIM Standards Overview

BIM overview shows the relationship of the commonly used specification documents in the countries listed below, also with respect to the institution type and date of usage.

Country	Institution, Type, Document
Finland	Building SMART Finland, Public, Common BIM Requirements
Norway	Statsbygg, Public, Statsbygg - BIM Manual 1.21 Boligprodusentene, Private, BIM Manual
UK	AEC (UK) Committee, Private, AEC (UK) BIM Protocol v2.0 The British Standards Institution, Private, PAS 1192-2:2013
Australia	Natspec, Public, NATSPEC National BIM Guide CRC for Construction Innovation, Public, National Guidelines for Digital Modeling
New Zealand	ANZRS, Private, ANZRS v.3
Canada	CanBIM, Private, AEC (CAN) BIM Protocol 1.0
USA	NIBS, Private, NBIMS-US™ V2 Air Force, Public, BIM Requirements
Spain	FIDE, Gov, FIDE (Spanish)
Singapore	BCA/CORENET, Gov, Singapore BIM Guide Version 1.0
Hong Kong	HKIBIM, Private, HKIBIM_Specification-Rev3-0
Denmark	Digital Construction, Gov, ICT Demands (Danish) - English Intro
Netherlands	RGD, Gov, Rgd BIM Norm (Dutch)

Figure 5. BIM standards overview (Martí Broquetas, 2013)

BIM Uses & Processes

Uses

The BIM shall be used for any existing state, prior to utilizing all BIM features, the capturing shall be processed in order to collect all possible data to be converted to visualized information. Below illustration will show all possible states of existing conditions those shall be captured to BIM. Also, it shall be used for design authorization for multiple purposes. The validation shall take place to Structural, Architectural or MEP works. Also, further designs shall be developed further within BIM processes. The BIM shall be used for detailed modelling of specified areas as a digital mock-up. This shall be used as a coordination point between all project parties (Harvard BIM Guide, 2019).

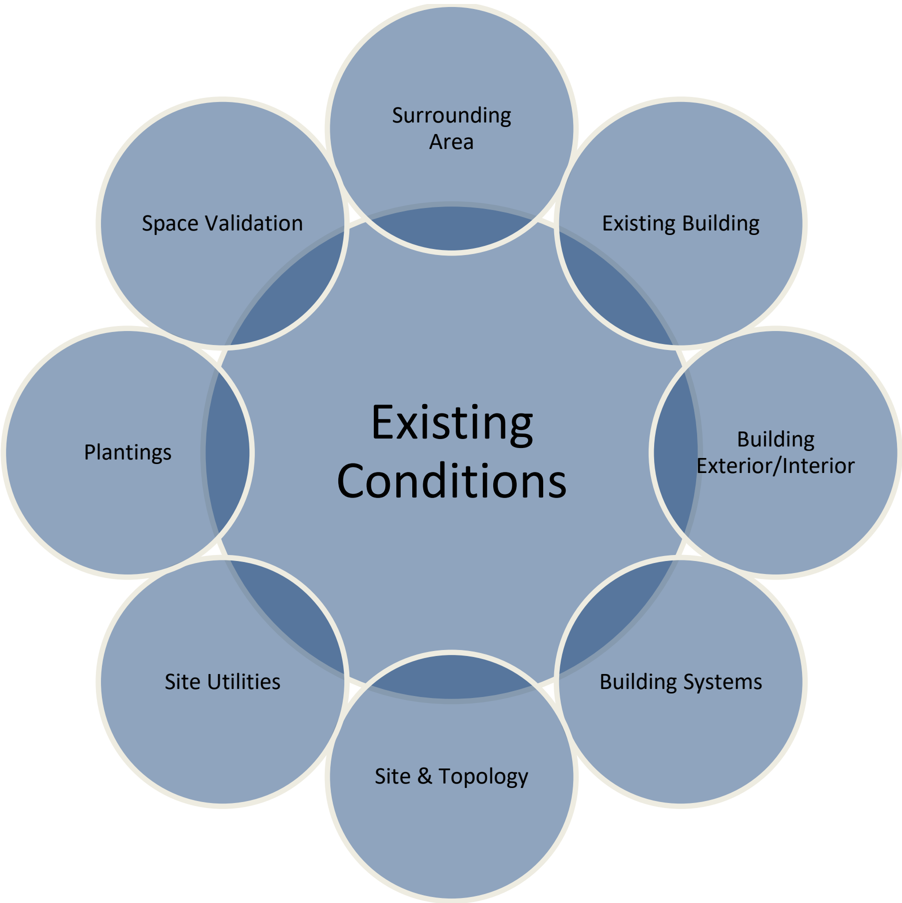


Figure 6. BIM existing conditions uses (Harvard BIM Guide, 2019)

BIM features serves perfectly the Facility Management (FM) areas that is continuously developing since it increases the facility maintenance and operation performance after construction stage. BIM gives any entity the privilege of digital data visualization, and utilization in storage, management, analysis, scheduling and other aspects. These types of values shall impact the management of any facility, regardless its scale, towards long-term operational efficiency. Enhancement shall be applicable by further add-values coming from integrating BIM with other building automation systems, such as Building Management System (BMS). Recently BIM can manage facilities in various methods, such as below areas (Harvard BIM Guide, 2019).

Figure 7. BIM uses in Facility Management (Harvard BIM Guide, 2019)

Implementation processes

Implementation is the process of converting plans into reality demonstration. This transformation requires drawing, specifications and other considerations. This course can’t be considered without project parties communication towards finalization and completion. The ‘BIM Implementation Plan’ is setting the parties requirements and responsibilities to be fulfilled during the project (whether construction or maintenance phase) duration, all these activities shall be with respect to time and allocated resources.

Project analysis includes status, stakeholders, monitoring, controlling, financial analysis and risk management. BIM scope shall be demonstrated in the implementation process by stakeholders. Merging and managing the BIM responsibilities and knowledge of stakeholders and the BIM objectives for the project, defining the tasks, responsibilities and roles of each collaborating party through responsibility matrix. After this stage of implementation, knowledge exchange between parties shall occur. BIM implementation time factor is called the timeline which is an execution schedule that is realistic and aligned with all stakeholders’ inputs (Construction Property, 2016).

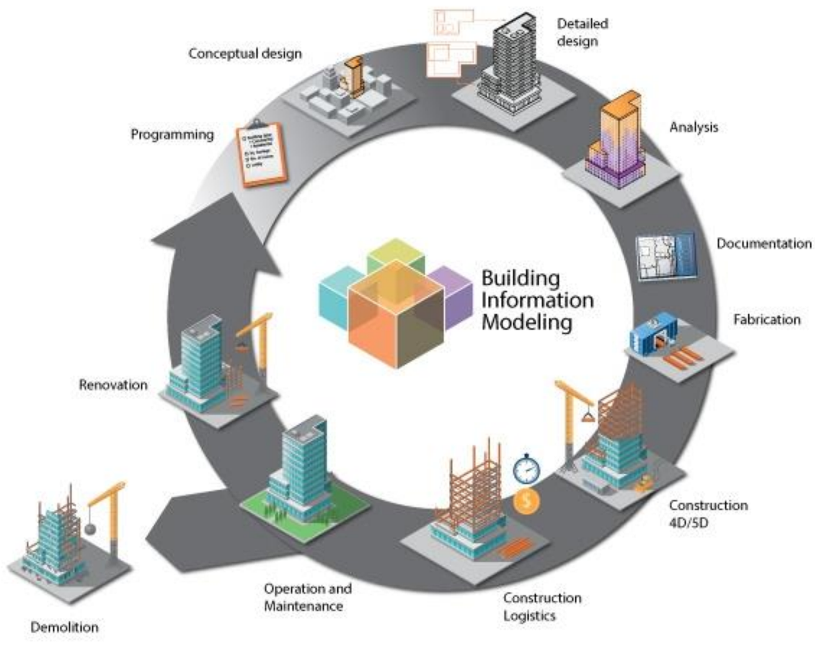


Figure 8. BIM process flow (Construction Property, 2016)

BIM Uses in Qatar

The BIM capturing uses in Qatar till date have included 2D DWG and laser-photogrammetric scanning to BIM, BIM for Facility Management (FM) and BIM role in information flow while construction to raise operation and maintenance efficiency. These efforts were published to public as part of innovative digital capturing ideas to BIM in Qatar. This study will continue their achievements by full capturing framework using all latest known global methods, prior to state-of-the-art integration with Building Management System (BMS).

Two-dimensional AutoCAD and 3D Laser-Photogrammetric Scanning to BIM

This case study is discussing the challenges faced in BIM reconstruction activities. Difficulties such as-built drawings accuracy and usage for capturing purposes accompanied by laser and photogrammetry scanning of a skyscraper in West bay, Doha, Qatar. The purpose is to evaluate all possible evacuation ways in case of emergency. This fifty-floor high-rise building was utilized for this study in its late stages of construction towards final interior works. The data capturing included two main sources: 2D as-built AutoCAD drawings and 3D laser and photogrammetric scanning.

The outcomes of the conversion and capturing included a scanned model of 5 mm accuracy and 122,000 measurements per second, that was imported to Autodesk Revit to be collaborated with CAD DWG as a final BIM model. Results in this stage showed variations and conflicts in the as-built dwg towards reality and scanned point cloud model, in order to solve this problem, manual measurement and investigation was done for all challenges faced to be part of the BIM final model. Additionally, to accomplish this study scope (emergency evacuation ways) the rating of building materials was required. Thus, manual data collection took place in order to be attached to the BIM (Barki, H., Fadli, F., Shaat, A., Boguslawski, P., & Mahdjoubi, L. (2015)).

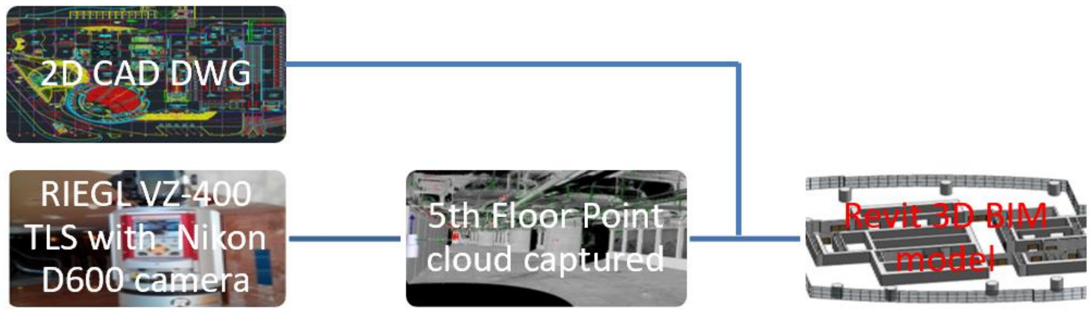


Figure 9. Case study process towards BIM (Barki, H., Fadli, F., Shaat, A., Boguslawski, P., & Mahdjoubi, L. (2015))

Facility Management towards BIM

In correspondence to the building operation and maintenance importance within existing buildings, this case study discussed and analyzed the Industry Foundation Classes (IFC) and Construction Operations Building information exchange (COBie) participation in benefit to Facility Management (FM). The main purpose of the study was registration of building maintenance schedules, assets, elements and components needed by professionals whom manage facilities. These requirements developed due to issues faced within hard and long data collection of facilities. Also, in order to achieve this level, Information Delivery Manual (IDM) and Employer's Information Requirements (EIR) took place in the study.

The results showed that IFC and COBie shall help in solving the problem stated previously, but it'll not, in the meanwhile, cover all range of requirements towards registration. Simplicity of information will be the dependency of succeeding, since complicated and unsupported data will fail, thus this shall trigger a future recommendation for researchers in this area (J. Patacas, N. Dawood, V. Vukovic & M. Kassem, 2015).

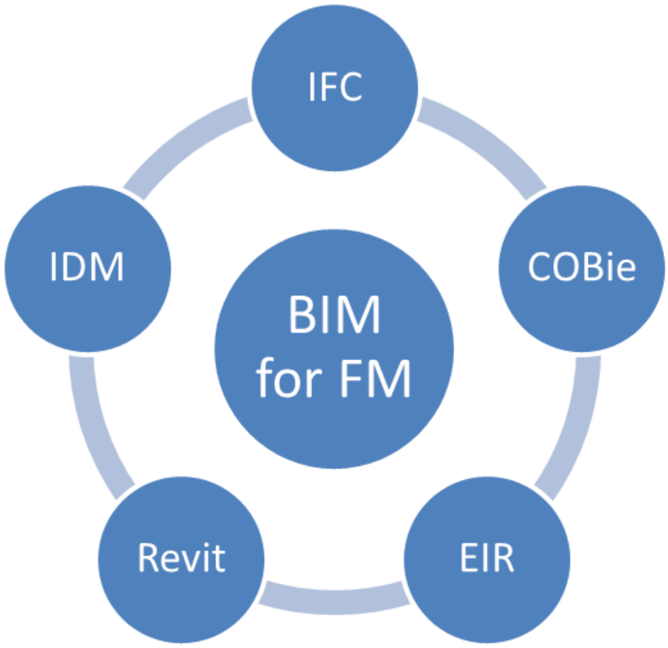


Figure 10. Aspects involved in the study (J. Patacas, N. Dawood, V. Vukovic & M. Kassem, 2015)

BIM Information Workflow towards O&M

Sustainable information flow within project to fulfil facility management and decision-making is the main study perspective. Workflow of data management while construction shall impact the time duration required within operation and maintenance phase of any building; since this is the most time and personnel consuming. The important information that is available on different parts of construction is usually lost and redundantly worked in future. BIM shall participate in such problem-solving process to electronically sustain information flow reaching operational phases. Lack of information leads to subjective and inaccurate decisions throughout project lifecycle and beyond. This study is improving the construction field towards best practice. The technique towards conclusion is driving from current and historical information about industry in Qatar, passing through key performance indicators of efficient building operation definition till decision factors taken into consideration by management.

The study results were accomplished by achieving its objectives and aims. Since a procedural framework was developed by defining the information required for efficient building operation within project initiation phase. A lot of factors were taken into consideration to reach interfering this technique into contractual and bidding stages between contractors and clients (S. Rodriguez-Trejo, A. Ahmad, M. Hafeez, H. Dawood, V. Vukovic, M. Kassem, K. Naji & N. Dawooda, 2017).

Figure 11. Study factors considered (S. Rodriguez-Trejo, A. Ahmad, M. Hafeez, H. Dawood, V. Vukovic, M. Kassem, K. Naji & N. Dawooda, 2017)

BIM Technologies, Tools & Techniques

Technologies

BIM that stands for Building Information Modeling is technology in the housing industry and is wide gaining popularity for its efficient outcomes. It has proven its art introducing exceptional features to any construction project. Moving beyond 3D BIM reaching 4D, 5D, 6D and 7D BIM. Integration of various technologies as Internet of

Things, Virtual Reality and others had been the focus of many researches nowadays (Stabiplan, 2019).

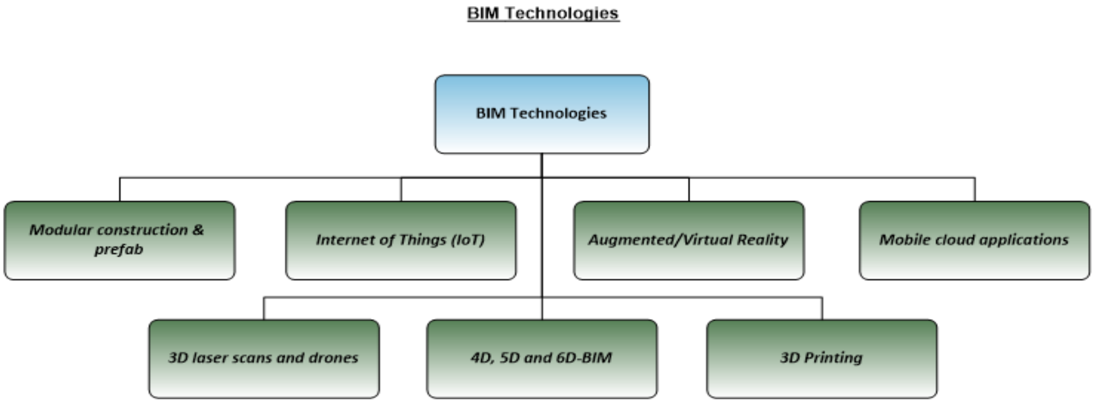


Figure 12. BIM Technologies present in the current market (Stabiplan, 2019)

Tools

BIM computerization and digitalization are widely used in construction field, especially within the AEC sector. Development of several areas in BIM is supporting different types of business to succeed in preventions of many challenges.

Software applications are enhancing construction industry and management of recent days. In fact, BIM software packages are playing a vital role in contractual bidding in pre-construction phase of many projects in the world. The high competition of these vendors is generating price reduction of the solution.

Table 2. BIM Commonly Used Tools From FinanceOnline (2019) and EcoDomus (2015)

S.N.	Software Name	Software Features
1	EcoDomus	Attach documents, visualize model and data, design coordination, integration with other building system, condition assessment, process visualization, analysis, mobile app, space management, procurement list and risk management
2	Autodesk BIM 360	Project delivery, construction management, project coordination, work-sharing, design review, visualization, QA/QC, safety management, mobile app, RFI and submittal management
3	Tekla BIMsight	Review model conflicts, communication, workflow illustration, 3D model navigation, IFC support, clash detection, multiple views and mobile app
4	ARCHICAD	Compatible with Windows and Mac, model designing, model attachments and work-sharing
5	Autodesk Revit	3D modelling, model coordination, building systems families support, clash detection, 4D BIM support,
6	Autodesk Navisworks	3D navigation, building analysis, real-time navigation, construction management, coordination, clash detection, model simulation and animation and BIM 360 Glue support
7	BIMobject	Cloud-based, support various building systems, object sharing, mobile app and optimize workflow

8	BIMx	Mobile app, 3D modelling, 2D/3D integration, 3D navigation, model collaboration and drawing sheets access
9	Procore	Construction management, user communication, project management, budget management, quality management and safety management
10	Hevacomp	Building analysis, 3D designing, model simulation, UK standards compliance and extensive energy analysis
11	SketchUp	3D modelling, components and buildings library, free version, documentation support and educational friendly
12	Midas Gen	Extensive structural analysis, 3D modelling and auto-design features
13	Buildertrend	Home builders and remodelers friendly, construction management, project management, cloud-based, documentation, change orders, warranty management, financial tools and customer management

Techniques

BIM is an intelligent three-dimensional model-based approach that supports AEC professional's workflow with developed insight and tools towards efficiency, management, and many others (Shimonti Paul, 2018).

Elements of BIM

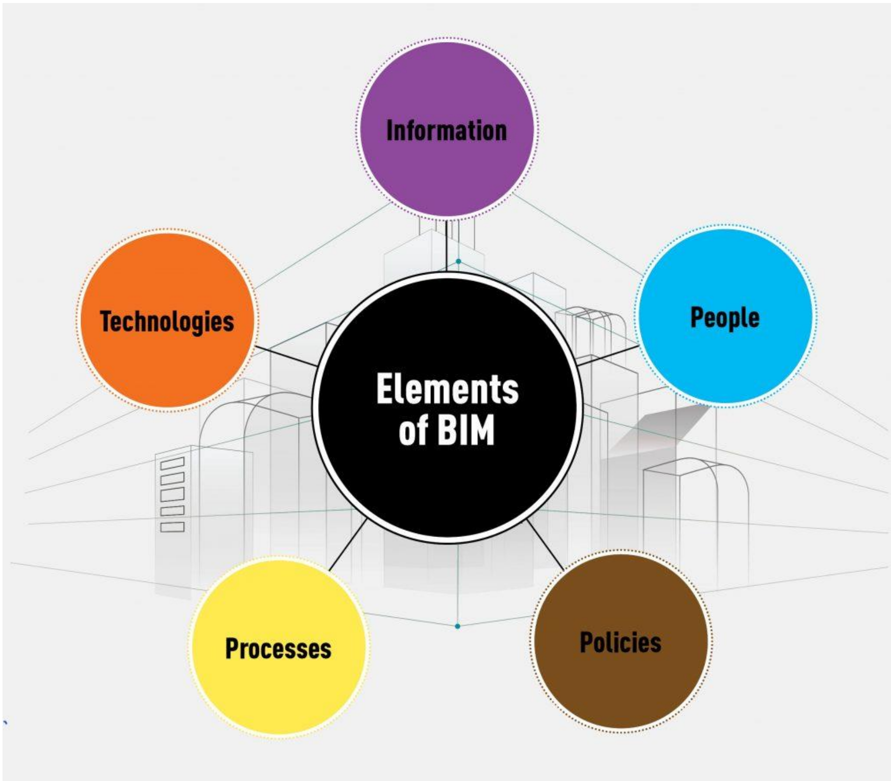


Figure 13. Elements of BIM (Shimonti Paul, 2018)

Key Features of BIM

- Scheduling, planning, operation and designing in coordinated three-dimensional based model
- High value of monitoring and controlling of project changing factors
- Mobile communication between all project parties
- Better arrangement for change orders and requests

Levels of BIM

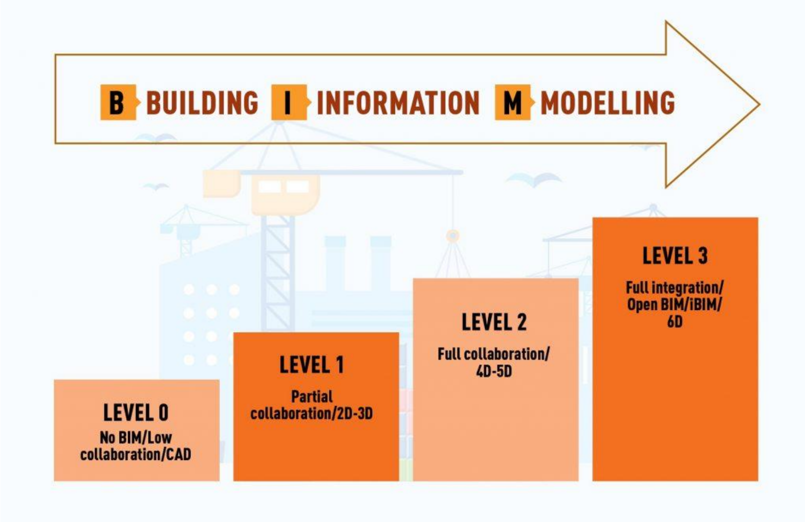


Figure 14. Levels of BIM (Shimonti Paul, 2018)

Main levels of BIM:

- Level 0
  - No collaboration between parties
- Level 1
  - Medium collaboration through 2 & 3D CAD drawings
- Level 2
  - BIM is being followed with minimal deficiencies
- Level 3
  - Optimal efficiency is achieved through full collaboration

Main BIM Techniques

The BIM definition and standards will vary according to its application. Development and improvement of BIM applications had been very widely spreading in the globe, due to its achievements.

Table 3. BIM Applications in Building Operation Lifecycle (Ghaffarianhoseini, Ali & Zhang, Tongrui & Nwadigo, Okechukwu & Ghaffarianhoseini, Amirhosein & Naismith, Nicola & Tookey, John & Raahemifar, Kaamran (2017))

Subject	Outcomes	Technique	Limitation
Scanning	3D laser scanning automation	Scan-to-BIM	Complex scenarios
As-built reconstruction	Process automation	Vision-based algorithm	Harsh conditions, camera calibration
Structural simulation	BIM to finite element	Cloud-BIM-FEM	Requires predefinition
Monitoring	Virtual reality	Green BIM	Lack of technology
Energy visualization	Process visualization	BIM-GIS	User access control
Low-carbon buildings	LCB parameters	Fuzzy BIM	-
Facility Management	Buildings improvement	7D BIM	-

Digital Transformations Initiative at Qatar University

Background

The Digital Era

Digital transformation and innovation have been penetrating all aspects of economy, industry, government, healthcare, society, and education; large scales of conversion (e.g. in enablers, platforms, processes, business models, etc.) have been described as “digital transformation”. Apart from enabling, enhancing, and in some cases disrupting a whole segment or sector, Digital Innovation have been related to enhancement of economic process. Digital transformation at scales have led to notions such as “Digital Economy”, “Digital Life”, “Digital Enterprises”, “Digital Campus”, “Digital Identity”, “Digital Citizens”, “Digital Learning”, “Digital Competency”, “Digital Workplace”, etc (Mahmoud Abdulwahed and Hassan El-Rashid, 2017).

Qatar National Vision 2030 and ICT/Digital Strategies

The digital agenda has been part of the governmental initiatives towards Qatar National Vision 2030 end-goals and aims. Qatar National ICT Strategy 2015-2020 aims at addressing the role of ICT in Qatar socio-economic development. Digital innovation plays fundamental role as developmental economic sector, and as a booster of other sectors; Digital innovation allows economic diversification and growth, drives entrepreneurship, and creates employment opportunities (Mahmoud Abdulwahed and Hassan El-Rashid, 2017).

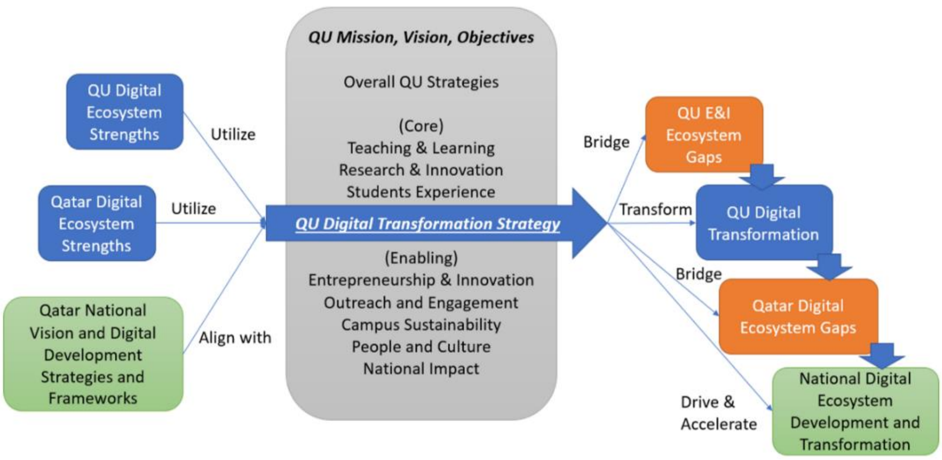


Figure 15. Conceptual diagram of QU Digital Transformation strategic context (Mahmoud Abdulwahed and Hassan El-Rashid, 2017)

- Mission Statement: Providing high quality undergraduate and graduate programs that are digitally enriched.
- Vision Statement: Enabling QU to have digitally distinctive excellence in education and analysis. Enabling QU to become the institute of digitally native or digitally aspirational future students and college, enabling QU to undertake its important national role in digital socioeconomic development
- Strategic Objectives:
  - Objective 1: Enhancing all aspects of excellence in the QU education system through digital transformation
  - Objective 2: Digitally enable QU transformative education aspects of learner-centric, research-informed, digitally enriched, and entrepreneurial
  - Objective 3: Produce digitally competent graduates with the digital skills and values to maximize adequate impacts
  - Objective 4: Excel in digital innovation and analysis that is centered, relevant, measurable, solution-oriented, impactful, collaborative, and transformational
  - Objective 5: Enhance institutional excellence, governance, and sustainability through digital innovation and transformation

BIM for Facility Operation & Maintenance

Recently, Building Information Management technologies have well influenced facility management approaches all over the construction field aspects. BIM has demonstrated potential for solving issues showed within the operation of buildings. Facility owners are currently following an alternative selection of business towards reducing of operational and maintenance prices, improving delivery, aligning business processes, underpinning future construction modifications, and accordingly acquire increment of return-on-investments (ROIs) (Burcin Becerik-Gerber, A.M.ASCE; Farrokh Jazizadeh; Nan Li; and Gulben Calis (2012)).

In the industry, application of BIM in Facilities Management (FM) for sustainable and digital building information and management had been widely used and known by its effectiveness. Building Management System (BMS) shall enhance BIM contribution to Facility Management (FM), where BMS is a connected software and hardware in order to monitor and control building's systems; for example HVAV, lighting, security and power (Ahmad et al., (2012) and Mccaffrey, et al., (2015)). According to Rounds in 2018, cost of operation shall reach 80% of the total project cost, which shall be controlled by BMS, but not individually, a platform that holds three-dimensional model with data management and interface is required, which is the BIM. BMS can also achieve reliability, efficiency, savings of time and cost, comfort and performance enhancement (Smartek, 2019).

However, in order to reach an optimal use of BIM towards FM, integration of information systems shall take place, as pre-mentioned, systems such as Computerized Maintenance Management Systems (CMMS), Electronic Document Management Systems (EDMS), Energy Management Systems (EMS), and Building Automation Systems (BAS) or Building Management System (BMS) (Burcin Becerik-Gerber, A.M.ASCE; Farrokh Jazizadeh; Nan Li; and Gulben Calis (2012)).

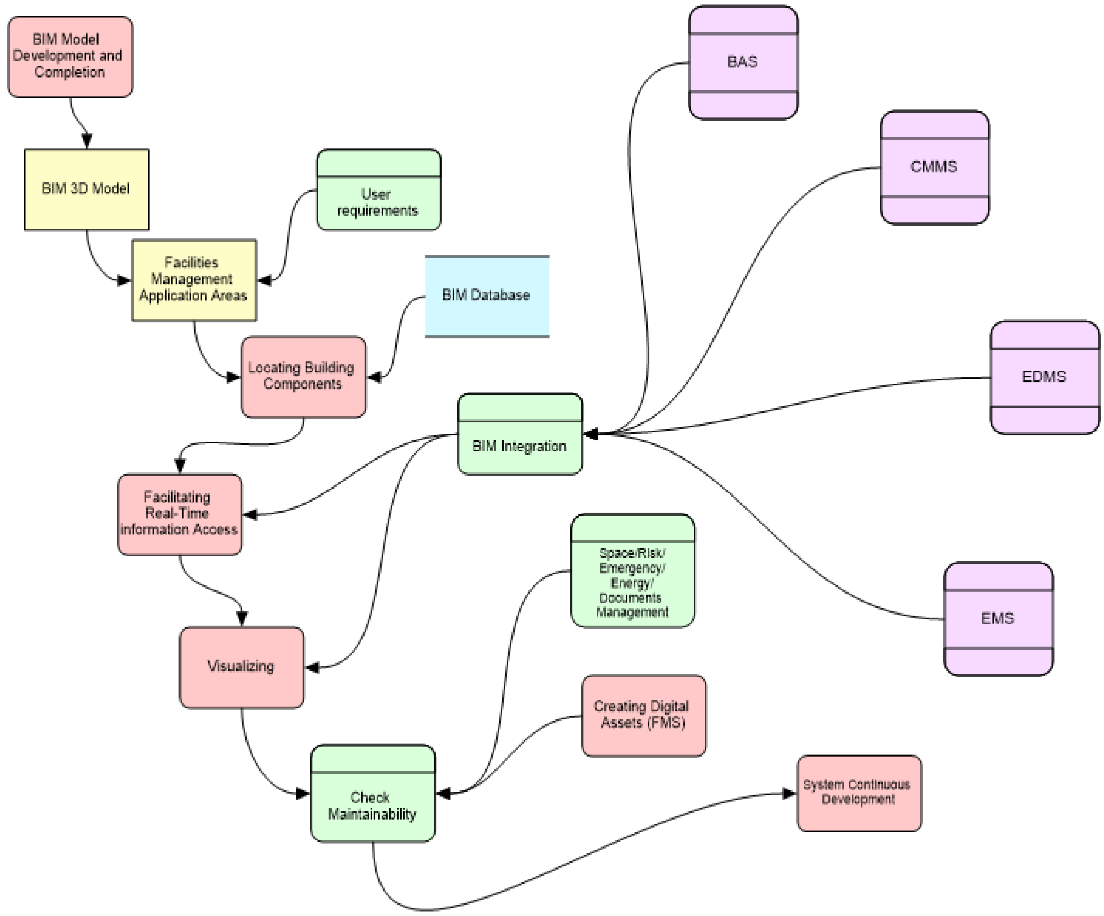


Figure 16. BIM for Facility & Operation Maintenance data transfer (Burcin Becerik-Gerber, A.M.ASCE; Farrokh Jazizadeh; Nan Li; and Gulben Calis (2012))

Table 4. Information Requirements for FM Personnel (Burcin Becerik-Gerber, A.M.ASCE; Farrokh Jazizadeh; Nan Li; and Gulben Calis (2012))

FM information	Information required		
	CMMS	EDMS	BAS
Maintenance troubleshooting	• WO system • Components information • Information validation	• O&M • Reporting • Location • Schedules & Planning	• Equipment • Sensors • Design vs. Actual

		• 3D Visualization	• Operational sequence • Analysis
Complaints	• WO system • Historical log	• Equipment location • Sensors location	• Sensors information • Visualization

Importance of BIM-BMS integration towards FM

The integration will praise the importance of the BIM in facility management, since the information from BIM Model merged with real-time sensing from BMS will raise the efficiency of managing any facility regardless its size. After illustrating the importance of BIM in project management, next part will demonstrate few benefits of BIM towards the facility management. Including the fact that building design and construction cost is around 20% of the building lifecycle costs (Igor Starkov, 2013).

According to Neil Parker from EcoDomus in 2011, a survey was completed in The University of New Mexico towards the BIM benefits within FM systems. The candidates took place in the survey had managed facilities between 1,000,000 square feet (sf) to 5,000,000 sf in their career with approximately 30,000 work order annually. Around 96% of the participants have a problem with the facility data, with different level of problems, while 4% are fully accepting the conventional method of facility management.

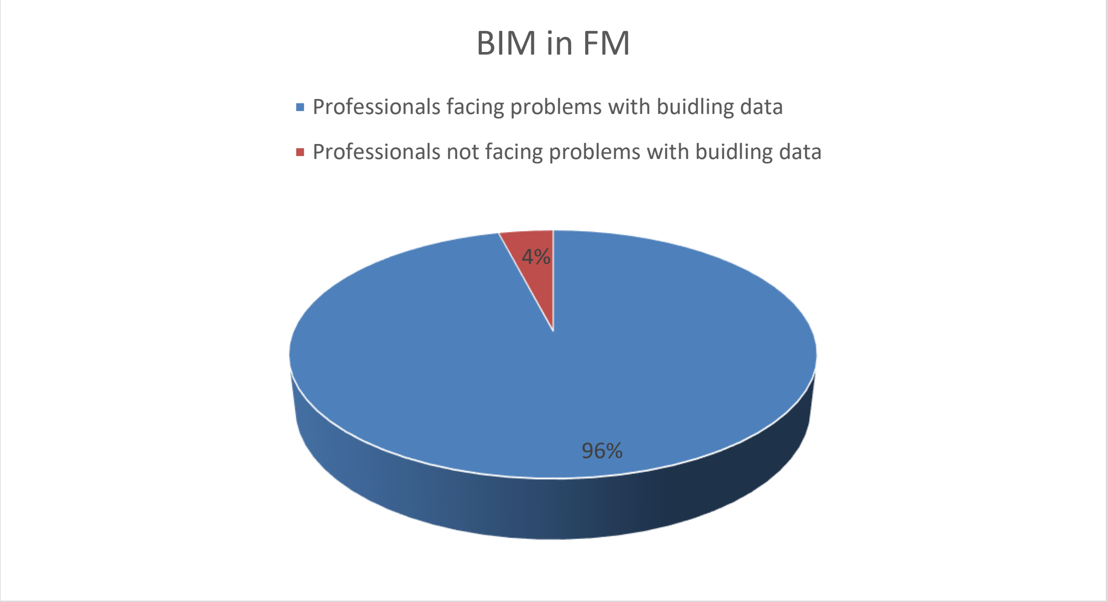


Figure 17. Neil Parker survey in 2011 with FM professionals on building data opinion

On the other hand, Igor Starkov in 2013, had made an extensive study of the savings EcoDomus shall generate from Eastern Service Area FAA Tower facility. The research outcomes in Operation & Maintenance (O&M) were as following:

Table 5. Overall Time Savings in Eastern Service Area FAA Tower Facility (Igor, 2013)

Activity	Current Duration (hrs)	BIM Usage Duration (hrs)	Net Time Savings (hrs)
Corrective Maintenance	More than 5	0.5	4.5
Preventive Maintenance	More than 9	3	6

Table 6. Detailed Time And Cost Savings In Eastern Service Area FAA Tower Facility (Igor, 2013)

Activity (annual)	Current Duration (hrs)
Maintenance Duration (hrs)	168 hrs
BIM Time Savings (hrs)	100 hrs
BIM Time Savings (%)	More than 60%
BIM Cost Savings ($ M)	$6.6M
Projected Cost Savings ($ M, 10 years)	$66M

EcoDomus Applications in FM

Mobile Data Editing

Edit and review BIM parameters through mobile or tablet, any additions shall be attached to the BIM model (such as pictures, datasheets, certificates, etc.). Barcoding is also enabling through mobile, in order to speed up the on-site work (EcoDomus, 2015).

Mutual Information Platform

Manage attachments in EcoDomus Common Data Environment (CDE) – use all required data in order to manage workflows, comply with PAS1192 needs for CDE, integrate documents with COBie, use tags to filter documents (EcoDomus, 2015).

Data Quality Control

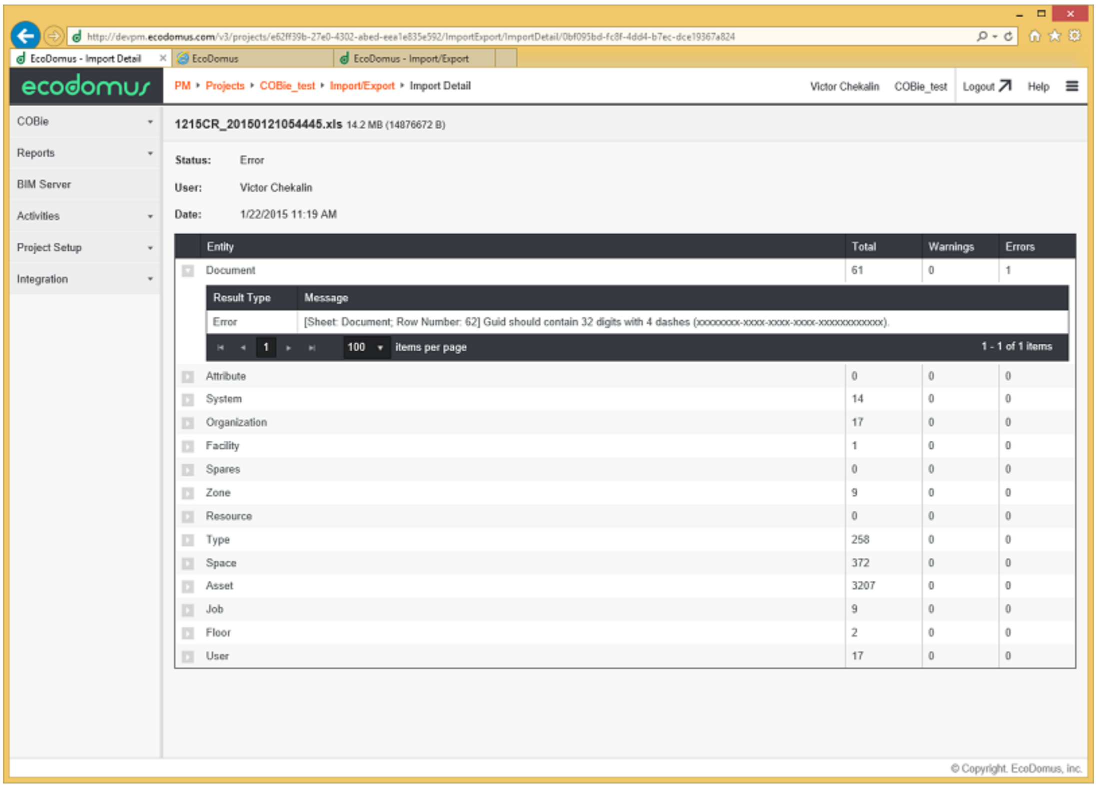


Figure 18. Information Validation Control (EcoDomus, 2015)

BIM QA/QC area unit supported BIM references and standards. If detailed tips area unit on the market then a quantitative review is potential, and automatic verification can be done through the EcoDomus PM software system.

COBie Editing

The EcoDomus platform utilizes COBie by providing a browser-based internet 3D interface. This interface enables for the gathering and validation data and supply a method for corroborative and writing the COBie information during a virtual building (EcoDomus, 2015).

Online 3d Navigation

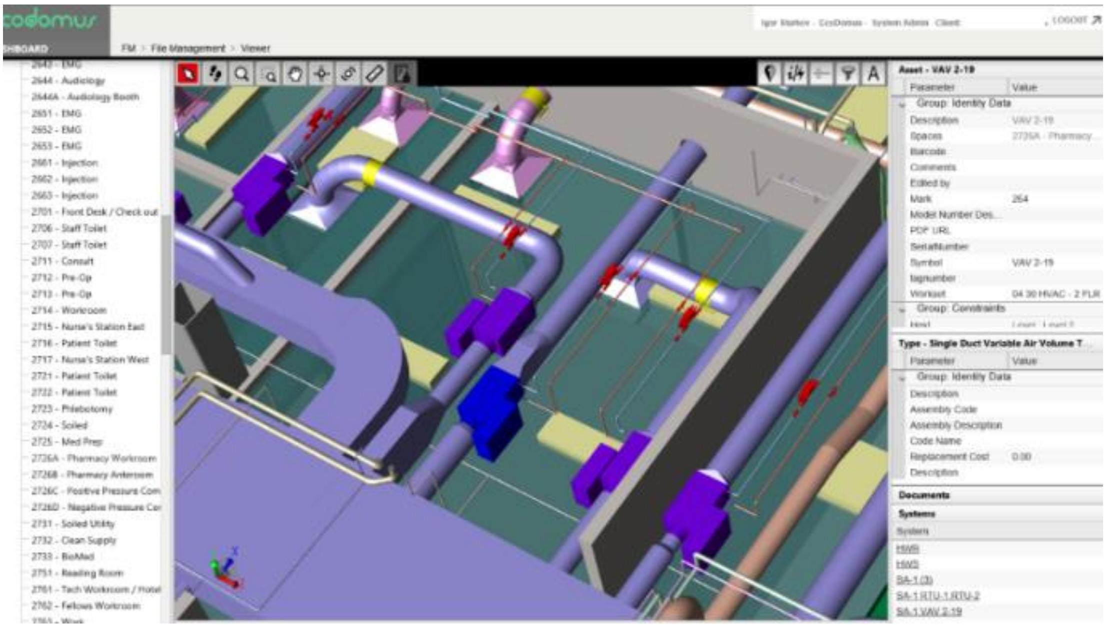


Figure 19. Online 3d Navigation (EcoDomus, 2015)

Visualize the equipment assets in 3D view, such as: MEP components and tackle problems, i.e. pipeline leakage. Review all required documents and pictures.

Portfolio Assets View

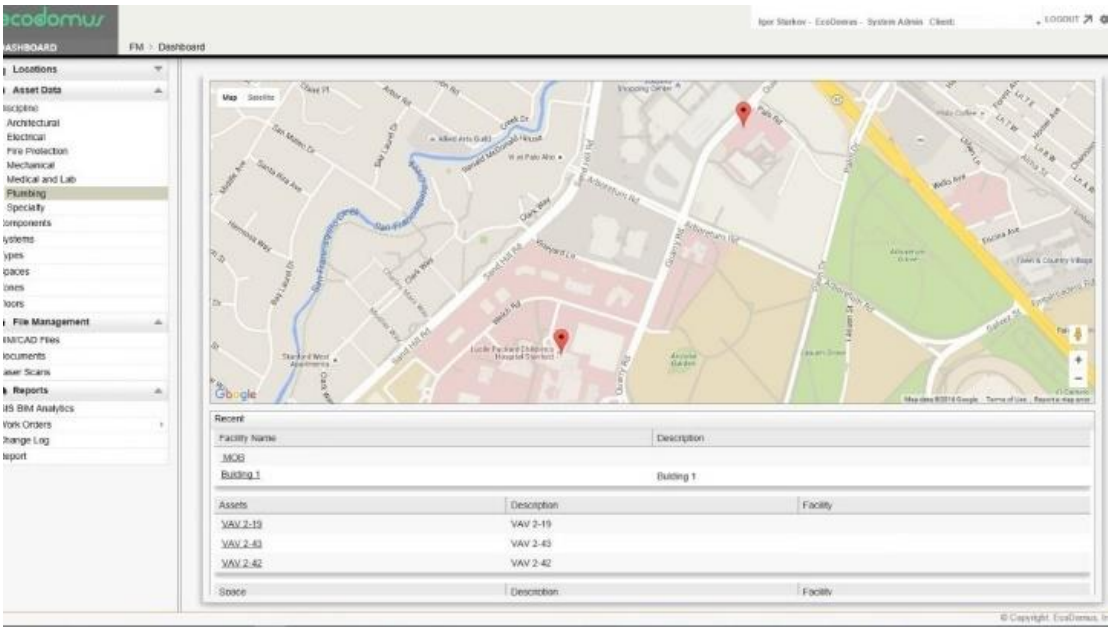


Figure 20. Assets View (EcoDomus, 2015)

EcoDomus FM shall segregate data by its location, along with problems alerts. Combination of GIS and BIM is applicable, where system components shall be visualized through GIS navigation feature.

Documentation

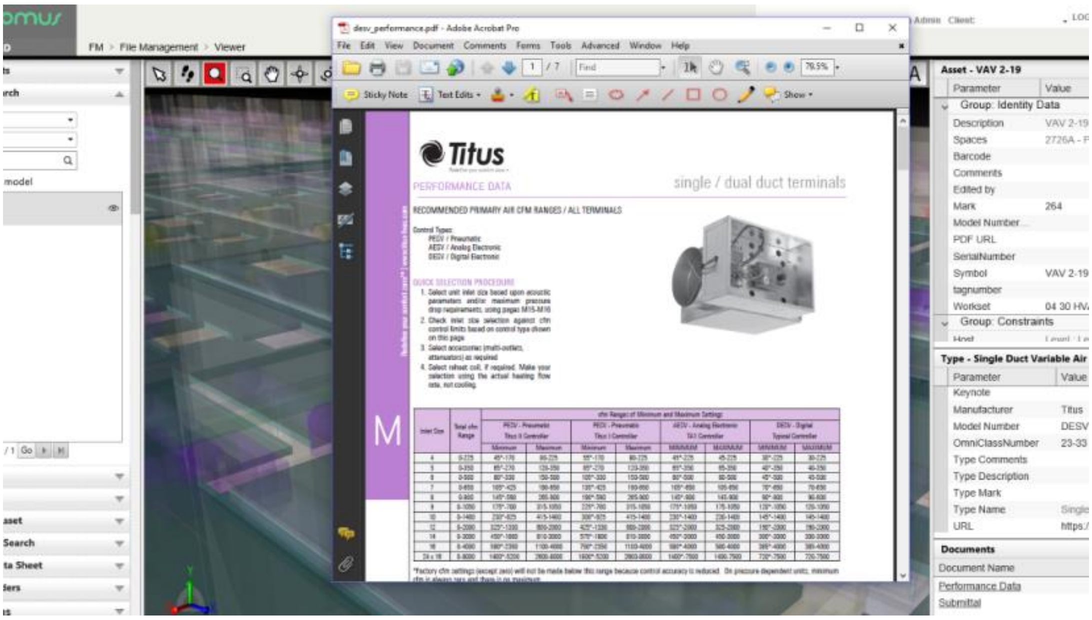


Figure 21. Documentation (EcoDomus, 2015)

According to COBie rules, documents shall be reviewed in connection to equipment, building, zones and locations. Range of documentations includes warranty, certificates, datasheets, drawings and many others.

BIM and BAS

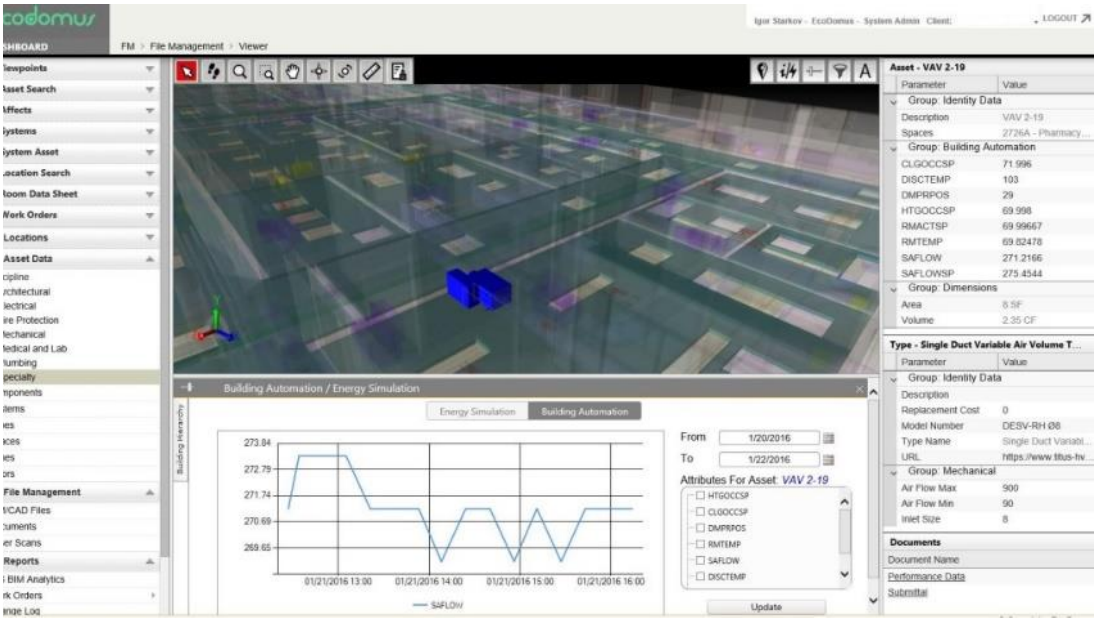


Figure 22. BIM and BAS (EcoDomus, 2015)

Integration of BIM and Building Automation Systems (BAS) through EcoDomus to enable sensors real-time reading following among 3D based model. Monitor HVAC equipment performance by reviewing data points values.

Laser Scanning Interface

Figure 23. Laser Scanning Interface (EcoDomus, 2015)

Review all required information in BIM through Cloud server-based for laser scanning. EcoDomus interface allows to view, monitor and control all required facilities, and measure distances between any 2 points.

Advanced Reports

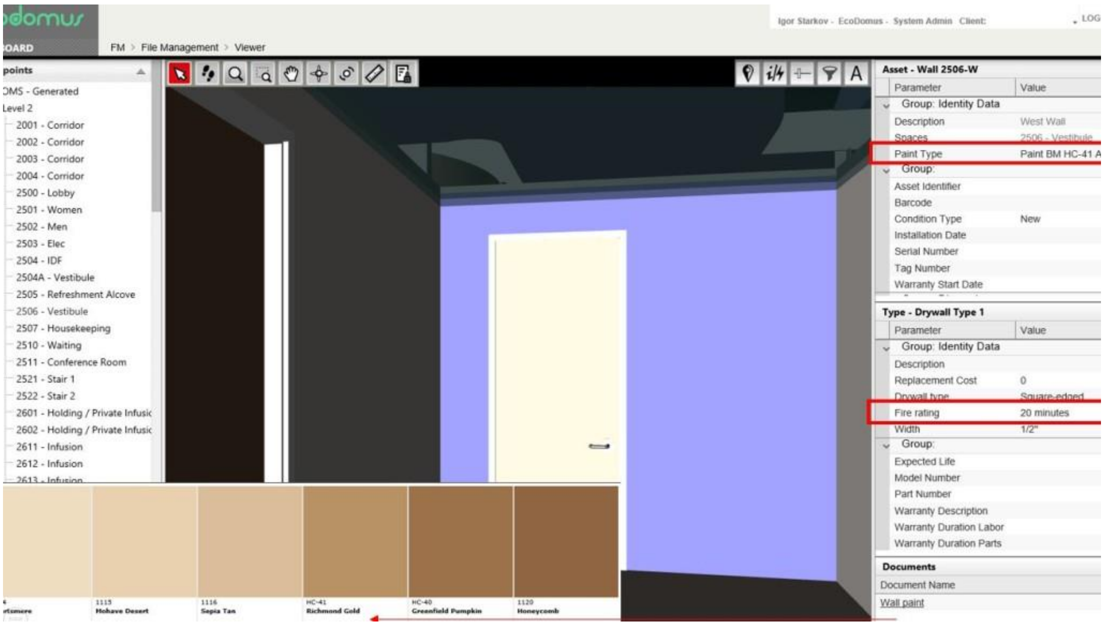


Figure 24. Advanced Reports (EcoDomus, 2015)

Monitor the schedules and plans, also calculate the total surface area required to finalize the material quantity. Review the fire ratings for walls and doors, and quickly locate them on the floorplan (EcoDomus, 2015).

The BIM Process of Capturing Existing Facility

Accuracy and Specifications

BIM functionalities requires accuracy and information richness to fulfill their functions. A globally used terminology to describe data accuracy level of BIM elements is ‘Level of Detail’ (LoD). It defines geometric and non-geometric approaches for information provided by different project parties. It’s crucial to allocate the required LoD prior to analyze or schedule any project, such as time, cost and/or information logical relationship. LoD generally relates to project budget, duration, complexity, requirements and application. For the existing building capturing, the accuracy shall be described using different parameters that will differ according to the data sources and technology approached. For example, laser scanner accuracy shall be described by its dimension precision towards reality with respect to capturing distance and environment (Volk, Rebekka & Stengel, Julian & Schultmann, Frank. (2014)).

Informational Analysis

Model View Definitions (MVD) and Information Delivery Manual (IDM) shall both be described as framework for data exchange and processing with a BIM model, information exchange and redundancy prevention shall be achieved as well. They define all information exchange parameters in BIM, also outline practical, technical and organizational problems relationship. The information requirements and their workflow utilized by users are generally described as Exchange Requirement Model (ERM) (Volk, Rebekka & Stengel, Julian & Schultmann, Frank. (2014)).

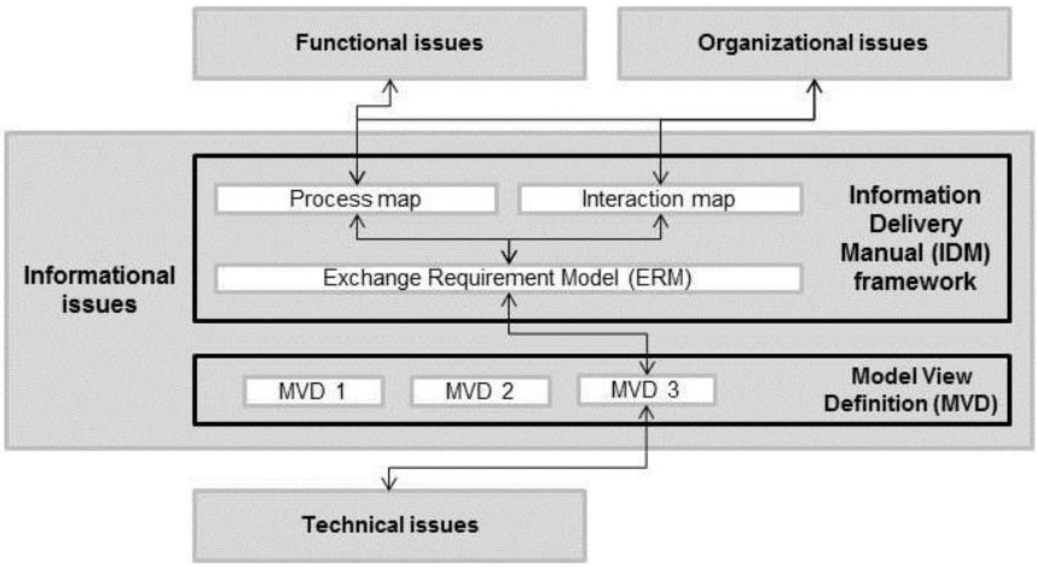


Figure 25. Information Delivery Manual (IDM) framework in BIM (Volk, Rebekka & Stengel, Julian & Schultmann, Frank. (2014))

Figure 26. BIM information/delivery elements (Volk, Rebekka & Stengel, Julian & Schultmann, Frank. (2014))

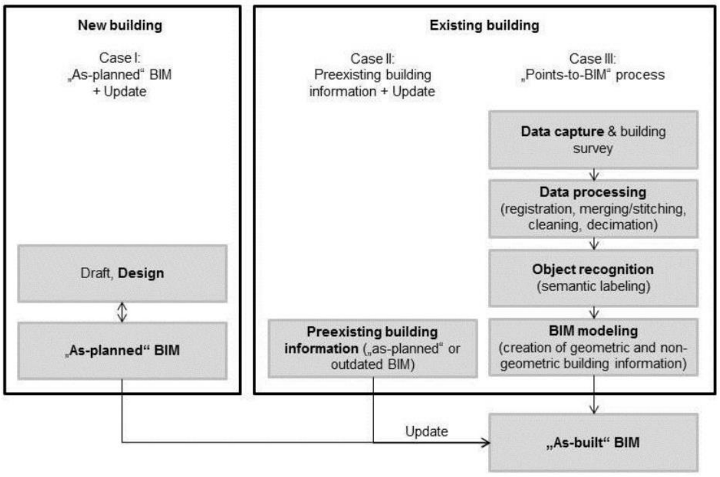


Figure 27: BIM processes for new and existing buildings (Volk, Rebekka & Stengel, Julian & Schultmann, Frank. (2014))

Data capture

To capture the required information/data for existing buildings, there are two main techniques: Non-contact and Contact. In-depth through Non-contact Technique there are few approaches as Image-based, Range-based and some others. Laser scanning, photography and video grammetry are examples of the non-contact approaches. While contact, requires physical contact between existing buildings and different instruments (Volk, Rebekka & Stengel, Julian & Schultmann, Frank. (2014)).

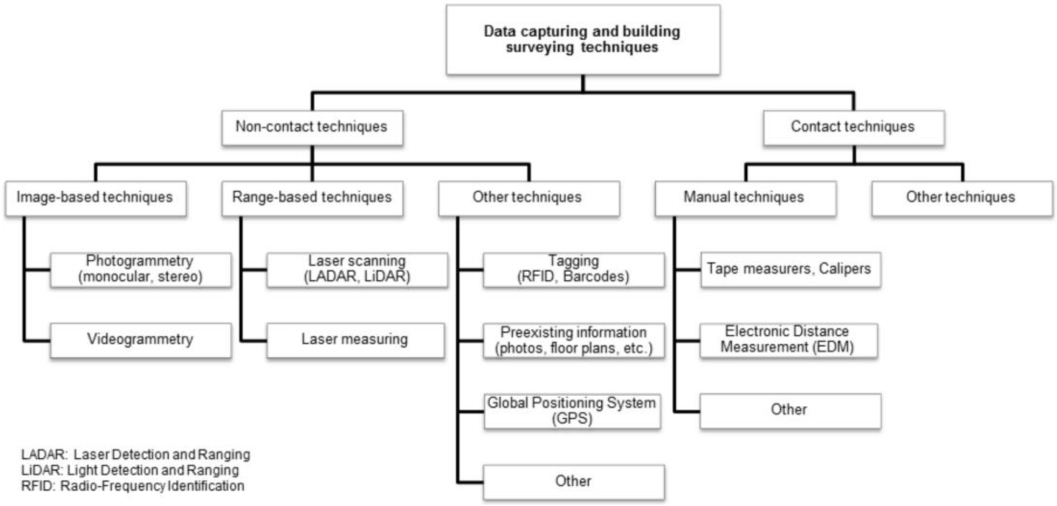


Figure 28. Data capturing and surveying methods (Volk, Rebekka & Stengel, Julian & Schultmann, Frank. (2014))

Table 7. Data Capturing Techniques By Decisive Features (Volk, Rebekka & Stengel, Julian & Schultmann, Frank. (2014))

Decisive features	Digital Capturing Methods			
	3D laser scanning	Photogrammetry	RFID	Barcoding
Capturing	Yes	Yes	Yes, limits	Yes, limits
Time	–	↓	↓	↓
Cost	↑	–	–	↓

Quality	↑	↑	–	–
BIM	Yes	Yes	No	No
Data size	↑	–	↓	↓
Automation	–	–	↓	↓

Data processing

The dependencies are high for the data proper process, since the LoD and its accompanied information requirements is a crucial factor. Also, the data capturing technique and size with their time and effort required is directly related to each other's. Data process is performed to modify the BIM objects to captured building extensive information, such as the importance of capturing fittings. Reference frame includes the merging and alignment of scanned point cloud information. The data shall be matched throughout coordinates and common overlapped data which will automate the processing. Then, noise and other unneeded information shall be cleaned to enhance the information according to application (Volk, Rebekka & Stengel, Julian & Schultmann, Frank. (2014)).

Physical recognition

The captured building information is utilized to define objects and their functional specifications and features. The recognition of physical appearance includes identification of profile, collection of all relevant data as well as cleaning of data noise (Volk, Rebekka & Stengel, Julian & Schultmann, Frank. (2014)).

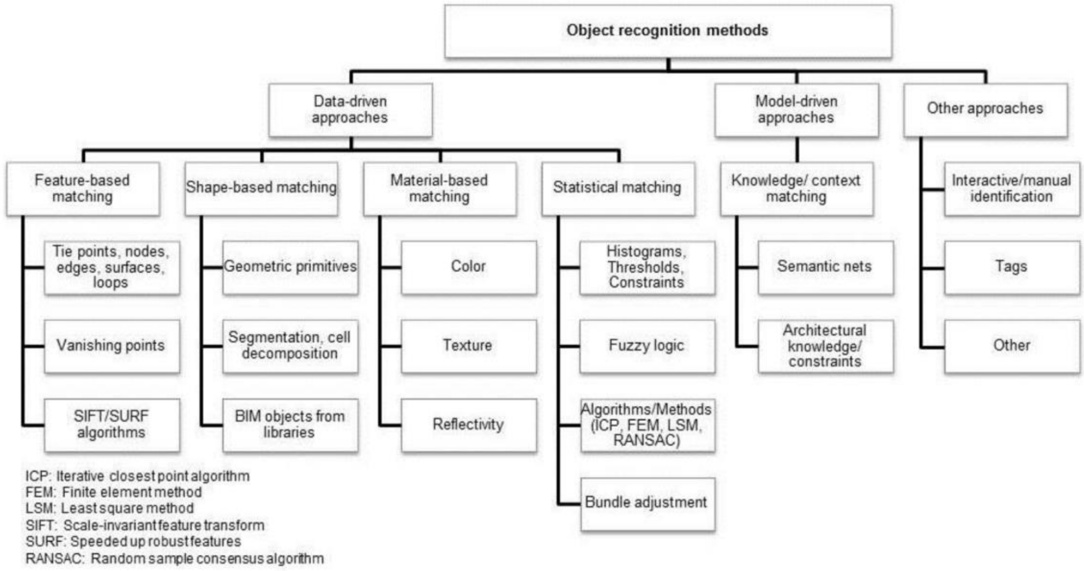


Figure 29. Data recognition techniques (Volk, Rebekka & Stengel, Julian & Schultmann, Frank. (2014))

Modeling

Modeling describes the development of BIM elements that illustrates building components, including each geometric and non-geometric attributes and relationships. BIM must be modeled through user requirements, specifications, and LoD; according to the capturing techniques used. There are many BIM modeling tools to be utilized in order to reach the project needs (Volk, Rebekka & Stengel, Julian & Schultmann, Frank. (2014)).

3D Laser Scanning Techniques for Data Capturing

Fundamental of Laser Scanning

Introduction

3D scanners aren’t the same as cameras, both applications are to capture physical objects and components, however with different technology-approach. While a camera collects color data pattern towards a limited view with certain range, a 3D scanner collects series of points in distance regarding surfaces inside its range. The "picture" produced describes series of distances to a physical profile surface at every point within the frame. This describes the 3-dimensional position of every point within the range. Number of scans to be developed depends on the size and complexity of the surface or object. Multiple scans, regardless their number, from different angles and directions are required for few projects (Fausto Bernardini, 2002).

Contact Technique

3D contact scanners, generally make a direct contact with an object in order to start data collection, often contain a robotic arm probe with a sensing end point. The arm shall be controlled automatically as a robotic arm, or manually to contact the surface required to be scanned. X, Y and Z coordinates of the point shall initiate by tip contact to take multiple position record. A point-cloud mesh will be created accordingly and visualized as a three-dimensional mesh diagram (Mostafa A-B Ebrahim, 2014).

Coordination Machine (CMM)

The physical object shall be scanned in 3D through the CMM method. A CMM (Coordinate Measuring Machine) is one of the well-known techniques for scanning by contact. A CMM is as any other contact method scanning, which measures the object through multiple coordinates in order to create a 3D diagram. CMM also shall be operated manually (by hand) or automatically (PC/Controller). Probes of CMM are not specifically sensing endpoint, while shall be a mechanical, laser, optical or other method of scanning (Mostafa A-B Ebrahim, 2014).

Figure 30. Coordinate Measuring Machine (CMM) (Mostafa A-B Ebrahim, 2014)

Non-Contact Technique

Non-contact 3D scanners, as the name refers, shall operate without direct contact with the associate object surface. Instead, active or passive methods shall be used to scan a non-contact 3D. The end result's includes points mesh to be utilized through various applications (Mostafa A-B Ebrahim, 2014).

Non-Contact Active Techniques

Active scanners emit radiation or light rays to receive its reflection in order to identify the profile of the scanned object, with no physical contact.

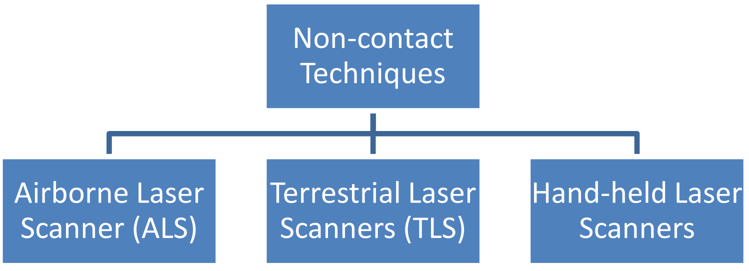


Figure 31. 3D laser non-contact scanner techniques (Mostafa A-B Ebrahim, 2014)

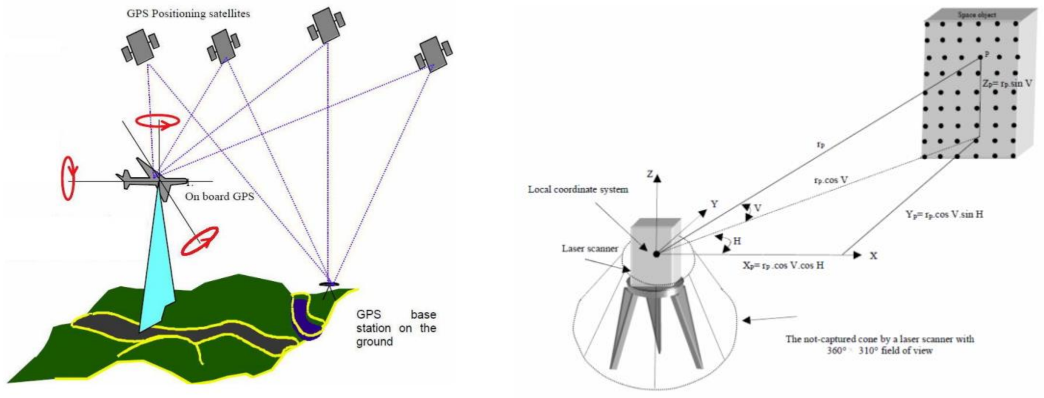


Figure 32. ALS and TLS system fundamental components (Mostafa A-B Ebrahim, 2014)

3D Laser Scanning Applications

Applications

Industrial, architectural, civil surveying, urban topography, mining, reverse engineering, quality, archaeology, dentistry, and dimensional mechanical inspection are simply a few of the versatile applications of laser scanning. Digitalization through scanning is considered one of the most simply methods (Mostafa A-B Ebrahim, 2014).

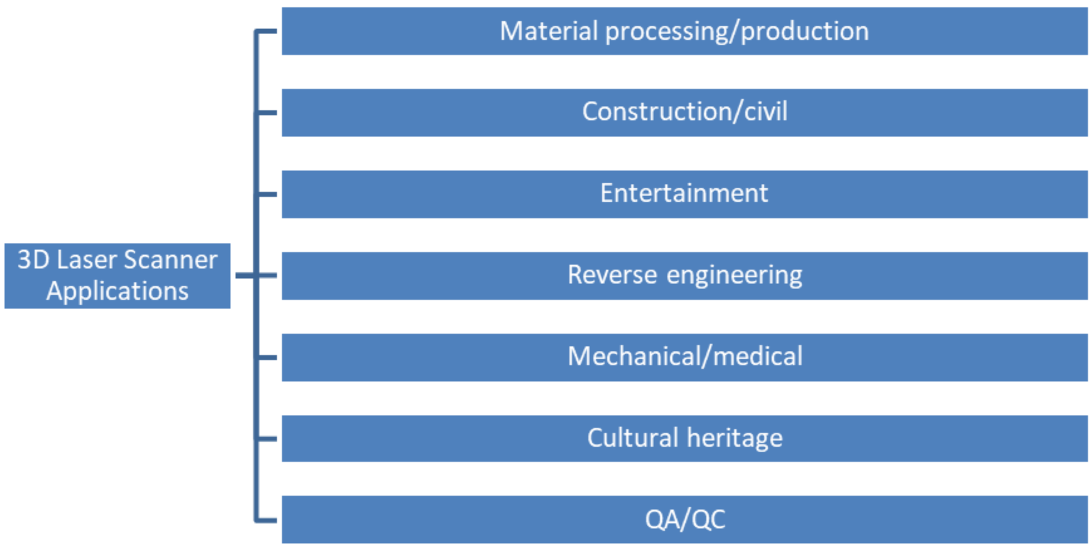


Figure 33. 3D laser scanner applications (Mostafa A-B Ebrahim, 2014)

3D Laser Scanners Used in The Market

Few brands used nowadays in the market to fulfil the possible applications. Below tables will show some necessary information towards the manufacturers of 3D laser scanners within current market (Mostafa A-B Ebrahim, 2014).

Table 8. Summary Of Technical Specifications Of The Laser Scanning Systems Used (Mostafa A-B Ebrahim, 2014)

Manufacturer	Trimble (GS101)	Leica (HDS3000)	Z+F (Imager 5003)	FARO (LS 880 HE)
Technique	Time-of-flight		Phase difference	
View Degree	360x60	360x270	360x310	360x320
Distance m	2 to 100	1 to 100	1 to 54	Less than 78
Accuracy mm	6	4	6	±0.3
Control	PC/Tablet	PC	PC	PC/Tablet
Camera	Built-in	Built-in	Add-on	Add-on
Software	PointScape	Cyclone	LaserControl	FARO Scene
Time	1.5 hr	2 hrs	7 min	7 min
Pixels (25m)	16.7 mm	20.8 mm	15.7 mm	15.5 mm

Table 9. 3D Laser Scanners Products Overview (Leica, Faro, Owler, Ametek, 3D Digital Corp, Topcon, Maptek, Shape Grabbet, Surphaser, Trimble, Zeiss, Teledyne & ZF, 2018)

Manufacturer	Product Range	Products Applications	Scanning Ranges (m) Operating Temp. (°C)	Turnover (2015) in Million USD	Country of Origin
Leica Geosystems	BLK360, RTC360, ScanStation P40/P30/P50,	Archeology, Heritage, Architecture, Buildings, BIM, Civil infrastructure, Forensics, Plant & Ships	0.4 - >1000 -20 to +50	818	Switzerland
Ametek (Creaform)	HandySCAN 3D, MaxSHOT 3D	Aerospace, Automotive, Consumer products, Manufacturing, Heavy industries, Medical, Oil & Gas, Power generation	0.1 – 10 +5 to +40	3700	Canada
Faro	FocusS, FocusM, Freestyle 3D X, Stormbee & Focus	Assets/Facility management, BIM, CAD, Crime scene, Inspections, Calibrations, Reverse engineering, Virtual simulation	0.6 to 350 -20 to +55	389	USA
3D Digital Corp	Optix, AuSIS, Escan,	Aerospace, Architecture, Automotive, Consumer products, Education, Manufacturing, Medical care, Multimedia	0 to +40	7.7	USA
Topcon	IP-S3, IP-S2, GLS-1500/2000, IS	Survey, Construction, 3D measurement, Mapping & GIS, Agriculture, Mobile control	40 – 500 -20 to +60	1300	Japan
Maptek	Maptek X/L/SR3	Exploration, Evaluation, Mining, Rehabilitation, Mapping	2.5 – 2400 0 to +50	20	USA
Shape Grabber	PLM300/600, PRM330, SG Scan head series	Automotive, Aerospace, Medical, Inspection, 3D modeling,	0 to +50	5	Canada
Surphaser	75USR, 100SR, 100IR, 400HQ4, 400HP4	Reverse engineering, Dimensional control, Large volume metrology, As-built conditions, BIM, Historic Preservation, Architecture, Forensics, Animation	0.25 – 140 +5 to +40	17.8	USA
Trimble	SX10, TX8, TX6, S7, S9	Urban environments, Civil infrastructure, Building construction, Oil & Gas, Industrial environments, Cultural heritage, Terrain, Forensics	250 – 600 -20 to +50	3000	USA
Zeiss	T-Scan CS/LV	Automotive, Aerospace, Machinery, Art/Archeology, Education	1.5 – 350 -10 to +40	5800	Germany
Teledyne Optech	Polaris, CMS	Civil, Construction, Transportation, Heritage, Mining, Forensics, Forestry, Coastal management, Shoreline mapping, Scientific research	125 – 2000 -20 to +60	26.5	Canada
Zoller + Frohlich	Imager 5016, 5010X, 5010C, 5010, 5006h, 5006EX, Profiler 9012,	Archaeology, Architecture, Rail, Heritage, Forensics, Infrastructure, Industry, Insurance, VR	0.4 - 360 -20 to +50	-	Germany

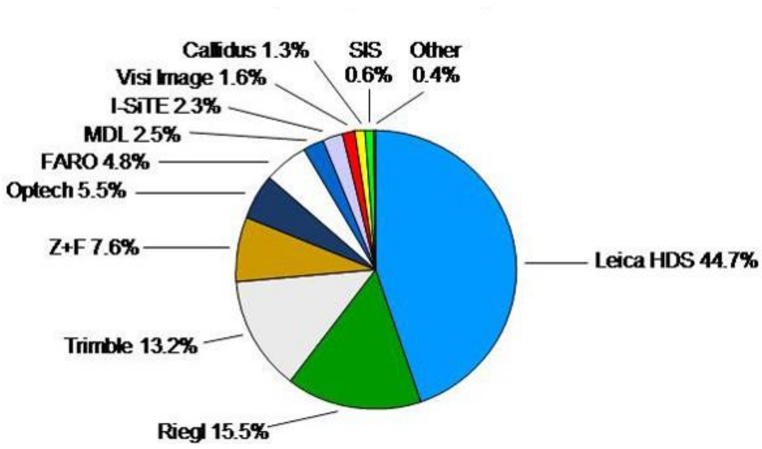
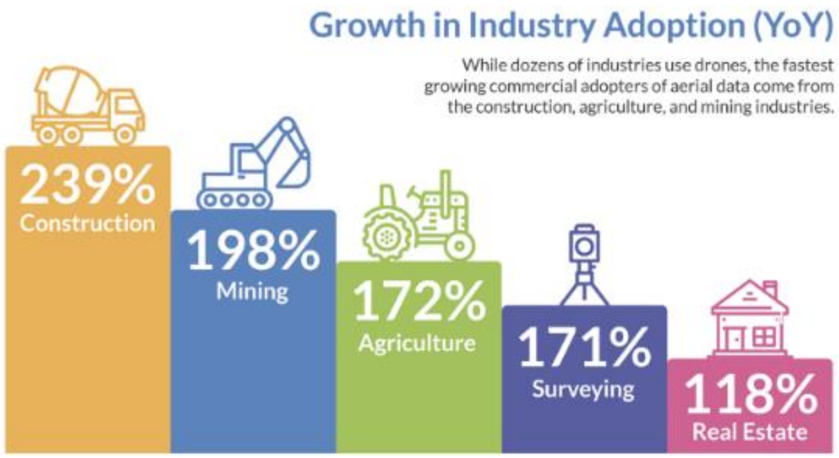


Figure 34. 3D laser scanner's manufacturers market shares (Spae3D, 2004)

Drones Applications for Construction

Many of the industries rely on drones, mostly in the construction industry. The usage of drones within construction field had been increasing dramatically reaching 239% last year (DroneDeploy, 2018).



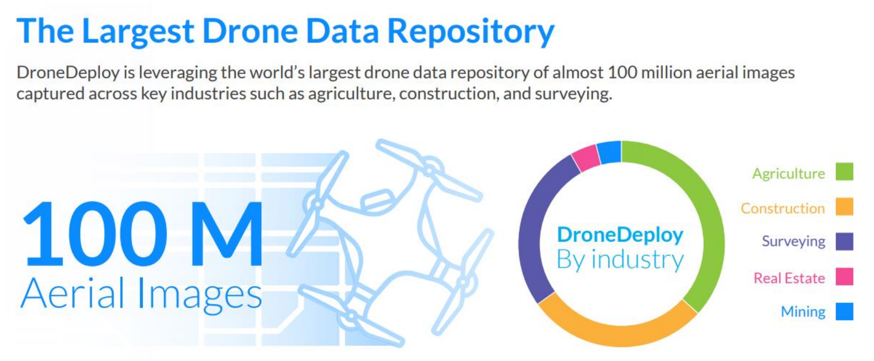


Figure 35. Drones growth and data repository per industry (DroneDeploy, 2018)

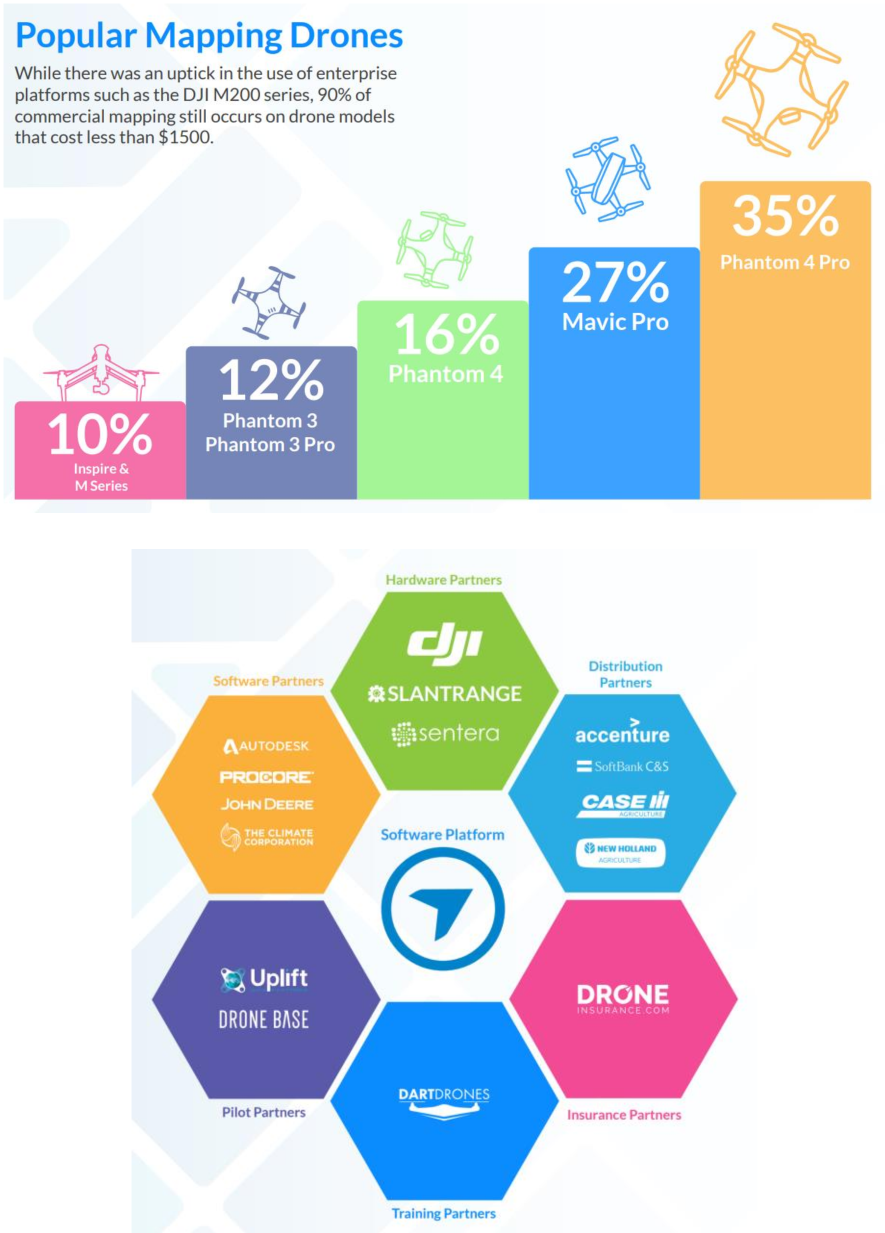


Figure 36. Mostly used mapping and software drones (DroneDeploy, 2018)

Relation between the hardware (drone) and software is always dependable upon application. Also, selection will depend on the project personnel and use, therefore below illustrations will show the distribution of project roles towards the uses.

Drones develops communication, coordination, monitoring and controlling projects. Enhance safety, time-reduction, resources management, fast-track surveying, and deliver accurate measurements as well.

Construction professionals reported this year vary of advantages from various drones. The breakdown of results is shown in Figure 37.

Figure 37. Drones benefits in construction (DroneDeploy, 2018)

Different tools are used along with drones to enhance the final results of data collected. Below figure will show the most well-known software platforms used in the market.

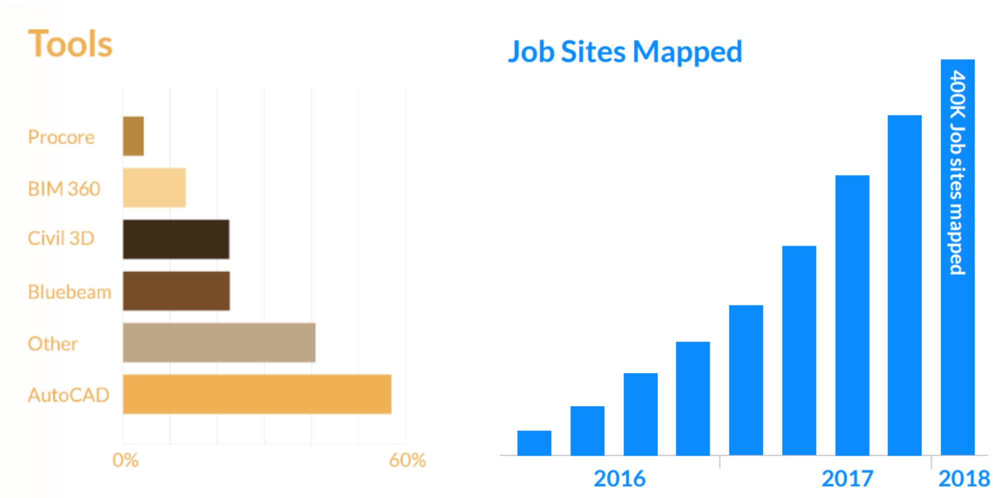


Figure 38. Mostly used drones tools with number of sites mapped per year (DroneDeploy, 2018)

Main Drone Usage Phases in Construction Industry

The drones are having crucial applications towards diverse industries, and each application carry different level of usage and approaches. Below, demonstration will show different uses and applications.

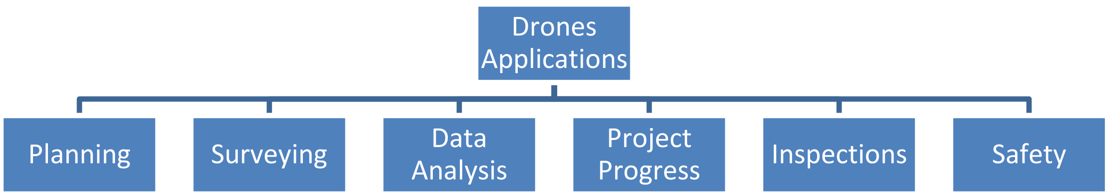


Figure 39. Drones applications (Blake Anderson, 2015)

UAV Thermographic Applications

Thermography or thermal imaging are terminology towards the technology of utilizing infrared capturing technique. Thermograms are the output of thermographic cameras, where infrared radiation is used. Thermal imaging applications are wide and important, For example: health care, inspections, archaeology, construction, maintenance, volcanology and many others (Wikipedia, 2019).

Utilizing thermographic technology is used through not only stand-alone cameras and sensor, but also drone cameras, which expand their efficiency and practicality. Having the camera built-in a UAV shall praise the application to building roof insulation, exterior walls insulation inspections, electrical towers connections insulation/resistance inspections, series of many electrical motors and engines work inspection from height, large-scale pipeline insulation inspections, refineries installations, tanks leveling, and many others (FLIR, 2019).

As studied by A.G. Entrop and A. Vasenev in 2017, University of Twente students, infrared thermography through drones shall have a huge impact on building external shell inspections and surveying. After developing a defined methodology of thermal capturing, the study explained further techniques on manually flying the drone on several missions through HT-8 C180 drone and FLIR thermal camera. The trips included capturing of the university campus, with several outcomes, such as: maintaining certain height of flying for error readings reduction, various angles and constant velocity (A.G. Entrop & A. Vasenev, 2017).

Research Contribution

This research is contributing to construction sector in various aspects, these aspects are all towards development and enhancement of Building Information Modeling (BIM). The study is discussing in-depth all valid tools and techniques of digital capturing existing building into BIM, which is a contribution towards any individual or organizational party that would implement the same. Also, a detailed comparison is held at the end of the study, to illustrate the various difference of each practice with respect to time, cost and quality. First time in Qatar, UAV real-time thermal surveying and image capturing in favor of buildings envelope and roof insulation efficiency evaluation was described and implemented as well. Furthermore, the objectives of the research are commonly linked with QU Digitalization Initiative goals, which adds an educational institutional privilege for QU and beyond.

The case was implemented and executed in one of the biggest academic universities in the Middle-east, which make it practical for any other similar organization to utilize. This study is written in a framework structure that shall give the reader the best understanding of the topic in order to execute the same. This framework is developed considering a solution package that is robust, mobile, easy-to-use, non-knowledge based, low cost, high quality, unneeded accessories attachments, no coding, parallel to existing initiative objectives, no COBie involvement, simple aerial data capturing utilization and first time in Qatar integration between BIM-BMS systems along with thermal-based evaluation for buildings exteriors.

The biggest add-value is the BIM – BMS integration, which is rarely discussed due to its complexity and technical competency high requirements. However, in next several sections the reader will find a full detailed demonstration of integrating both BIM 3D model with up-running BMS. Also, the advantages and success case studies will be discussed afterwards. Therefore, below representation will give a better understanding of this research outcomes and contribution towards the construction, educational and innovative aspects.

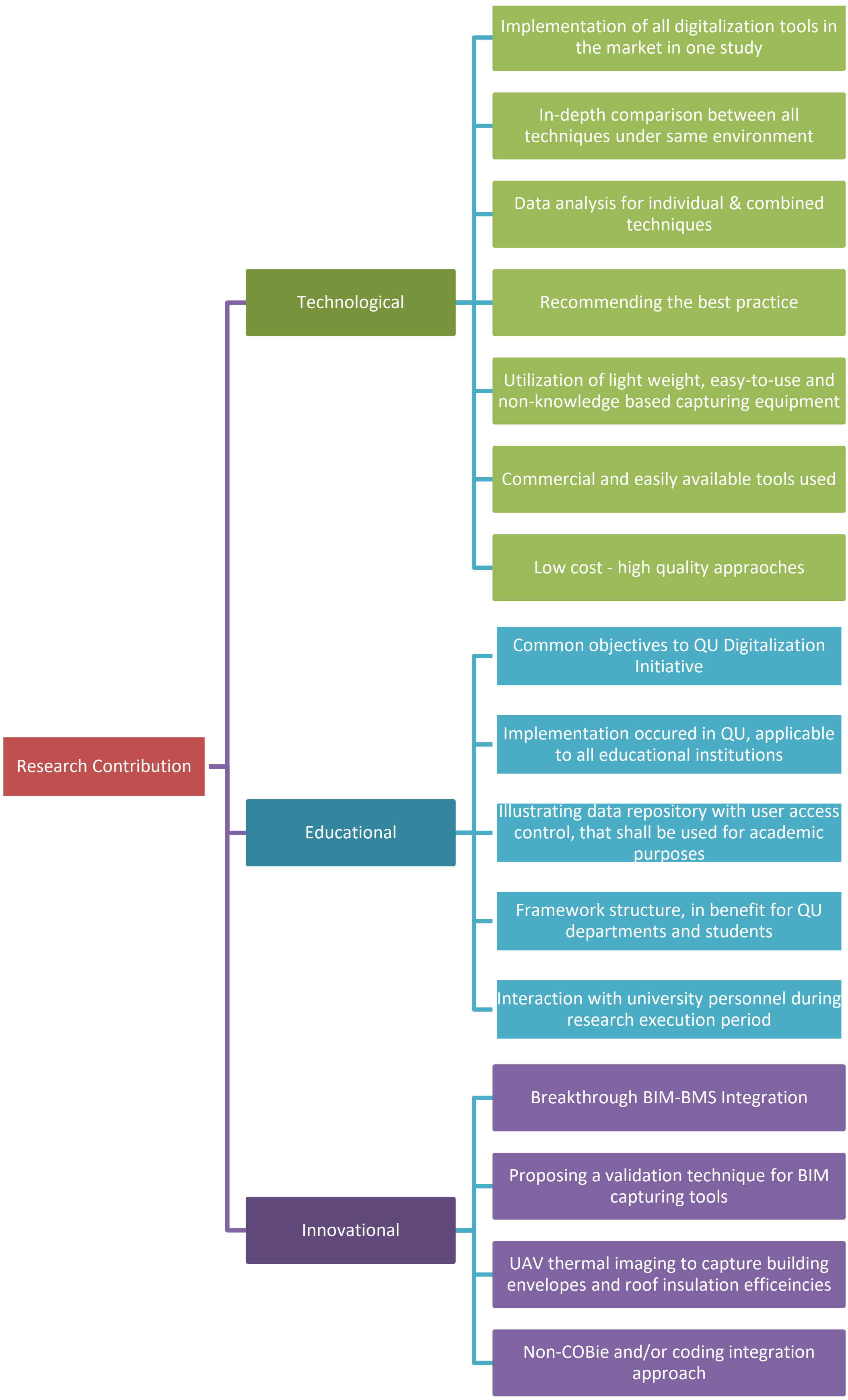


Figure 40. Research contribution

CHAPTER 3: RESEARCH METHODOLOGY

Introduction to Research BIM Objectives

General BIM objectives towards research is usually similar in various applications. The methodology with respect to objectives shall be shown in different ways with different tools according to the end-goal of the research, while few milestones and outcomes shall mostly remain similar with ambiguous variations (BIM Framework, 2014).

Generally the research inputs will start from experimental knowledge accompanied with previous studies. This starting point will pass through aims and strategy establishment, frameworks available, challenges, capabilities market status, etc. to reaching the objectives, such as:

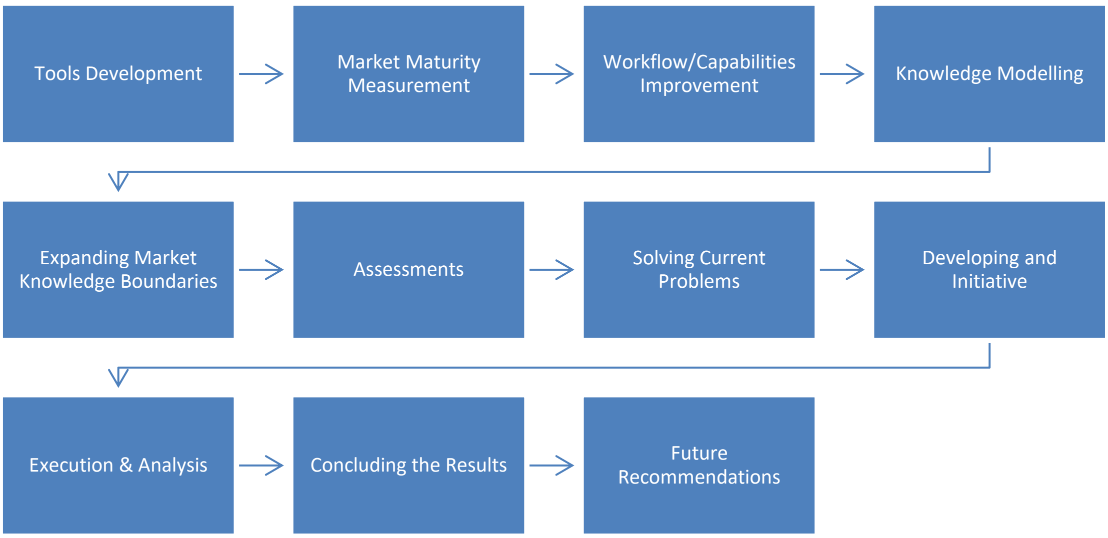


Figure 41. General research methodology (BIM Framework, 2014)

This research is aiming creation and development of an intuitive framework towards the Building Information Modelling (BIM) to be used in-benefit of Qatar University already existing buildings in relation with its Digitalization Initiative. This framework shall be used in-depth to plan and implement all necessary activities in direction to gain a complete digital campus (BIM enabled). Thus, in order to accomplish this aim, the following objectives shall be demonstrated and described:

- Define the cruciality and outcomes of BIM towards the global perspective
- Define the latest BIM processes and tools used to accomplish similar goal
- Define in detail the methods and techniques held to enable an existing building of privileging BIM benefits
- Define the capabilities of the BIM towards the Facility Management
- Develop an integration method between BIM and Building Management System (BMS) in favor of Facility Management
- Develop ideas to benefit from this framework academically within and beyond Qatar University community
- Illustrate the difficulties and challenges shall be faced during framework accomplishment
- Verify and assess the research outcomes by driving it to future recommendations and conclusion

BIM Process Map

As in the methodology previous section, the process map for BIM is generally wide in similarities. The correlation appears in the development of the BIM model with dissimilarity only in the application, tools and approaches. Below figure shall provide a descriptive mapping of model development in BIM. Along with BIM execution process which may differ from case to another on several dependencies. As appears in below process map holding BIM execution process.

This research process map is including the activities will be carried out since developing the aim and objectives of the topic up to framework completion. Research process shall be as following: The processes shall be flowed to attain the research aims and objectives. This will happen through extensive development of each process activity to include all needed requirements. These processes will be categorized as phases, and they'll be shown as following:

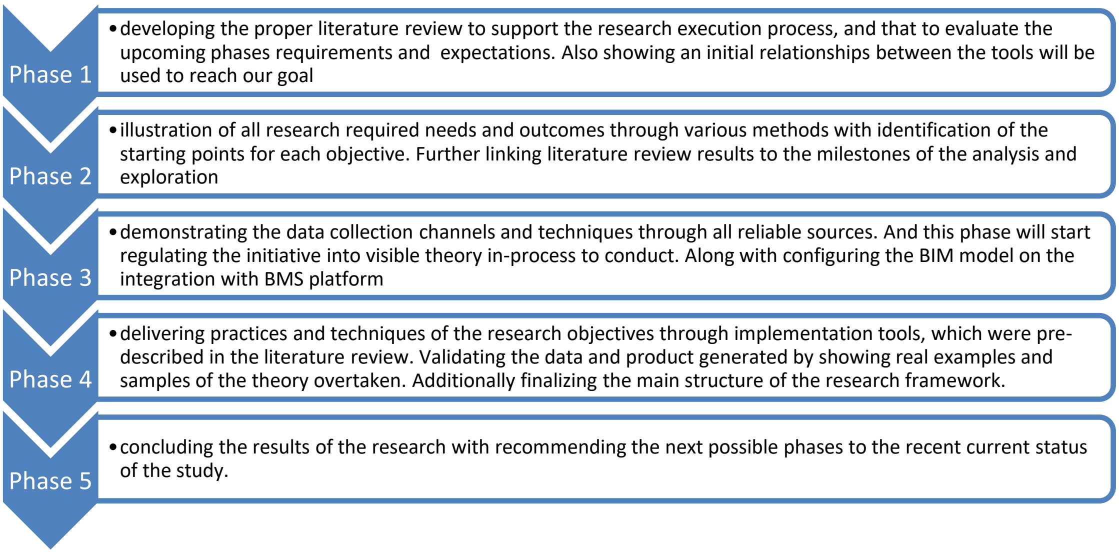


Figure 42. Sequence of phases used within the research methodology

Data Collection

Data collection method will depend on requirements and capabilities of project owner. Since data availability, collection, processing and cleaning process will vary from a stakeholder to another. However, generally, the data collected to achieve a proper BIM model will be through few but not limited to the following:

- 3D scanner
- UAV & drones
- As-built CAD drawings

To start such activity, at least one the upper options should be available to proceed. In this research topic we'll discuss the three methods, since they were used individually and coordinated. Therefore, below table will explain the reliable source used to gain such data from the existing building.

Table 9. Data Collection References

S.N.	Type of Data	Source of Data
1	As-built CAD drawings	Qatar University – Office of Capital Projects
2	3D point-cloud	3D laser scanner – Leica BLK360
3	3D photogrammetric model	Drone footage – DJI INSPIRE
4	BACnet real-time data values	Existing BMS

BIM and BMS Integration

After collecting and processing the data through diverse resources, the BIM model shall be ready for further development heading to praise the Facility Management (FM) of the existing building. To acquire an add-value in FM, BMS would be integrated with the complete BIM model to exchange crucial real-time sensor data values. In our study, BMS is existing, which accounted as privilege to the integration process.

While, to do that, an integration platform must be used. In this case, EcoDomus was used for that purpose to role as a gateway between both BMS and BIM. EcoDomus platform is also having an extensive feature towards the FM, such as:

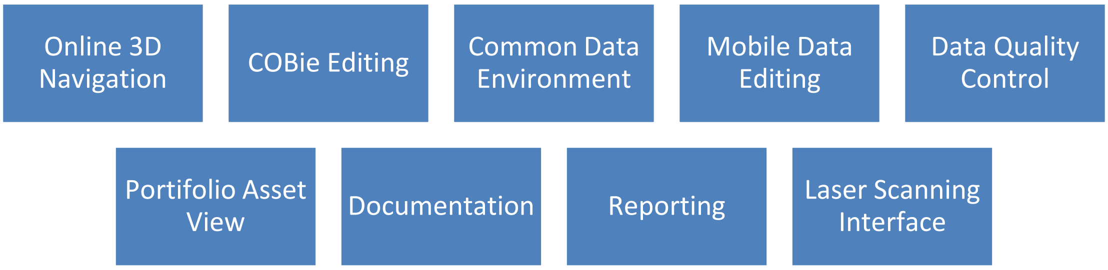


Figure 43. EcoDomus BIM-BMS integration tools

Which means that EcoDomus integrates any BMS data values to the BIM model by enabling sensor location, information, and values tracking through 3D BIM pre-developed model. Along with energy consumption measurement and logging, and many other features.

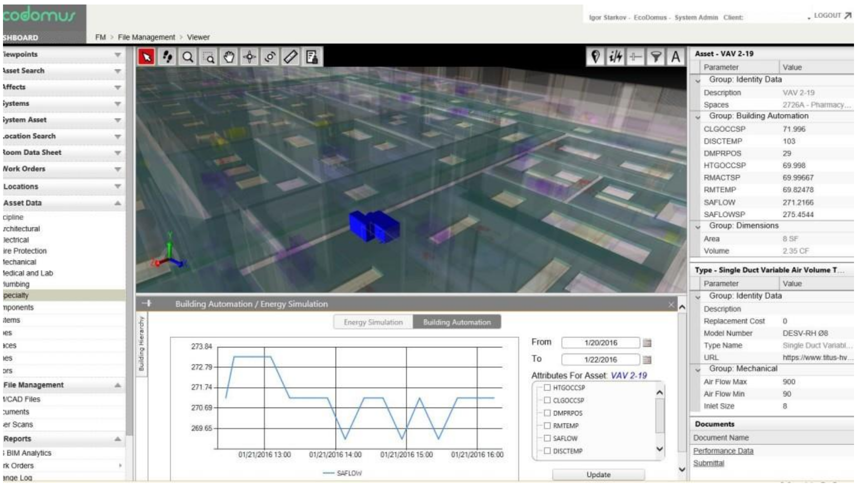


Figure 44. BIM and BAS integration through EcoDomus

Digital Repositories for Large Data

On the other hand, another academic approach shall be sharing the model with the others within Qatar University community, and that to utilize the model for different purposes in the future. Also, this would help the successor of this research to collect most possible data to proceed in the exact study path. However, students shall benefit in their curriculum related to BIM development all over the College of Engineering. To exchange BIM model data, the following procedure shall be followed:

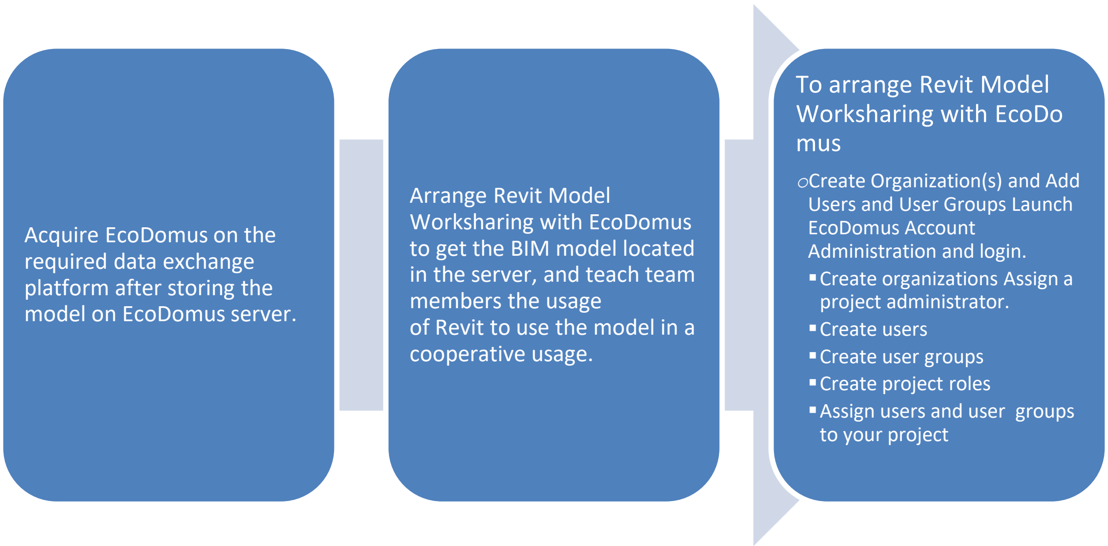
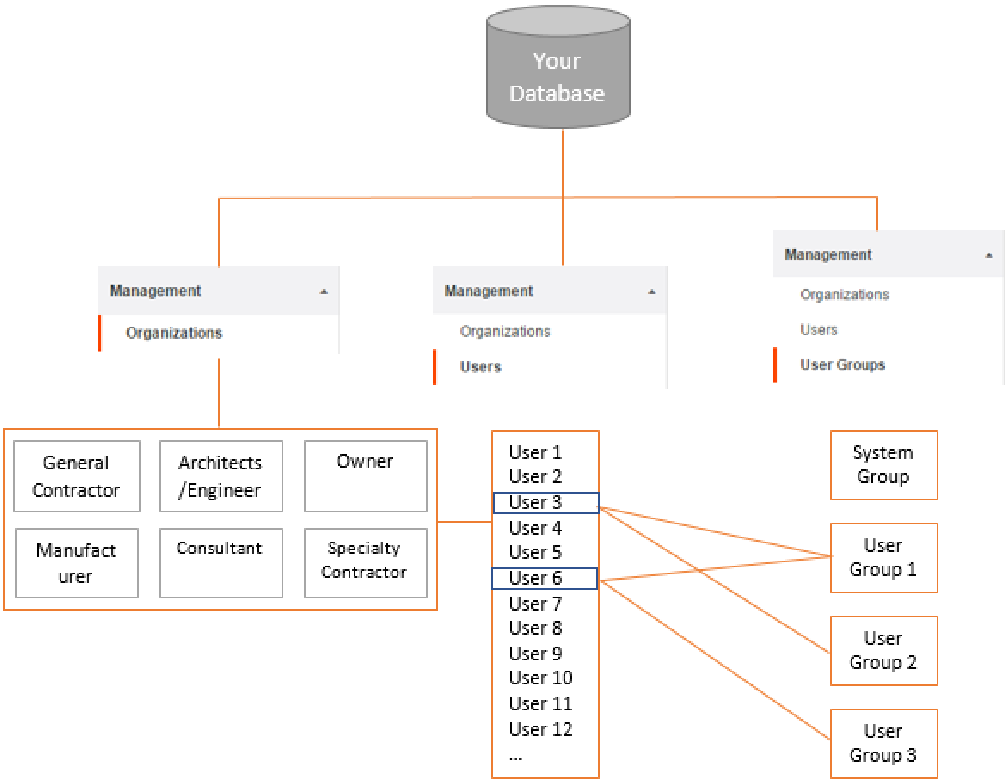


Figure 45. EcoDomus data repository process flow



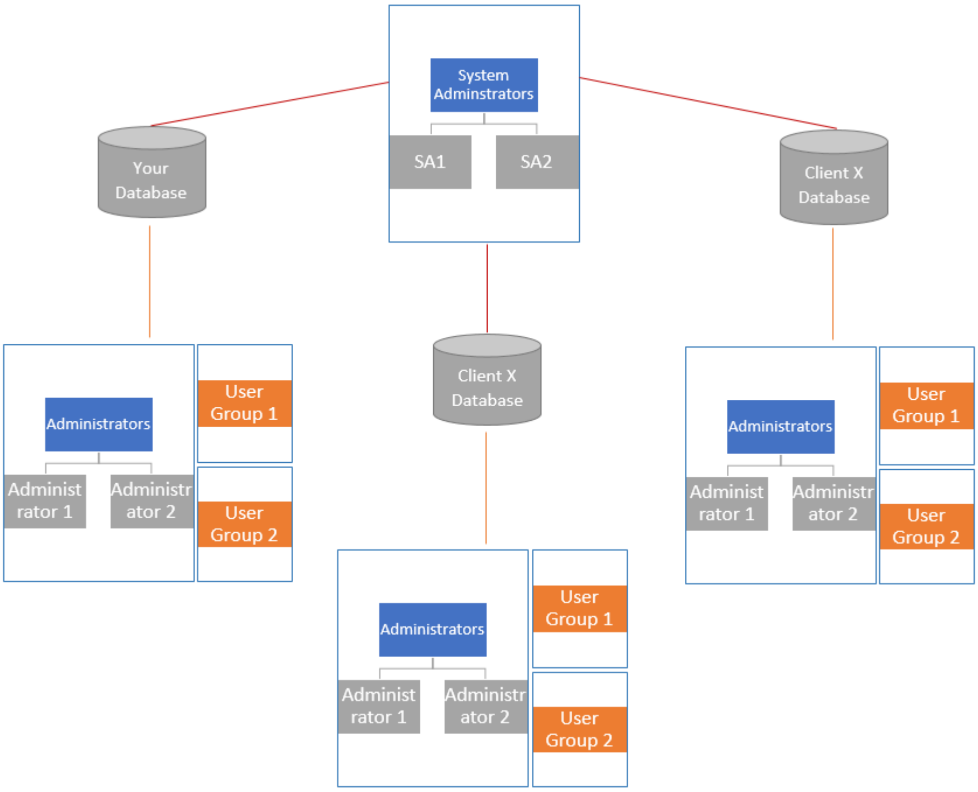


Figure 46. Database features in EcoDomus (EcoDomus, 2015)

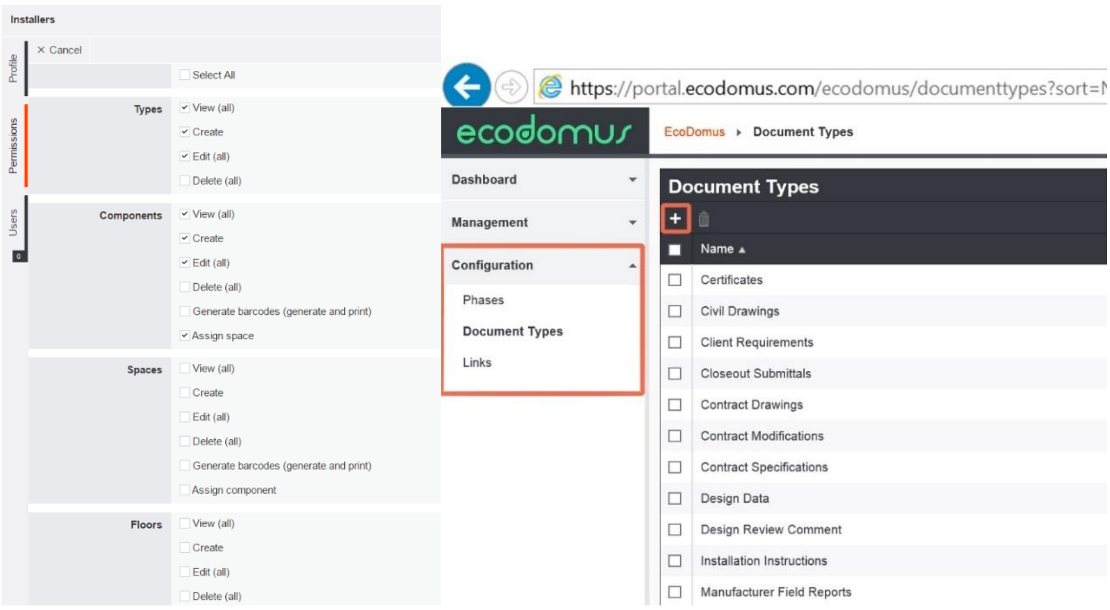


Figure 47. Types of permissions and documents in EcoDomus

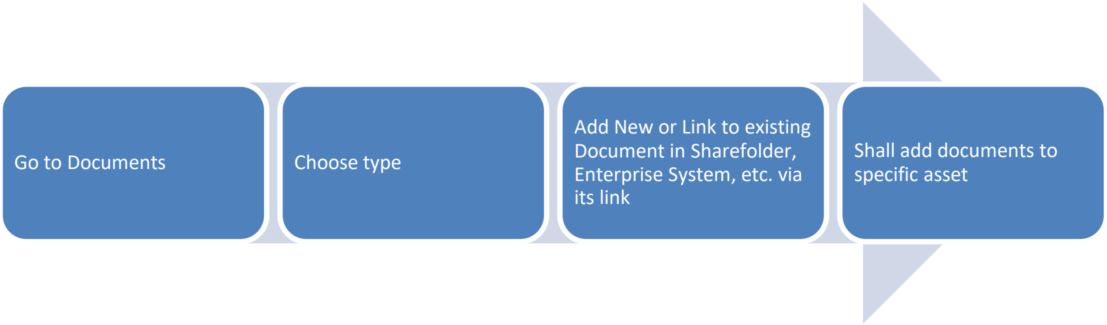


Figure 48. Add and view documents and model in EcoDomus

CHAPTER 4: DATA COLLECTION, PROCESSING AND RESULTS

Introduction

In this chapter, the data collection and processing will be discussed extensively throughout the whole processes. Also, the tools used to gather the data will be demonstrated and mentioned with full methodology and approaches individually. All through this chapter, the Qatar University (QU) master and digitalization initiative will be described and linked to the objectives of this study. Furthermore, the digital capturing will be explained in different categorize, such as: 3D laser scanning, UAV/Drones and CAD to BIM. These aspects will be expressed before BIM and BMS integration explicit enlightenment. In addition to incorporating the resulted product into academic applications. The academic BIM repository will take place to share the model with university community. The data capturing flow map will include all capturing tools (mentioned in Chapter 2: Literature Review), with data/information process stream; as in Figure 49.

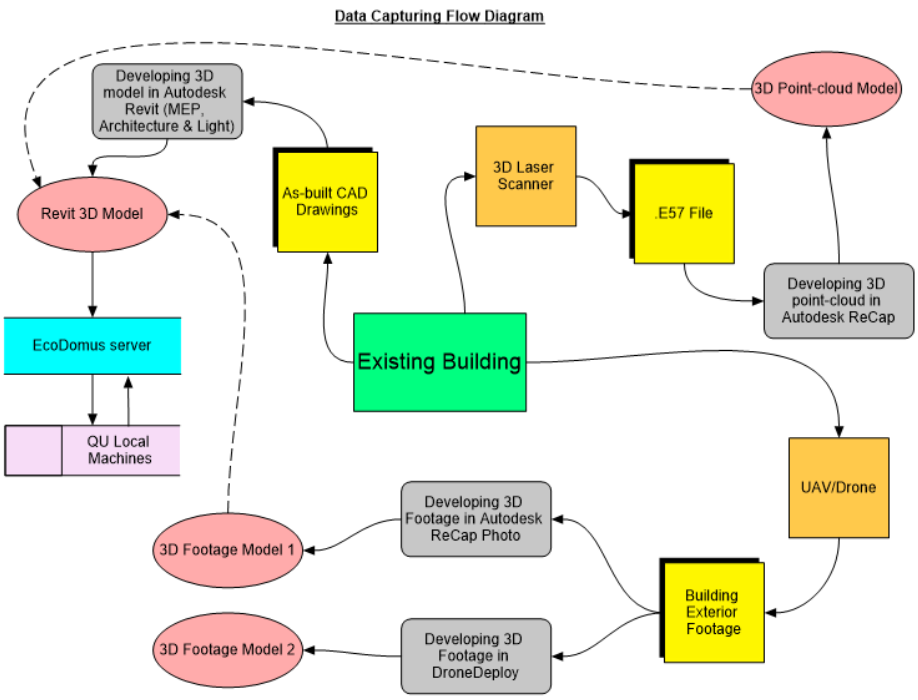


Figure 49. Digital data capturing flow diagram

After developing and completing the BIM 3D Model, an integration process will take place between BIM and BMS platforms. This coordination will affect the facility management of the university in an extraordinary scheme. Furthermore, data exchange between platforms shall be done though a third-party software called EcoDomus, which will convert both real-time BACnet data values to be read through BIM. This integration progression will be as shown in Figure 50.

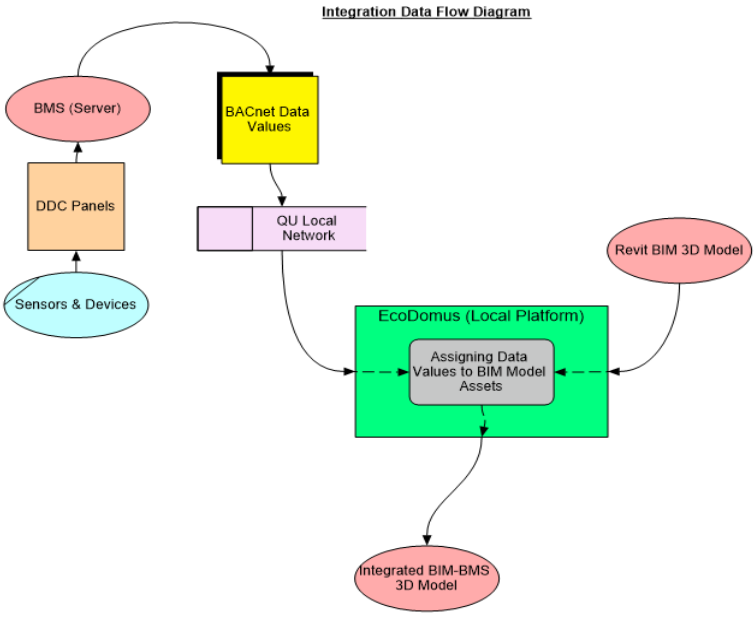


Figure 50. Integration of BIM and BMS data flow diagram

QU Master Plan

Qatar University is seeking an exceptional development on every educational and academic aspect towards continuous improvement, growth, innovation and advancement. This valuable and critical role establish enormous responsibility on the university to evolve state-of-the-art plans regularly. An example is QU Master Plan that holds diverse objectives concerning a Smart QU Campus with specific objectives, strategy, values, characteristics, timeline and budget. Illustration of few parameters of the Master Plan shall be as following:

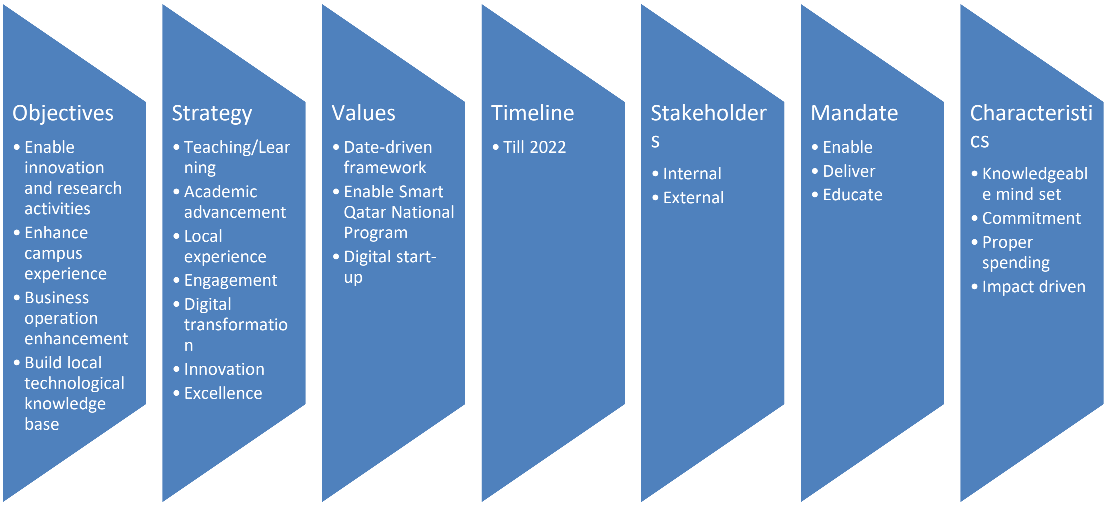


Figure 51. QU Master Plan main parameters

QU Digital Transformation Initiative

In addition to QU Master Plan, an important initiative was taken by the university to fulfill transformation of all existing buildings into digital smart campus. This start-up was recognized through concrete vision, values, strategy, objectives and plan. Part of the initiative took place within Qatar National Vision 2030 (QNV) that include various economical and financial strategic characteristics. Digital Transformation comes under the umbrella of many plans, such as:

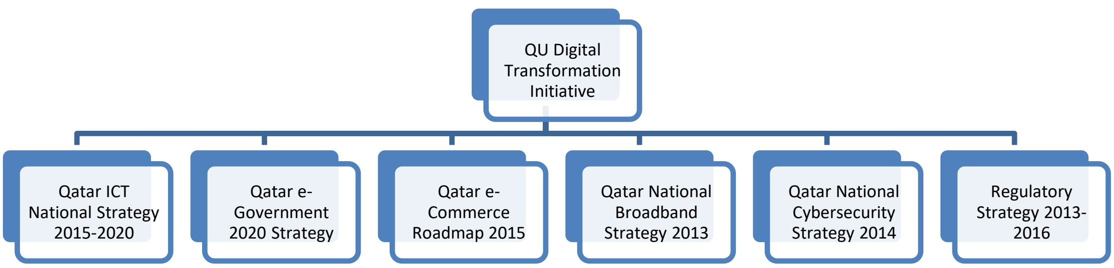


Figure 52. QU Digital Transformation Initiative associated plans (Mahmoud Abdulwahed and Hassan El-Rashid 2017)

Sectors which will be positively affected by the transformation would be transportation, education, health care, agricultural and sports. There are variety of opportunities utilized by QU in the digitalization, as an example: efficiency economy transformation, digital innovation economy, E-Systems, world cup 2022 and community transformation acceptance.

The revolution is accompanied by few benchmarks, like EU digitalization framework for educational organizations. The EU framework stands on mission, vision, strategy, implementation plan, management models, staff and students' competency, innovative approaches, engagement, recognition, analysis, digital promotion, redefined curricula, knowledge share promotion, partnerships and infrastructures.

Qatar University digitalization related assets and organizations have an enormous role to digitalization. These organizations are:

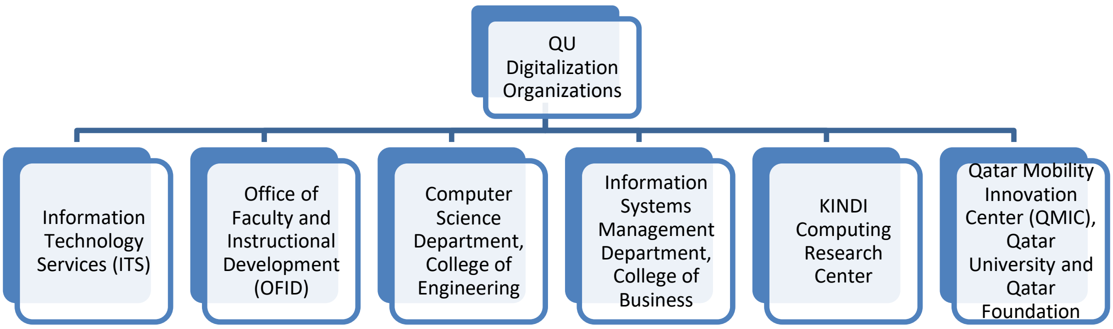


Figure 53. QU Digitalization organizations with digital initiative (Mahmoud Abdulwahed and Hassan El-Rashid 2017)

Other assets are in-use and developed by Qatar University since years such as educational, training, IT platforms and main assets; which all massively support the dynamic moves by the institution.

Digital Capturing Processes

CAD-to-BIM Capturing

In several tools available nowadays in order to convert an existing building into BIM model, three mains mostly used will be provided within this study. Firstly, the CAD-to-BIM tools, which always starts from holding As-built 2D CAD drawings of the building. These drawings quality is directly proportional to the 3D model outcome accuracy, since in that case the conversion source will be only the drawings. In our research, the as-built is mostly equally to reality with minimal neglectable differences.

The capturing process will embrace few activities and stages in order to be achieved as a final 3D Revit Model. Process mapping would be virtuous to reveal the method in-depth with further details; as shown in below figure.

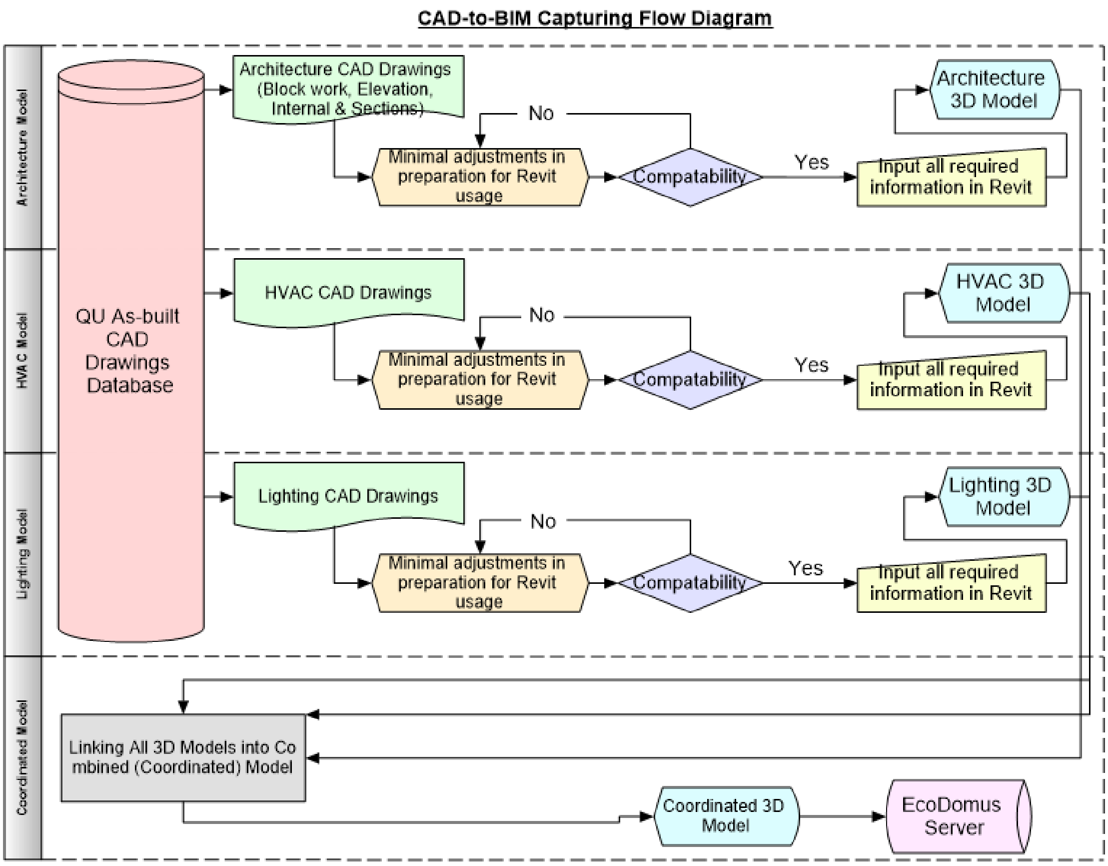


Figure 54. CAD-to-BIM capturing process map

The digital capturing CAD-to-BIM will be attained thru three different models: Architecture, HVAC and Lighting. Each model will be developed individually through Autodesk Revit. The Architecture Model will be the first before both HVAC and Lighting. Finally, a Coordinated Model will be reached by linking all three models together. The CAD-to-BIM Architecture Model passed through some stages, as shown in upper figure, these were enough to complete the model within the required standards and quality. In particular, let's review the activities in more details, as will be shown below.

Stakeholders Structure

Below structure will show the human resources required to interfere in this stage in order to completely achieve its targets and objectives. This section will hold only the professional background of each stakeholder, further information will be explained in upcoming sections.

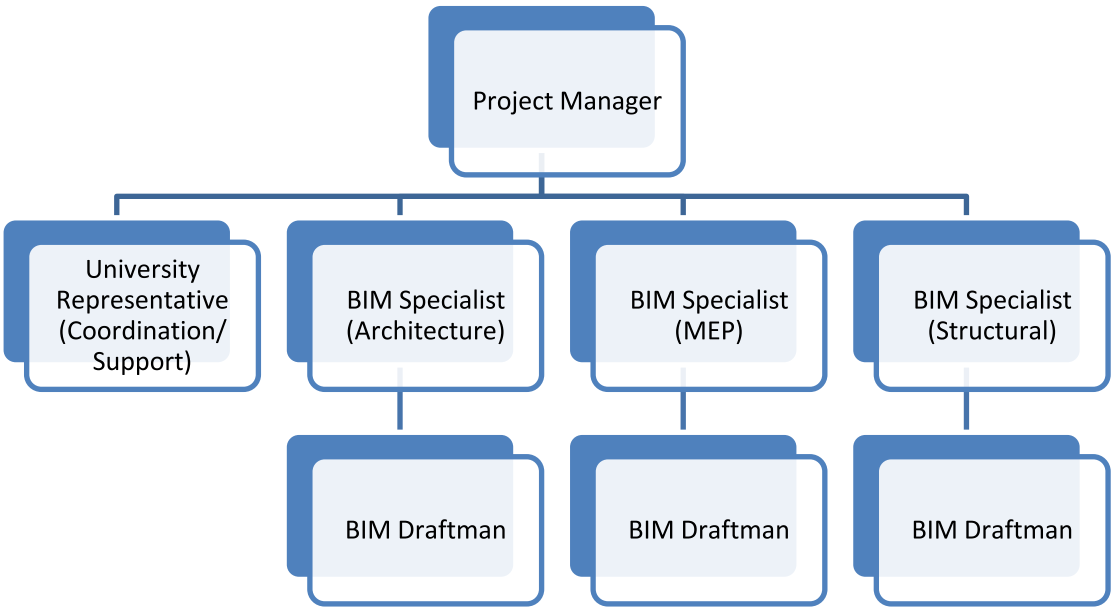


Figure 55. Key stakeholders of the study (CAD-to-BIM)

In this research, the thesis author was acting as Project Manager to communicate the CAD As-built drawings from University authorities and representatives towards the BIM Specialists. Also, the BIM Specialists structure is applicable for generality, while this CAD-to-BIM was processed by one BIM Specialist that carried out the conversion of structural, MEP and architectural work; for drafting as well.

Work Breakdown Structure

Series of work activities occurred to achieve the CAD-to-BIM with its defined quality. Also, these activities affected the final project completion dates in terms of duration and timeline. Afterward will define each activity duration to illustrate the weighted importance of each towards their schedule.

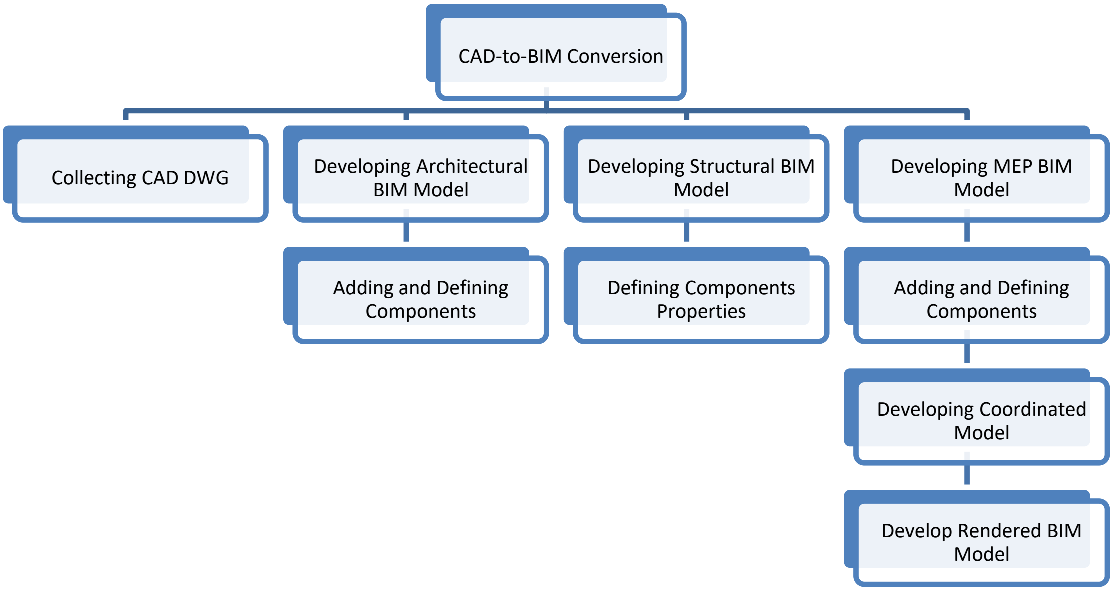


Figure 56. Work Breakdown Structure of CAD-to-BIM

This macro view of the work carried out shall illustrate the overview tasks to be taken into consideration while conversion process. Afterwards breakdown of the cost shall take place to define the activities spending.

Cost & Time Breakdown Structure

Budget and time are vital aspects of any project and two of the three main components. Therefore, below demonstration will show each task defined properties towards money and time.

Table 10. Time & Cost Breakdown Structure for CAD-to-BIM

S.N.	Activity	Duration (hours)	Cost (QAR)	Rate (QAR/hr)
1.0	CAD-to-BIM	160.25	5,475	36.17
1.1	Collecting CAD DWG	-	-	-
1.2	Architectural/Structural Model	80	2,190	27.38
1.3	Developing MEP Model	80	2,738	34.23
1.3.1	Developing Coordinated Model	0.25	547	Neglected
	Additionally			
A	MSI High-performance Laptop	-	18,250	-
B	Revit & AutoCAD Educational Version	-	-	-
C	Mouse	-	100	-
	Grand Total		23,825 QAR	

The total cost of the CAD-to-BIM may vary much, since in this study the conversion occurred in Egypt that holds lower human-work rate than other countries. As shown in the table, the hourly rates aren’t the same for Architectural/Structural and MEP works, but close with little increase variation towards MEP development; which requires more components definition and drafting. The final spending required for this method of capturing shall be approximately 23,825 Qatari Riyal.

Linking Work and Stakeholders Breakdown Structure

In order to achieve more understanding towards the topic, an illustration will be developed to show the link between the activities and their project stakeholder responsible for its execution.

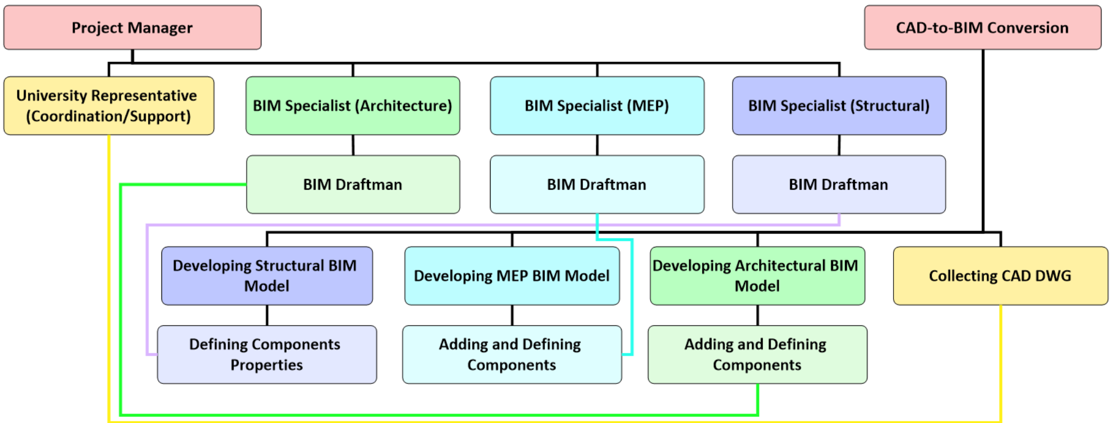


Figure 57. Linking of WBS and Stakeholders Breakdown Structure

The outcomes of this capturing technique shall be as the following series of illustrations below. Which will describe the similarity between the As-built referenced 3D BIM Model and reality in terms of Architecture, Structure, Lighting and HVAC.

List of CAD drawings are listed below, those were the reference As-built drawings for the BIM model.

Table 11. As-built Drawings References

Structure	Foundation/Columns/Retaining Wall
Architecture	AB-2173-AR-B2-1/2/3/5-REV-1.dwg
Lighting (Electrical)	TAKE-ASB-EL-B2-001/3
HVAC (Mechanical)	QU-ASB-CS-HVAC-01/2

Architecture Model

The architectural transformation process started from the building existence along with its 2D CAD drawings. The capturing process will embrace few activities and stages in order to be achieved as a final 3D Revit Model. Process mapping would be virtuous to reveal the method in-depth with further details; as shown in Figure 58.

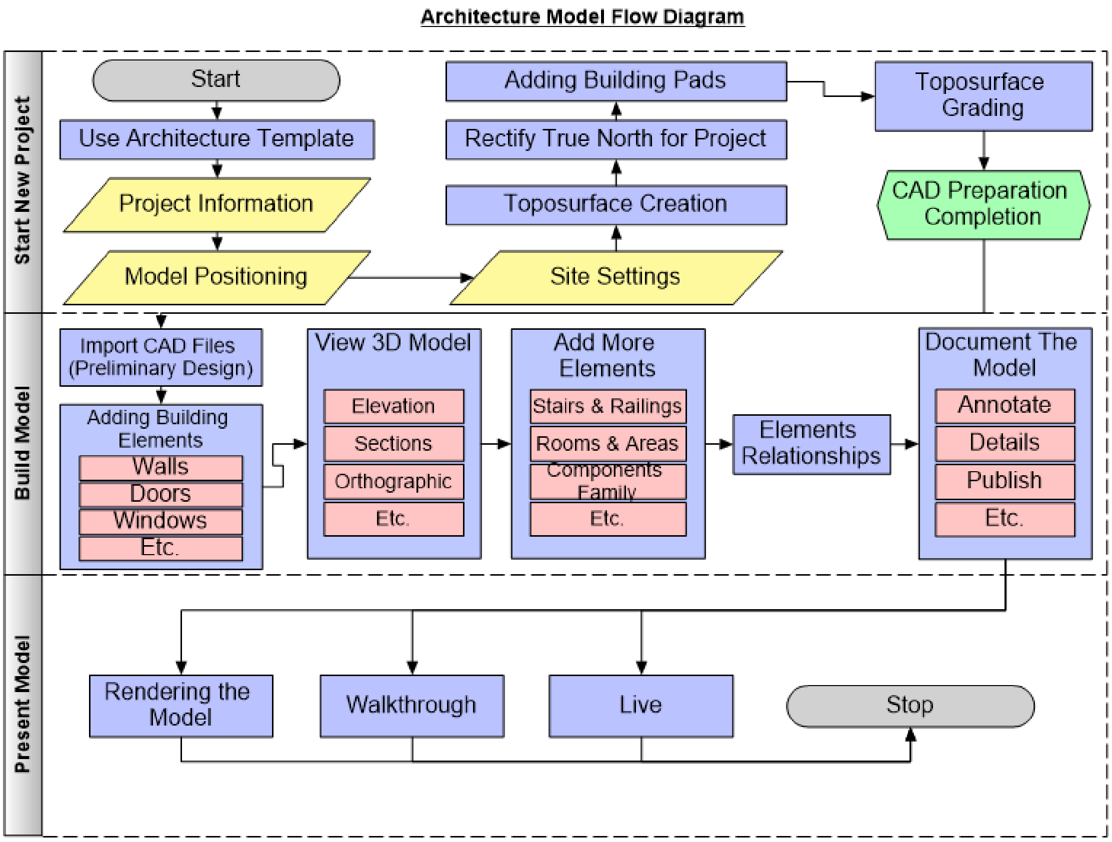


Figure 58. Autodesk Revit architecture model flow diagram

The upper process map is well-defining the process of capturing the Architectural model, with few routine selections and modifications to be done in Autodesk Revit. Afterwards the CAD conversion took place by drafting, adding, modifying and adjusting components and elements to acquire final model, prior to rendering.

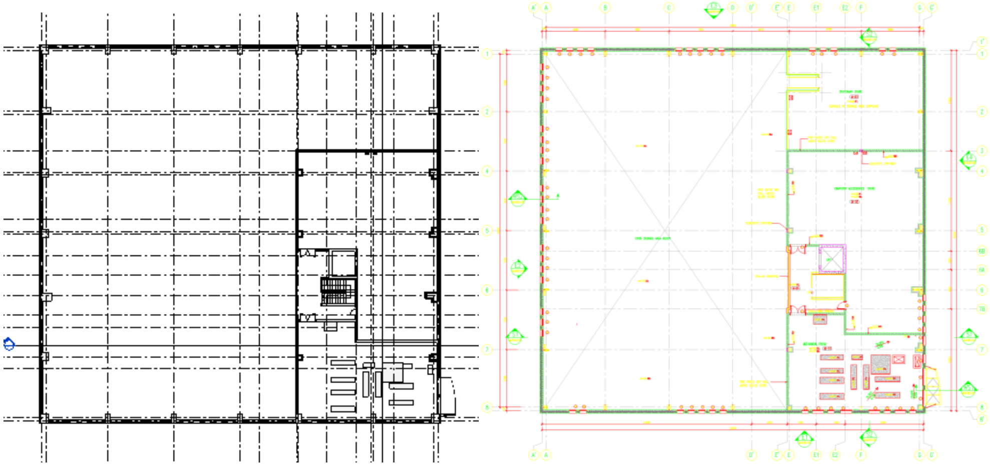


Figure 59. Top 2D view for both Autodesk Revit and AutoCAD for the same plan

Figure 60. Side Elevation 2D view for reality, Autodesk Revit and AutoCAD

Above demonstrations shows the comparison of AutoCAD drawings and Autodesk Revit Architectural Model along with real building.

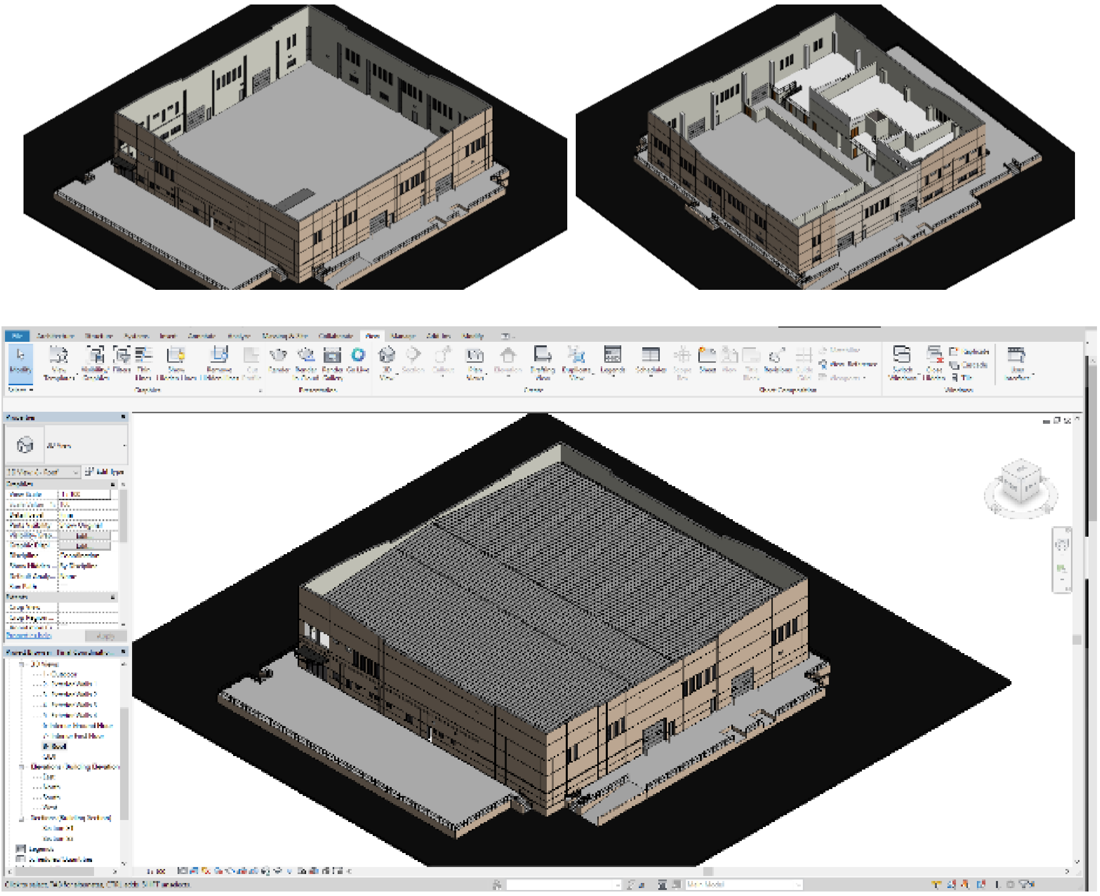


Figure 61. 3D view of the architecture model

Above Figure 62 shows the gradual stages of developing the 3D model on Autodesk Revit.

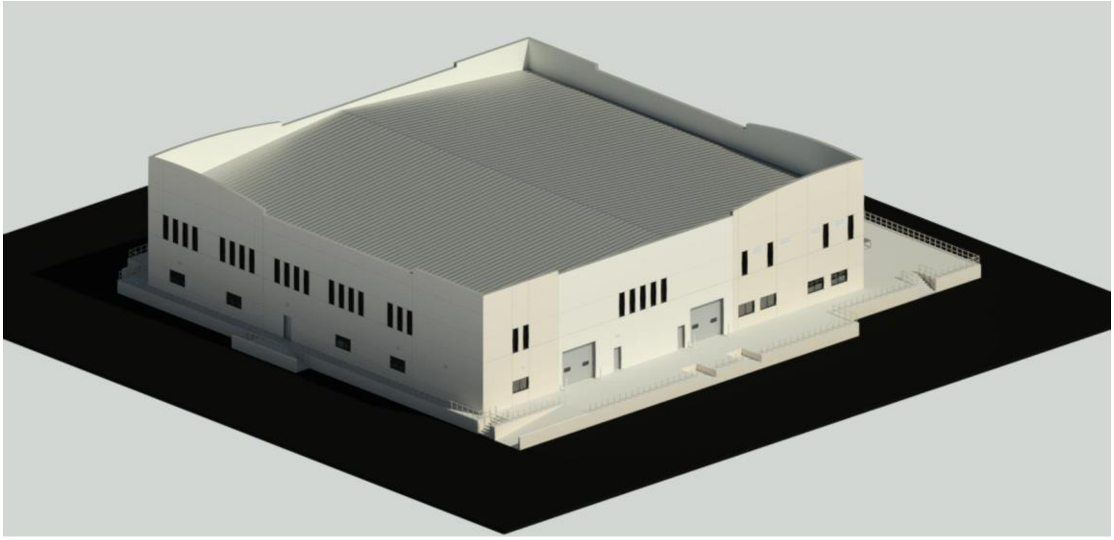


Figure 62. Rendered architecture 3D model

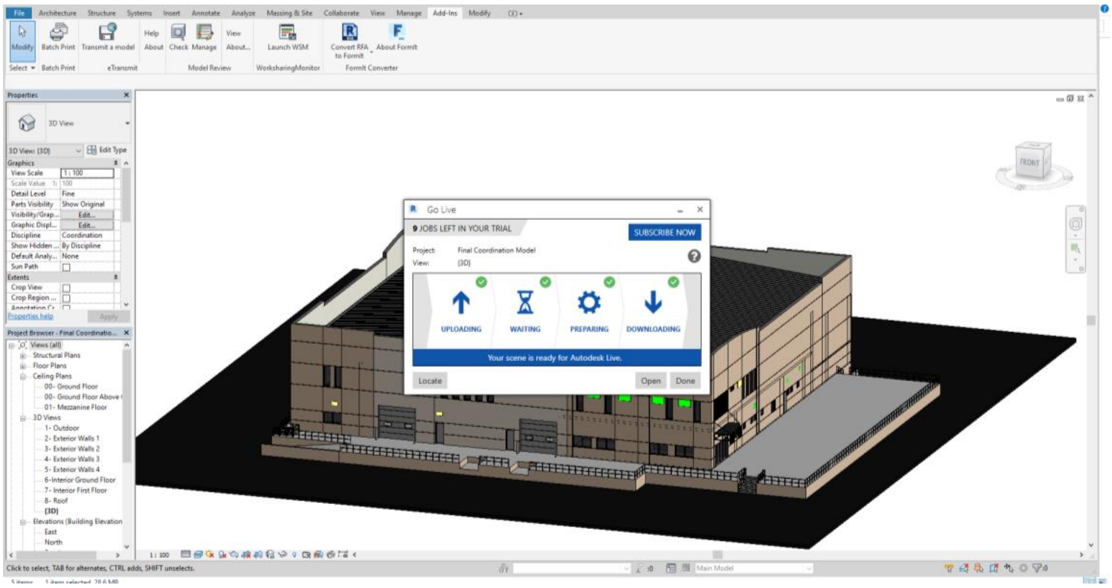


Figure 63. Model preparation for Live

Figure 64. Architecture model in Live

The final rendered model is shown in Autodesk Revit and Live to be shown in more details.

HVAC Model

After completion of Architecture Model, as shown in previous section, the HVAC Model shall begin in developmental stage. In order to acquire a complete Architectural – HVAC Model, validation at the end of this part would take place. Achieving HVAC Model thru Autodesk Revit will be processed in certain methodology, keeping in mind all research objectives and goals. The process map to the model shall be as following and shown in below figure.

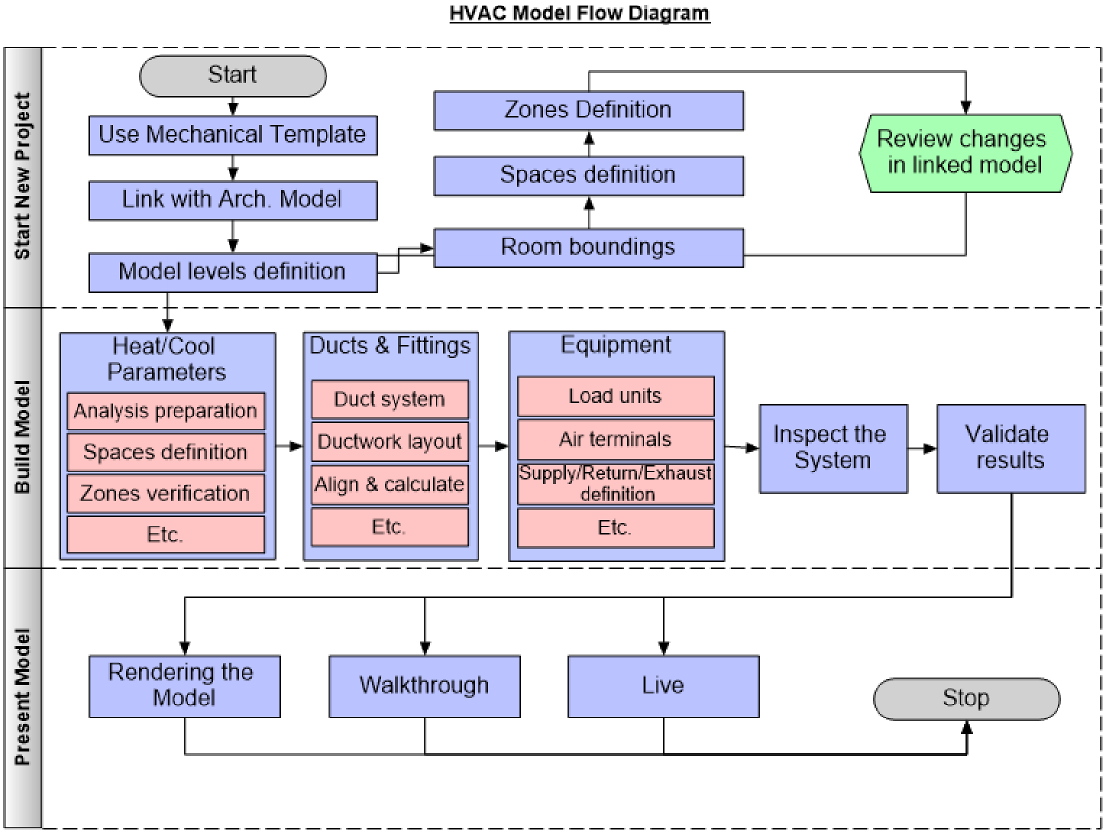


Figure 65. Autodesk Revit HVAC model flow diagram

The CAD-to-BIM HVAC Model passed through some stages, as shown in Figure 65, these were enough to complete the model within the required standards and quality. In particular, let's review the activities in more details, as will be shown below. The upper process map is well-defining the process of capturing the HVAC model, with few routine selections and modifications to be done in Autodesk Revit. Afterwards the CAD conversion took place by drafting, adding, modifying and adjusting components and elements to acquire final model, prior to rendering.

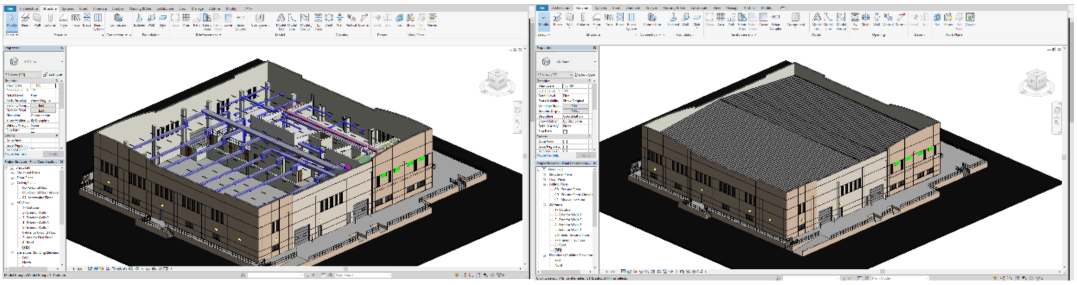


Figure 66. HVAC Model on Autodesk Revit

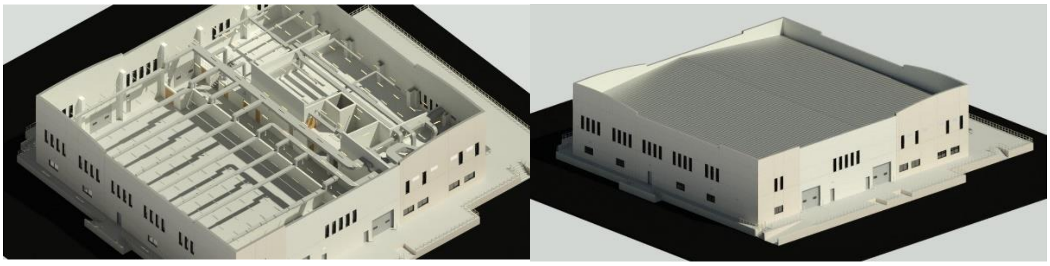


Figure 67. HVAC Model rendered on Autodesk Revit

The final rendered model is shown in Autodesk Revit to be shown in more details.

Lighting Model

After completion of Architecture and HVAC Models, as shown in previous sections, the Lighting Model shall begin in developmental stage. In order to acquire a complete Coordinated Model, validation at the end of this part would take place. Achieving Lighting Model thru Autodesk Revit will be processed in certain methodology, keeping in mind all research objectives and goals. Also, ending this model, automatically lead to a Coordinated Model; with few additional steps. The process map to the Lighting model shall be as following and shown in Figure 68.

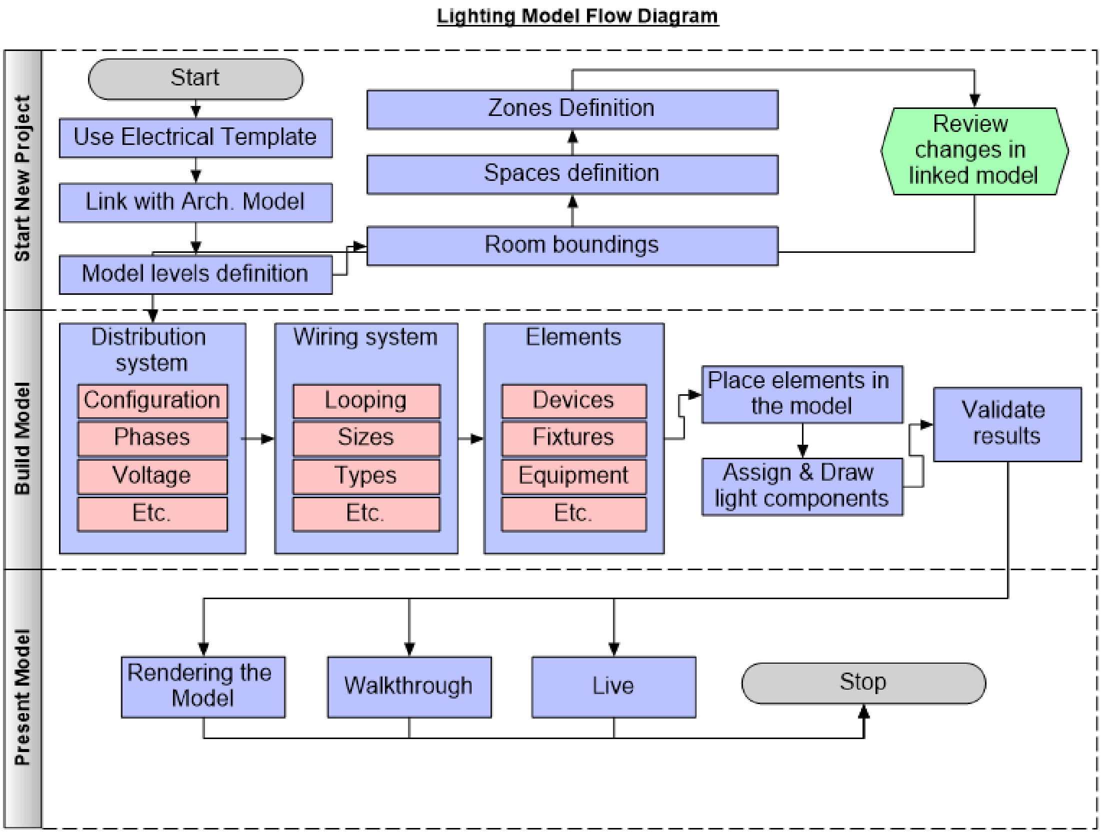


Figure 68. Autodesk Revit lighting model flow diagram

The CAD-to-BIM Lighting Model passed through some stages, as shown in above figure, these were sufficient to complete the model within the required standards and quality. In particular, let's review the activities in more details, as will be shown below. The upper process map is well-defining the process of capturing the Lighting model, with few routine selections and modifications to be done in Autodesk Revit. Afterwards the CAD conversion took place by drafting, adding, modifying and adjusting components and elements to acquire final model, prior to rendering.

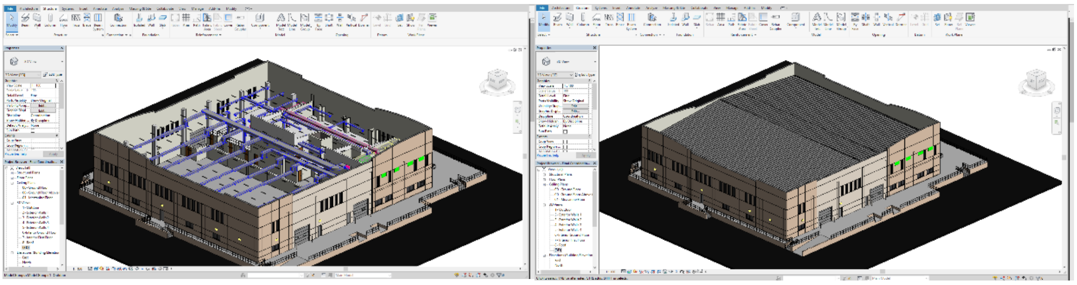


Figure 69. Lighting Model on Autodesk Revit

After acquiring the Lighting model, Autodesk Live will be used in order to show virtual control of the buildings lighting fixtures.

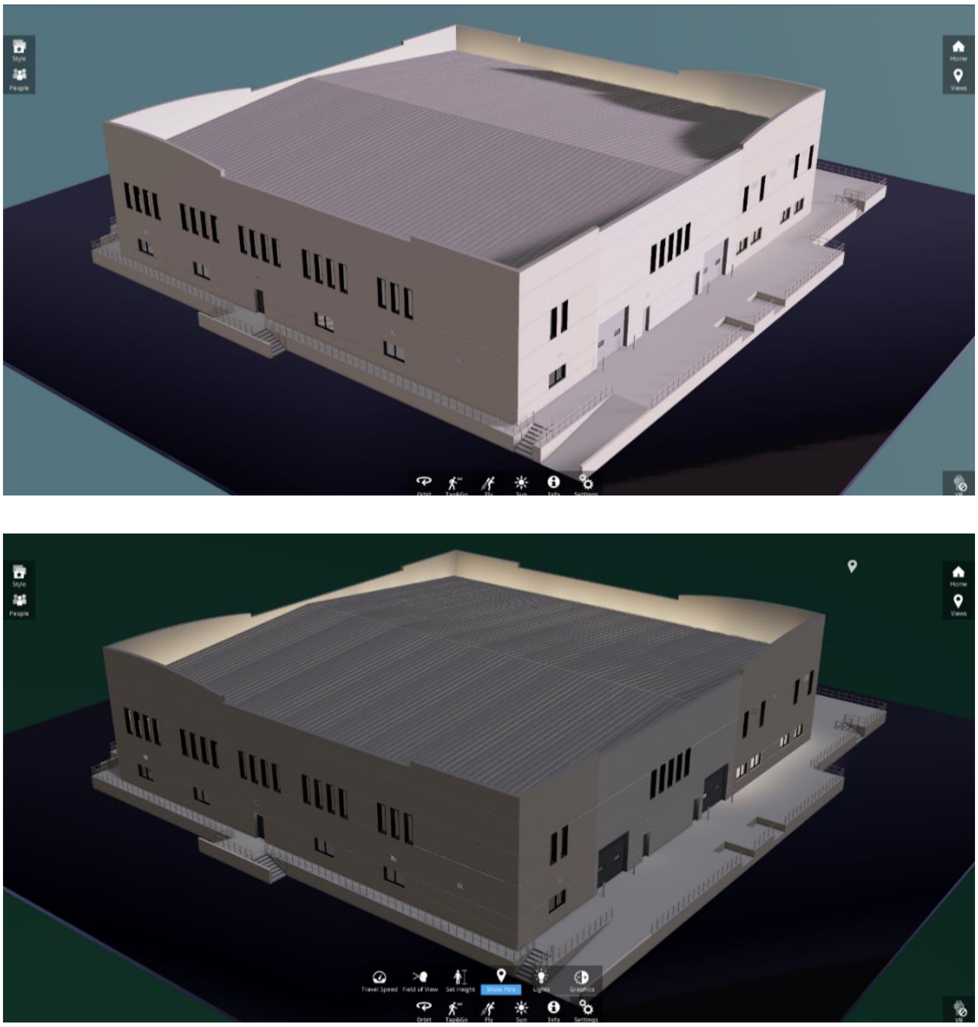


Figure 70. Lighting control in Live

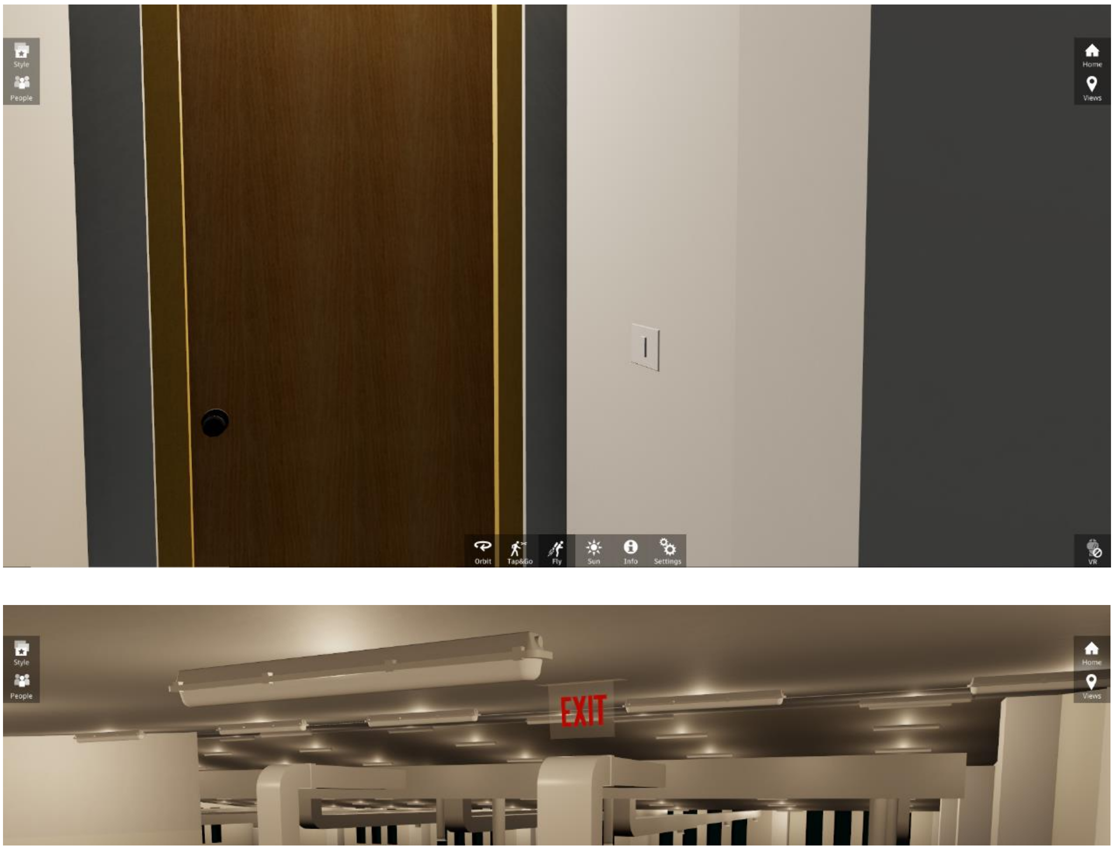


Figure 71. Lighting switches and fixtures shown in Autodesk Live

Coordinated Model

After completion of all three Models, as shown in previous sections, the Coordinated Model shall be ready to use. In order to acquire a complete Coordinated Model, linking activity will take place. The linking of models happens directly from Autodesk Revit with only enabling others to appear in the same template. This final model will be then applicable for use, since this model does include all systems which were developed all over the CAD-to-BIM technique process. Also, few screenshots will be held in this section to view the quality of the model reached, with all detailed components. The coordination happened between the architecture, lighting and HVAC models will all their systems within.

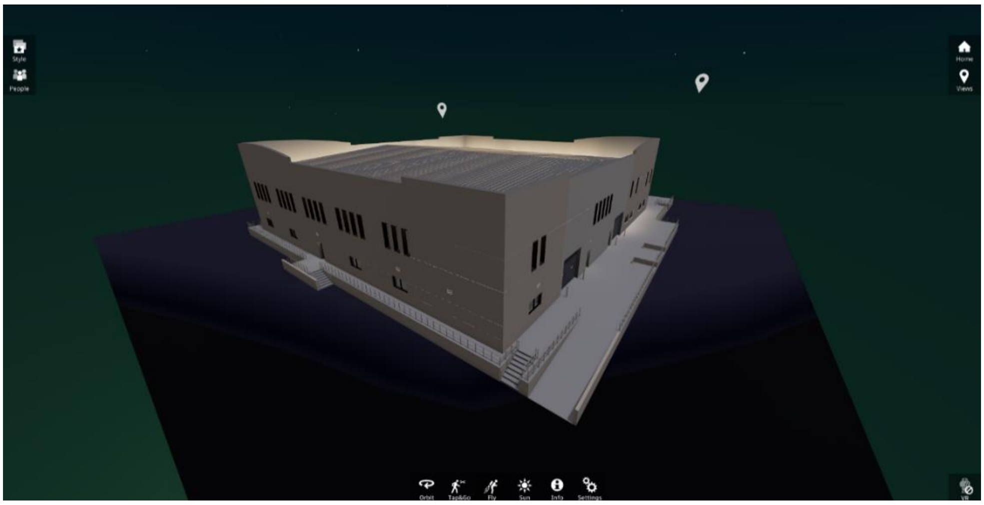
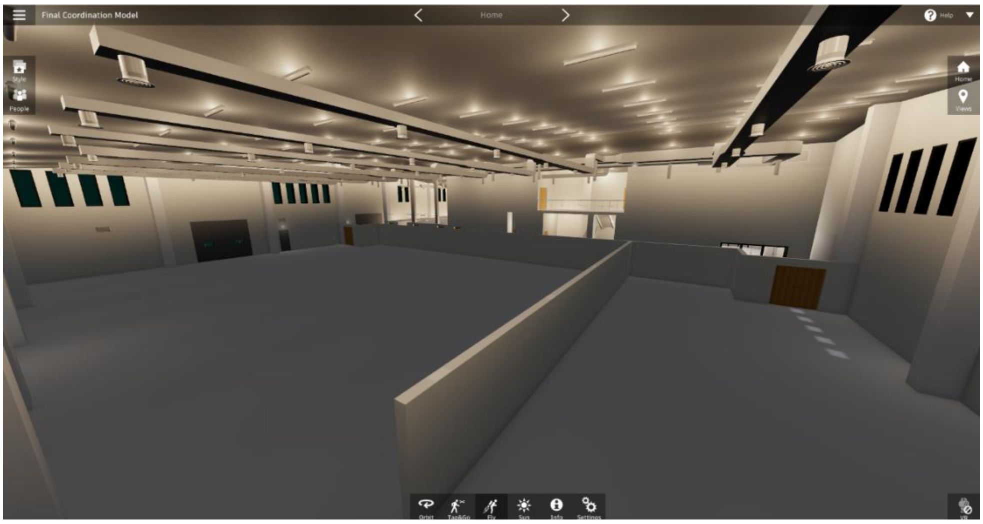
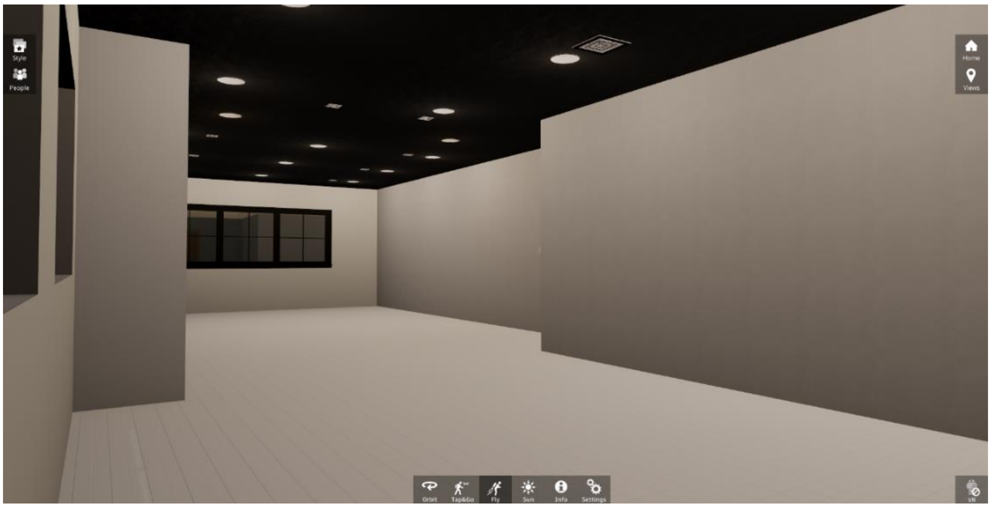


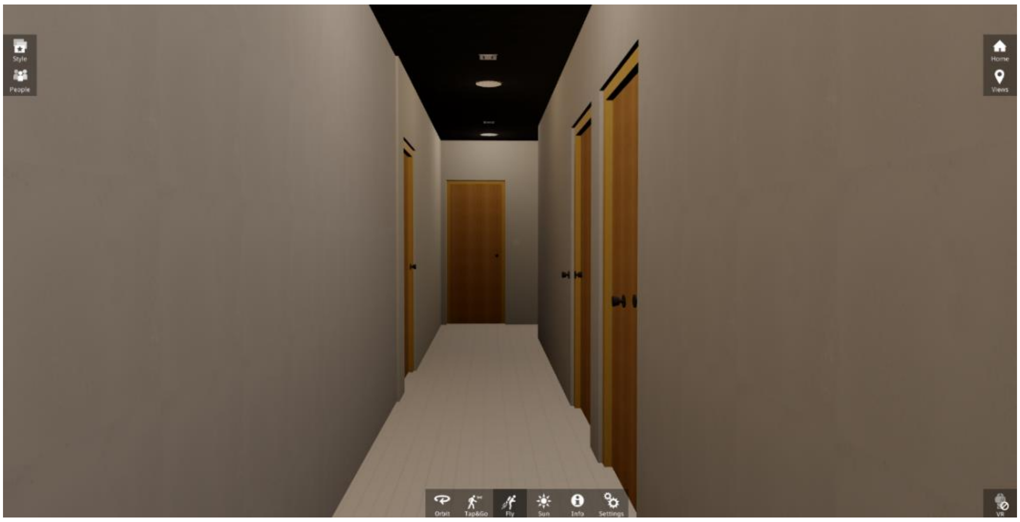
Figure 72. Coordinated Model in Autodesk Live

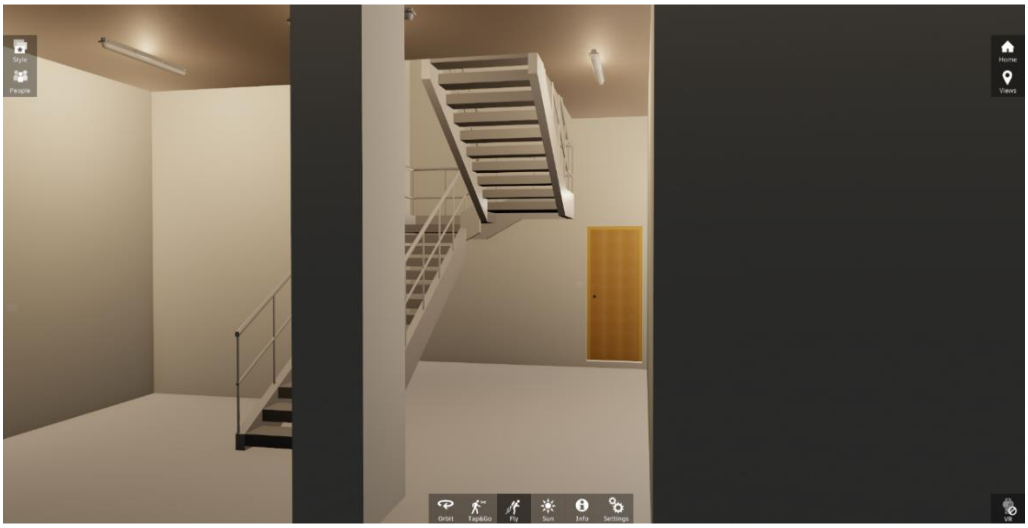
Figure 73. Controlling lighting system from Autodesk Live in the coordinated model

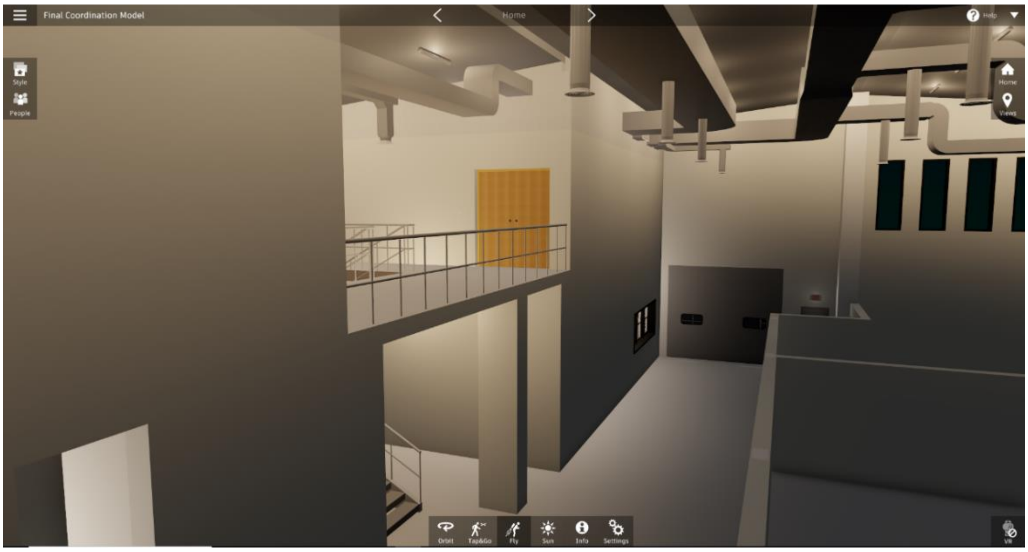

Home
Views


Final Coordination Model
Home








Final Coordination Model
Home

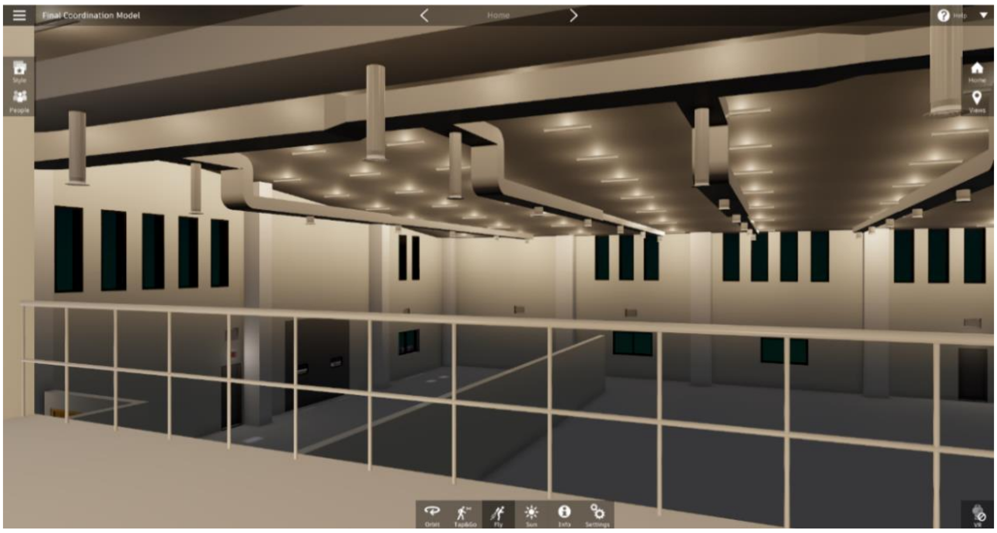


Figure 74. Coordinated model Interior from Autodesk Live

Figure 75. Final coordinated model and existing building

Reaching this point, the CAD-to-BIM tool was evaluated and used as one of the three digital capturing methods will be used through this study. As ReCap, this tool was used broadly by starting with gathering the two-dimensional as-built CAD drawings of the existing building from QU, afterwards using these documents to prepare three different individual models (architectural, HVAC and lighting) to be combined finally in a Coordinated Model, as shown in previous section.

Scan-to-BIM Capturing

The Scan-to-BIM is the second approach of this research to digitalize an existing building. This method will concentrate on fetching the existing state of the building through laser scanning technology. Also, the manufacturer of the scanner will be Leica Geosystems, that is one of the most important 3D Laser Scanners and other surveying tools globally nowadays. In order to achieve an acceptable version of the scan, couple of steps shall be followed, as appear in Figure 76, the flow diagram below will illustrate the general process of the laser scanning.

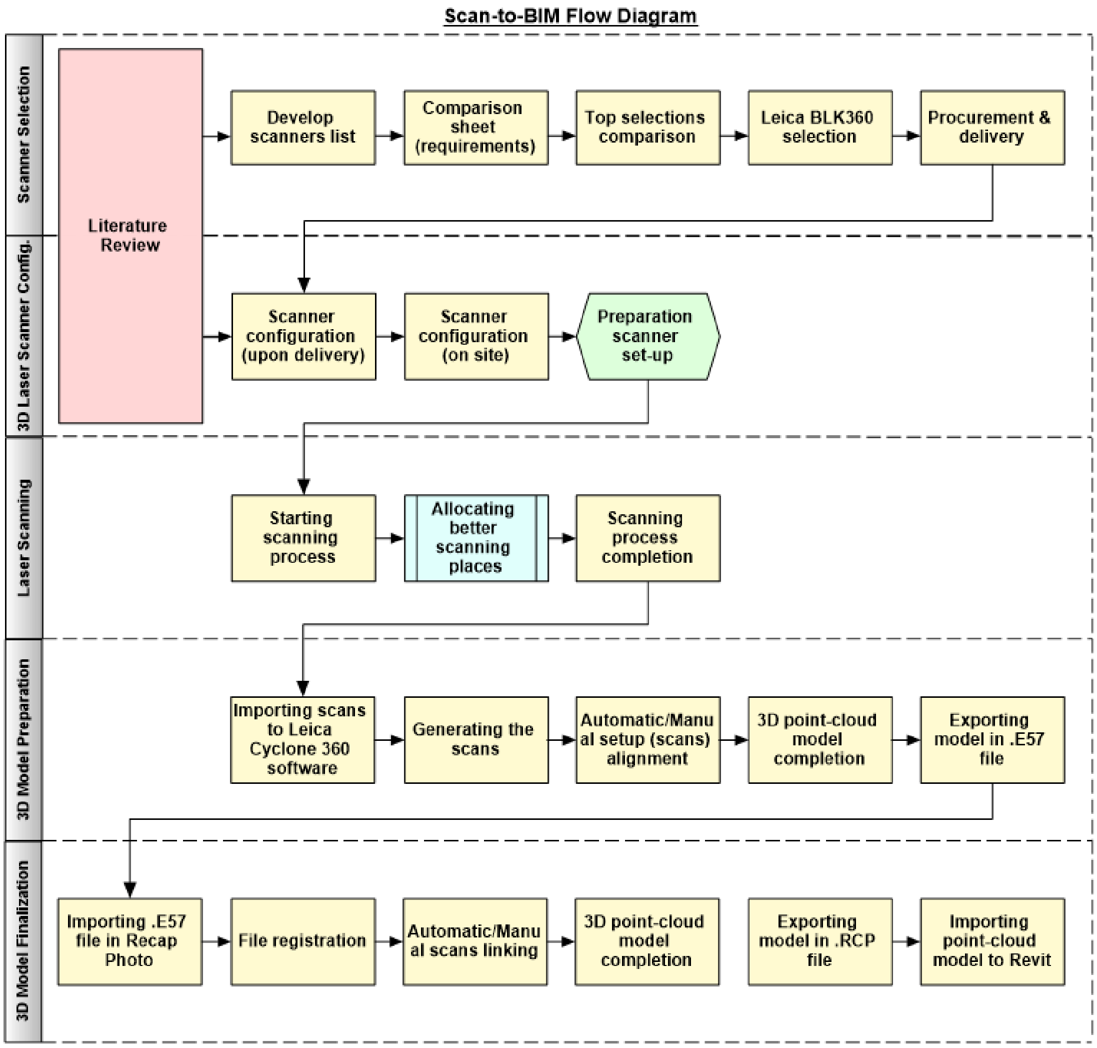


Figure 76. Leica BLK360 Scan-to-BIM flow diagram

In details description of the process shall be demonstrated within few stages occurred starting from On-site scanning reaching 3D Point-cloud Model completion. Therefore, several activities will be explained in-depth within the next sections, that reflects the overview process map.

Stakeholders Structure

Below structure will show the human resources required to interfere in this stage in order to completely achieve its targets and objectives. This section will hold only the professional background of each stakeholder, further information will be explained in upcoming sections.

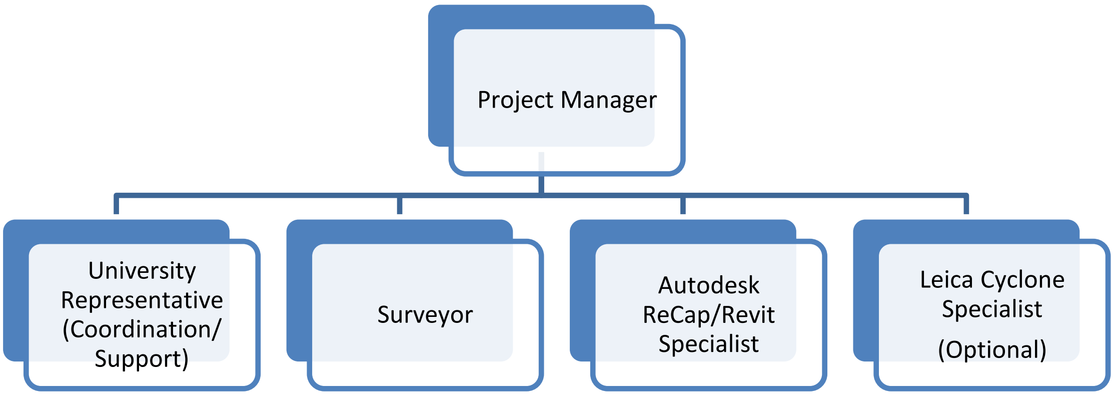


Figure 77. Key stakeholders of the study (Scan-to-BIM)

In this research, the thesis author was acting as Project Manager, Surveyor and Autodesk Specialist to communicate with University authorities and representatives towards the access permissions to the building to be scanned. While upper structure is applicable for generality.

Work Breakdown Structure

Series of work activities occurred to achieve the Scan-to-BIM with its defined quality. Also, these activities affected the final project completion dates in terms of duration and timeline. Afterward will define each activity duration to illustrate the weighted importance of each towards their schedule.

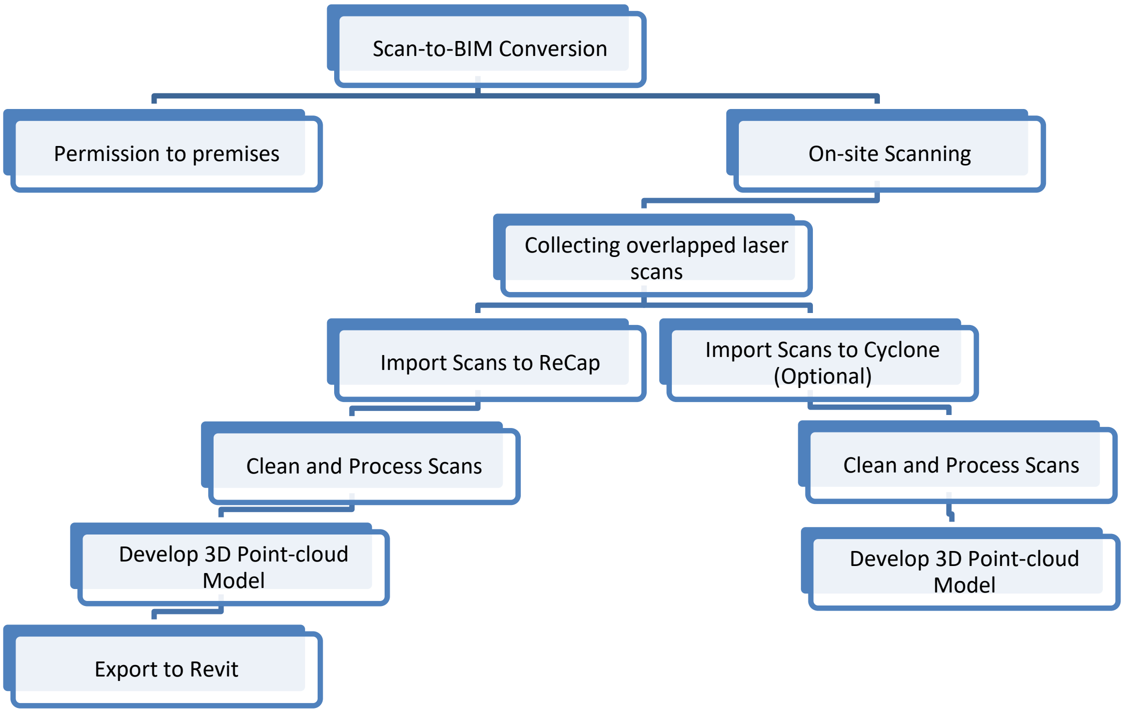


Figure 78. Work Breakdown Structure of Scan-to-BIM

This macro view of the work carried out shall illustrate the overview tasks to be taken into consideration while conversion process. Afterwards breakdown of the cost shall take place to define the activities spending.

Cost & Time Breakdown Structure

Budget and time are vital aspects of any project and two of the three main components. Therefore, below demonstration will show each task defined properties towards money and time.

Table 12. Time & Cost Breakdown Structure For Scan-to-BIM (*Excluded item from total calculation; optional)

S.N.	Activity	Duration (hours)	Cost (QAR)	Hourly Rate (QAR/hr)
1.0	Scan-to-BIM	23.5	-	-
1.1	Permission to Premises	-	-	-
1.2	On-site Scanning	7	-	-
1.2.1	Import Scans to ReCap	6.5	-	-
1.2.2	Import Scans to Cyclone*	10	-	-
	Additionally			
A	MSI High-performance Laptop	-	18,250	-
B	Autodesk Package (ReCap–Educational Version	-	-	-
C	Mouse	-	100	-
D	Leica BLK360 Laser Scanner	-	80,300	-
E	Leica Cyclone/3DReshaper License (2 EA, one-time purchase)	-	18,250	-
	Grand Total		116,900 QAR	

The total cost of the Scan-to-BIM may vary much, since in this study the surveying and model development was created by the author (no cost), in other cases, it shall be negotiated with available companies located in Qatar. As shown in the table, the hourly rates aren't included for the same previous reason, but cost breakdown shows a one-time purchase of required assets. The final spending required for this method of capturing shall be approximately one hundred seventeen thousand Qatari Riyal.

Linking Work and Stakeholders Breakdown Structure

In order to achieve more understanding towards the topic, an illustration will be developed to show the link between the activities and their project stakeholder responsible for its execution.

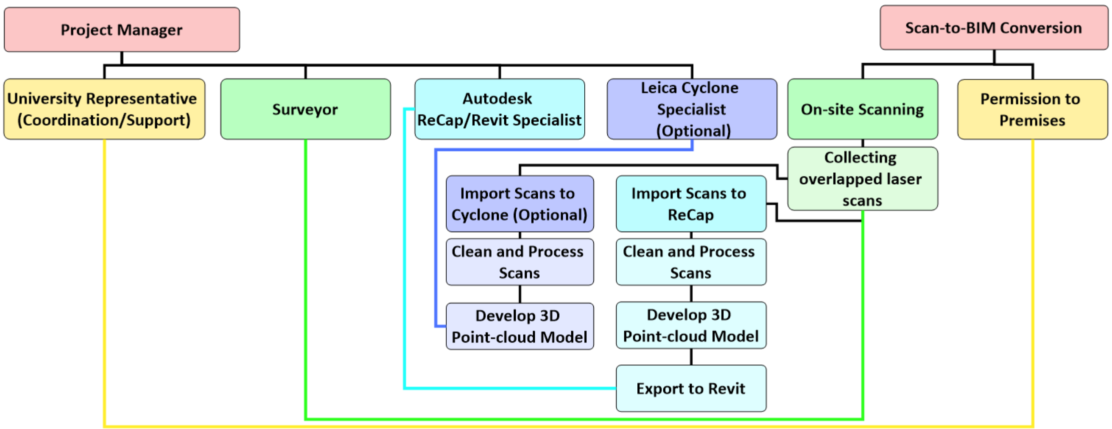


Figure 79. Linking of WBS and Stakeholders Breakdown Structure

The outcomes of this capturing technique shall be as the following series of illustrations below. Which will describe the similarity between the As-built referenced 3D BIM Model and reality in terms of Point Cloud 3D model.

On-site Scanning

The process started with configuring and acknowledging few facts about Leica BLK360 laser scanner. These important facts were some recommendations to be followed while and before scanning on-site.

Leica BLK360 set-up

The scanner components must be packed/unpacked within certain procedure. Below are the components to be used.

a) BLK360 instrument and hood with floor stand

b) Batteries

c) Charging station

d) AC/DC power supply

e) Mission bag

f) Tripod adapter

g) Tripod

Figure 80. Leica BLK360 componenets (Leica Geosystems, 2018)

After unpacking the package it's very crucial to identify the scanner main components, in order to fulfil the mission accurately. The instrument (scanning head) consisting of few components, as shown below.

a) Flash light for HDR camera

b) HDR camera

c) IR camera

d) Ring-shaped LED

e) Scanner 360 °

f) Power button

g) 360 ° WLAN antenna

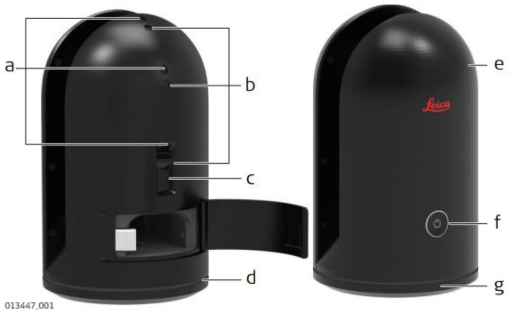


Figure 81. Leica BLK360 instrument (scanning head) components (Leica Geosystems, 2018)

After identifying the main components of the scanner, before practice, user interfacing shall be described within the requirement of an efficient scanning process. Thus, below will explain the basic interface information needed to start; let's start with powering up the device.

Table 13. Leica BLK360 Powering Up User Interface (Leica Geosystems, 2018)

Power button	Status	Next step
< 0.5 sec pressing	Turn on	Yellow blinking
< 0.5 sec pressing	Recording	Continuous green
> 2 sec pressing	Turn off	Stops blinking
> 5 sec pressing	Turn off (immediate)	Stops blinking

After switching on the scanner, make sure that the scanning procedure and interface is clear as well. Since the light indicator of the scanning head shows different LED light colours for various operational status. Generally, the LED switches in continuous, blinking and alternating, with diverse schemes such as: blinking in yellow for starting or switching off, continuous green for ready and counting in green is preparing for recording a scan. Additionally, before operating the instrument, setting up the components together shall take place. The full set-up of the Leica BLK360 will be as shown below.

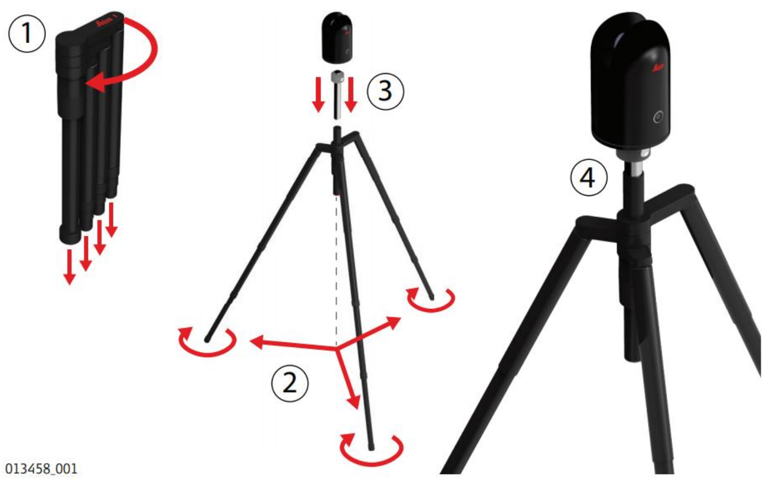


Figure 82. Leica BLK360 set-up (Leica Geosystems, 2018)

Table 14. Leica BLK360 Set-Up Procedure (Leica Geosystems, 2018)

Stage	Work process
1	Adjust the tripod legs and height
2	Legs screws tightening
3	Tripod adaptor to be placed on the tripod
4	Scanner fixation on the adaptor

Upper figure and table concerning the set-up on instrument with tripod, while Leica BLK360 shall be operated as floor stand as well. In our study, the scanner was always used on a tripod, therefore floor stand setup wouldn't be helpful to mention in this section.

Instrument recording and scanning

Choosing the exact location of the laser scanner is vital to manage prior to begin recording. According to the instrument components shown previously, selection of the optimum recording place would be achievable. Also, choosing the next scanning is related to identifying an overlap area (common part between both previous and next scan) which shall be chosen according to the scanning application. In this study, the stand-alone operational method was used, without another devices synchronization or pairing. Starting the device approached through specific procedure, this technique will be shown in below figure and table.

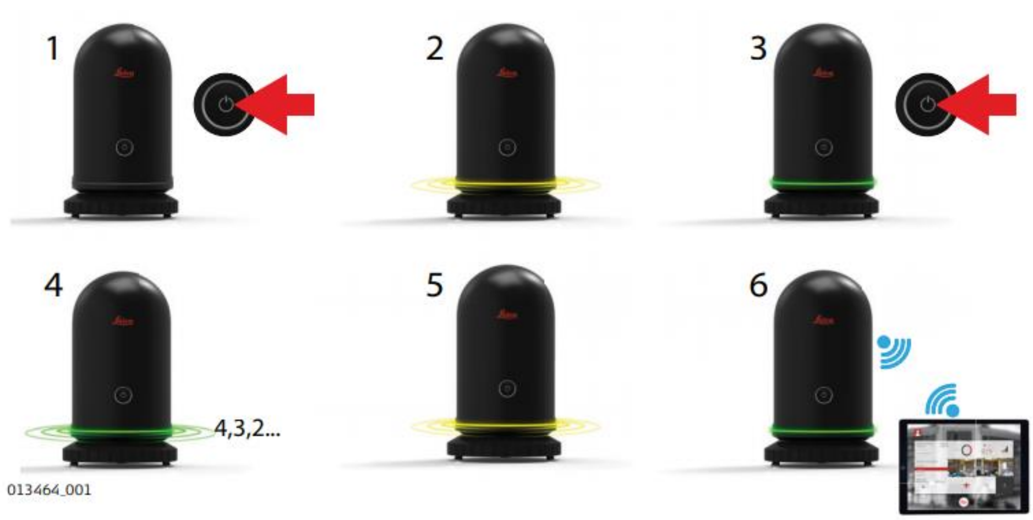


Figure 83. Leica BLK360 operational start-up (Leica Geosystems, 2018)

Table 15. Leica BLK360 Stand-Alone Scanning Operation (Leica Geosystems, 2018)

Stage	Work process
1	Switch on scanner
2	LED blinks yellow
3	Press power button for recording, after LED switch to green continuous
4	LED blinks green prior to recording
5	LED blinks yellow while recording
6	LED continuous green upon recording completion

Subsequently, important to understand the methodology of the tool imaging or recording. By recognizing the imaging procedure, improved scans will appear in Leica Cyclone software later stage. Moreover, BLK360 captures panoramic imaging in a 360-degree spherical image data using all three calibrated cameras in the scanning head. Hence, after allocating the laser scanner and being ready for the scan capturing, Figure 84 will show facts to be known to the user extensively.

Figure 84. Leica BLK360 imaging illustration (Leica Geosystems, 2018)

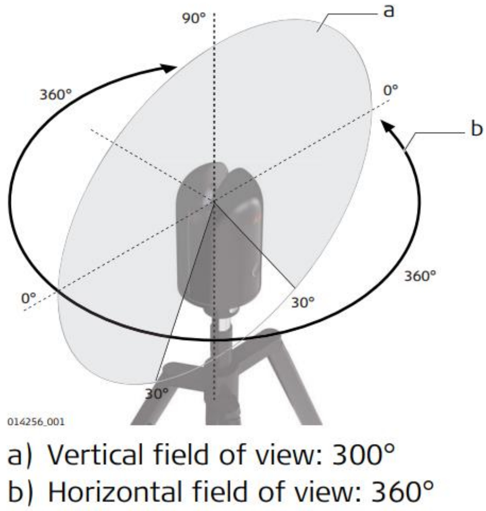


Figure 85. Leica BLK360 Field ov View (FoV) (Leica Geosystems, 2018)

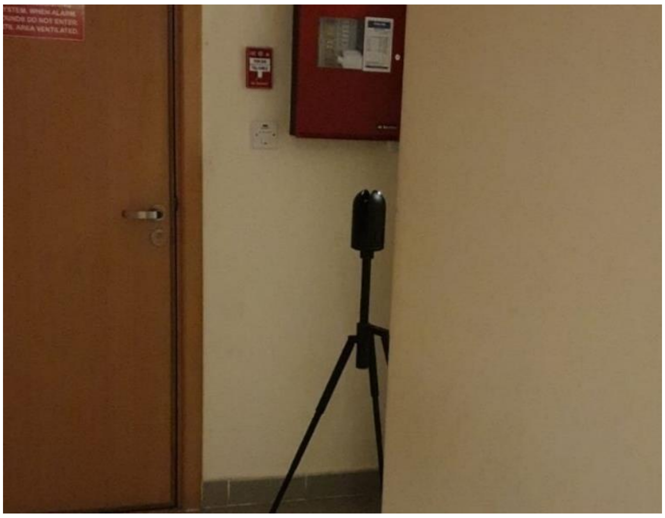


Figure 86. Leica BLK360 laser scanner on-site

Scans on Leica Cyclone 360

After completing all possible scans to cover the places required, the external storage memory card will be used to transfer the captures to PC (Leica Cyclone 360 software). Time for Cyclone to import the scans will relate to the quantity of registers required for a complete 3D laser scanned building or entity. In order to start with cyclone, the following process map shall be followed.

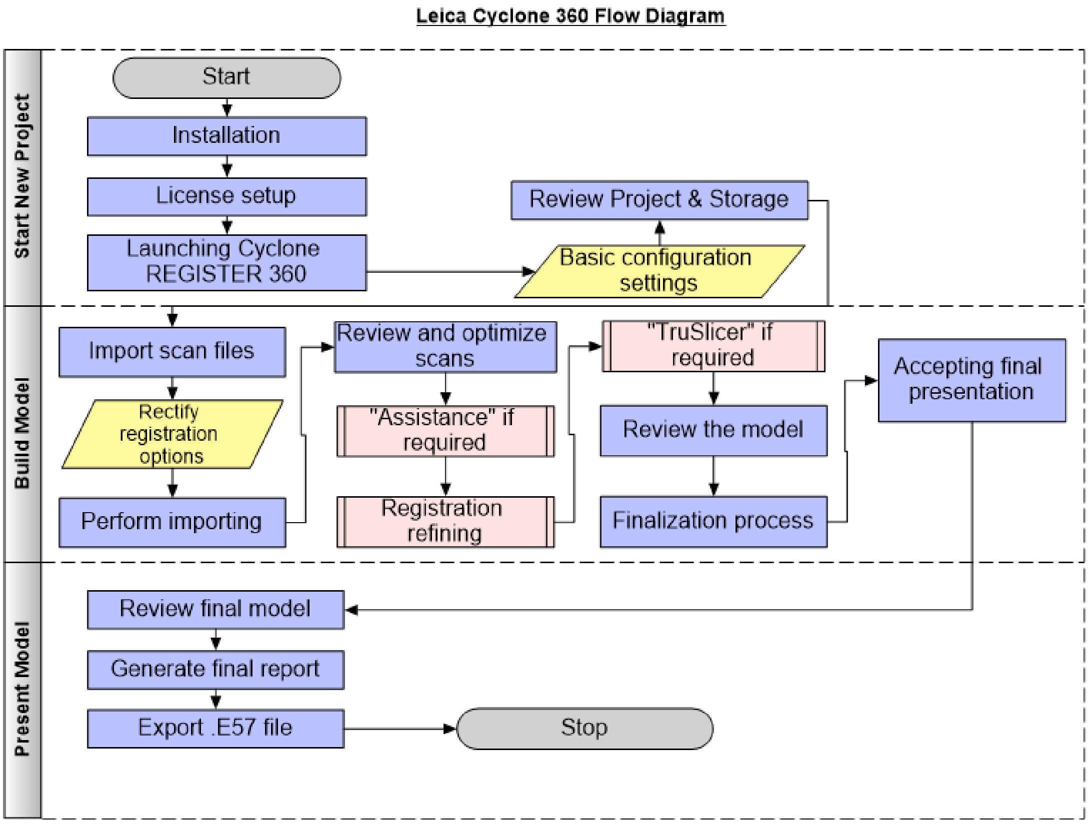


Figure 87. Leica Cyclone REGISTER 360 flow diagram

The registration on Leica REGISTER Cyclone 360 passed through some stages, as shown in Figure 87, these were sufficient to complete the point-cloud model within the required standards and quality. In particular, let's review the activities in more details, as will be shown below.

Workflow for Leica Cyclone REGISTER 360

The registration process will start in Leica Cyclone with importing the scans from the hard drive (storage) to the software; as appears in below figure. The storage drive is a memory card located and set in the Leica BLK360 scanner prior to laser capturing. Afterwards, this memory card will be used to import the scans from through PC or laptop. Also, iPad shall be used to monitor and control this process.

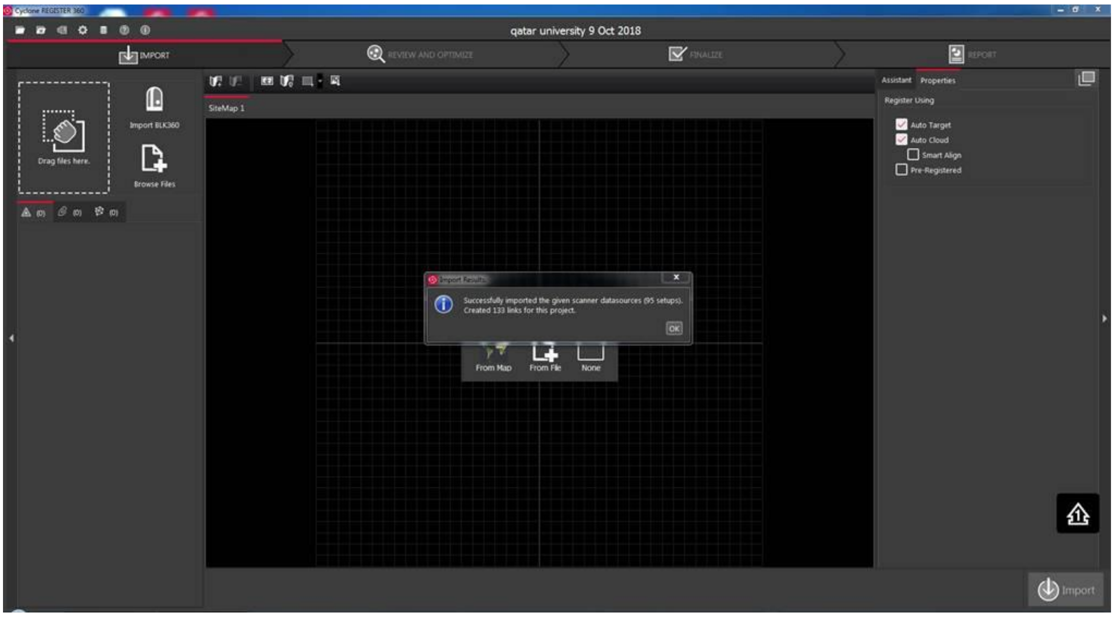


Figure 88. Leica Cyclone 360 importing process

Viewing the imported scans will be the next step into the Leica Cyclone scans processing and cleaning; as shown in below illustration.

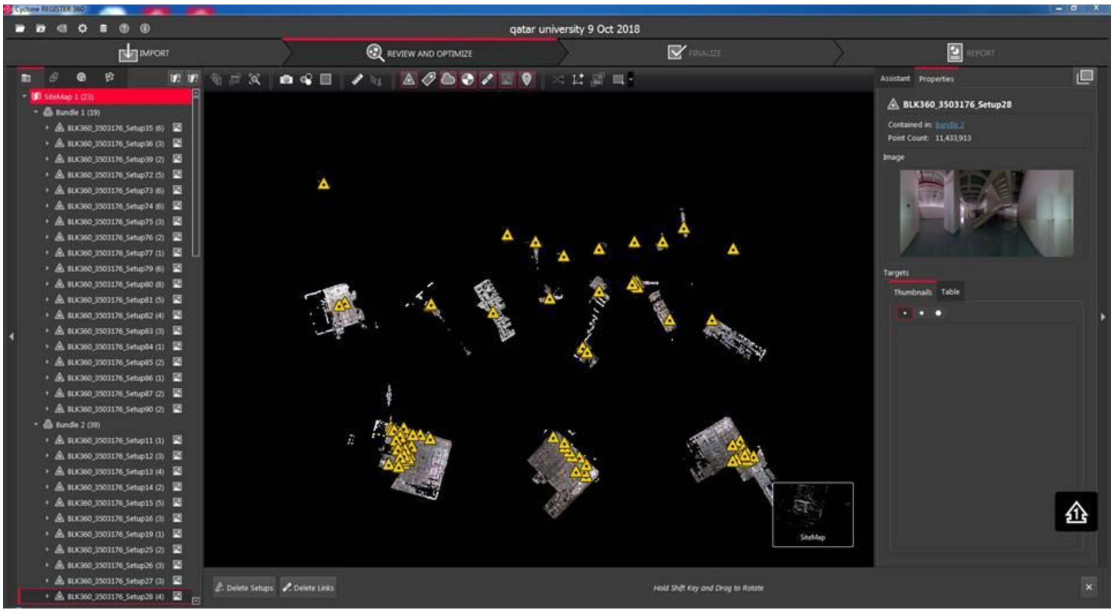


Figure 89. Leica Cyclone 360 reviewing & optimizing process

Afterwards, the scans will be optimized in order to reach a full 3D point-cloud model. After registering the scans in their proper way, this will be finalized with viewing the final registration report.

Scans on Autodesk ReCap

Achieving .E57 file from Leica Cyclone software was a pre-stage to acquire the final point-cloud model to be processed to Autodesk Revit at the final stage. Leica Cyclone software was used in this study as a pre-data processing towards Autodesk ReCap and reviewing the scans from the manufacturer software. In the general means, the scans shall be imported to ReCap directly for further image registration and integration towards 3D point-cloud model. Therefore, in this section, Autodesk ReCap images processing will be reviewed gradually and in-depth. Initially let's demonstrate the process flow diagram of the Autodesk ReCap workflow.

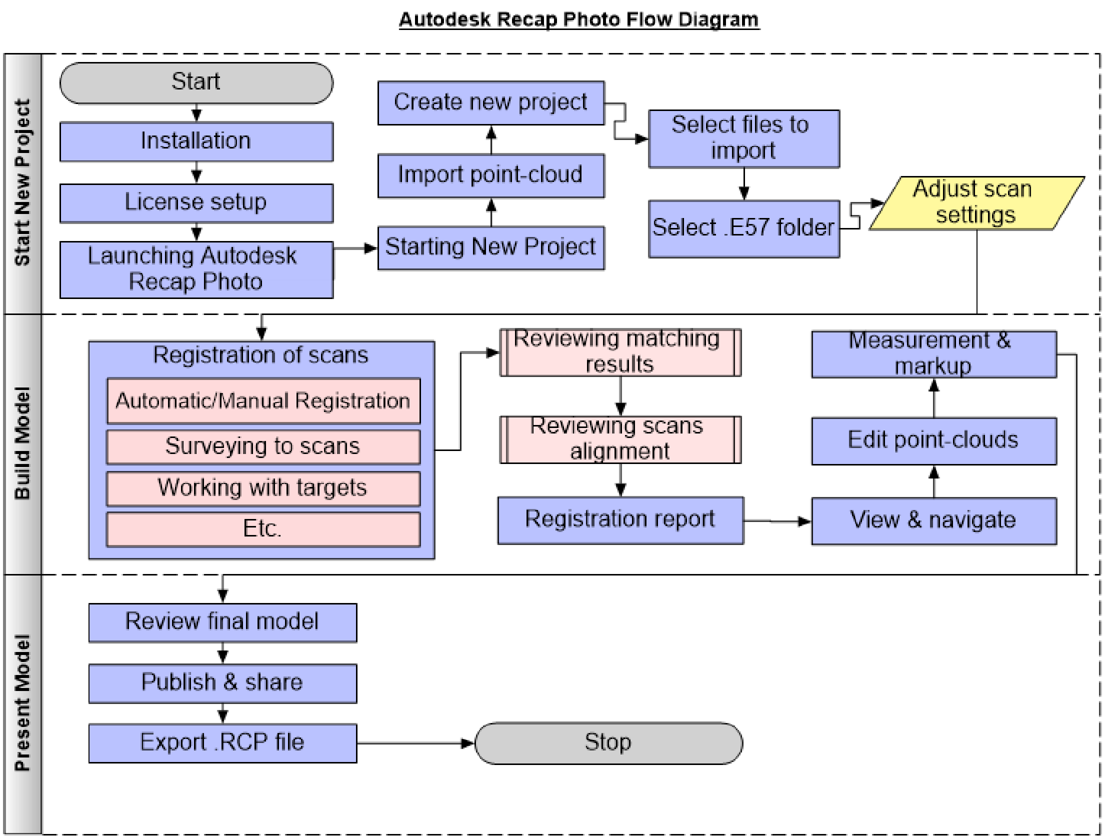


Figure 90. Autodesk ReCap flow diagram

The registration on Autodesk ReCap passed through some stages, as shown in Figure 90, these were sufficient to complete the point-cloud model within the required standards and quality. In particular, let’s review the activities in more details, as will be shown below.

Workflow for Autodesk ReCap

The process of holding a final 3D point-cloud model starts with importing the scans to ReCap. Then, registering them manually/automatically, in this study, the manual approach will be used.

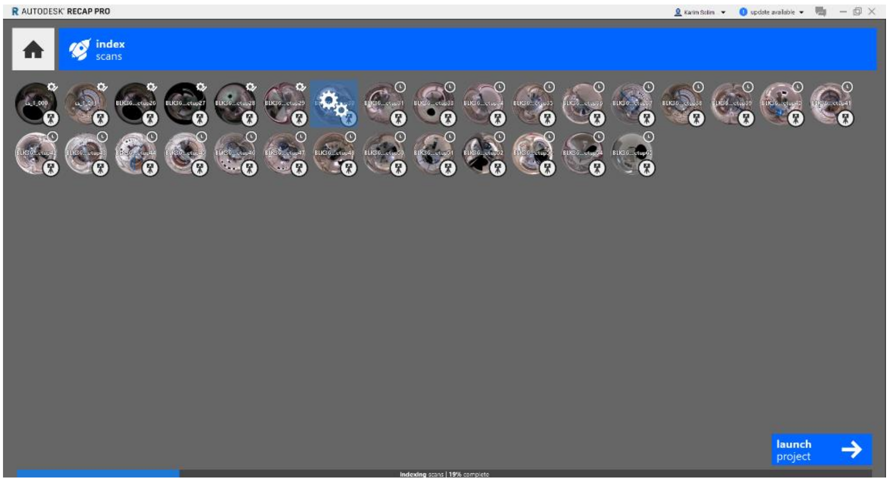
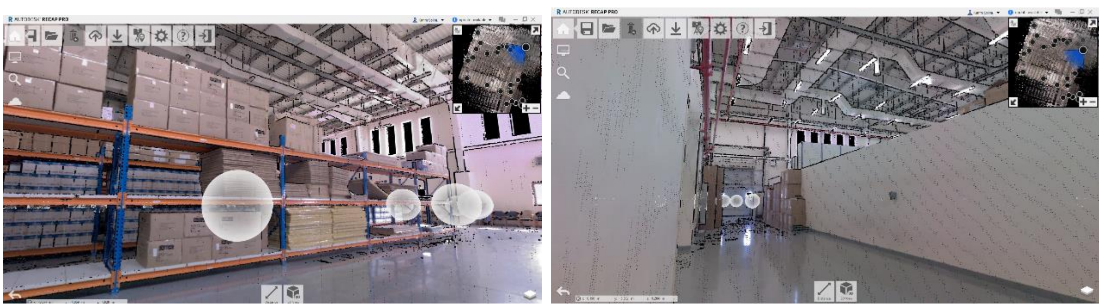


Figure 91. Autodesk ReCap importing scans

After acquiring a 3D based model, finalization and reviewing the registration will occur with exporting the model to be used in Revit.



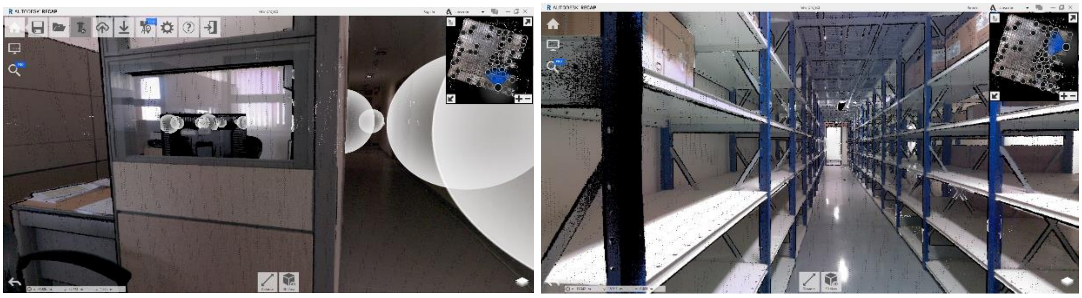


Figure 92. Autodesk ReCap scans

A copy of the registration report is shown in below illustration. In this study, the report results were defining the high quality of scanning occurred on-site.

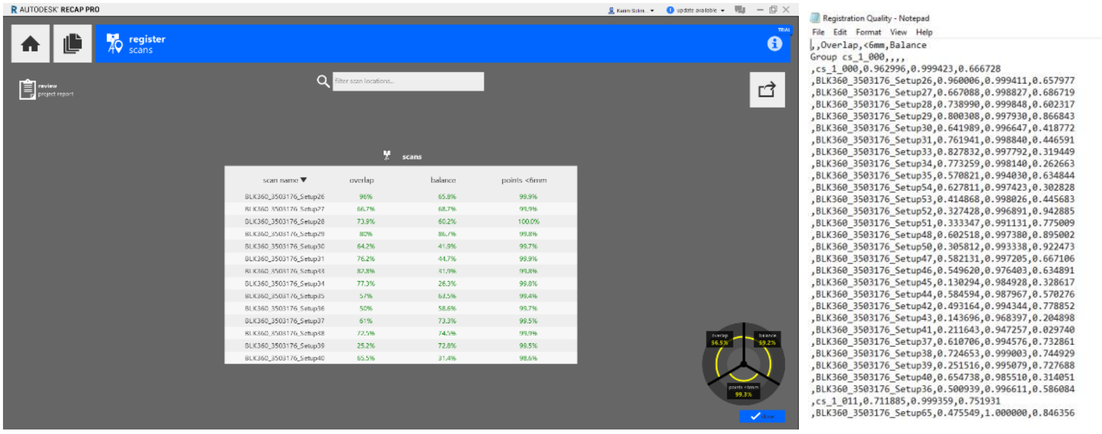


Figure 93. Autodesk ReCap registration quality report

Final stage of this process is to demonstrate the final 3D model in point-cloud, to review all required scans registration and linking, and that’s prior to exporting. In this phase, all possible data cleaning to captured scans are applicable. Also, validation of dimensions or setting out any required parameters shall occur. Various extensions of exporting are available in Autodesk Recap, and selecting one of them is according to application and shall take place in this stage as well.

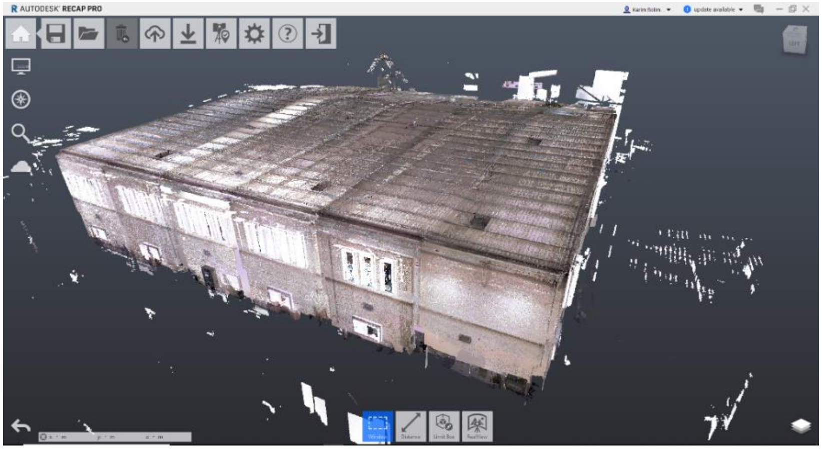


Figure 94. Autodesk ReCap 3D point-cloud final model

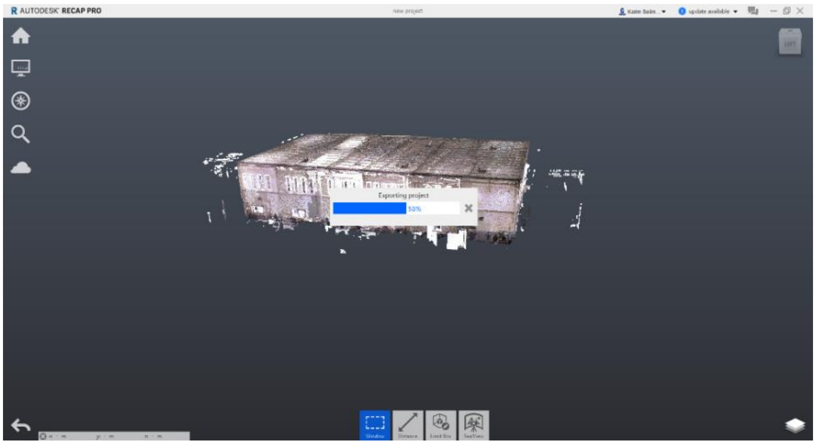


Figure 95. Autodesk ReCap 3D point-cloud model exporting

Point-cloud 3D Model on Autodesk Revit

Reaching the final stage of the Scan-to-BIM will start with importing the .RCP file into Autodesk Revit. This importing process, in this research, is to compare the As-built (which the Revit model was done upon) and the real physical state (Point-cloud model). The results have shown a magnificent similarity with minor neglectable differences, and this will be shown later in this section. Therefore, let's start illustrating the importing and matching of the point-cloud 3D model into Autodesk Revit by initially presenting the process flow of this activity.

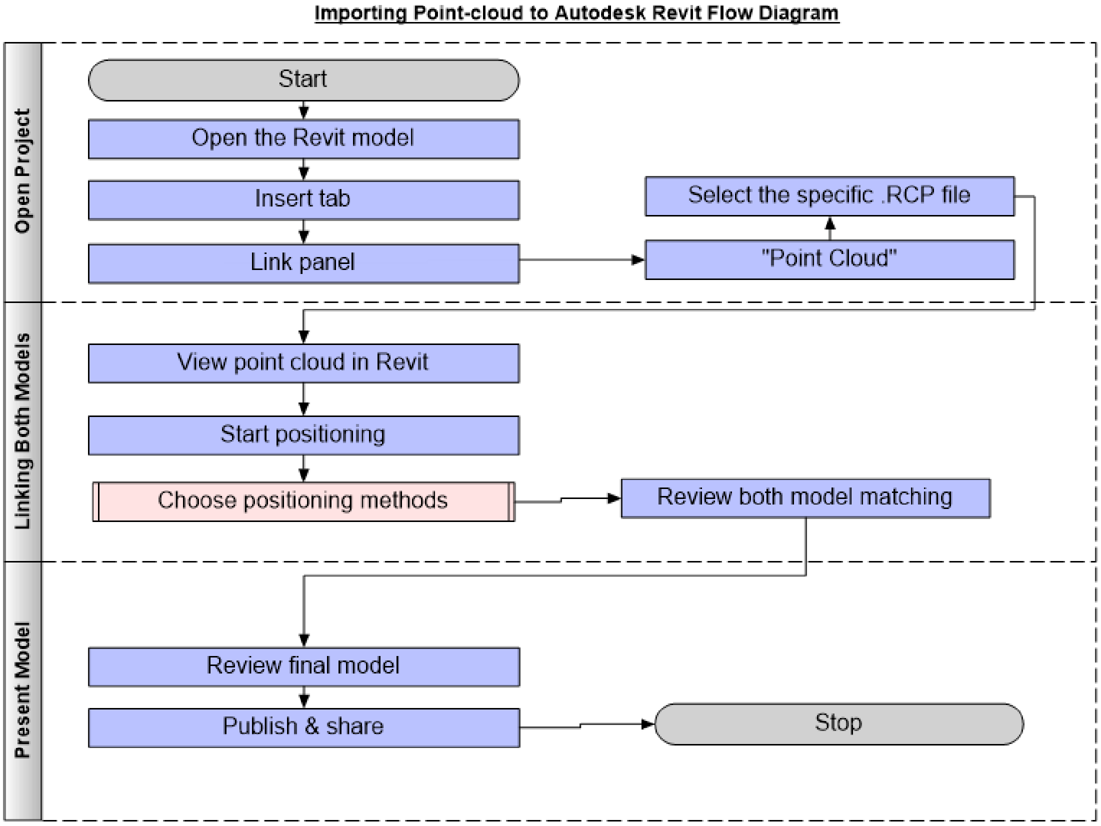


Figure 96. Importing point-cloud Autodesk Revit flow diagram

The registration on Autodesk ReCap passed through some stages, as shown in Figure 96, these were sufficient to complete the point-cloud model within the required standards and quality. In particular, let's review the activities in more details, as will be shown below.

Workflow for importing point-cloud to Revit

The importing of point-cloud model to the BIM process includes several stages. The initial stage was to import the point-cloud and linking both models through common point. This process was used in this study in order to compare the As-built (BIM model) with scanned (point-cloud) and review the design variations those weren't updated in the as-built DWG. For optimal results, the scanned point-cloud is used as a source of data to be imported in Revit and the BIM model is designed accordingly.

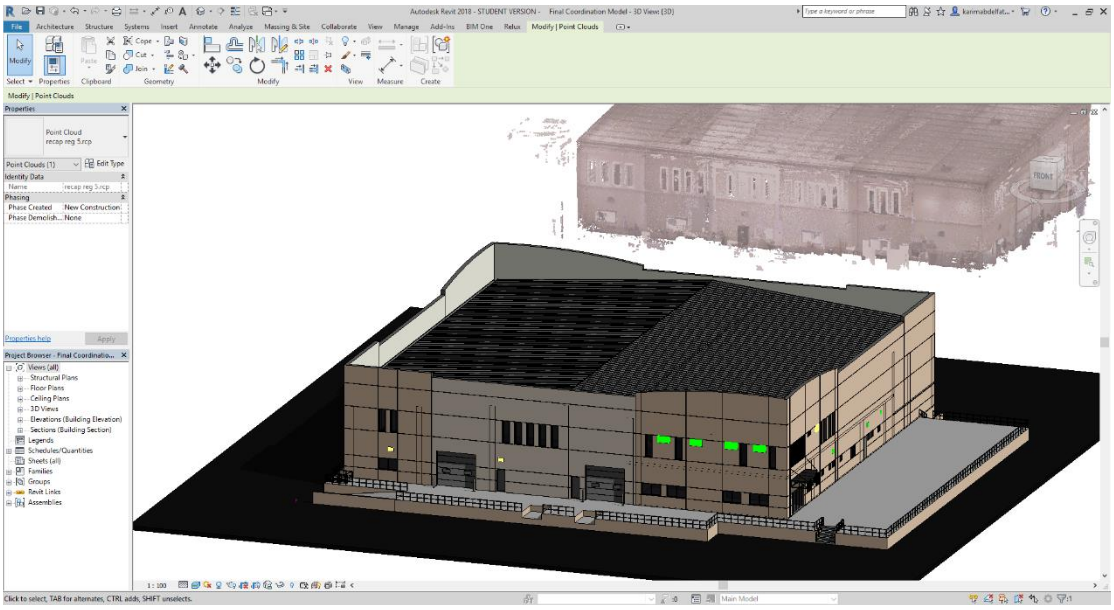


Figure 97. Matching origins between Revit and point-cloud models in Autodesk Revit

Few shots were taken to show the variation of dimensions between both models, those will show approximately no difference in all the main areas of the building.

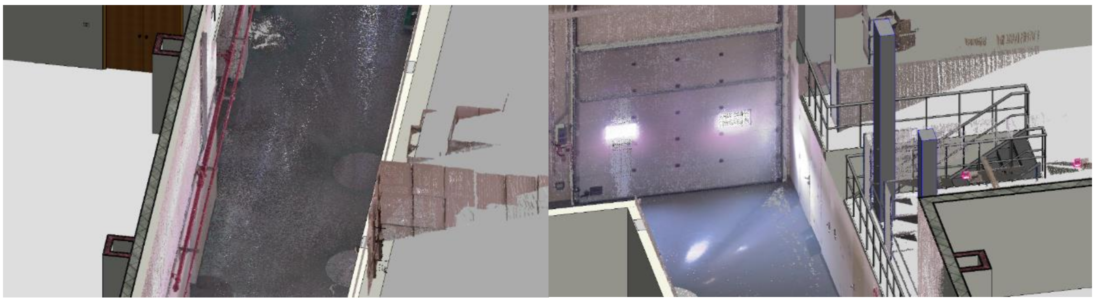


Figure 98. Interior Revit and point-cloud models origin matched in Autodesk Revit

In our study it's clear that the scanned model was used to compare both models and measure the as-built accuracy. In other cases, laser scanned model shall be used directly to be part of BIM data collection method without Revit model, or vice versa. Also, 3D laser scanned point-cloud shall be benefit toward Facility Management platforms with no intervention or pre-stages required, except for model cleaning.

UAV-to-BIM Capturing

UAV or Drones capturing is an image processing activity, which reflects that the source of final 3D model is series of pictures. These footages are taken within specific methodology, an overlap between the photos is not mandatory. Additionally, different angles of the entity must be captured, thus software shall combine, integrate and develop a 3D footage of the building. This model shall be utilized further to supplementary processes or activities; also, shall be exported as point-cloud model.

In this research, the UAV method will be part of exterior building capturing. Generally, UAV or Drone shall carry several types of instruments, such as camera, laser scanner or image sensors. Also, this tool is used for specific applications when it comes to BIM building computerization. In details description of the process shall be demonstrated within few stages occurred starting from On-site preparation and capturing reaching 3D Photogrammetric Model completion. Therefore, several activities will be explained in-depth within the next sections, that reflects the overview process map.

Stakeholders Structure

Below structure will show the human resources required to interfere in this stage in order to completely achieve its targets and objectives. This section will hold only the professional background of each stakeholder, further information will be explained in upcoming sections. It is always important to utilize the proper human resources in order to achieve the best results. Therefore, below structure is a generic and mostly used for the study purpose. In some cases, few responsibilities shall be merged towards lower number of personnel to achieve the same goal.

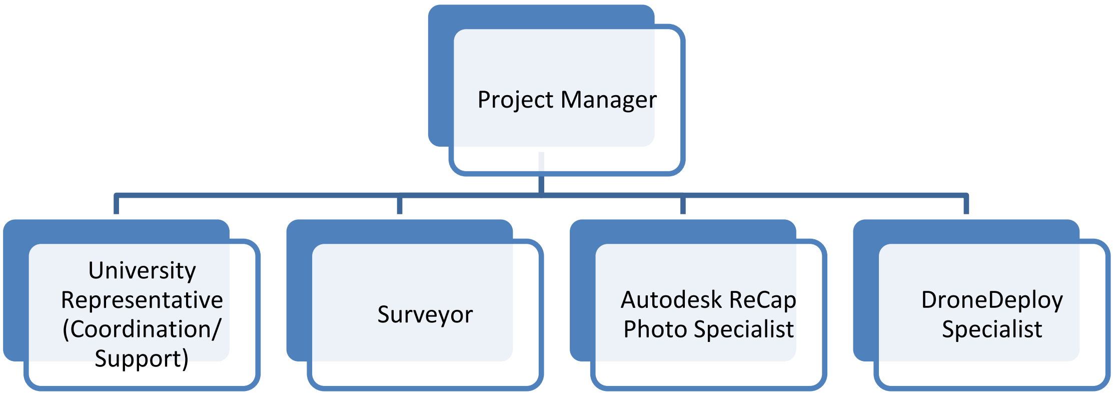


Figure 99. Key stakeholders of the study (UAV-to-BIM)

In this research, the thesis author was acting as Project Manager, Surveyor DroneDeploy and Autodesk Specialist to communicate with University authorities and representatives towards the flight permissions over the building to be captured. While upper structure is applicable for generality.

Work Breakdown Structure

Series of work activities occurred to achieve the UAV-to-BIM with its defined quality. Also, these activities affected the final project completion dates in terms of duration and timeline. Afterward will define each activity duration to illustrate the weighted importance of each towards their schedule.

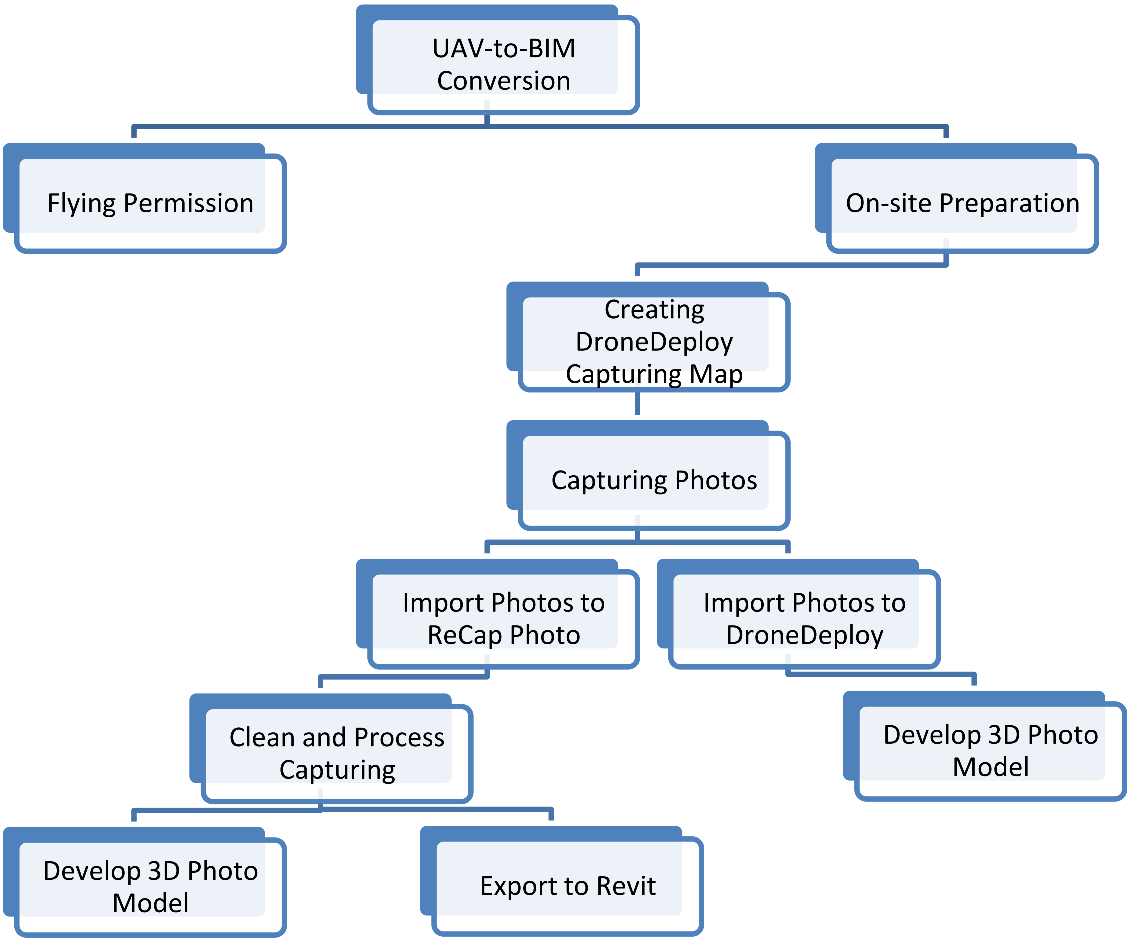


Figure 100. Work Breakdown Structure of UAV-to-BIM

This macro view of the work carried out shall illustrate the overview tasks to be taken into consideration while conversion process. Afterwards breakdown of the cost shall take place to define the activities spending.

Cost & Time Breakdown Structure

Budget and time are vital aspects of any project and two of the three main components. Therefore, below demonstration will show each task defined properties towards money and time.

Table 16. Time & Cost Breakdown Structure For Scan-to-BIM (*Optional)

S.N.	Activity	Duration (hours)	Cost (QAR)	Rate (QAR/hr)
1.0	UAV-to-BIM	6	-	-
1.1	Flying Permission	-	-	-
1.2	On-site Preparation	0.5	-	-
1.2.1	Developing Capturing Map	0.25	-	-
1.2.2	Capturing Mission Execution	0.25	-	-
1.2.3	ReCap Photo 3D Model Development	3.5	-	-
1.2.4	DroneDeploy 3D Model Development	1.5	-	-
	Additionally			
A	MSI High-performance Laptop	-	18,250	-
B	Autodesk Package (ReCap Photo) – Educational Version	-	-	-
C	Mouse	-	100	-
D	DJI Inspire Drone	-	10,950	-
E	DJI-Flir Thermal Camera*	-	32,850	-
F	DroneDeploy License	-	913	-
	Grand Total		63,063 QAR	

The total cost of the UAV-to-BIM may vary much, since in this study the surveying and model development was created by the author (no cost), in other cases, it shall be negotiated with available companies located in Qatar. As shown in the table, the hourly rates aren't included for the same previous reason, but cost breakdown shows a one-time purchase of required assets. The final spending required for this method of capturing shall be approximately one hundred seventeen thousand Qatari Riyal.

Linking Work and Stakeholders Breakdown Structure

In order to achieve more understanding towards the topic, an illustration will be developed to show the link between the activities and their project stakeholder responsible for its execution.

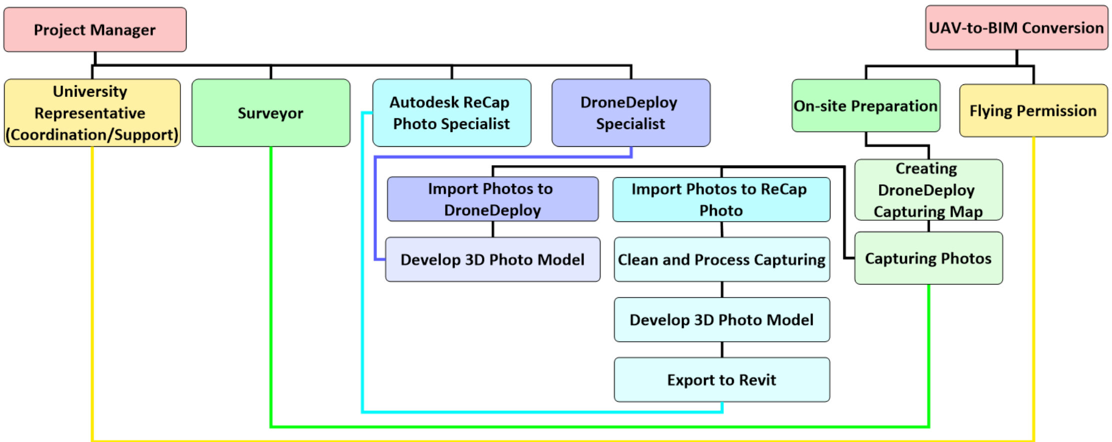


Figure 101. Linking of WBS and Stakeholders Breakdown Structure

The outcomes of this capturing technique shall be as the following series of illustrations below. Which will describe the similarity between the Drone Photo Capturing and reality.

Digital capturing & processing through DroneDeploy

As mentioned, in this study, UAV will be used to digitalize the building from exterior perspective through DJI Inspire drone using DroneDeploy software. This technique shall benefit the Facility Management as a routine activity, that survey the exterior of the building using UAVs as BIM model update from outside. Also, it shall be used to measure heat, that shall be used to investigate roof equipment efficiency.

In below process map diagram, the procedure of capturing external premises using DJI Inspire drone through DroneDeploy software will be demonstrated.

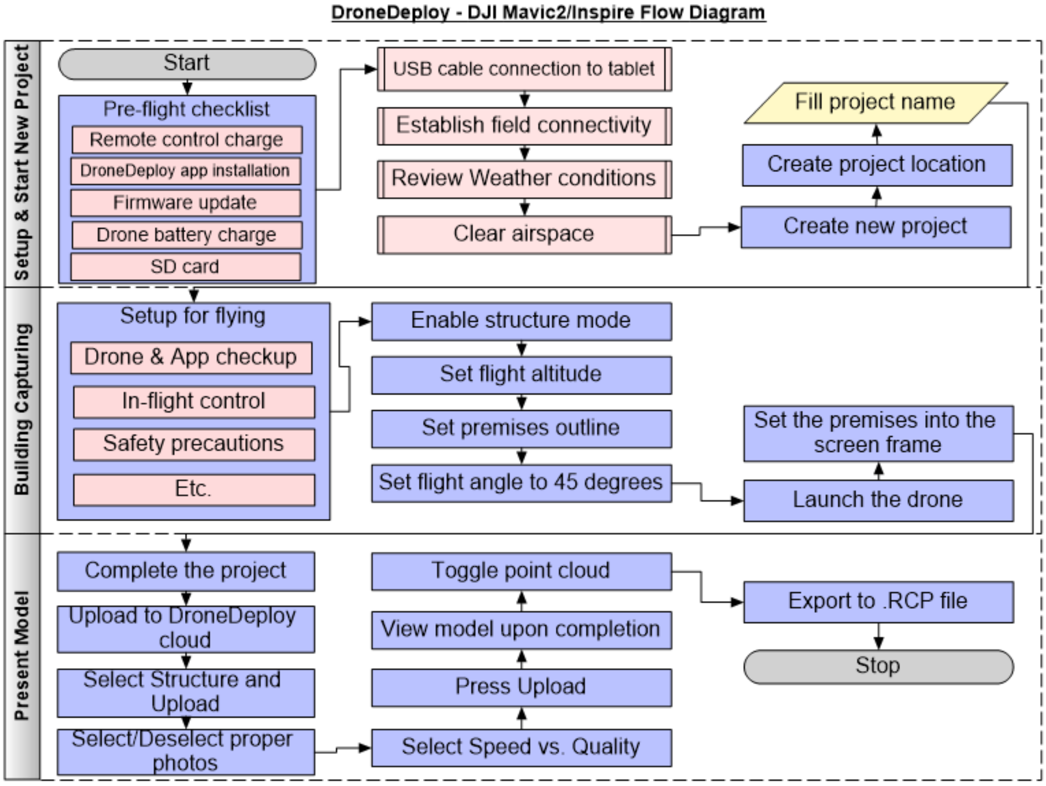


Figure 102. Capturing and processing UAV-to-BIM through DroneDeploy flow diagram

The capturing and processing on DroneDeploy passed through some stages, as shown in above figure, these were sufficient to complete the 3D model within the required standards and quality. In particular, let’s review the activities in more details, as will be shown below.

Workflow for capturing and processing through DroneDeploy

The capturing process starts by preparing and configuring all pre-requirements for flying the drone. Initially, make sure that the hardware (drone) and software (mission planner) are available prior to site work (capturing). As seen below, the Inspire was placed to its starting point after configuring the map on DroneDeploy.

Figure 103. DJI Inspire drone setup on-site

The drone will fly and capture automatically without any human interference throughout the whole mission. Illustration below shows the process of drone flying and capturing.

Figure 104. Adjusting and reviewing project mission through DroneDeploy app

Figure 105. DJI Inspire (in red square) performing project mission over premises

After photo capturing is over, processing and exporting the photogrammetric 3D model is applicable.

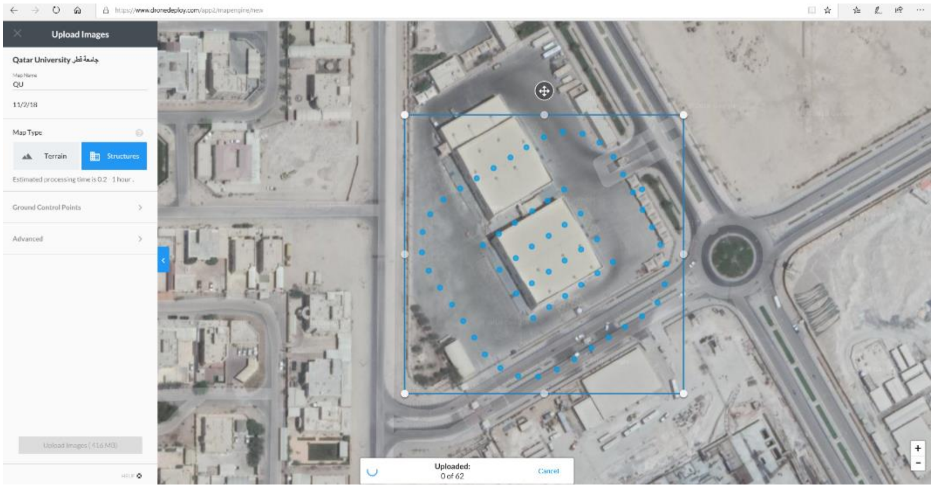


Figure 106. Uploading footage on DroneDeploy

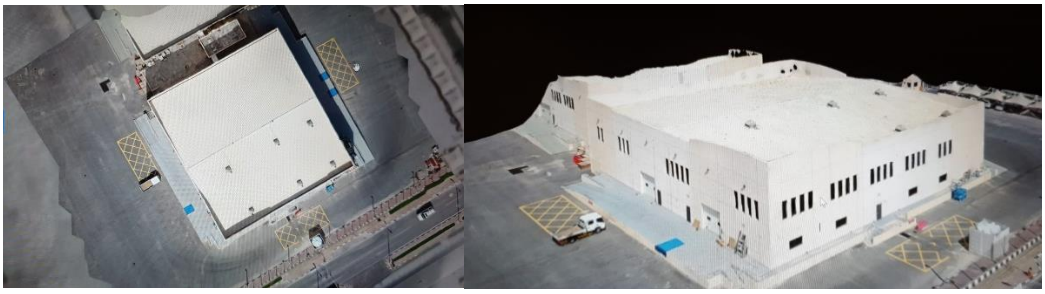


Figure 107. Model processed on DroneDeploy

Afterwards the Autodesk ReCap Photo capturing processing will be explained in the next section, with presenting all used techniques to process the images into a final 3D model.

Digital processing through Autodesk ReCap Photo

After using DJI Inspire drone and DroneDeploy software as tools to achieve 3D model, this section will discuss more about the footage processing through Autodesk ReCap Photo. This tool isn't essential successor, while either software shall be used to accomplish this application. Although using mission pilot software (DroneDeploy or an alternative) as a predecessor activity is necessary, and that in order to acquire building shots; as a source to further processes. However, in this research both tools were presented to show the differences and widely explain the most effective options used in the current market to cover the study requirements.

In below process map diagram, the procedure of external premises images transformation using Autodesk ReCap Phot will be demonstrated.

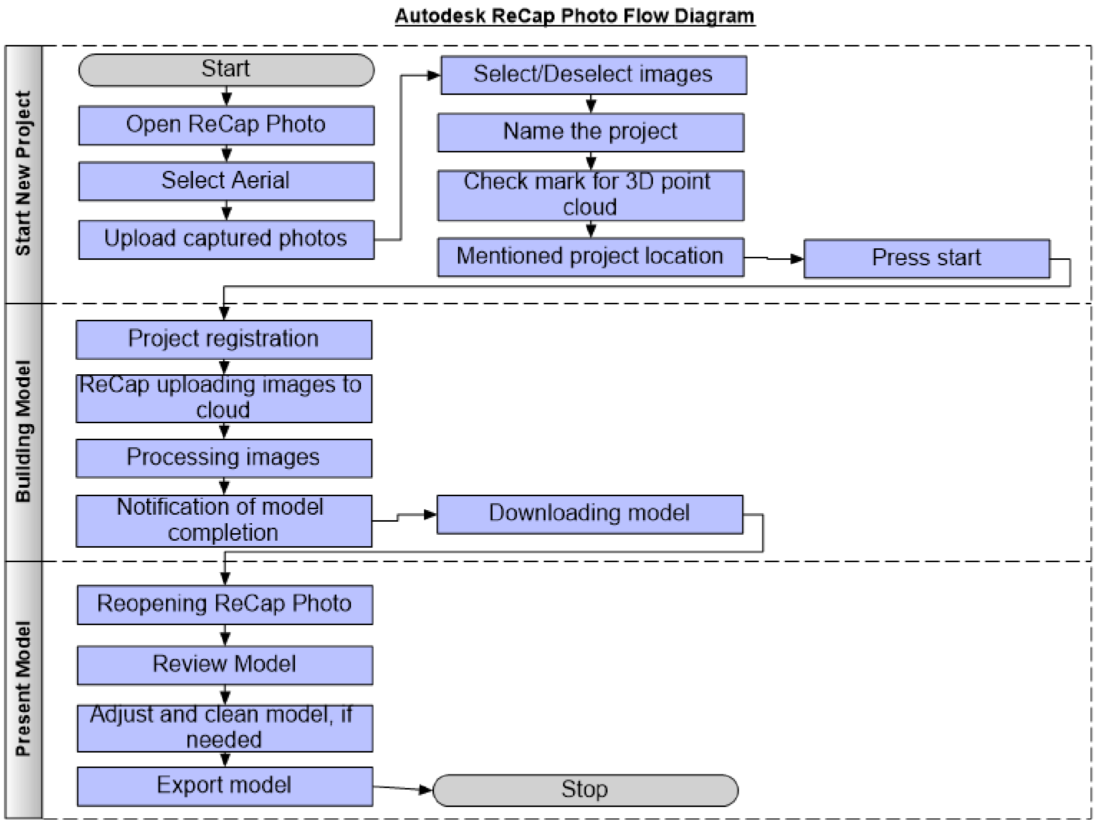


Figure 108. Images processing through Autodesk ReCap Photo flow diagram

The uploading and registration on Autodesk ReCap Photo passed through some stages, as shown in Figure 108, these were sufficient to complete the 3D model within the required standards and quality. In particular, let's review the activities in more details, as will be shown below.

Workflow for images processing through Autodesk ReCap Photo

The importing and processing of the photos captured by Inspire drone is the starting point of achieving a 3D model on Autodesk ReCap Photo. Firstly, as shown below, the photos shall be imported.

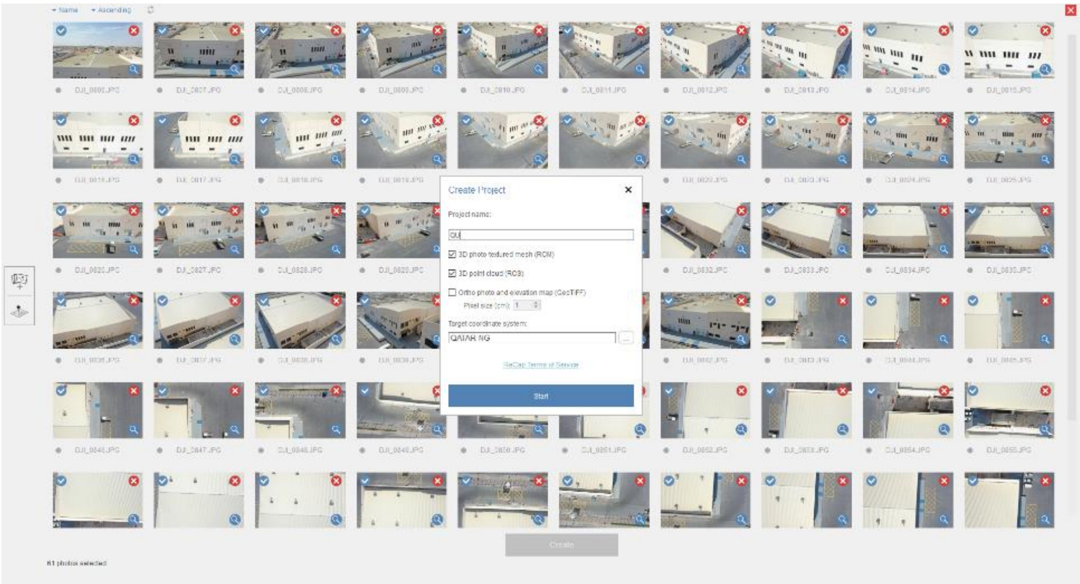


Figure 109. Selecting/Deselcting images prior to starting on Autodesk ReCap Photo

After importing, then configuring options, the ReCap Photo process the captures on its cloud, therefore, finally a full 3D model will be available for exporting. But prior to that, cleaning the model is applicable.

Figure 110. Pre-edited 3D model on Autodesk ReCap Photo

By ending elaboration of this tool, the study is directed to another phase. This section explained all three possible tools to be used in BIM enabling application of existing buildings. Furthermore, next phase shall be sharing this data and information with others within Qatar University community after integrating the BIM 3D model with the Building Management System (BMS) of the university. Thus, next section will start describing the integration process and capabilities used in order to develop both different protocols communication and management.

UAV Thermography

DJI Inspire supports different types of cameras, such as thermal photogrammetry camera. Which, as pre-mentioned in previous section, shall be used for various applications in the Facility Management. In this study, thermographic implementation took place, since FLIR thermal camera was used to capture upper roof and outer walls of the Central Store building in QU. Below illustrations shall describe the capabilities of this digital camera sensing. This feature was firstly done in Qatar within the study, since its thermal imaging capturing through UAV that was processed in favour of building envelope and roof insulation efficiency evaluation; and as shown in below figures, roof insulation cracks were found.

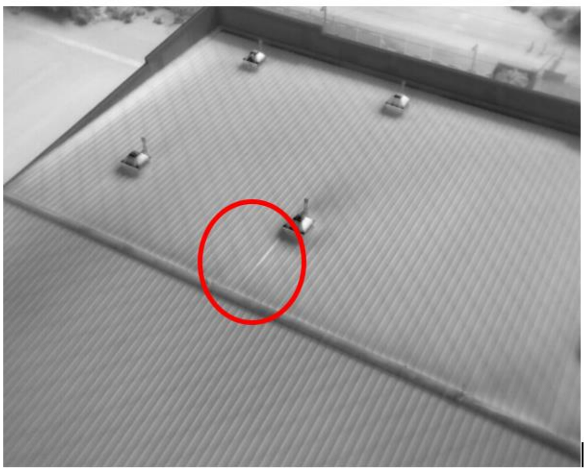


Figure 111. Thermal shot showing ceiling insulation defects by DJI Inspire drone

Figure 112. Thermal measurement by DJI Inspire drone

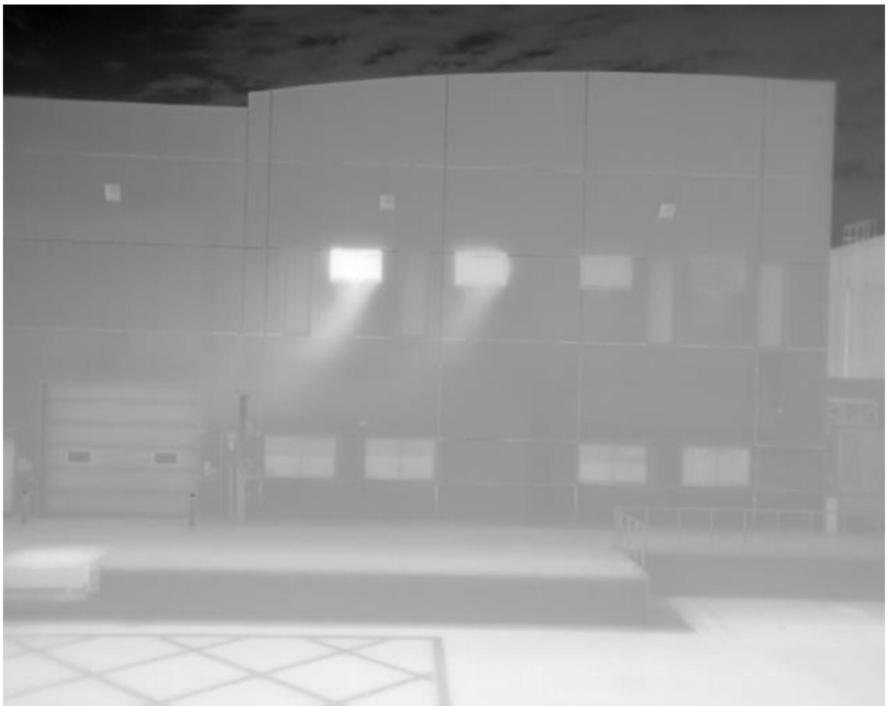


Figure 113. Thermal measurement footage by DJI Inspire drone

As seen from upper shot, that the colour thermal coding (which reflects the temperature measurement range) is showing which duct outlet that operates and expose heat, while the other is not. Resolution of thermal camera shall reach 640 x 480 pixel with 0.03°C sensitivity (accuracy: ±1% / ±1°C) to capture a digital high-quality photo for any designated area. Also, quality range shall support the height captures for multiple locations and assets at the same time, to save equipment, time and money.

BIM and BMS Integration

The integration of BIM and BMS shall be accompanied by series of challenges and constraints to be accomplished. Since both systems are running by dissimilar communication protocols. These types of languages to interact together will require a third-party interface or platform. The integration platform, in our case will require a server to act as interface for the data exchange will occur between both BACnet (BMS) and BIM protocols. Generally, this server shall be part of a local machine (computer), cloud, etc. that is stored and configured on a global or local scale. In our application, the server is based locally within the university network.

The global cloud server of EcoDomus (integration platform) cannot be used in our situation, since the university BMS must exchange information through public outlet that must pass through all firewalls. EcoDomus also provide software and license which shall be installed and configured on a PC/laptop and act as a local server. In this study, the installation, configuration and registration of EcoDomus local integration platform will be described fully with respect to the university digitalization and master plan requirements and objectives. Thus, below process diagram shall explain the integration methodology.

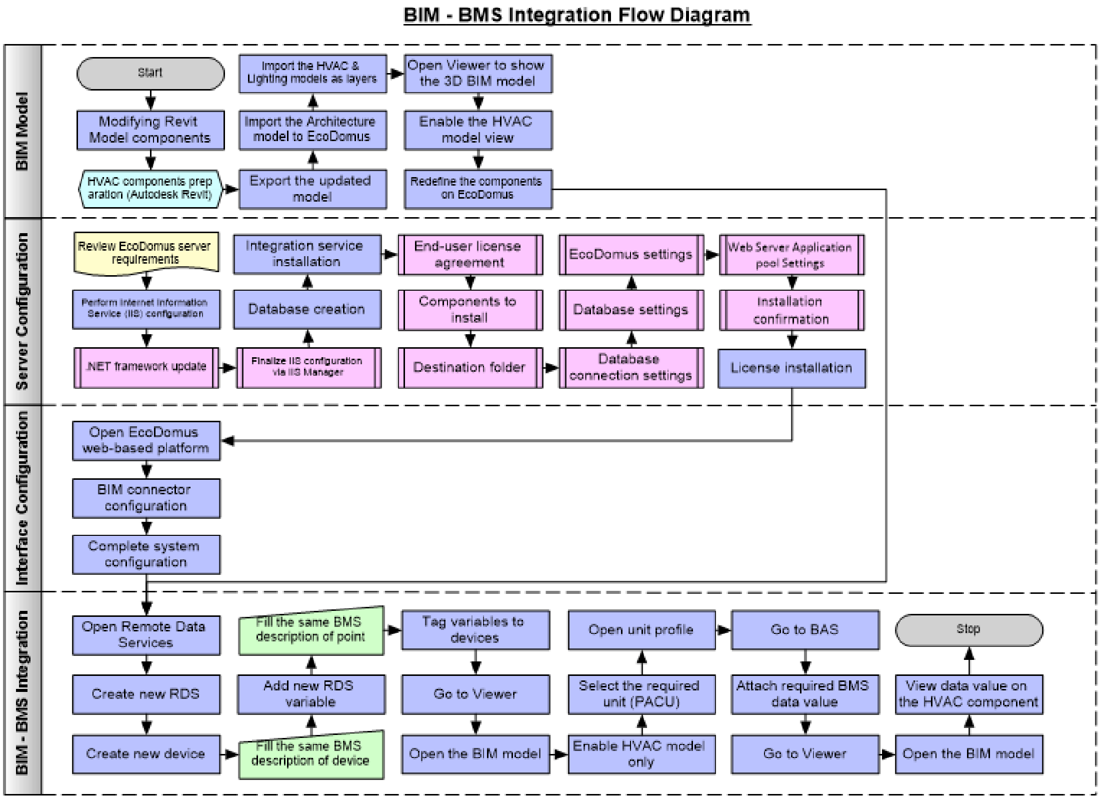


Figure 114. BIM and BMS integration flow diagram

As shown in Figure 114, the integration process went through several activities in series and parallel sequence. Therefore, this research will explain each phase individually, starting from adjusting the BIM model in Autodesk Revit till viewing BMS data variables on the BIM model through EcoDomus platform. Further explanation will review the phases and stages in-depth and logical pattern.

Stakeholders Structure

Below structure will show the human resources required to interfere in this stage in order to completely achieve its targets and objectives. This section will hold only the professional background of each stakeholder, further information will be explained in upcoming sections. It is always important to utilize the proper human resources in order to achieve the best results.

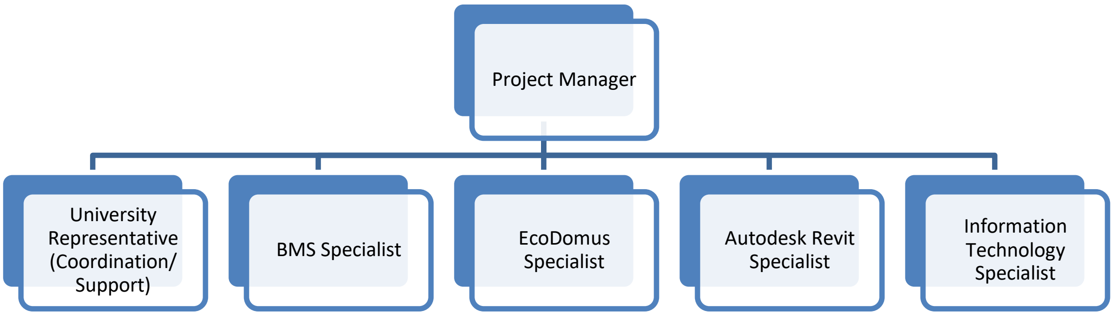


Figure 115. Key stakeholders of the study (BIM-BMS integration)

In this research, the thesis author was acting as Project Manager, BMS specialist, Information Technology specialist and EcoDomus specialist to communicate with University authorities and representatives towards the BMS access permissions for integration. Assistance was taken for BMS by university personnel, EcoDomus and Information Technology by EcoDomus and BIMTEC technical teams.

Work Breakdown Structure

Series of work activities occurred to achieve the integration with its defined quality. Also, these activities affected the final project completion dates in terms of duration and timeline. Afterward will define each activity duration to illustrate the weighted importance of each towards their schedule.

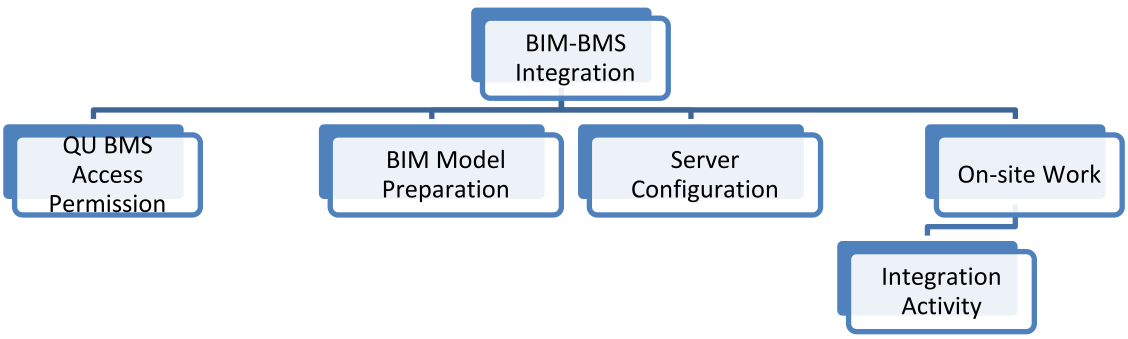


Figure 116. Work Breakdown Structure of BIM-BMS integration

This macro view of the work carried out shall illustrate the overview tasks to be taken into consideration while conversion process. Afterwards breakdown of the cost shall take place to define the activities spending.

Cost & Time Breakdown Structure

Budget and time are vital aspects of any project and two of the three main components. Therefore, below demonstration will show each task defined properties towards money and time.

Table 17. Time & Cost Breakdown Structure For BIM-BMS Integration

S.N.	Activity	Duration (hours)	Cost (QAR)	Rate (QAR/hr)
1.0	BIM-BMS Integration	4	-	-
1.1	BMS Access Permission	-	-	-
1.2	BIM Model Preparation	1.5	-	-
1.2.1	Server Configuration	1	-	-
1.2.2	On-site Work	1.5	-	-
	Additionally			
A	MSI High-performance Laptop	-	18,250	-
B	EcoDomus – Demo Version	-	-	-
C	Mouse	-	100	-
	Grand Total		18,350 QAR	

The total cost of the integration may vary much, since in this study the personnel involved were not charged, also the EcoDomus (integration platform) fee isn't included since it was a demo version with free license. Therefore, realistic evaluation of this process cost will exceed thousands of Qatari Riyal, in other cases, it shall be negotiated with available companies located in Qatar. As shown in the table, the hourly rates aren't included for the same previous reason, but cost breakdown shows a one-time purchase of required assets.

Linking Work and Stakeholders Breakdown Structure

In order to achieve more understanding towards the topic, an illustration will be developed to show the link between the activities and their project stakeholder responsible for its execution.

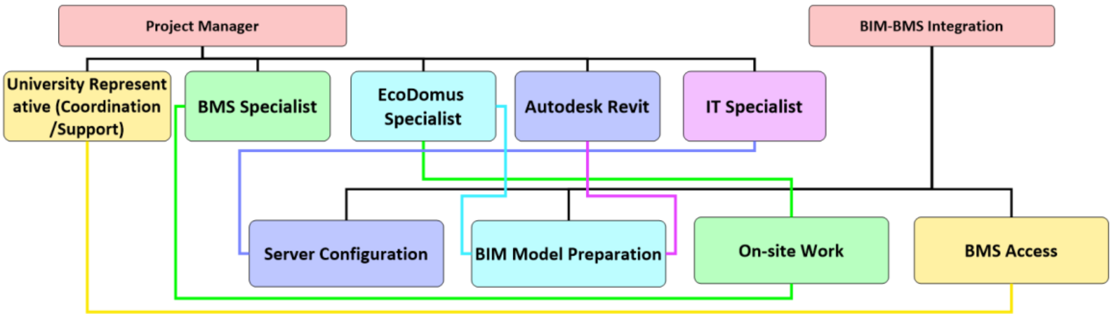


Figure 117. Linking of WBS and Stakeholders Breakdown Structure

The outcomes of this capturing technique shall be as the following series of illustrations below. Which will describe the similarity between the Drone Photo Capturing and reality.

BIM Model Preparation

This is the first phase to start with in-process to acquire BIM – BMS integration. The BIM model preparation as a pre-requisite to all the incoming work to be done.

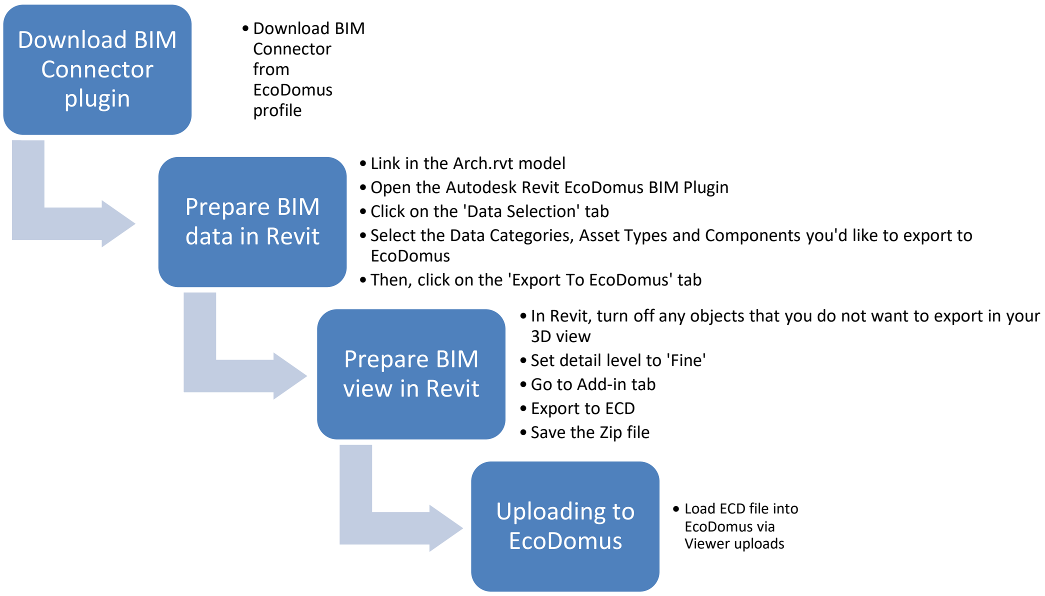


Figure 118. BIM Model preparation prior to integration

Local Machine Server Configuration

Afterwards, a server shall be developed to exchange the BIM and BMS data, and act as a gateway to both different protocols to communicate. In our case, it'll be a local server.

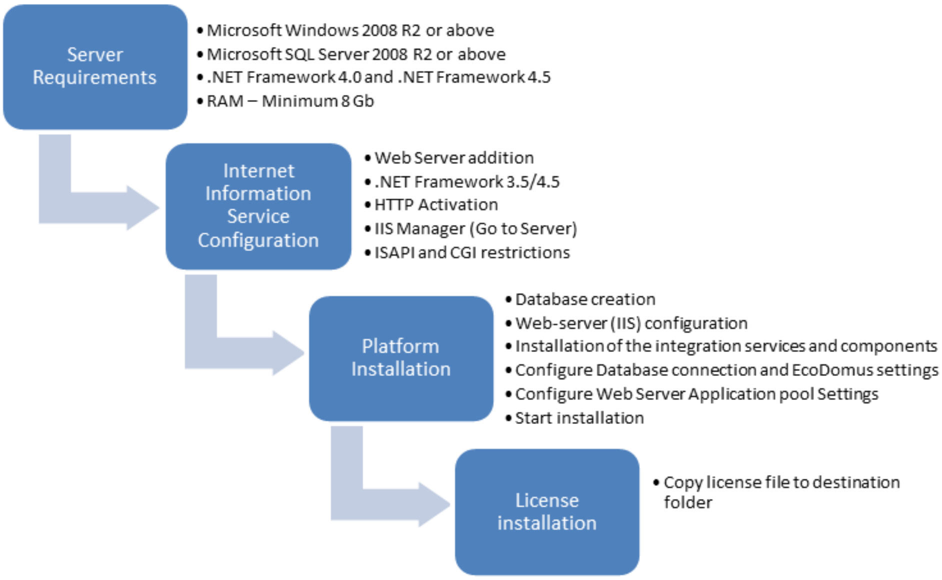


Figure 119. Local machine server configuration for integration

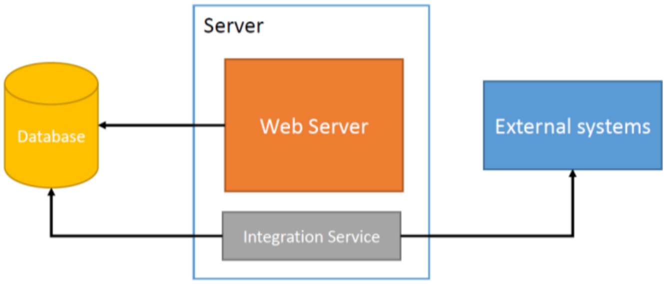


Figure 120. EcoDomus architecture diagram (EcoDomus, 2015)

EcoDomus Interface Configuration

Prior to initiating the integration process, there are few configurations to take place. Having a server is mandatory for interface to operate properly.

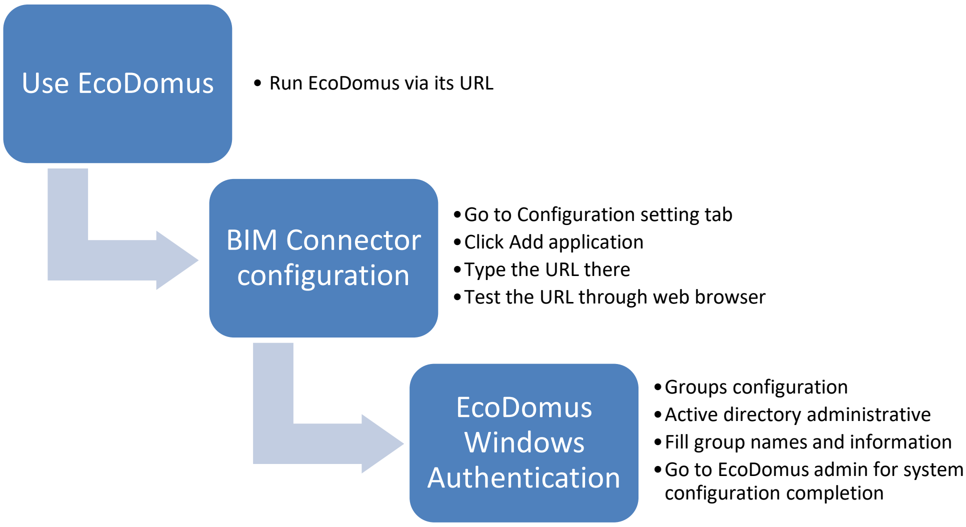


Figure 121. EcoDomus interface configuration

BIM & BMS Integration

Use BACnet scanner to check the connectivity of the local machine to BMS server and that's as shown in below screenshot.

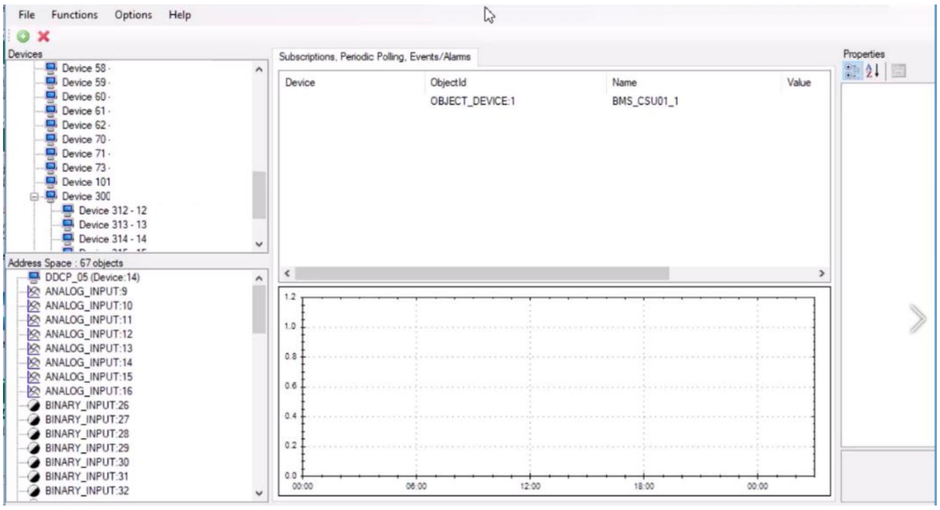


Figure 122. BACnet scanner

In the use of EcoDomus, first open the web browser and enter the EcoDomus URL. Head to Remote Data Services to create new devices with filling all its required information. Afterwards, new variable with its information is required to tag it to BIM components. Afterwards, the components shall be linked to BMS variables but through the BIM viewed. After tagging the real-time variables, the BIM viewer shall be ready for a fully integrated 3D model that is including BIM management features with BMS real-time sensors readings and storage benefits.

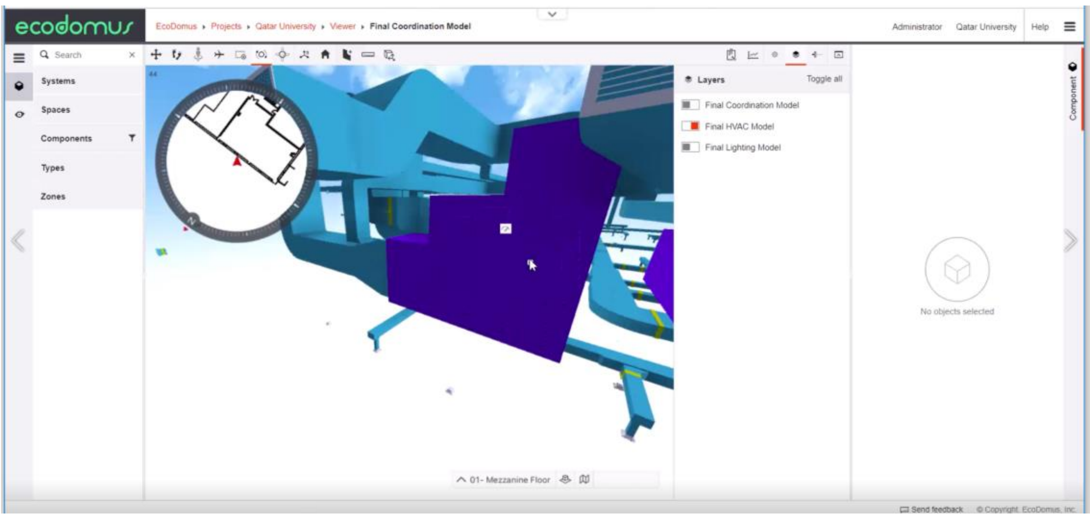


Figure 123. View real-time BMS data variables on BIM components on EcoDomus

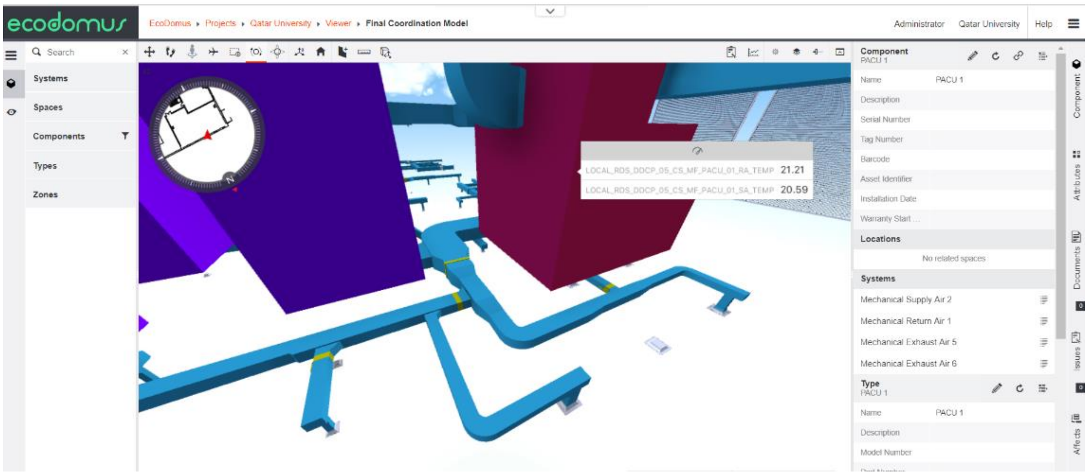


Figure 124. Example of single real-time integration between BMS and BIM values on EcoDomus (PACU-01)

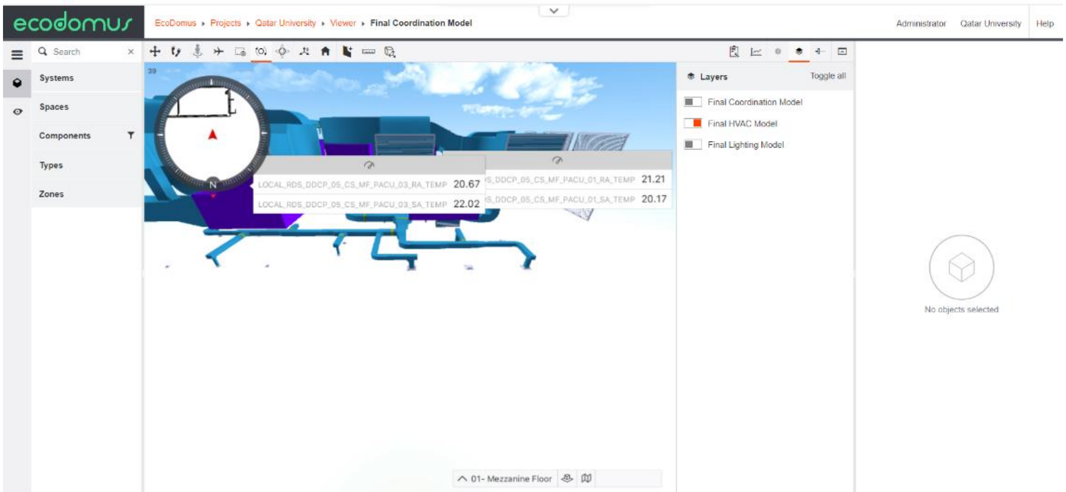


Figure 125. Example of multi real-time integration between BMS and BIM values on EcoDomus (PACU-01 and 03)

The upper mentioned process shall occur on scanned/captured model as well, since the model shall be imported to EcoDomus and run the same BMS data values attachment to BIM captured or scanned model. In below demonstration, the building exterior capturing through UAV was imported directly to EcoDomus. Also, 3D laser scanned model was imported for the same application.

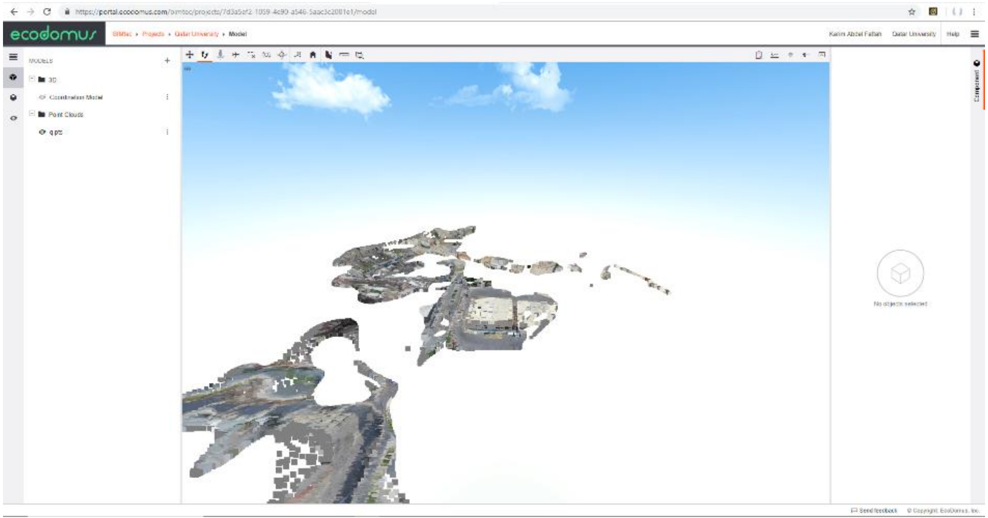


Figure 126. Exterior capture by UAV imported in EcoDomus

EcoDomus platform is also having a mobile app for iOS and Android. This feature shall add to the software positively towards Facility Management sector. Below representation will show few screenshots for the model through EcoDomus iOS app.

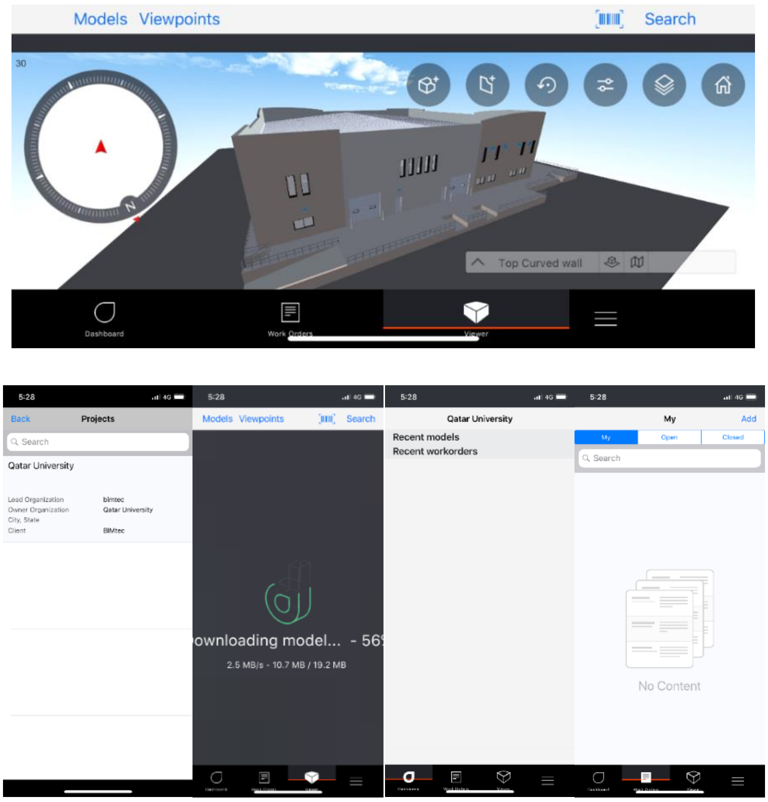


Figure 127. EcoDomus iOS app user interface

After showing all means of BIM and BMS integration, starting from an overview process map reaching completion and finalization of the whole activity, below will explain the profound relationship between the integration and QU digitalization objectives. For recalling, this study was first founded in order to develop a framework that will support QU digitalization plan which aims to university smart campus. Thus, relating integration values and outcomes with QU plans is crucial.

BIM Data Repository

Prior to BIM and BMS integration, a data sharing platform within QU community shall be developed. This implementation is part of aiming this study objectives and goals to QU digitalization initiative. Part of this well-established move by the university, is to spread the technological achievements to all institute members for faster improvement growth and better rates.

In this research, the data storage and exchange will be EcoDomus platform. This is the same interface platform that was used to integrate both BIM and BMS in real-time. EcoDomus is including few crucial features that shall support the study objectives. As mentioned previously in the Data Repository section that EcoDomus shall store additional materials to the BIM model with all its components, documents from all types as well. The document types shall include but not limited to drawings, spreadsheets, contracts, instructions, reports, certificates, submittals, etc. with controlled user access. Also, documents shall be attached to be specific assets as a visual database.

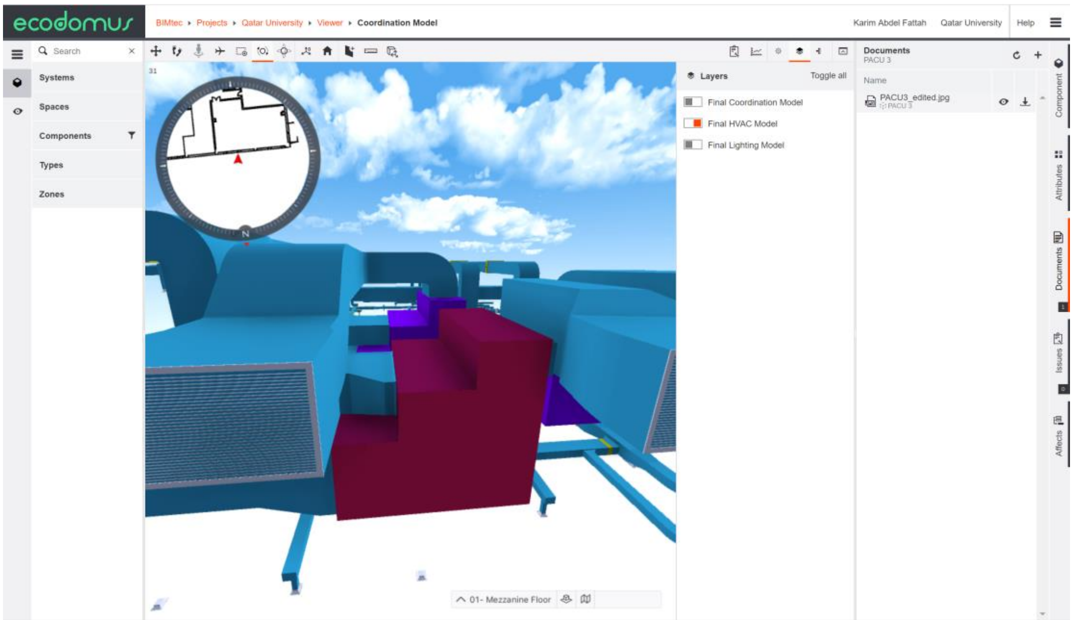


Figure 128. Attaching documents to EcoDomus components

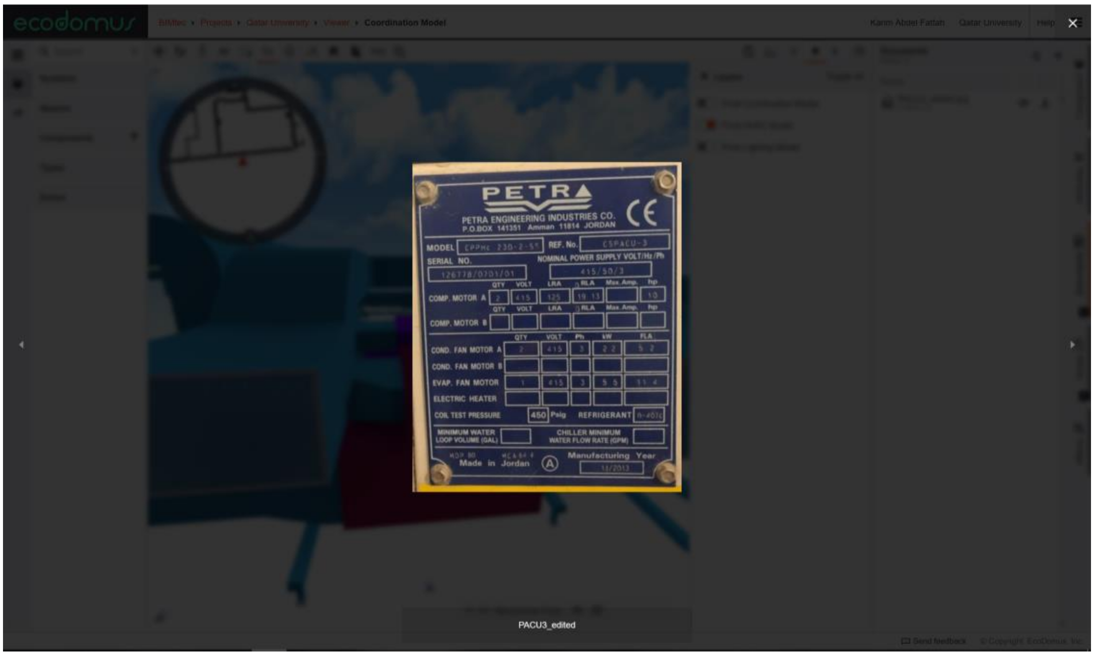


Figure 129. Viewing attached documents to EcoDomus

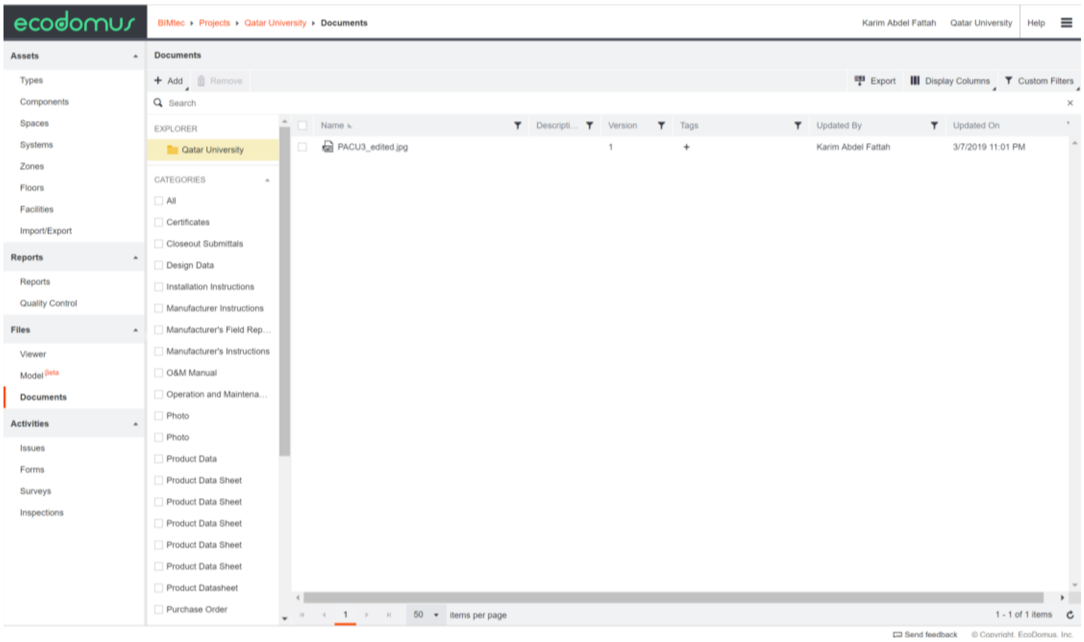


Figure 130. Categorizing documents in EcoDomus

BIM Model Usage in BIM Ops

The usage of BIM 360 Ops is crucial for a full usage of BIM features towards Facility Management (FM). First, let’s describe the methodology of the Ops full operation. Below illustration will show more details towards the basic features will benefit in FM.

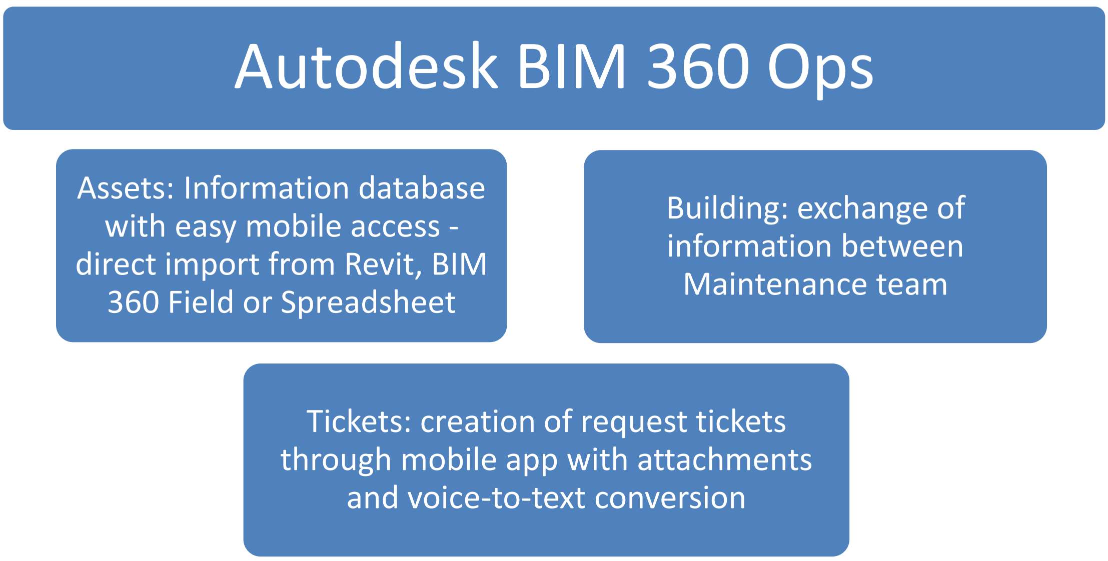


Figure 131. BIM 360 Ops main features (Autodesk BIM 360 Ops, 2019)

In this study, the Revit model components were utilized to be imported to BIM 360 Ops as below.

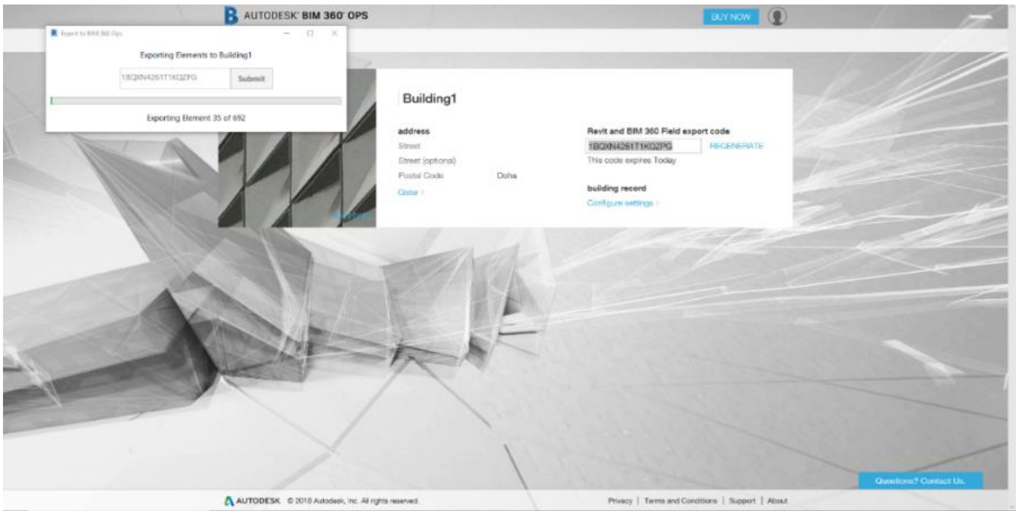


Figure 132. Importing Revit components to Ops

This stage starts with generation of code from Ops to be used in Revit, this will initiate the collection of BIM model components information.

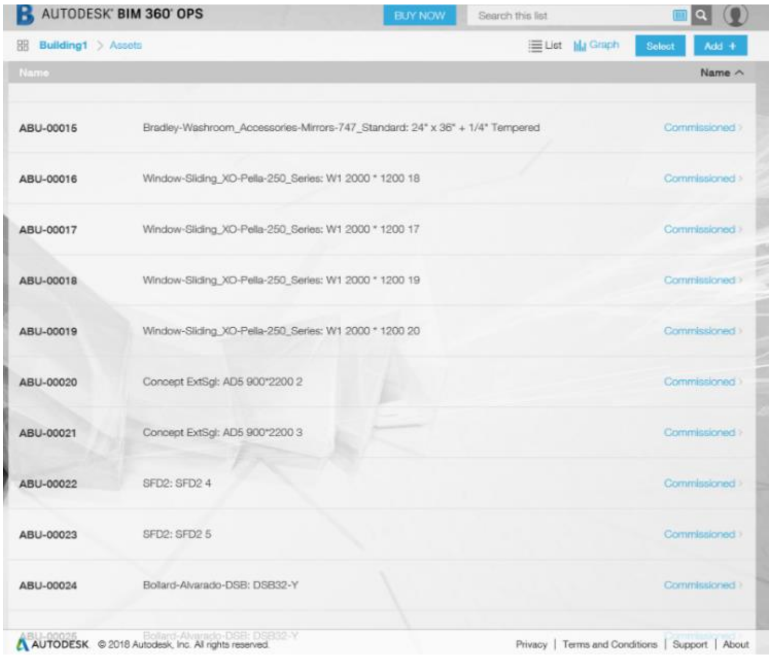


Figure 133. List of building components in Ops

Having all components in Ops will initiate the maintenance activity of any building, since all information shall be added to the database. Also, this information exchange shall occur between parties.

CHAPTER 5: DATA ANALYSIS

After collecting and processing all data required, through different techniques and methods, analyzing process shall take place. Since, all previously mentioned capturing techniques shall be used individually to fulfil the need of BIM digital capturing. While, selection most appropriate way, will depend on others application, circumstances, and other factors. Analyzing all data shall give an opportunity for the users the select their method properly. Therefore, analysis of data will start with a comparison between all used techniques including all required factors to be taken into consideration.

Cost Analysis

The analysis will start with cost, which is one of the main project components. Below breakdown and illustrations will show more details (all costs are in Qatari Riyal).

Table 18. Cost Comparison Between All Capturing Techniques

Activity	Option 1 (CAD-to-BIM)	Option 2 (Scan-to-BIM)	Option 3 (UAV-to-BIM)	Integration (BIM-BMS)
Permissions	-	-	-	-
Data Collection	-	-	-	-
Data Capturing	-	-	-	-
Data Processing	-	-	-	-
3D Model Development	5,475	-	-	-
Assets & Additions	18,350	116,900	63,063	18,350
Grand Total (QAR)	23,825	116,900	63,063	18,350

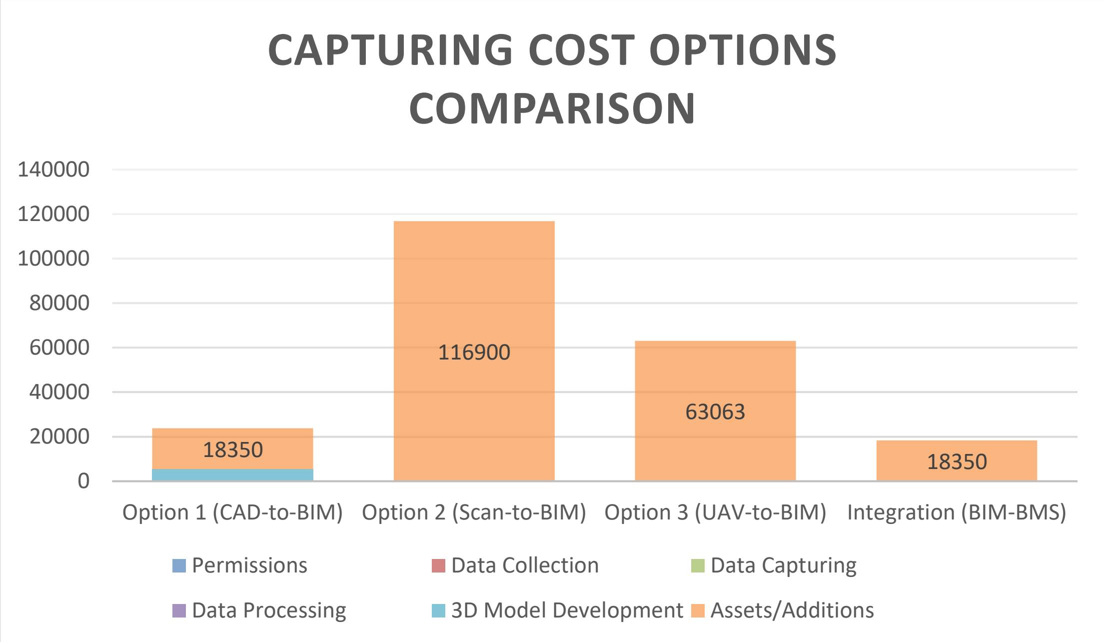


Figure 134 . Capturing cost options comparison chart

Some tools can't fully operate individually and carries an accurate outcome. For example, UAV techniques can't be used to capture interiors, also it's a photogrammetric version. Furthermore, the CAD DWG aren't accurate enough because it's As-built drawings, which shall carry few design variations from reality. Scanning is accurate and reflects reality, but it's not fair in terms of quality to be illustrated as a final BIM model. Integration cost is including only asserts cost for the reason mentioned previously, that the solution package was provided as demo version – free of charge as well as the personnel support. The technical team associated for EcoDomus platform or integration process were not charged, for future references about the activity, a commercial tender shall be applicable. More details will be discussed in the next section; however, the best option cost will be illustrated below.

Table 19. Cost Comparison For Best Option Between Capturing Techniques

Activity	Revit for Modelling	Laser Scanning for Interior	UAV Drone for Exterior	BIM-BMS Integration
Permissions	-	-	-	-
Data Collection	-	-	-	-
Data Capturing	-	-	-	-
Data Processing	-	-	-	-
3D Model Development	5,475	-	-	-
Assets & Additions	18,350	98,550	44,713	-
Sub Total (QAR)	23,825	98,550	44,713	-
Grand Total (QAR)	167,088			

The above cost was estimated as, the capturing of interior occurred through laser scanner, exterior with UAV drone and modelling by Revit. Also, the cost of common assets (e.g. PC) was included only once within CAD-to-BIM cost. Also, integration is part of the best practice that shall be excluded from total cost; since in the study as pre-mentioned it had special circumstances. Any possible capturing mean shall be associated by integration towards the facility management benefits.

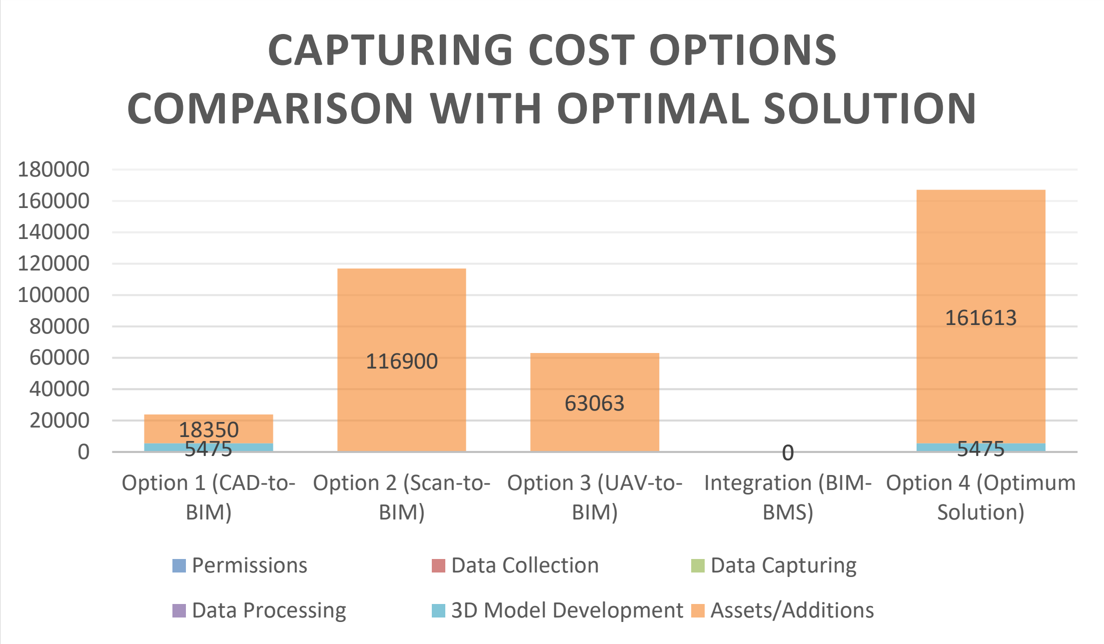


Figure 135. Capturing cost options comparison with optimum solution chart

Time Analysis

After analyzing the cost perspective of this study, through different techniques and methods, time analyzing process shall take place. Since, all previously mentioned capturing techniques shall be used individually to fulfil the need of BIM digital capturing. While, selection most appropriate way, will stretch the schedule dates and all activities timeline. Therefore, analysis of data will start with a comparison between all used techniques including all required factors to be taken into consideration (time unit is hours).

Table 20. Time Comparison Between All Capturing Techniques

Activity	Option 1 (CAD-to-BIM)	Option 2 (Scan-to-BIM)	Option 3 (UAV-to-BIM)	Integration (BIM-BMS)
Permissions	-	-	-	
Data Collection	-	-	-	-
Data Capturing	-	7	1	-
Data Processing	-	1	1	-
3D Model Development	160.25	15.5	4	-
Assets & Additions	-	-	-	-
Grand Total (hours)	160.25	23.5	6	4

The above time was estimated as, the capturing of interior occurred through laser scanner, exterior with UAV drone and modelling by Revit.

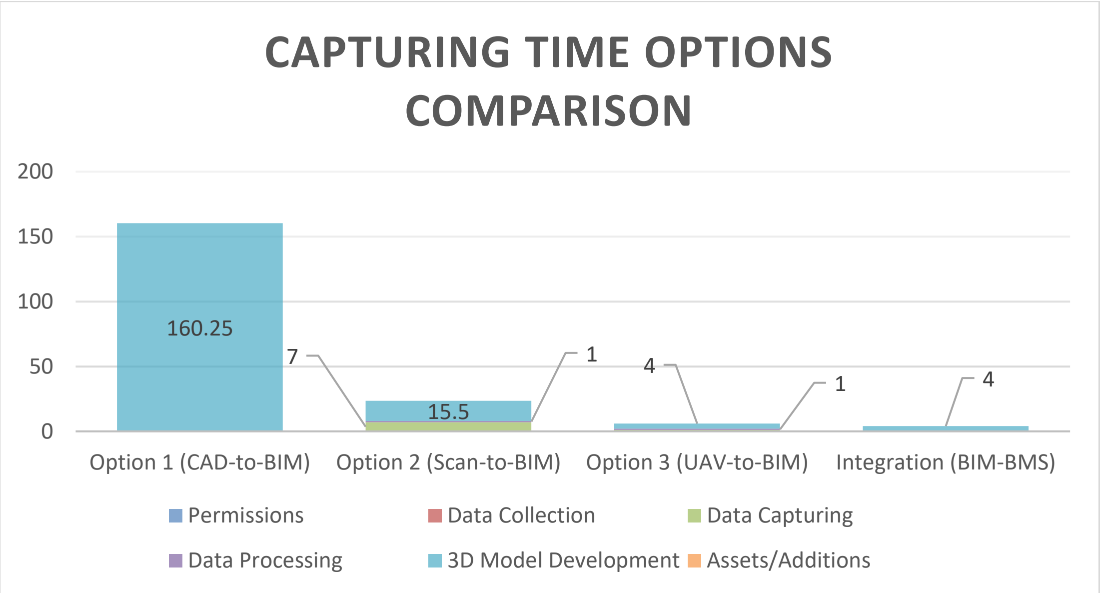


Figure 136. Capturing time options comparison chart

Some tools can't fully operate individually and carries an accurate outcome. For example, for the same reasons mentioned in the Cost Analysis. More details will be discussed in the next section; however, the best option time will be illustrated below.

Table 21. Time Comparison For Best Option Between Capturing Techniques

Activity	Revit for Modelling	Laser Scanning for Interior	UAV Drone for Exterior	BIM-BMS Integration
Permissions	-	-	-	-
Data Collection	-	-	-	-
Data Capturing	-	7	1	-
Data Processing	-	1	1	-
3D Model Development	160.25	15.5	4	4
Assets & Additions	-	-	-	-
Sub Total (hours)	160.25	23.5	6	4
Grand Total (hours)	193.75			

The above time was estimated as, the capturing of interior occurred through laser scanner, exterior with UAV drone and modelling will occur depending on the data captured to Revit. Therefore, in this case the optimum solution will be on-site laser scanning and UAV drone capturing, afterwards these data will be imported to Revit for a realistic BIM model development.

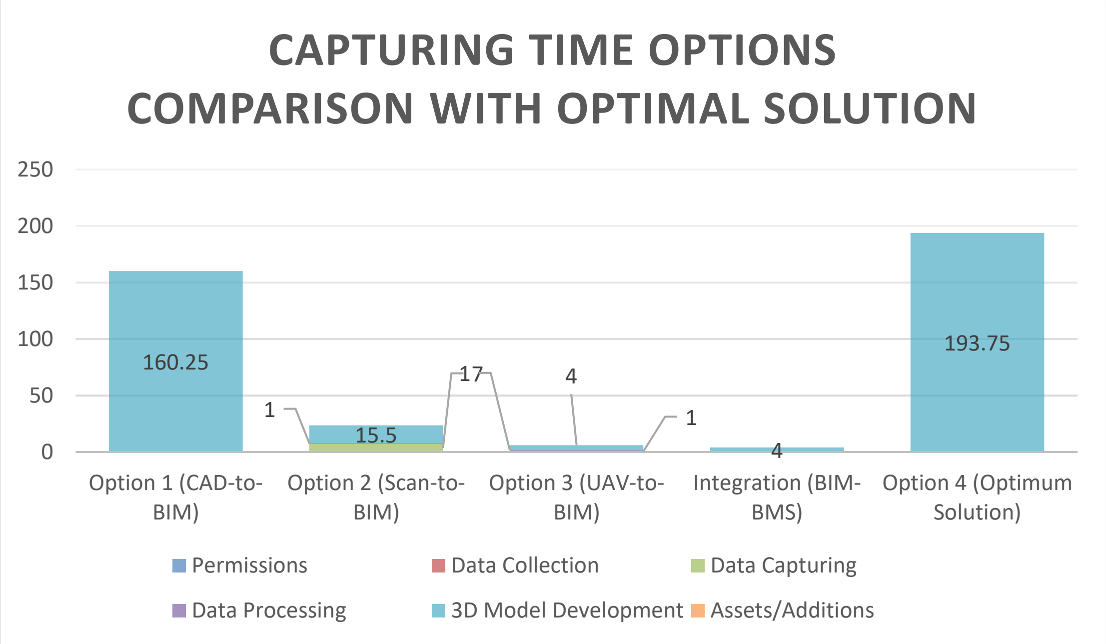


Figure 137. Capturing time options comparison with optimum solution chart

Quality Analysis

After analyzing the time and cost perspectives of this study, through different techniques and methods, quality analyzing process shall take place. Since, all previously mentioned capturing techniques shall be used individually to fulfil the need of BIM digital capturing. While, selection most appropriate way, will stretch the schedule dates and all activities timeline. Therefore, analysis of data will start with a comparison between all used techniques including all required factors to be taken into consideration.

Table 22. Quality Comparison Between All Capturing Techniques (Leica, 2018) (Andy Putch, 2017)

Activity	Option 1 (CAD-to-BIM)	Option 2 (Scan-to-BIM)	Option 3 (UAV-to-BIM)	Integration (BIM-BMS)
Data Type	3D Model	Point-cloud 3D Model	Photogrammetric 3D Model	Real-time Signal
Min. Data Accuracy (%)	100	99.4	98.9	100
Maximum Range (m)	32,000	46	122	-

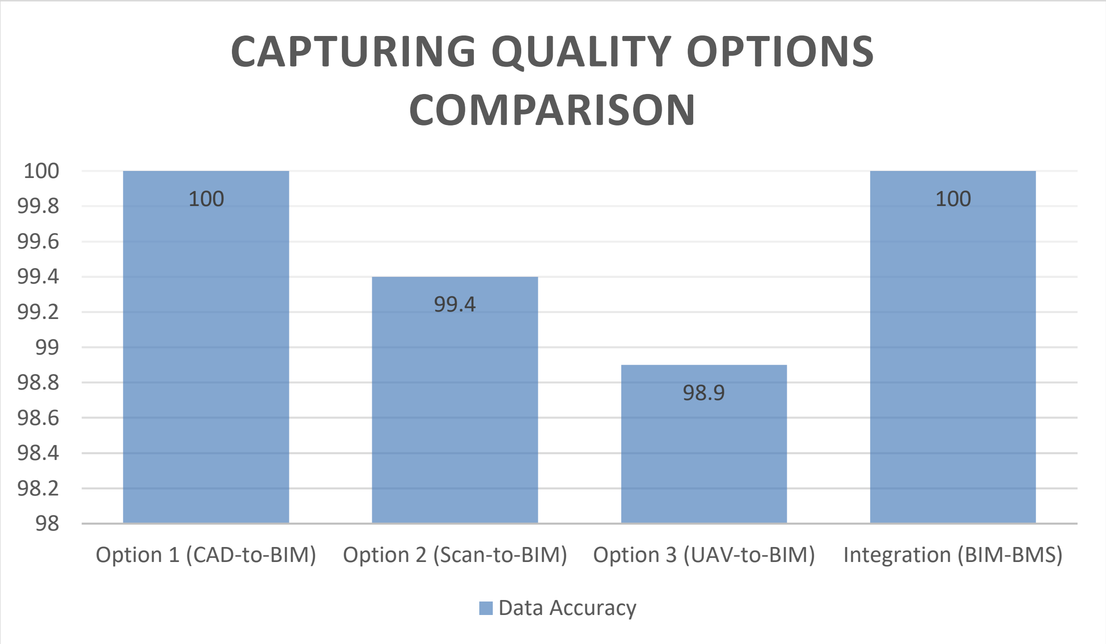


Figure 138. Capturing quality options comparison chart

After showing the various differences between range and accuracy ranges of the three capturing techniques, few supporting information shall be shown, such as the distance measurement screenshots for all of them in comparison. Common side of the building width will be measured to verify the differences. West side of the building will be taken as reference.

Figure 139. West side of the building captured in reality, for comparison and data validation between used techniques

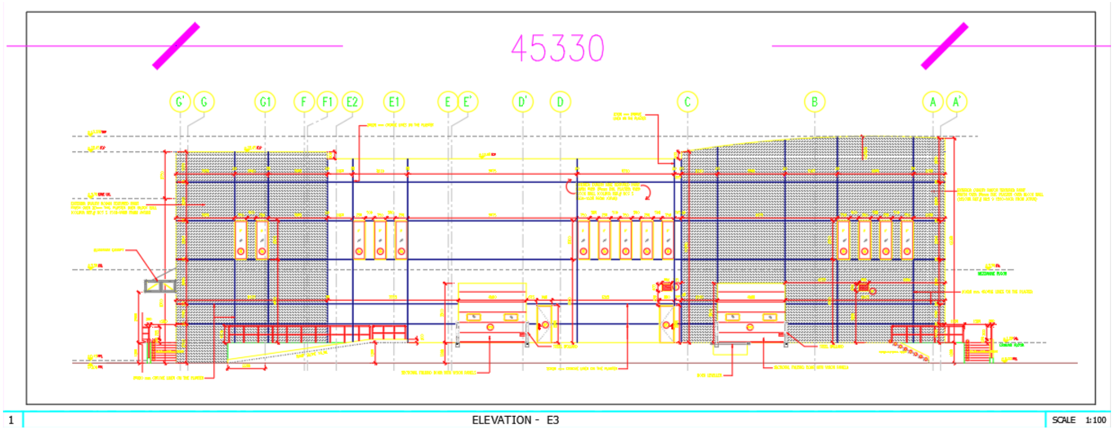


Figure 140. Width measurement of the west side in AutoCAD

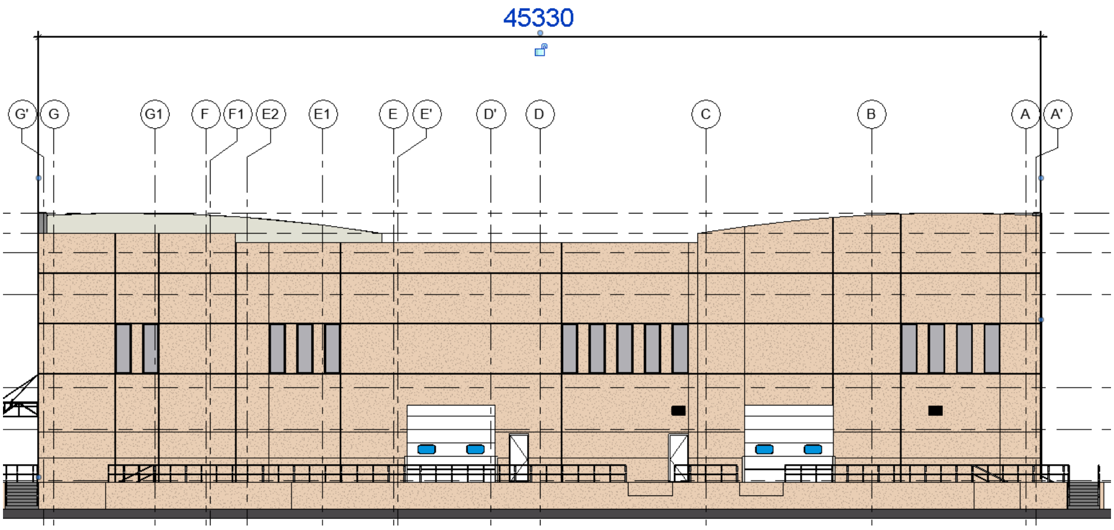


Figure 141. Width measurement of the west side in Revit

Figure 142. Width measurement of the west side in ReCap Photo

The exterior was compared between CAD, Revit and ReCap Photo. However, the interior will be compared through CAD and ReCap, since the Revit have proven that it’s the exact same as the CAD, so it won’t be part of the interior comparison; as shown below.

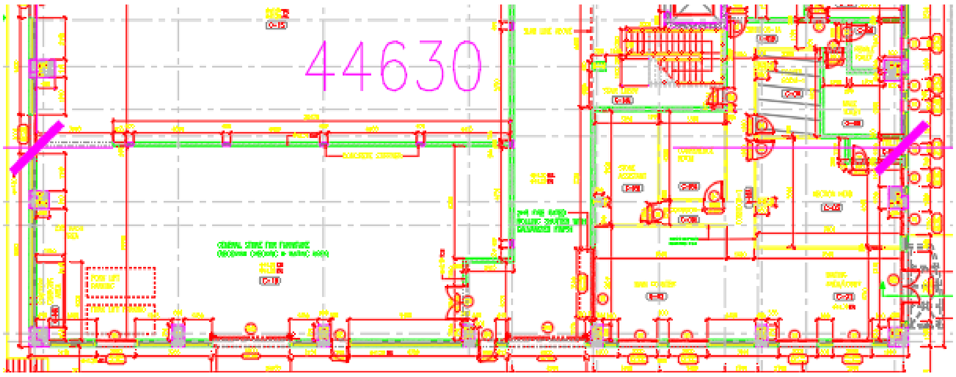
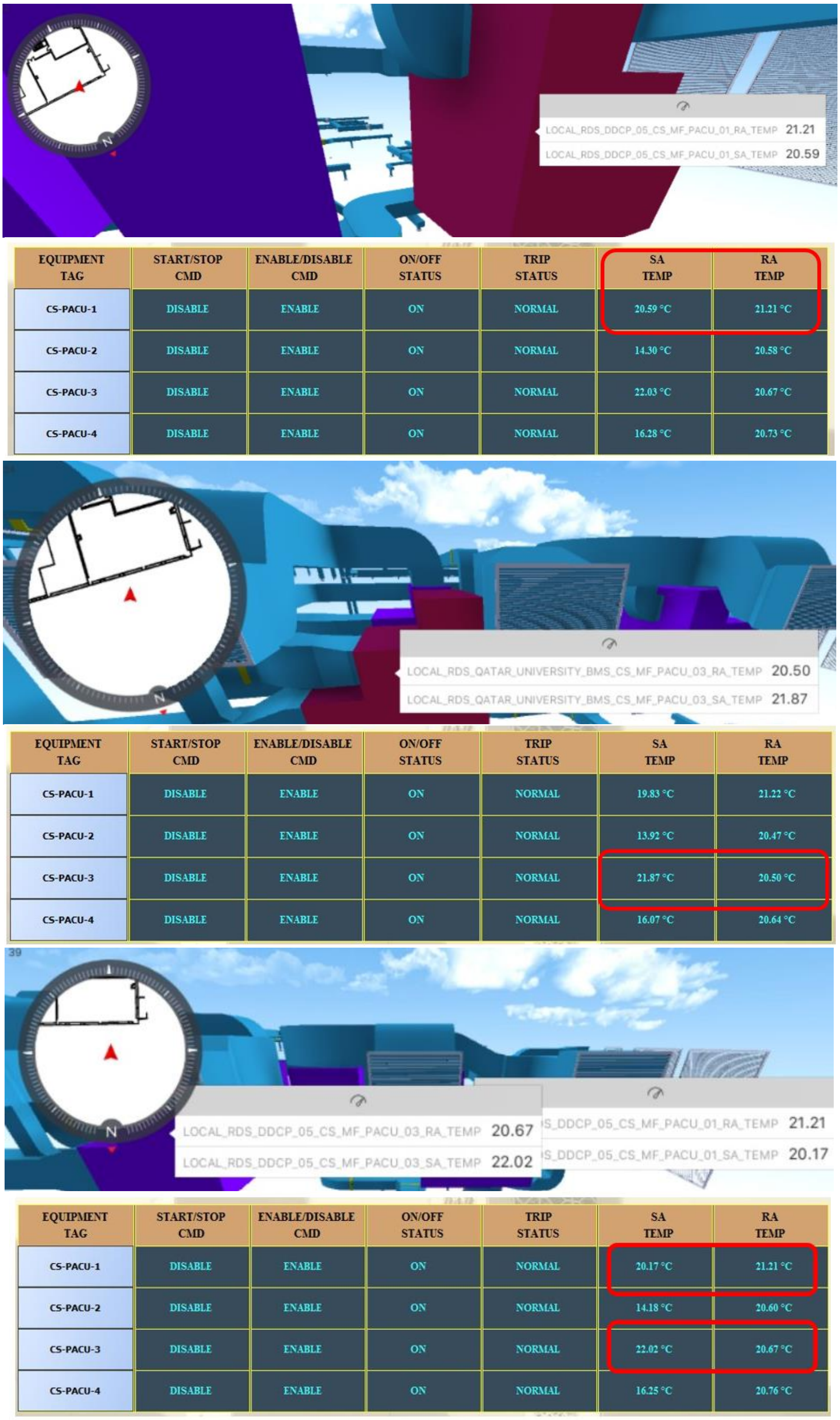


Figure 143. Width measurement of the west side interior in CAD

Figure 144. Width measurement of the west side interior in ReCap

Concerning integration phase, calculation or evaluation of accuracy isn’t the same as the capturing techniques, since the others are more materialistic in terms of comparison and accuracy references. Therefore, BIM-BMS integration will be precision measured in terms of signal readings. In another words, will investigate whether the real-time values appearing in EcoDomus is the same as BMS or not.



EQUIPMENT TAG	START/STOP CMD	ENABLE/DISABLE CMD	ON/OFF STATUS	TRIP STATUS	SA TEMP	RA TEMP
CS-PACU-1	DISABLE	ENABLE	ON	NORMAL	20.59 °C	21.21 °C
CS-PACU-2	DISABLE	ENABLE	ON	NORMAL	14.30 °C	20.58 °C
CS-PACU-3	DISABLE	ENABLE	ON	NORMAL	22.03 °C	20.67 °C
CS-PACU-4	DISABLE	ENABLE	ON	NORMAL	16.28 °C	20.73 °C

EQUIPMENT TAG	START/STOP CMD	ENABLE/DISABLE CMD	ON/OFF STATUS	TRIP STATUS	SA TEMP	RA TEMP
CS-PACU-1	DISABLE	ENABLE	ON	NORMAL	19.83 °C	21.22 °C
CS-PACU-2	DISABLE	ENABLE	ON	NORMAL	13.92 °C	20.47 °C
CS-PACU-3	DISABLE	ENABLE	ON	NORMAL	21.87 °C	20.50 °C
CS-PACU-4	DISABLE	ENABLE	ON	NORMAL	16.07 °C	20.64 °C

EQUIPMENT TAG	START/STOP CMD	ENABLE/DISABLE CMD	ON/OFF STATUS	TRIP STATUS	SA TEMP	RA TEMP
CS-PACU-1	DISABLE	ENABLE	ON	NORMAL	20.17 °C	21.21 °C
CS-PACU-2	DISABLE	ENABLE	ON	NORMAL	14.18 °C	20.60 °C
CS-PACU-3	DISABLE	ENABLE	ON	NORMAL	22.02 °C	20.67 °C
CS-PACU-4	DISABLE	ENABLE	ON	NORMAL	16.25 °C	20.76 °C

Figure 145. EcoDomus & BMS real-time values readings

Overall Analysis

The integration process will not use in the breakdown analysis since it's not part of the comparison, but it was an activity with zero cost and 8 hours duration. Thus, after illustrating main three aspects of the capturing techniques (cost, time and quality), it's possible to show the overall information demonstrated in previous parts of this chapter. The figures will show more comparative method of the capturing methods.

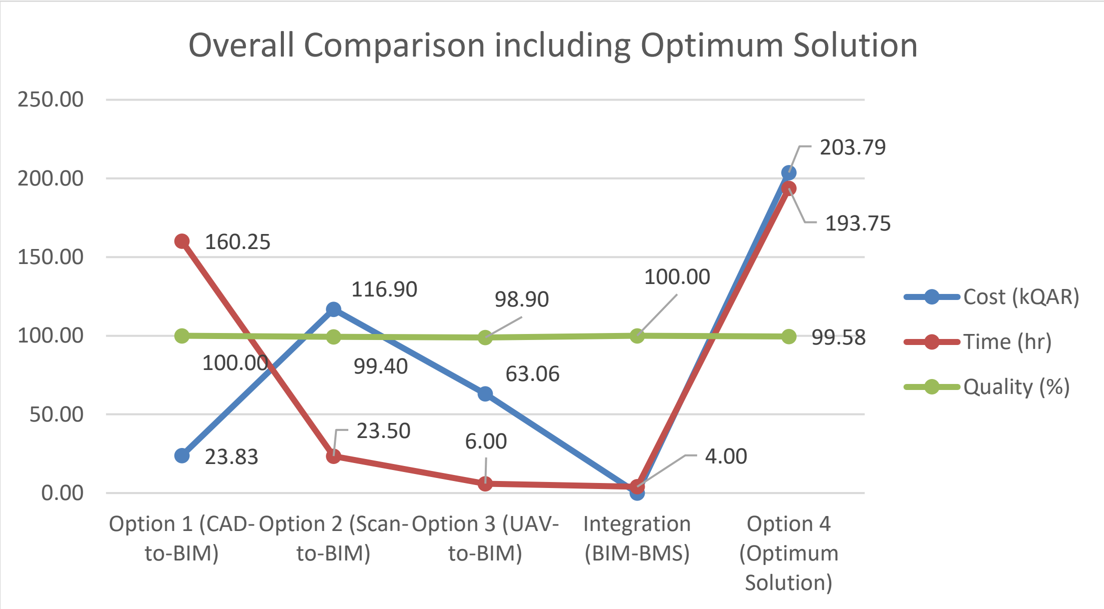


Figure 146. Overall Capturing time options comparison with optimum solution chart

As shown above, the CAD-to-BIM is having the least cost as 24k QAR with highest time and quality as 160.25 hr and 100% within the three capturing techniques. Next, is Scan-to-BIM, which falls and raise dramatically in time (23.5 hr) and cost (116.9k QAR) with a slight reduction in quality by 99.4%. Prior to best option, UAV-to-BIM maintains the lowest 6 hr time along with moderate cost of 63k QAR and quality of 98.9%. Integration process is accompanied with time and quality of 4 hr and 100 %. Optimum solution came with the highest time and cost of 193.75 hr and 204k QAR and average accuracy (quality) of 99.6%.

CHAPTER 6: DISCUSSION, RECOMMENDATIONS & CONCLUSION

In this chapter a general discussion on the process of data collection, processing, cleaning, presentation and analysis will be carried out. Addition to, showing the relation between the study outcomes and Qatar University Digitalization Initiative objectives. Moreover, the general advantages of all results accompanied by the completion of this research. Afterwards, Recommendation section will include few information towards the involved parties along with the Construction industry as a whole. Prior to mentioning the possible options of future work, the conclusion will be illustrated.

Discussion

This research had come with few advantage points to be discussed, such as all the various capturing techniques used nowadays in the industry along with the optimal fourth method, which is a merge of all mentioned ways by including the best practice of each. Also, the proper route of utilizing the BIM model achieved, using the BMS features. Integrating BIM and BMS will acquire the optimal value of any building towards its facility management efficiency, Moreover, BIM 360 Ops with its mobile app and diverse options of maintenance tools, will boost the FM privileges of the BIM 3D model. Reaching the final analysis of all data represented all over the study, for better understanding.

Relation to QU Digitalization Initiative

Below table will show the relation between the 20 QU Digitalization Initiative objectives, and the study results and achievements.

Table 23. Relation Between The Research And QU Digitalization Initiative (Mahmoud Abdulwahed & Hassan El-Rashid, 2017)

S.N.	QU Digitalization Initiative Objectives	Research Related Outcomes
1	Develop digital competency of QU community and beyond	Interacting with all digital capturing techniques in the modern construction industry
2	Deploy digitisations in various aspects of students experience & lifecycle	Capturing occurred in QU, and this study shall take place in any educational activities/curriculum
3	Enhance effectiveness and efficiency of governance	All possible data will be shared with QU Facility Department, addition to the advantages listed
4	Position QU as driver of national digital ecosystem development	Topic and applications of the study are pioneer within Qatar and first to accomplish
5	Develop QU digital competency framework	The study shall be used as a full framework of digital capturing within QU and beyond
6	Embed QU curriculum with necessary digital competency for digital society	Capturing occurred in QU, and this study shall take place in any educational activities/curriculum
7	Integrate QU digital competency framework with existing digital competency	All successful achievements within the research was held and applied on QU assets and systems
8	Establish Qatar Digital Competency Committee between QU	Clear requirements of digital capturing are listed within all parts included in the study
9	Qatar community members participating in digital competency development programs	The study shall be used as a full framework of digital capturing within QU and beyond
10	Integration level with existing digital competency development programs in Qatar	Research outcomes shall be shared in detail with all Qatar developmental programs

11	Develop digitally enabled student's life cycle and experience	Further developments shall take place by other students by the support of the author
12	Develop digitally enabled and enriched research and development	All capturing parameters were taken into consideration, addition to the integration process which is recently new in Qatar
13	Continuously updated digital assets inventory	Shall be done through EcoDomus (BIM+BMS) to ensure optimal results
14	Develop Digitally Enabled University Management, Operations, and Processes	All possible data will be shared with QU Facility Department
15	Optimize Operational Costs and Enhance Revenue Generations through Digitalization	Advantages of the research work will be listed below in this section
16	Develop holistic digital/physical campus framework	This framework is intuitive with latest breakthrough approaches
17	Develop continuous improvement processes for undertaken digital transformation projects	Future works shall take place to continuously develop in the research work; support from author
18	Level of enhancement in operational costs	Advantages of the research work will be listed below in this section
19	Develop Qatar digital ecosystem through digital knowledge and assets into industry	All possible data will be shared with QU Facility Department, to participate work into industry
20	Capitalize on digital transformation developments in QU and Qatar	The study shall be used as a full framework of digital capturing within QU and beyond

Importance of BIM & BMS Integration

Importance of BIM & BMS integration occurred in this study shall be taken into consideration as referred case studies mentioned in “Importance of BIM-BMS integration towards FM”. The commercial outcomes of this study cannot be verified temporarily, since it was the first to be completed in Qatar and it will require time interval to review the cost and spending of the implementation. And since it was newly executed, thus studying the commercial and financial impact of this research work is included in the “Future Works”.

Recommendations

After showing importance of BIM individually and integrated with BMS towards FM, in different locations and project sizes, recommendations shall be listed as below.

Figure 147. Recommendations for the research

Conclusion

This study main objectives, which were listed in the Introduction section, are achieved. Since, this research goals were acquiring a reality captured BIM model in three-dimensional state to be utilized in BMS integration in terms of a framework to be part of QU Digitalization Initiative and beyond. The BIM model was created by capturing the existing building through major well-known techniques (AutoCAD drawings, laser scanning and un-manned aerial vehicle) with highest quality possible, as shown in Data Analysis section; best practice of capturing was explained and described in-depth. The coordinated BIM model was then used in EcoDomus platform to be interfaced with the real-time BMS sensing variables; as part of the main study aim to accomplish a proper BIM and BMS integration. Additionally various tools were introduced to fulfill a wide selective techniques for using BIM in the FM (such as: BIM 360 Ops and Data Repository) prior to fully explain the best practice in terms of cost, time and quality.

The research of existing buildings digitalization through Building Information Modeling was described in chapters 1 and 2. Afterwards, the research route was explained in chapter 3 with all details required. All digital capturing techniques was implemented and explained in detail, in chapter 4, as example: As build 2D CAD conversion to Revit BIM 3D Model, 3D Laser scanning to ReCap and UAV photogrammetric capturing to ReCap Photo. Chapter 5 illustrated all data captured analysis from three main perspectives (cost, time and quality). Reaching, chapter 6, which demonstrated the discussion and recommendations towards research work.

Recapping is that QU Digitalization Initiative objectives are met throughout this study, in order to boost the startup of digital capturing and BIM enabling the existing buildings in the campus. All capturing techniques used are the recent ones in the market, and comparison was done, in order to select the most proper methodology according to the application. Also, the benefits of BIM throughout project planning, execution, close out and operation maintaining were illustrated fully. Few recommendations are listed for reaching better outcomes while utilizing this study as future preference.

Concluding that, after illustrating all possible methods of digital capturing with detailed comparison, this study held a validation methodology for BIM digital capturing through different techniques implemented. Also integrating BIM with BMS shall praise the results and outcomes of FM. Including thermal imaging for building exterior evaluation. These breakthrough approaches, first time in Qatar, shall benefit any operational demand with no respect of the size. Future works shall include few aspects to be discussed or studied on later stage to by any other academic candidate, which will praise the full solution package that is provided in that research.

This study have shown the enormous benefits of the following:

- Combining data management (BIM) and real-time sensing (BMS) in one platform (EcoDomus);
- Centralizing all Building Management Systems of various locations with their BIM model in one platform;
- Managing facility operation and maintenance through EcoDomus mobile app
- Maintenance personnel accessing the malfunctioned items regardless their location with identifying the exact state and place of the needed equipment;
- Interfacing sensing log with required information for further usage;
- Operation and maintenance personnel continuous monitoring of building status;
- Non-COBie or programming integration between BIM & BMS;
- Fully and not partial integration making benefit of all BIM and BMS features;
- Illustrating all capturing techniques in-depth with explaining the best practice;

- Written in framework structure that demonstrate all requisites, processes and outcomes of the work completed;
- The framework shall be used in any similar application within same objectives for individual or organizational approaches.

Future Works

Few ideas shall be used as developmental aspects to this study in the future, within or beyond QU community, as shown below examples:

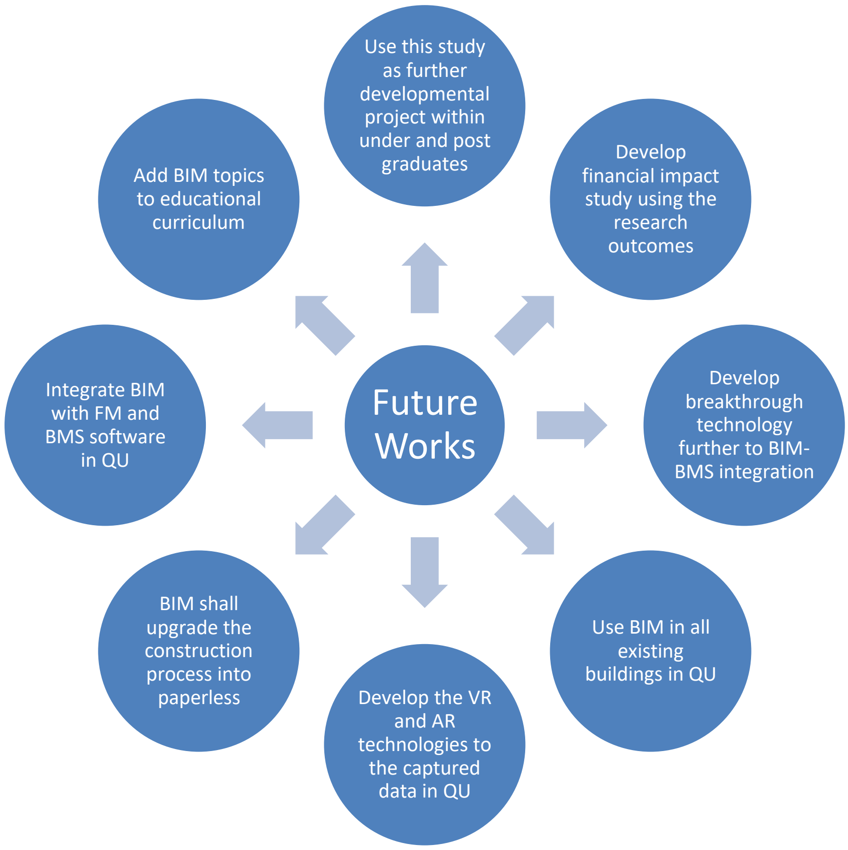


Figure 148. Future works of this research

The most important and crucial future work recommendation shall be utilizing of this study within QU facility systems. Since the current situation is defining decentralized BMS for each individual building, which will have positive effect, but can’t be compared with centralizing the service. After centralizing the service, BIM integration shall occur in order to have the full benefits of the service towards Facility

Management aspects (e.g. Energy savings).

The results of BIM-BMS integration, which was held in the discussion section, is compatible and applicable with QU facility systems, and shall gain the same benefits. This shall be the most critical recommendation for this research.

Other recommendations shall consider integration with other crucial building systems, such as the ones stated in Figure 149.

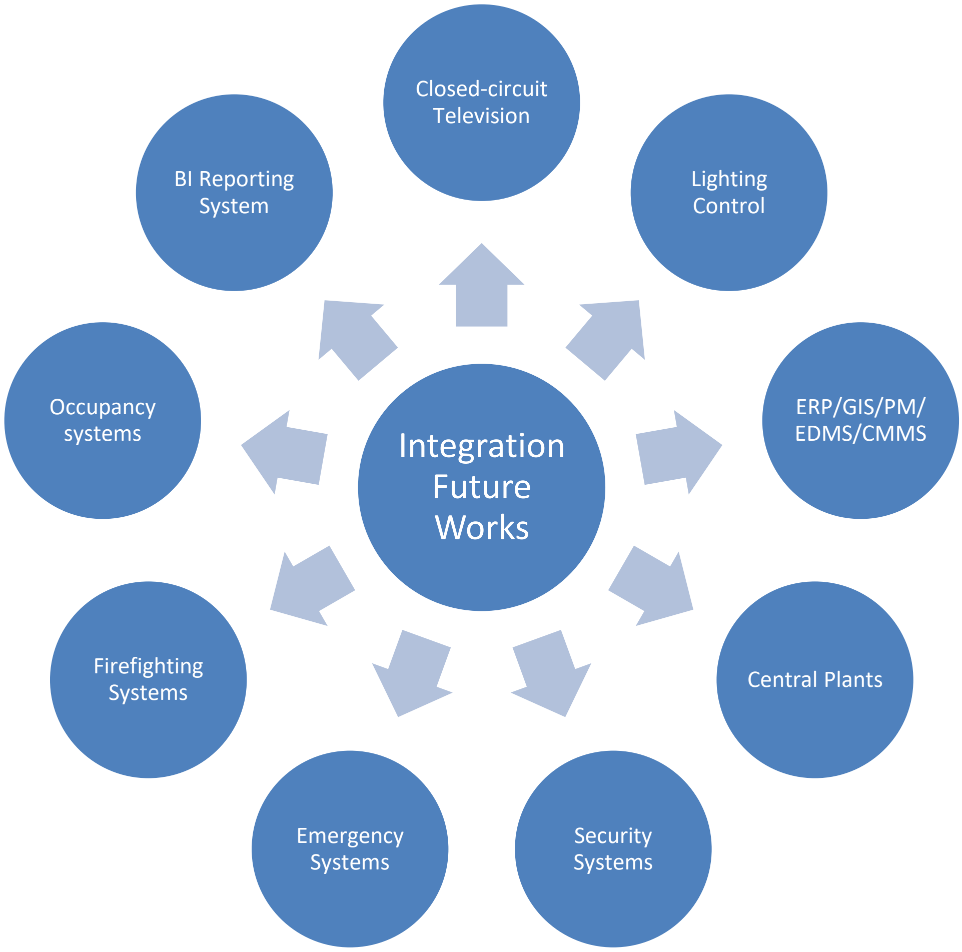


Figure 149. Integration future works of this research

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