POLITECNICO DI TORINO

Master Degree in
Architecture Construction City

Master Degree Thesis

A BIM-GIS Integrated platform for data visualization of building assets

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December 2020

Acknowledgements

I would like to thank my supervisors Prof. Anna Osello and Eng. Matteo Del Giudice for having guided me with their patience and their experience through these unusual months in 2020.Thanks to Monica Dettori which helped me like friends during these time.Thanks to Prof. Massimiliano Lo Turco and Prof. Giulio Tonolo Fabio for having introduced me to BIM and GIS for the first time and for having transmitted this profound interest for it to me through his lessons.Thanks to My wife, for her constant support through the years, for her endless patience even during my hardest times, and especially for her infinite love, which kept me from falling apart. Grazie.

A BIM-GIS Integrated platform for data visualization of building assets

Abstract

In response to the goal of building sustainable cities under the condition of increasing urbanization, the improvement of capabilities in managing building stocks in urban area is becoming an important task. John Wilmoth, Director of UN DESA's Population Division, says “Managing urban areas has become one of the most important development challenges of the twenty-first century.Our success or failure in building sustainable cities will be a major factor in the success of the post-2015 UN development agenda.”(United Nations,2014).The concept such as “smart city” and city “digital twin”(DT) were proposed in recent years. We need to make sure the city leaders are equipped with the data and tools they need to make effective decisions.However, currently in the decision-making stage the high-detailed building data information is usually separated from the low-detailed three-dimensional model when we describe buildings from single building scale to the urban community scale.This separation of building data creates a lot of uncertainties and difficulties to optimize the decision in community level scenario simulation.So in the building management approach one of the challenges is to provide different stakeholders an integration platform at the both urban-scale and building-scale for monitoring and analyzing the behavior of the building stocks.

This thesis proposed a query-based dashboard platform to extract information from the integrated BIM(Building Information Modeling)-GIS(Geographic Information System) data, in which has the ability to summarize building's information on queries and dynamically show graphical representation to all different stakeholders and in this way able to optimize their decision.In order to test and validate the process the case study of FCA Mirafiori, the historic industry district in the southern suburbs of Turin is presented.

Keywords:DT(Digital Twin),BIM(Building Information Modeling),GIS(Geographic Information System).

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1.Introduction

1.1 Background and Objective

In response to the goal of building sustainable cities under the condition of increasing urbanization, the improvement of capabilities in managing building stocks in urban area is becoming an important task. John Wilmoth, Director of UN DESA's Population Division, says "Managing urban areas has become one of the most important development challenges of the twenty-first century.Our success or failure in building sustainable cities will be a major factor in the success of the post-2015 UN development agenda."(United Nations,2014).The concept such as "smart city" and city "digital twin"(DT) were proposed in recent years. We need to make sure the city leaders are equipped with the data and tools they need to make effective decisions.However, currently in the decision-making stage the high-detailed building data information is usually separated from the low-detailed three-dimensional model when we describe buildings from single building scale to the urban community scale.This separation of building data creates a lot of uncertainties and difficulties to optimize the decision in community level scenario simulation.So in the building management approach one of the challenges is to provide different stakeholders an integration platform at the both urban-scale and building-scale for monitoring and analyzing the behavior of the building stocks.

To achieve above goal one of the main technical prerequisites is the need for new methods that able to integrate building-scale and urban-scale data which are got from real landscapes and characterizing the actual condition of ongoing transformations and in this way support the overall design of the community.These representations could become the urban scenarios for simulations and checks both for master plans, architectural designs and building assets management, analyzing their relationships with the built environment.Geographic Information System (GIS) and Building Information Modeling (BIM) offer some possibilities.At the building scale, Building Information Modelling (BIM) is known as a new technology that developed specifically to serve designing activities of the building-scale.BIM focuses on the micro level representation of building components, such as walls, windows, and mechanical, electrical and plumbing (MEP) systems.It is used as a tool for researchers in

Architecture, Engineering and Construction (AEC) fields to collaborate between different parties in order to manage the different level of detailed building information. On the other hand, at the urban scale, Geographic Information System (GIS) technologies provide powerful scalable visualization and spatial analysis.The adoption of GIS has become part of the mainstream in large-scale mapping, from building blocks to geographic regions.GIS provides macro-level descriptions and exact geographic coordinates of an object, such as cities, land, and building landscapes.Therefore given their relative strengths, integrating GIS and BIM data could be very beneficial to support the overall design of the community.With rapid development of technologies, the technique of translation data model between BIM and GIS is evolving fast. For example, several research have attempted to integrate GIS and BIM models, specifically based on Industry Foundation Class (IFC), the major data exchange format in the AECO industry(Niu et al, 2015).And recently the capabilities of GIS software in reading Revit Autodesk(.rvt) format is also developed (Rahman and Maulud, 2019). Most of these research focus on the translation between GIS and BIM data from one data format to another to support spatial visualization.However, there are still limitations in exploiting the data into the 3D analysis and sharing the visualization results to all the stakeholders in the same stage.

This thesis aims to develop a query-based platform to extract information from the integrated BIM-GIS data, in which has the ability to summarize building's information on queries and dynamically show graphical representation to all different stakeholders and in this way optimize their decision.For example, enables designers to inspect their designs information statistics(building opaque and transparent surface area, etc)and compare them with other buildings in the same region, and supports decision maker and community in gathering building simulation data(actual and simulated building heating consumption, etc)to help them form a more comprehensive understanding for different design scenarios.In order to test and validate the process the case study of FCA Mirafiori, the historic industry district in the southern suburbs of Turin is presented.

1.2 Overview of Research Steps

There are four steps for this research.An overview of these steps is shown in Figure 1 and descriptions of each step are described next.

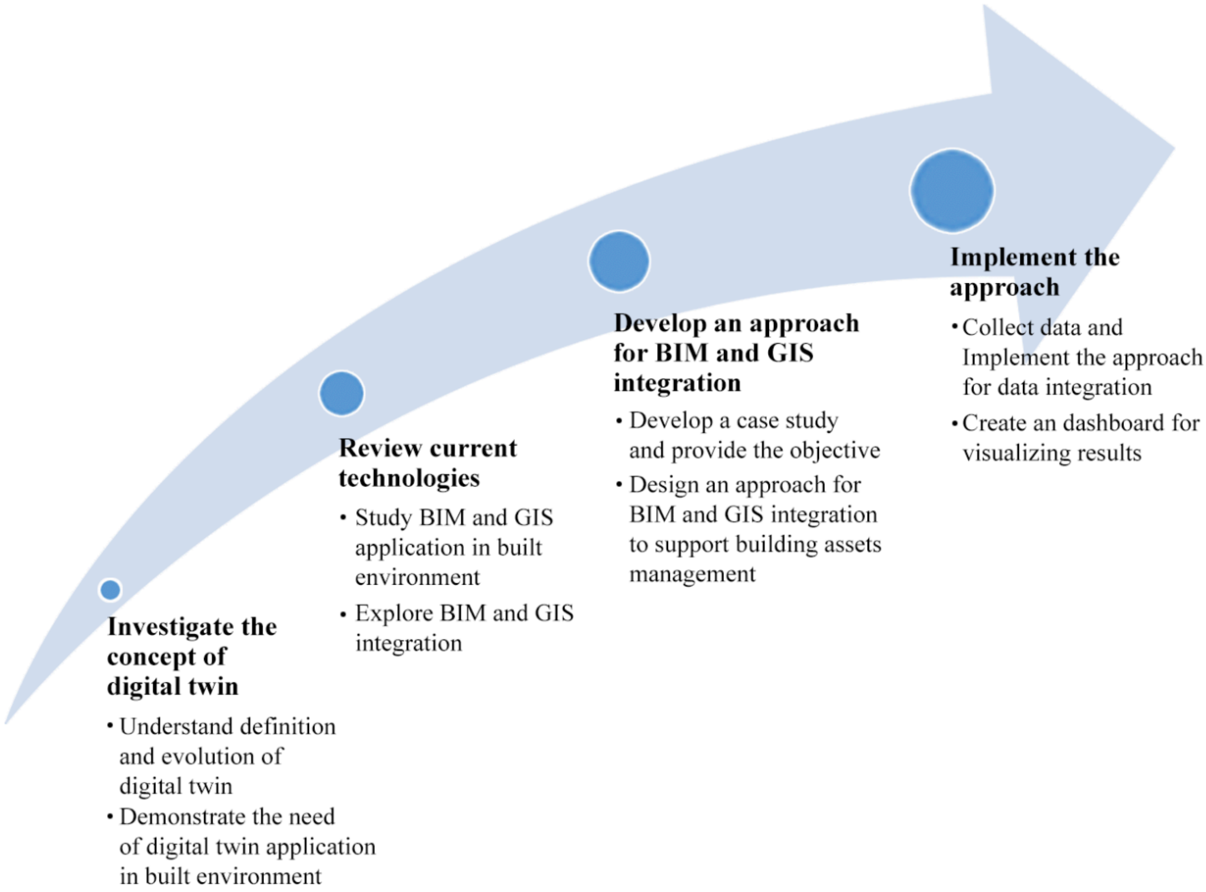


Figure 1. An overview of research steps.

(1)Investigate the concept of digital twin

In this step(Chapter 2.1), aims to investigate the state of art of digital twins concept. Understand the definition and evolution of "digital twin"(DT).Research the current state of DT across the industries and demonstrate the need of DT application in built environment to find ideas on what might become possible in the future cities and find the tools and technologies enable to achieve the DT concept in building assets management.

(2)Review current technologies

This step(Chapter 2.2) aims to review the technologies that can help to address the domain problems, and explore potential solutions. Review the evolution and application of BIM and GIS over the past decades and explore the existing researches on the integrated application between BIM and GIS in order to provide a better understanding of current situation and future direction of the emerging field.

(3)Develop an approach for BIM and GIS integration

Based on the review of BIM and GIS integration methodology, this step(Chapter 3.1) aims to develop a workflow for integrating BIM and GIS in the building assets management process by studying the case study of FCA Mirafiori. A query-based dashboard platform is proposed to research in which has the ability to summarize multiple forms of building's information on queries and dynamically show graphical representation to different stakeholders and optimize their decision.

(4)Implement the approach

The implementation process of the approach which contains three main parts:(1)Data Collection,(2)Data Transformation and Integration,(3)Data Visualization.Four categories heterogeneous datasets are collected.Then transfer and integrate them into the same platform to obtain a single database.Finally, after uploading the dataset and their representation inside the web environment, we can obtain the Dashboard which able to store, handle, visualize and display these information on building assets.In this way we can have graphical and technical outputs that meet the demands of users and implement a 3D visualization and interactive platform oriented to public participation for building assets management.

2.The State of Art

2.1 Digital Twin

The term “digital twin” is now becoming a widely familiar concept used for engineered products, production machines, production lines and built environments.Gartner classified “digital twin” (DT) as one of the top 10 technological trends with strategic values for 3 years from 2017 to 2019(Qi et al.,2018).What does it mean?How does it evolved over time?How will digital twins transform the industry?What value and benefits can digital twin bring to the future cities and how to achieve it?This chapter aims to research the current state of digital twins across the different industries and find ideas on what might become possible in the future cities.

2.1.1 Definition and Evolution of Digital Twin

Digital Twin implementation started approximately in 2010 when NASA adopted its use in their technology roadmaps and proposals for sustainable space exploration. In this report, the “digital twin” (DT) is defined as follows:

> "A Digital Twin is an integrated multi-physics, multi-scale simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin.The Digital Twin is ultra-realistic and may consider one or more important and interdependent vehicle systems, including propulsion / energy storage, avionics, life support, vehicle structure, thermal management / TPS, etc. Manufacturing anomalies that may affect the vehicle may also be explicitly considered”(Shafto et al.,2010).

In the same years, the US Air Force also proposed similar ideas establishing that the “digital twin” would be part of the long-term vision of the USAF for the next 30 years(AFRL, 2011).The general idea was that each aircraft should have a specific associated digital model. And the main goal, by updating the model based on travel and damage suffered, was to determine when structural damage is most likely to occur, thus providing the optimal maintenance intervals.The concept has been proposed for next generation fighter aircrafts and NASA vehicles, along with a description of the challenges and implementation of as-built in order to move a step ahead in solving issues before they occur.This wide implementation in aerospace industry become a flagship to appear as a as a central concept in Internet of Things (IoT). Digital twins are seen to play an important role in the Fourth Industrial Revolution(Alonso et al.,2019).

How does it evolved over time?Strictly speaking, the concept of digital twins is not new.It is recognized that the concept of "digital twin" was firstly introduced by Dr. Michael Grieves in 2003 as part of his research into product lifecycle management at University of Michigan. However prior to Grieves' coinage, industry used terms as diverse as "digital shadows", "digital avatars" and "digital models".For example, General Electric, Siemens and Rolls Royce were designing rotors, turbines and engines with the aid of simulations decades before the term was coined. Similarly, the oil and gas industries have been working with simulations of fuel reservoirs since the 1980s.These kinds of digital representations of a physical object has been used in computer-aided design for over 30 years.From the idea behind these seminal examples, the concept was formalized in 2014, with the publication of Michael Grieves' white-paper on digital twin.The concept contains three main parts: a) physical products in Real Space, b) virtual products in Virtual Space, and c) the connections of data and information that ties the virtual and real products together(Grieves,2014).Since then, with the spread of the concept and the development of new technologies, more and more largest companies use DT to improve production efficiency and the concept is explained more diversified across the industry and academia.Table 1 lays out existing definitions of the DT from key players in academia and industry(ARUP,2019).

SOURCE	DEFINITION
CAMBRIDGE CENTRE FOR DIGITAL BUILT BRITAIN *(Academia)*	A digital twin is a realistic digital representation of something physical.
DASSAULT SYSTÈMES *(Software)*	A "Virtual Twin" is a virtual representation of what has been produced. We can compare a Virtual Twin to its engineering design to better understand what was produced versus what was designed, tightening the loop between design and execution.

DELOITTE *(Consulting)*	A digital twin is a near-real-time digital image of a physical object or process that helps optimize business performance.
GARTNER *(IT)*	A digital twin is a digital representation of a real-world entity or system. The implementation of a digital twin is an encapsulated software object or model that mirrors a unique physical object, process, organisation, person or other abstraction. Data from multiple digital twins can be aggregated for a composite view across a number of real-world entities, such as a power plant or a city, and their related processes.
GENERAL ELECTRIC *(Conglomerate)*	A digital twin is a living model that drives a business outcome.
IBM *(Software)*	A digital twin is a virtual representation of a physical object or system across its lifecycle, using real-time data to enable understanding, learning and reasoning.
MICHAEL BATTY *(Academia)*	A digital twin is a mirror image of a physical process that is articulated alongside the process in question, usually matching exactly the operation of the physical process which takes place in real-time.
MICHAEL GRIEVES *(Academia)*	The digital twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro (atomic level) to the macro (geometrical level). At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its digital twin.
MICROSOFT *(Software)*	A digital twin is a virtual model of a process, product, production asset or service. Sensor-enabled and IoT-connected machines and devices, combined with machine learning and advanced analytics, can be used to view the device’s state in real-time. When combined with both 2D and 3D design information, a digital twin can visualize the physical world and provide a method to simulate electronic, mechanical, and combined system outcomes.
NASA *(Government / Research)*	A digital twin integrates ultra-high fidelity simulation with the vehicle’s on-board integrated vehicle health management system, maintenance history and all available historical and fleet data to mirror the life of its flying twin and enable unprecedented levels of safety and reliability.
SIEMENS *(Conglomerate)*	A digital twin is a virtual representation of a physical product or process, used to understand and predict the physical counterpart’s performance characteristics.

Table 1. Definitions of “digital twins” across the industry and academia(ARUP,2019).

The increasing popularity of DT reflects the inevitable trend that the virtual world and the physical world are becoming increasingly linked to each other and integrated as a whole.In recent years, as more and more researchers devoted to the research of DT, the number of relevant publications begun to grow exponentially(Tao et al.,2018). Later then, to promote the further applications of DT in more fields, Tao et al.(2019) extended the existing 3-dimension DT model(Figure 2) and added another two dimensions (DT data and services) to propose a five-dimension DT model(Figure 3) to promote the further applications of DT in more fields.

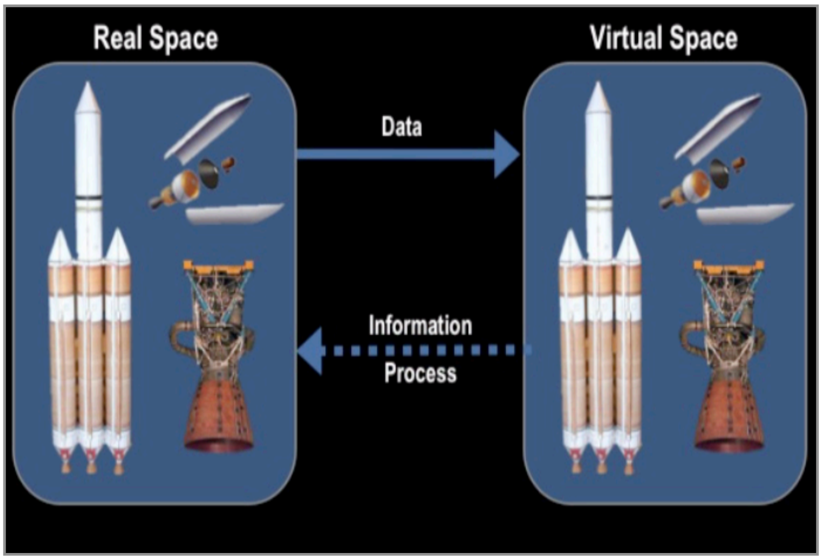


Figure 2. Three-dimensional model of the DT(Grieves,2014).

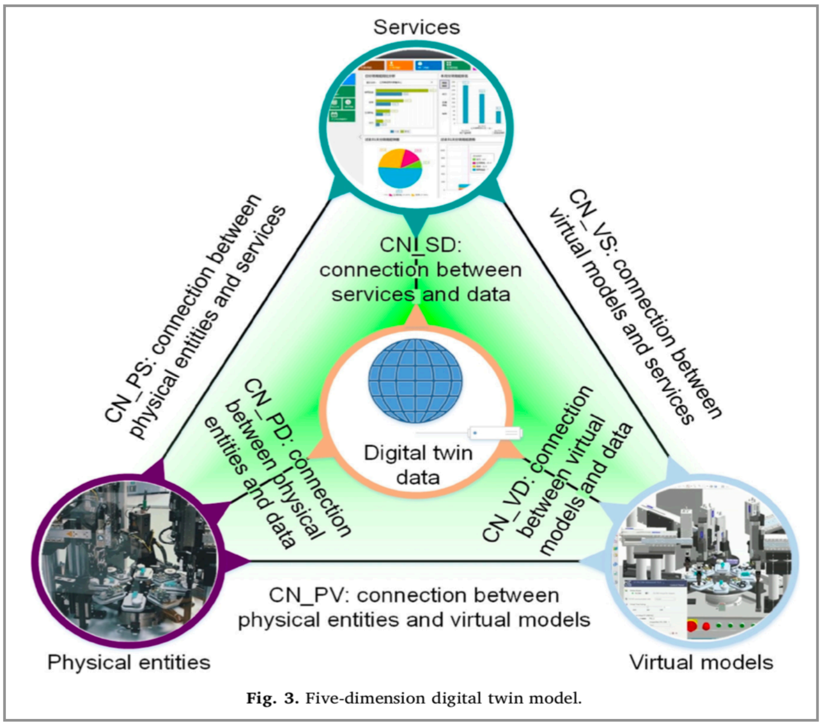


Figure 3. Five-dimensional model of the DT(Tao et al,2019).

Compare to the three-dimensional model, DT data and services are new key drivers in the Five-dimensional model.Firstly, as DT deals with multi-temporal scale, multi-dimension, multi-source, and heterogeneous data. Some data is obtained from physical entities, including static attribute data and dynamic condition data. Some data is generated by virtual models, which reflects the simulation result. Some data is obtained from services, which describes the service invocation and execution. Some data is knowledge, which is provided by domain experts or extracted from existing data. Some data is fusion data, which is generated as a result of fusion of all the aforementioned data.Secondly,Against the background of product-service integration in all aspects of modern society, more and more enterprises begin to realize the importance of service. Service is an essential component of DT in light of the paradigm of Everything-as-a-Service (XaaS).DT provides users with application services concerning simulation, verification, monitoring, optimization, diagnosis and prognosis, prognostic and health management (PHM), etc. And a number of third-party services are needed in the process of building a functioning DT, such as data services, knowledge services, algorithms services, etc. Lastly, the operation of DT requires the continuous support of various platform services, which can accommodate customized software development, model building, and service delivery(Qi et al.,2019).In sum, as we look at the evolution of digital twin, we can see that there are various definitions of digital twin across the industry that includes the promises and value yet to be achieved.And with rapid developments in the field of new technologies, has begun to change presenting new trends and demands.

2.1.2 Application fields of Digital Twin

The DT and its application may vary in scale and complexity with respect to size and scope.Through the integration with mobile Internet, cloud computing, big data analytics and other technologies, DT is potentially applicable for many fields where it involves the mapping, fusion, and co-evolution between the physical and virtual spaces. As shown in Figure 4, the DT applications can be found in smart city, construction, healthcare, agriculture, cargo shipping, drilling platform, automobile, aerospace, manufacturing, electricity, etc(Tao et al.,2019).

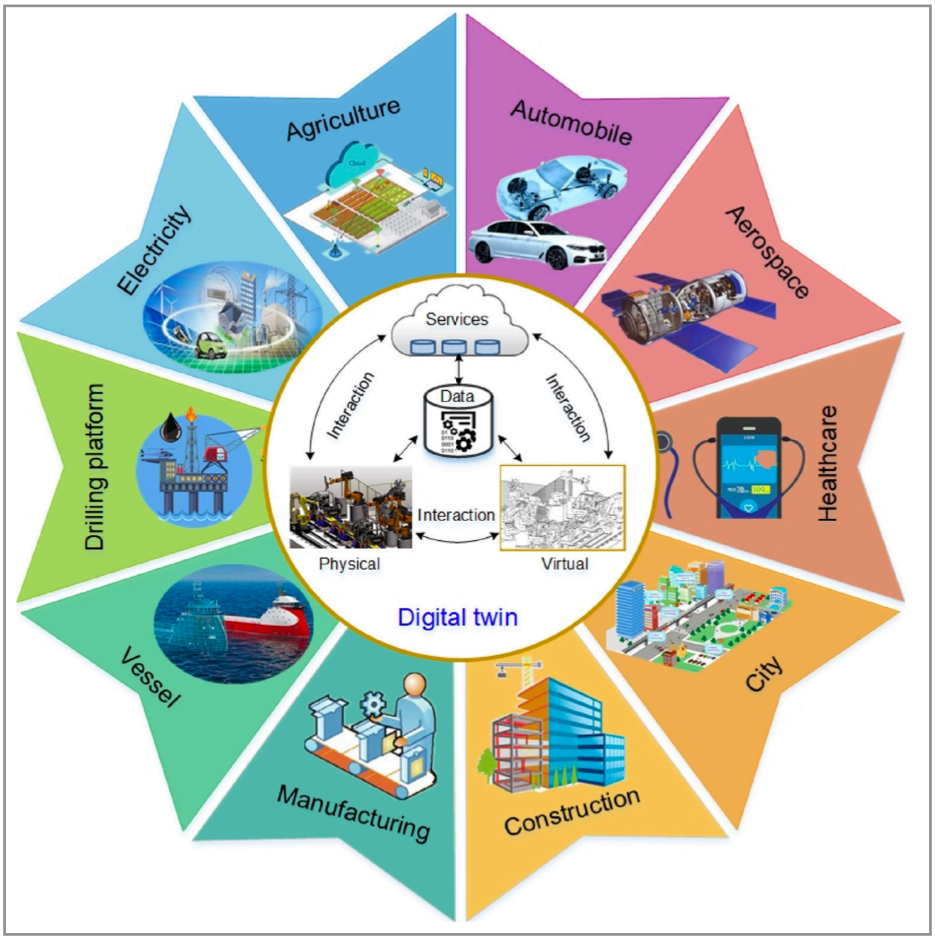


Figure 4. Different application fields of digital twin(Tao et al.,2019).

For example, in automotive manufacturing, Siemens is creating digital twin products to enable realistic simulations to optimize a car before it has been built(Siemens, 2019).Meanwhile, software company such as Microsoft is promoting the use of machine learning and IoT to help companies optimize their operations(Microsoft,2019).At DHL, an international courier service, the employment of digital twins is underway, and the firm is exploring the challenges and opportunities of integrating them into their core operations(Dohrmann et al.,2019).The software industry is creating products to integrate, analyze and manage high-throughput data, targeted at smart cities, product manufacturing and asset management. At the city scale, the Smart City Digital Twin paradigm has been introduced to increase the transparency of human-infrastructure-technology interactions through the exchange of spatiotemporal information(Mohammadi et al.,2017).In the aviation industry, Airbus, Boeing, AFRL, and NASA used DT to mirror actual conditions, identify defects, predict potential faults, and solve the problem of airframe maintenance(Zheng et al., 2019). In the healthcare field, Sim&Cure developed patient-based digital twin for treating aneurysms(Marchal, 2018).Based on the Predix platform,GE built a digital wind farm, by creating a DT for every wind turbine, to optimize maintenance strategy, improve reliability, and increase energy production(GE,2015). All of these examples bringing together the physical and digital worlds which illustrate the state-of-the-art in hybrid digital-physical systems changing environmental and operational conditions.

2.1.3 Digital Twin in Built Environment

As mentioned above, in other industries digital twin-based concepts have been developing over the past decade, especially more intensely over the past few years.However, using a digital twin in the built environment and as a city model is an exceedingly new concept.The use of digital twins in a city concept is a larger vision compared to industrial design.Recent research by C40 shows that urban policy decisions made before 2020 could determine up to a third of the remaining global carbon budget that is not already locked in by past decisions(Erickson, 2015).So the decisions made by the stakeholders involved in the city plan will determine whether the world is on a high or low carbon pathway.Mayors and city leaders are therefore key actors in delivering a just transition to a low-carbon economy(Foxon, 2011).We need to make sure they are equipped with the data and tools they need to make effective decisions. Smart cities and digital twins offer some possibilities.

The concept of the smart city has existed since 2000(Hall et al.,2000).But in fact, there is no generally accepted definition of smart cities that would correspond to the smart cities concept on a global level(Neirotti et al.,2014).The basic idea of a smart city is to effectively use digital technology and big data to deal with urban challenges.Smart cities are exploring the way for the collection of so-called "big data", i.e., simply, cheaply, and efficiently created databases or sensor networks (internet of things, IoT), which collects information from various sources to test and create sophisticated simulations on urban processes and also behavioral aspects of their citizens.Since the 2000s, thanks to the development of new technologies and the exacerbation of the critical issues of the traditional city, the concept of the smart city has received more and more attentions.It provides an intelligent conceptual response to the main challenges that urbanization brings with such as traffic, scarcity of resources, lack of green areas, deterioration of infrastructure, negative effects on human health, management of natural disasters, waste management, energy consumption and air pollution(Dembski et al.,2020). The smart city is becoming a product for the rationalization and technologization of the city.

How to achieve it? The concept of digital twin perfectly into this scenario, providing the smart city with a valuable tool for being truly smart.The promise of the digital twin for city is to help provide a simulation environment, to test policy options, bring out dependencies and allow for collaboration across policy areas, whilst improving engagement with citizens and communities(ARUP,2019). This could be transformative.The digital twin for urban planning has the potential to tackle these issues which concern with urban complexity by visualizing complex processes and dependencies in urban systems.Usage possibilities include simulation of people's movement and emergency evacuation, flood risk representation, smart building design and energy management through occupancy detection, road traffic modeling and simulation, monitoring and forecasting air quality, modeling green infrastructure and simulating a project before it is built, visualizing problems before they become reality.Furthermore, the digital twin favors communication and collaboration between different political areas, taking into account the heterogeneous needs and requirements of its citizens by enabling participatory and collaborative planning. While improving the involvement and commitment of citizens and communities: through the construction of a viewable and inter-actable platform, citizens could propose and understand development options and compromises, and therefore constitute political and community support for positive infrastructure investments.

This is an area ripe for research.For example, in England, the Cambridge Centre for Smart Infrastructure and Construction has established a project entitled “Digital Cities for Change”.The research team is currently developing a digital twin pilot for the Cambridge sub-region in collaboration with local authorities. The Cambridge Digital Twin pilot project will test how isolated policies from transport, housing, environment and energy can be bridged using the digital twin, and quantify some of the interdependencies among transport, air quality housing and energy infrastructure in relation to changes and uncertainties(SCW, 2019).In Finland, by carrying out the project in Kalasatama, a high quality digital twin city models of the Kalasatama area and to share the models as open data was produced. The models serve as a platform for designing, testing, applying and servicing the entire lifecycle of the built environment such as wind simulation which has been recognized by many of the relevant parties already during the regional planning stage.(Figure 5).

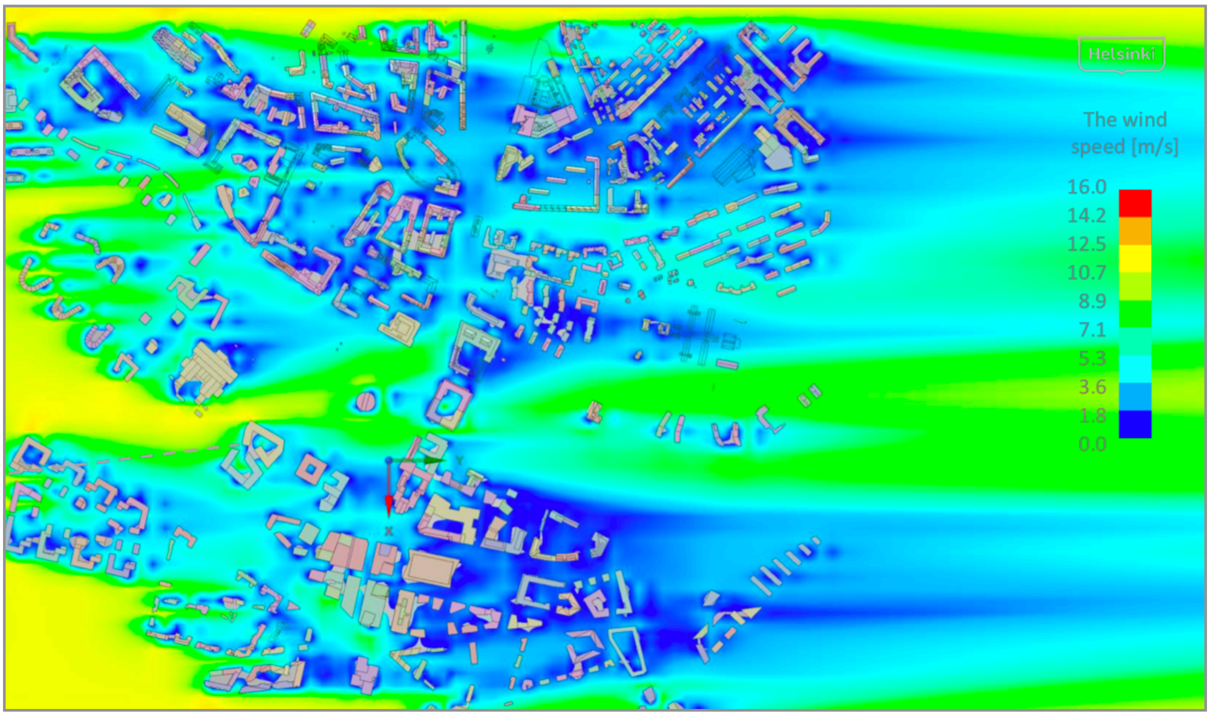


Figure 5. The south wind blows from the left side of the picture (Helsinkl, 2019).

In Asia, "virtual Singapore" was co-developed with the French firm Dassault Systèmes, by leveraging its existing software platform.From bus stops to buildings, Virtual Singapore is a data-rich, live digital twin developed to produce a central platform for the modelling done by different government agencies.It becomes the world's first city-scale digital twin which draws on IoT sensors, big data and cloud computing, combined with 3D models, geospatial datasets and BIM(Dassault, 2017). "Virtual Singapore" offers a platform that can be used by urban planners to simulate the testing of solutions in a virtual environment.The interplay of map and terrain data, real-time traffic, and demographic and climate information show how a single change could affect the lives of millions of people, and the systems they depend upon.And also in Hong Kong Arup is building a city scale digital twin platform to map space, people, and activities in the physical city to a virtual city. The digital twin incorporates GIS, BIM, IoT, cloud computing and AI technologies which is able to monitor, predict and control aspects of the physical city by incorporating a closed-loop data stream(Figure 6). This city scale information model (CIM) platform operating system included the following functionalities:

(1)3D modelling and spatial analysis

(2)Visualization of simulation data and statistics

(3)Building data dashboard

(4)Parametric design module

(5)Real-time data visualization and analysis.

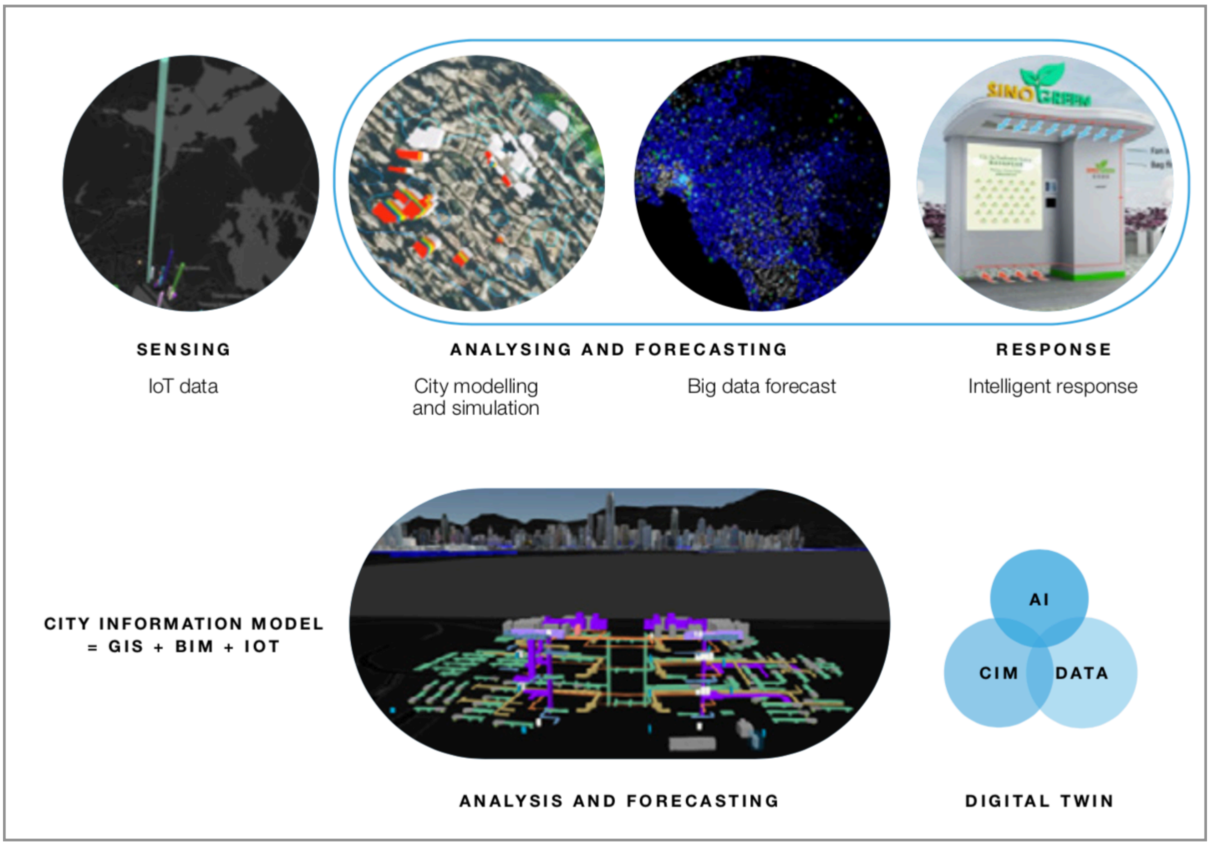


Figure 6. The holistic view of the Neuron City framework(ARUP,2019).

In sum, we can see that originally developed for industrial systems, the digital twin concept is now spreading to the smart cities environment.The digital twin concept and the urban modeling paradigm, are transforming how cities are designed, monitored, and managed. Although until now there are few cases where the digital twin concept is applied in the built environment, it will increase rapidly in the foreseeable future.The installed base of deployments is expected to grow from just a handful of early implementations in 2019 to more than 500 by 2025, according to global tech market advisory firm, ABI Research(ABI, 2019).

2.2 BIM and GIS

As mentioned above we can say “Smart City” and “City Digital Twin” are visions to integrate multiple Information and Communication Technology (ICT) and Internet of Things (IoT) solutions in a secure fashion to manage building assets.The digital infrastructure and its components have to be considered in a holistic approach for all planning and execution work.It needs mass data, both static and dynamic, current and historical, geometrical and semantic, microscopic and macroscopic etc.Once collected, management and application of these data often use technologies such as Building Information Modeling(BIM) and Geographic Information System(GIS).On the technical side, integration of BIM models in GIS or geospatial data from GIS in BIM authoring systems is an essential requirement for the evolution of integrated workflows.Authoring systems of GIS and BIM data are technologically different and designed for different purposes.But on the practical level grows the need to process the results of each system in joined workflows.In building-scale,BIM can be used to create, manage and share the lifecycle data of vertical facilities such as buildings while in urban-scale GIS can be used to store, manage and analyze data describing the urban environment, which is horizontally distributed(Figure 7).

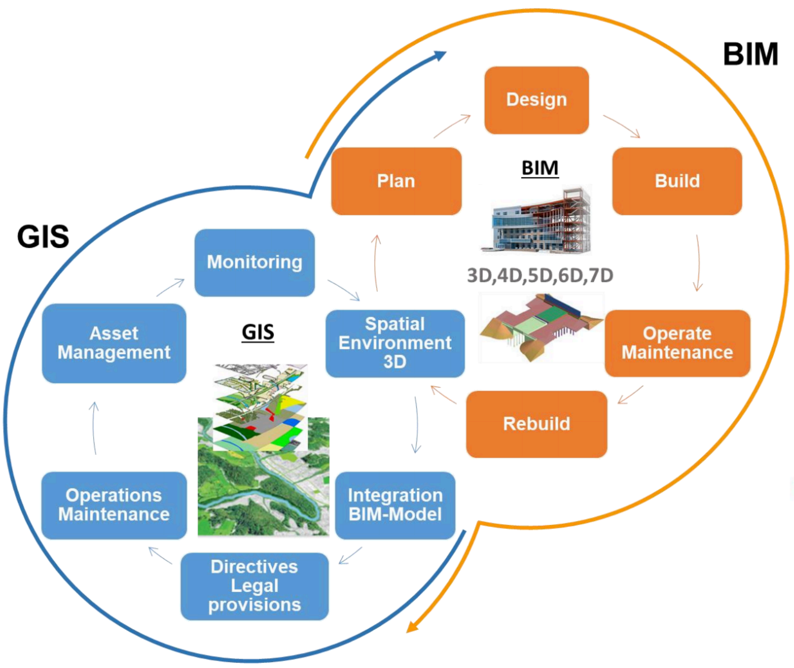


Figure 7. BIM and GIS authoring Systems interacting in infrastructure lifecycle (DR.A.Carstens, 2019).

Hence, integrated application of BIM and GIS is essential in “Smart City” and “City Digital Twin” applications where data of both facilities and urban environment are required.This chapter aims to review the evolution and application of BIM and GIS over the past decades and explore the existing researches on the integrated application between BIM and GIS in order to provide a better understanding of current situation and future direction of the emerging field.

2.2.1 Overview of BIM

Over the past 20 years,Building Information Modeling (BIM) has transformed the Architecture,Engineering, Construction(AEC) industry and attracted increasing attention from researchers and practitioners (Zhao, 2017).The most accepted definition of BIM is given by National BIM Standard-United States(NBIMS-US) project committee as “a digital representation of physical and functional characteristics of a facility”(NBIMS-US,2016). Where did it come from?The concept of BIM is not attributed to one person but is a rich history of innovation from the United States, Central and Northern Europe. All these engaging stories come down to the race to create the perfect collaborative solution to disrupt the 2D CAD work flows (Bergin, 2012).Technological limitations have often prevented visionary ideas from becoming a reality as soon as they were dreamt up, and the same was true of BIM. The conceptual basis of the BIM system go back to the earliest days of computing when thinkers imagined using computers and software to capture the visual design and technical specifications of buildings in a way that would be easy to adjust and adapt as needed.In 1962, Douglas C. Engelbart gives us an uncanny vision of the future architect in his paper Augmenting Human Intellect:

> “the architect next begins to enter a series of specifications and data–a six-inch slab floor, twelve-inch concrete walls eight feet high within the excavation, and so on. When he has finished, the revised scene appears on the screen. A structure is taking shape. He examines it, adjusts it… These lists grow into an evermore-detailed, interlinked structure, which represents the maturing thought behind the actual design.”(D.C.Engelbart, 1962)

Engelbart suggests object based design, parametric manipulation and a relational database.However, computers, databases, and other necessary IT infrastructure just didn’t exist in the same way it does now.Though people had the idea of BIM, they were forced to wait for technology to catch up.Then the idea of “Building Description System”(BDS) was developed in the 70’s.In 1975 Charles M. Eastman, published his description of a working prototype described a system that is very much like modern BIM in the AIA Journal.The article described interactive defined elements where information about maps, facades, perspectives and sections are combined in the same document. Each alteration only had to be made once and thereafter was altered in all other drawings. Details about costs, the required materials and supplies became easy to generate.Eastman’s paper basically described BIM as we know it now.And in 1977, Charles Eastman created GLIDE (Graphical Language for Interactive Design) in the CMU Lab and it exhibited most of the characteristics of the modern BIM platform.In 1986 RUCAPS(Really Universal Computer-Aided Production System) was used to assist the renovation of Heathrow Airport’s Terminal 3.It is commonly accepted as the software that kickstarted the history of BIM by the academic circles and regarded as a forerunner to today’s BIM software (Eastman et al, 2008).In 1982, Gábor Bojár started developing ArchiCAD and making ArchiCAD the first BIM software available on a personal computer (Bergin, 2012).Then Irwin Jungreis and Leonid Raiz developed an architectural version of Pro/ENGINEER that could handle more complex projects than ArchiCAD.By 2000, they had a program called Revit, a made-up word that’s supposed to connote revision and speed.Revit used a parametric change engine made possible through object-oriented programming, and by creating a platform that allowed time attribute to be added.This enables contractors to generate construction schedules based on the BIM models and simulate the construction process.As software boomed and started to bleed into all industries in the early 2000s, this led to the maturation and mainstream adaptation of BIM technologies.The term BIM appears for the first time in 2002, in the white paper published by Autodesk entitled "Building Information Modeling”(Autodesk, 2002).

However, nowadays although BIM is popular across the world, the average application of BIM is still at a low level.Some clients and constructors are not aware of the differences between BIM and CAD and underestimate the value of BIM.This situation has been improved since the UK government introduced its goal to achieve Level 2 BIM and made mandatory for all centrally-procured construction projects, which means that the entire AEC industry was quickly forced to adapt not to be left behind in the process since 2016.There are four levels of BIM application(Figure 8).They are Level 0 (2D CAD drafting only is utilized), Level 1 (a mixture of 3D CAD for concept work, and 2D for drafting of statutory approval documentation and production information), Level 2 (collaborative working and information change through a coordination process) and Level 3 (iBIM which creates international open data' standards, establishes a new contractual framework, creates a cooperative cultural environment and trains the public sector client to use BIM).The results of a survey conducted in 2013 indicate that 47% of companies claimed that they had already reached Level 2 and some companies even claimed that they had arrived at Level 3 (NBS, 2013).This already had the result of positively increasing the awareness of using BIM and the adoption of BIM raised from 48% in 2015 to 54% in 2016.

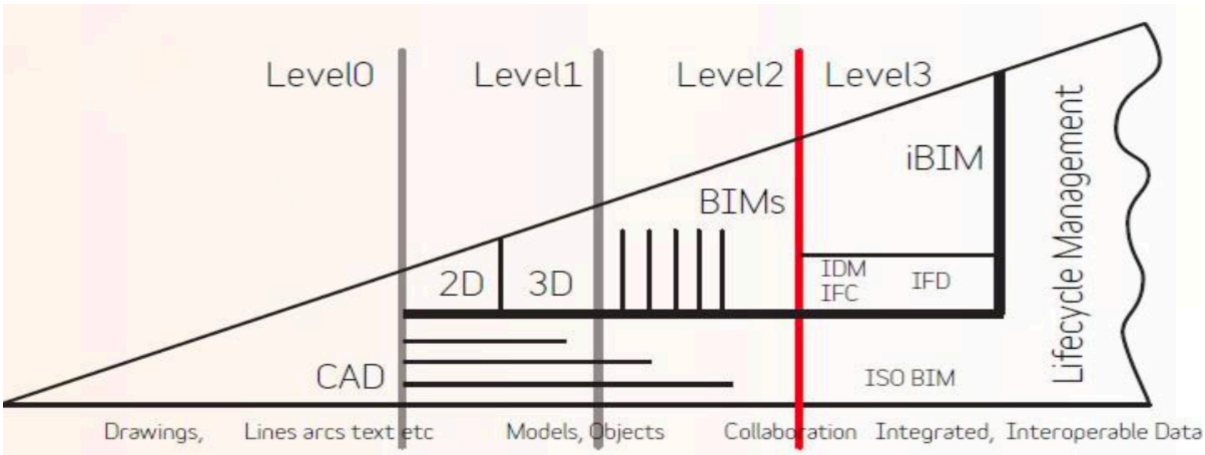


Figure 8. Levels of BIM (NBS, 2013).

After summarizing the historical development of BIM in the past few decades, it also worth to conclude the importance of BIM which is not only as a software technology and design tool, but also a project management tool and process consisted of all aspects, disciplines, and systems of a facility within a model(Figure 8), with which all stakeholders (owners, architects, engineers, contractors, subcontractors and suppliers) can collaborate more accurately and efficiently than traditional processes (Azhar et al, 2012).According to a white-paper from Autodesk (2002), BIM not only benefits for faster delivery and lower cost, but also results in better quality work during the phase of design, construction, and operation.BIM can benefit in many areas for its multi-functional characteristics.Traditional processes used to design construct and manage buildings often generate unexpected cost increases and delays during both the design phase and the construction phase, not to speak of the many errors that occur due to poor or no communication between the various professionals involved and the documents that they produce(Eastman et al., 2011).This is because of the traditional approach to buildings construction and delivery methods, which are based on paper communication, silos like subdivision of disciplines and unnecessary repetition and rewriting of information(J.Eynon, 2016).These repeated activities have always been a potential source of errors and misunderstandings, leading to errors, data loss, delays and wasted money.

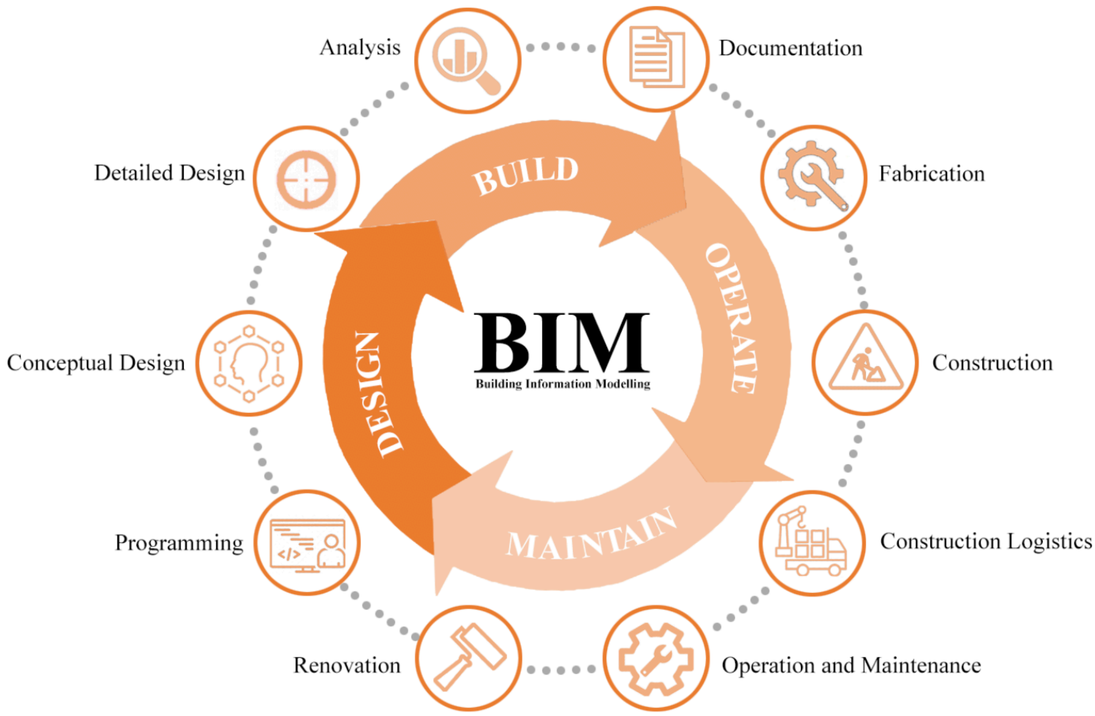


Figure 9. Integration of BIM between various project's area.

Moreover, those discipline-specific analyses often happen to be carried at the end of the design phase, when most of the important changes are more difficult to realize, which means that they are also more expensive and time-consuming to perform.While BIM process draws the project different stakeholders together earlier so that the individual parties can coordinate their design input, encouraging a more integrated approach to project design and delivery.For example, during the early virtual design stage, architects and engineers can build a virtual model in a 3D environment which provides an initiative view of design drawings. The combination of 3D presentation of building geometry information and spatial relationships and other information embedded in building objects, such as quantities and properties of building objects can detect design defects easier (Li, 2016).Additionally, 4D BIM which covers schedule information allows people to “build buildings twice", which means that people can first construct a virtual construction on-screen and then build it physically on-site when the project begins.In this way different project stakeholders can pay more attention on the beginning of the whole life cycle.The clearest way to see and understand this benefit of using BIM we can take a look at the MacLeamy Design Effort/Effect curve diagram(Figure 9) which highlights that the further you are through the design process, the higher the cost of design change will become.BIM advocate shifting design effort forward in the project and front-loading it in order to reduce the cost of design changes compared to the traditional delivery methods, in which the effort increases slower, but peaks later, when construction documentation needs to be produced.

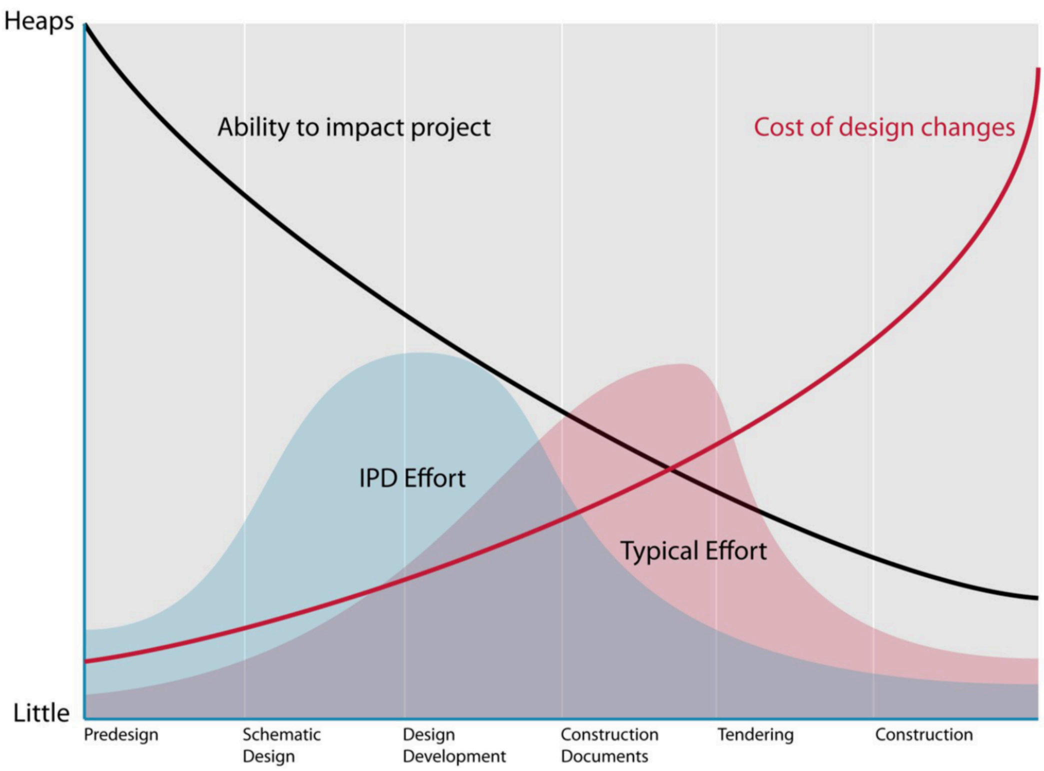
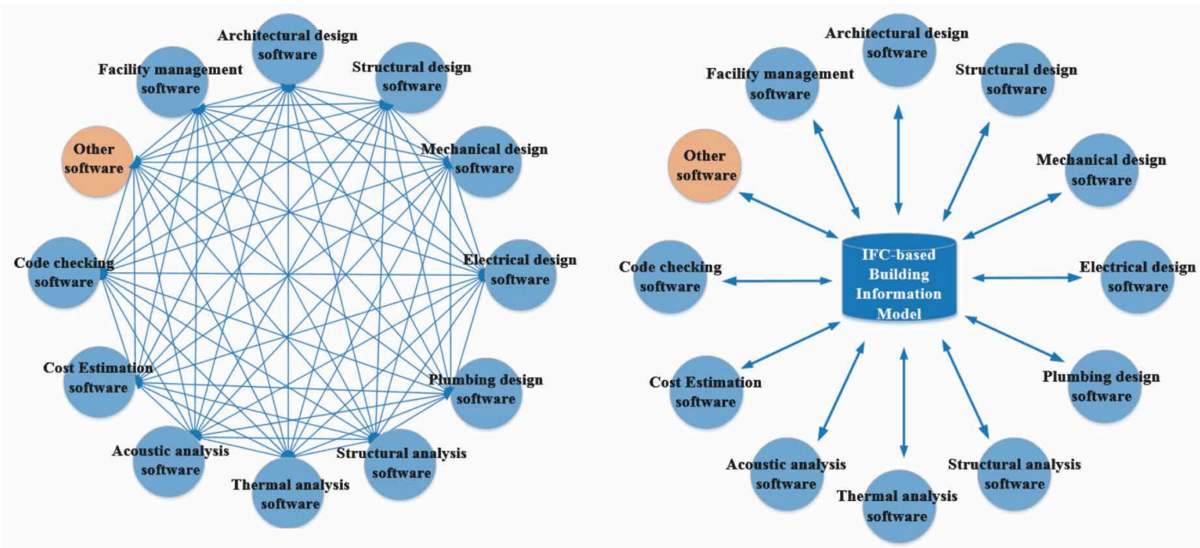


Figure 10. The MacLeamy curve diagram(A. Pollara, 2017).

Another important advantage of BIM is the standardization of files and its information, enclosed in the concept of Interoperability with the aim of not losing or distorting the information exchanged between the various operators.Among various BIM standards,Industry Foundation Class(IFC), developed by buildingSMART, is the major data exchange format to facilitate building data interoperability in the AECO industry.IFC conveys all information needed to construct a facility, such as dimensions, materials and other attributes.It is basically an open file format that allow the exchange of information among different licensed software such as Revit, Archicad and ALLPLAN, facilitating the interoperability between them.For example, a structural engineer imports the architectural model for structural design and analysis, and then exports a new model to the architect for collaborative design. IFC schema acts as a medium for bidirectional data sharing and exchange between heterogeneous software(Figure 10).According to a non-exhaustive survey, over 200 software tools have import or export capabilities of IFC data models (BuildingSMART, 2013).After two decades of development, IFC has become a standard for data interoperability between heterogeneous software tools (Olawumi et al. 2017).The development of IFC has played the most potential part of BIM—interoperability, which is also the basis for its extensive development.



(a) Traditional method.

(b) BIM-based method

Figure 11. Data interoperability between various software tools(Lai and Deng, 2018)

The BIM benefits itself also in the graphical display of the model in which it is possible to establish for every object and for the whole model a level of detail in its visualization.The LOD(Level of Development)concept is introduced in BIM to enable construction players to specify and articulate with a high level of content clarity as well as reliability of the 3D models at various stages.LOD is associated with Level of Detail(Lod) which defines the amount of details included in the building model elements.On the other hand, LOD is the degree to which the element's geometry and related information regarding the components have been thought by construction players when using the model.It means that LOD is the degree to which project team members could rely on the information while using the model. In essence, Level of Detail is an input to the element, while LOD defines reliable output(AIA, 2013).Furthermore, it allows model users to define the use of the building models, as well as to allow construction players to clearly understand the usability and the limitations of the received building models.There are five levels of LOD, which consist of LOD 100, LOD 200, LOD 300, LOD 400 and LOD 500. These levels are covered from conceptual to as-built and facility management.The information on each LOD characteristic is shown in Figure 12.

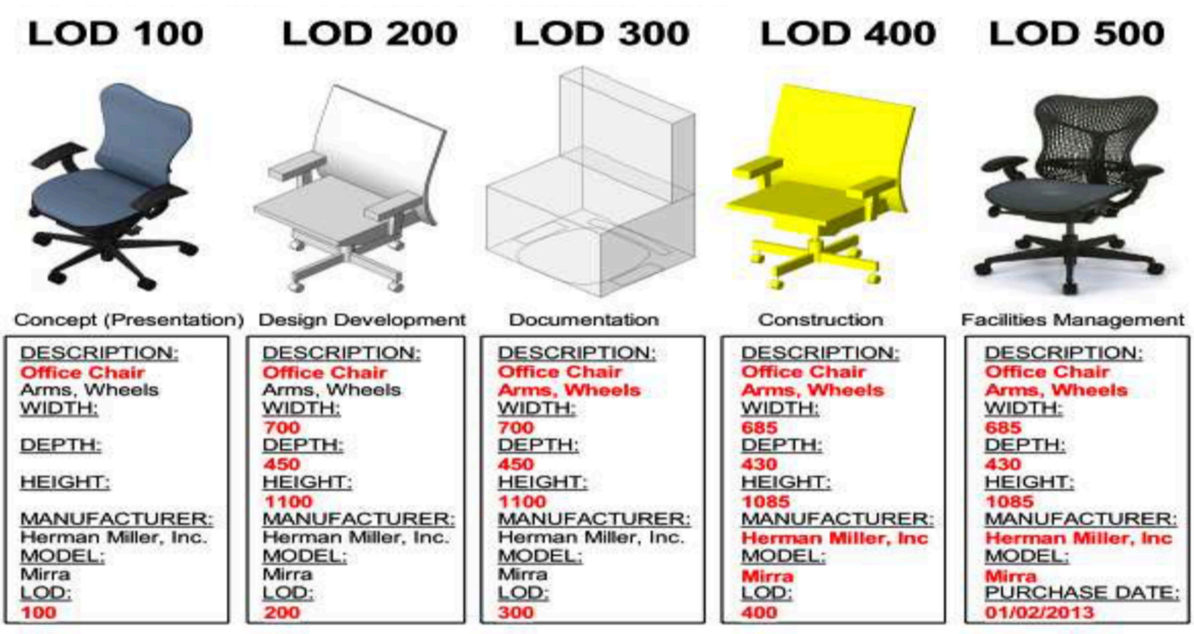


Figure 12. The Level of Development(Latiffi, A.A, et al, 2015).

Each level represents specific content requirements, authorized use of the model as well as specific purpose of the model.LOD 100 is a conceptual level.The model elements is represented graphically in a symbol.The information in LOD 100 is usually used for project pre-planning, feasibility studies and basic cost estimation.From the development of LOD 100, it can derive other information for LOD 200 such as width, depth, height as well as the manufacturer of the product.LOD 200 is a design development of a product.The building model elements in LOD 200 are represented as generic systems, object with accurate quantity, size, shape, location as well as the orientation of the product.At this level, performance analysis could be conducted to determine which building model elements to be used.The next level of LOD is LOD 300 where it is on the documentation of a product.Apart from that, LOD 300 also consists of a non-graphic information such as estimating and scheduling.Moreover, LOD 300 is more precise in terms of their quantity, size, shape, location as well as orientation as it is defined by the client.Specific details on the performance aspect of the components may be added with necessary information defined by client in order to develop construction documents.From LOD 300, it can develop detailed information for LOD 400 which is a fabrication of elements.LOD 400 is compatible with the construction of the product and more suitable for fabricators and contractors.It is because the model elements in LOD 400 are represented as a specific system and object that consist detailing of orientation, fabrication and installation information.Lastly, LOD 500 is represented as as-built model that consists of information needed in facility management.LOD 500 could be considered as a fully accurate digital representation of a manufactured product.

2.2.2 Overview of GIS

Geographic Information System (GIS) is a computer based information system used to digitally represent and analyze the geographic features present on the Earth' surface and the events that taking place on it.It was introduced in the 1960s to meet the needs of state management in some developed countries, such as the United States and Canada.It is an extension of cartography—the science of making maps—and allows individuals to visualize, analyze, question, and interpret data.It can provide excellent decision support to bridge the gap between the requirements and the reality.A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information.These data contain both thematic and geometric (spatial) information which can be represented in raster or vector form.In other words, GIS is both a database system with specific capabilities for spatially referenced data as well as a set of operations for working with the data.It may also be considered as a higher order map.Nowadays GIS is widely used in local and regional planning for managing, integrating and visualizing spatial datasets.

There are different definitions for Geographic Information System, each developed from a different perspective or disciplinary origin.Defining a GIS can be done by either explaining what it can do (Functions) or by looking at the components.An analysis of the three letters of the acronym GIS gives a clear picture of what GIS is all about:

G—Geographic: Implies an interest in the spatial identity or locality of certain entities on, under or above the surface of the earth.

I—Information: Implies the need to be informed in order to make decisions. Data or raw facts are interpreted to create information that is useful for decision-making.

S—System: Implies the need for staff, computer hardware and procedures, which can produce the information required for decision-making that is data collection, processing, and presentation.

The first application of the concept was in 1832 when Charles Picquet created a map representing cholera outbreak across 48 districts of Paris.This map was an early version of a heat map, which would later revolutionize several industries.Inspired by Picquet,John Snow adopted the same principle to depict cholera deaths in London in 1854.He evolved the concept by presenting an argument developed from a spatial analysis of data.In the early 20th century, a printing technique called photozinco-graphy was introduced, which allowed users to separate layers from a map.This meant different themes could be printed, but this did not represent a full GIS since there was no opportunity to analyze mapped data.

When was the term GIS first used?The concept of GIS was first introduced in the early 1960s, and it was subsequently researched and developed as a new discipline. The GIS history views Roger Tomlinson as a pioneer of the concept, where the first iteration was designed to store, collate, and analyze data about land usage in Canada.The second phase of development in GIS history occurred throughout the 1970s, and by the 1980s the concept progressed as national agencies adopted it, and invested parties began determining best practice. By the late 1980s, there was a focus on improving the usability of technology and making facilitates more user-centric.There is little widespread information available on how the technology has been adopted and deployed. Those pursuing development in the field of GIS had different goals, meaning there was no set direction for research to follow. A single path finally surfaced when GIS became the focus of commercial activity with satellite imaging technology. Mass applications were thus initiated for business and private use.As the system continuously advanced in Canada throughout the 1970s and 1980s, by the 1990s it was driven by mainframe hardware, with data sets from the entire Canadian landmass.Throughout the 1990s, software company Esri released ArcView, a desktop solution for mapping systems. The influx of the Internet saw widespread adoption of GIS heading into the millennium, and the technology reached governmental authorities.In 1994, the Open Geospatial Consortium (OGC), an international voluntary consensus standards organization was established.Until now in the OGC, more than 500 commercial, governmental, nonprofit and research organizations worldwide collaborate in a consensus process encouraging development and implementation of open standards for geospatial content and services, sensor web and Internet of Things, GIS data processing and data sharing.In 2004, inspired by the success of Wikipedia and the difficulty of obtaining free geographic data, OpenStreetMap was born, a collective project for the creation of a free and editable map of the planet.The geo-data underlying the map are considered the primary output of the project, and are freely downloadable.The release of Google Earth and Google Maps in 2005, and the subsequent release of numerous other mapping sites and virtual globes, enabled users to leverage a powerful means of disseminating data.Hundreds of thousands of such additional sources are now available, although their value lies more in visualization than in systematic analysis.GIS has evolved into a technology that supports a wide range of activities, from scientific research to management, but has not yet reached its full potential as a platform for studying alternative futures and for designing landscapes that achieve certain goals.

Finally, the trend towards continuous monitoring, in real time, towards which the "geographical world" is moving, will require technologies that are more focused on dynamism and change, rather than on a photographic vision of the present.These challenges, which Good-child in 2009 indicated as the future objectives of GIS, are at the center of today's technological developments: Google Maps, as well as other specific applications, already allow some functionalities in real time, such as displaying the presence of public transport and their arrival time, taxis nearby, shop opening hours.

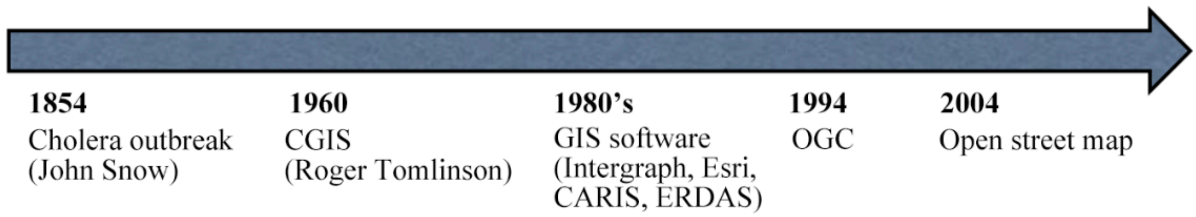


Figure 13. GIS milestones:from a concept to a science.

On the other hand, GIS also have various different modern applications.The practice of GIS has been growing and the number of GIS users has increased significantly. The main strength of GIS lies in its capability to assimilate different types of data with a geographic component.It provides integrated solutions for different areas(Shasmi, 2005).As GIS can handle different types of data in conjunction with geographic information, it can be effectively used as a decision−making tool to help in better communication and cooperation among various stakeholders and better project management.Working with GIS has remarkable benefits among vertical application domains(Table 2).It can Identify problems—to highlight issues that are driven by geography;Monitor changes—to map temporal trends;Manage and respond to events—to deliver real-time situational awareness;Perform forecasting:—visualizing the outputs of forecast models;Set priorities—help to set priorities based on spatial analysis;Understand trends—helps you gain insight into data that might be missed in a spreadsheet.

By Subject	By Industry
Business and Economy	Business
Disasters and Humanitarian	Education and Research
History and Culture	Government
In the News	Health & Human Services
Infrastructure and Construction	International Organizations
Nature and Conservation	Journalism and Media
People and Society	Libraries and Museums
Planning and Design	Natural Resources
Science and Technology	Non-profits and NGOs
Sports and Entertainment	Transportation
Travel and Recreation	Utilities

Vertical Application Domains

Table 2. GIS application domains.

In general, A working GIS integrates four components:(1)Data—GIS integrates many different kinds of data layers using spatial location.GIS data includes imagery, features, and base maps linked to spreadsheets and tables.(2)Analysis—Spatial analysis evaluates suitability and capability, estimate and predict, interpret and understand.(3)Maps—Maps are the geographic container for the data layers and analytics to work with. GIS maps are easily shared and embedded in apps. From printed maps to live maps.(4)Software—To manage the data, perform the analysis, set-up the map layouts and share the results. For mobile phones, tablets, in web browsers and on desktops.However, the complete collection of these information is not easy because a city in itself is very complex and a 3D city is in general a vast collection of features, networks and surfaces(Reitz and Schubiger-Banz, 2014).To transform this huge amount of data into useful information and support future developments and applications, it is needed to structure 3D data into a geometric and semantic data model (Prandi et al, 2015). Although there are many possibilities, it is considered as prerequisite that all data must be converted to an information model of CityGML on the back-end since CityGML provides an open common platform to integrate city level information from different resources.

CityGML is a common information model for the representation of 3D urban objects (OGC, 2012). It is realized as an open data model and XML-based format for the storage and exchange of virtual 3D city with all its appropriate information.It covers broad thematic fields of city objects: geometrical and topological aspects can be accurately described and linked with their semantic part (Prandi et al, 2015).3D models incorporate a very important aspect in their visualization, namely appearance i.e. the observable characteristics of their surfaces.Semantics and geometry modeling obeys to a coherent model with two hierarchies in which objects are linked, this way it is possible to query/analyze the city model either by thematic or geometrical object properties or both simultaneously (Kolbe, 2009).

CityGML extends the GML standard with semantic and appearance aspects of 3D city models and introduces the concept of Levels of Detail (from LOD0 to LOD4) in which objects become more detailed, both geometric and thematically, while the LOD increases (Kolbe, 2009).Meanwhile, the CityGML files can contain multiple representations for each object in different LODs simultaneously and show the generalized objects over different scales (Mao et al., 2012) according to the needs of users.

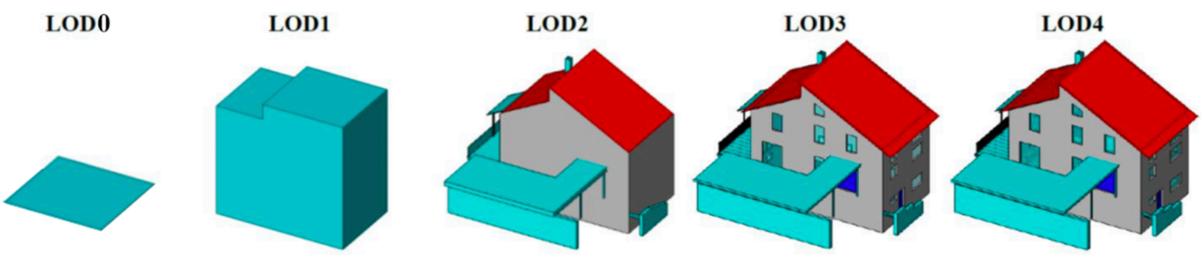


Figure 14. Five Levels of Detail (LOD) defined in CityGML (Gröger et al, 2012).

Specifically,LOD0 explains the footprint of the building in 2.5D and always used for regional and landscape scale representation.Models with LOD1 are basically referred to as the block model with flat roofs.LOD2 is a basic block model with a different roof style(flat or slop). LOD3 and LOD4 models incorporate windows and doors which have close exterior views, while their internal components are quite different.LOD4 contains interior spaces and interior walls. However, the building model in CityGML is less complete and mature as in BIM, even in LOD4 (Amirebrahimi et al., 2016).

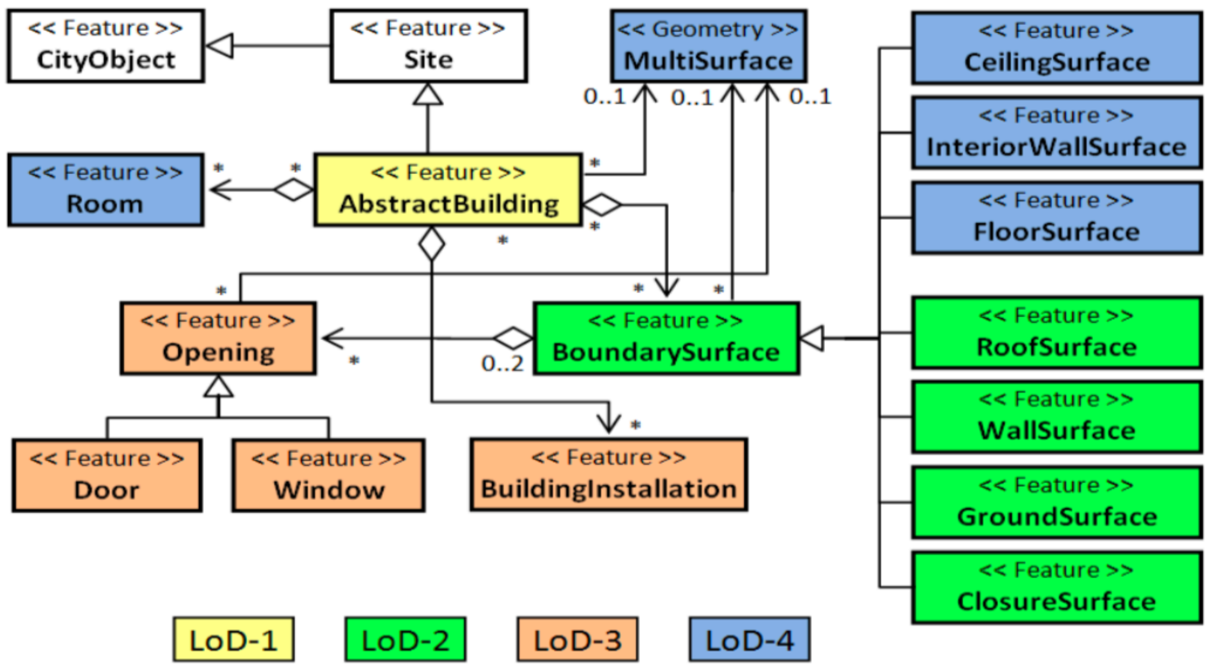


Figure 15. CityGML building model (El-Mekawy et al. 2012).

However, although in this way it is possible to render 3D views directly from CityGML, a client may still have difficulty visualizing several of Gigabytes, which includes fully textured buildings models, a terrain model and aerial imagery(Rodrigues et al., 2013).Hence, CityGML models are essential to represent and analyze 3D city objects, but not to present or visualize 3D city models directly.Additionally, the detailed and complex structure of CityGML based on heavy XML causes pressure for efficient visualization of CityGML files since reading XML based schemas is complex in JavaScript applications (Gaillard et al., 2015, Mao et al., 2012). In order to visualize CityGML data on the web, parsing methods capable of retrieve information from CityGML and recode it to a more presentation friendly format, namely X3D, JSON and KML/COLLADA, are used (Rodrigues et al., 2013) while maintaining the richness, in terms of semantic information, of models contained in CityGML files (Gaillard et al., 2015).

In sum the advantage of GIS is to integrate different data acquired by sensors in real time and provide better decisions, more efficiency and improved collaboration which can provide great benefits for the “smart city” and “city digital twin” ecosystem. Semantically enriched vision of GIS will help evolve cities into tomorrow’s much smarter cities since geospatial/location data and applications may be recognized as a key ingredient of “smart city” vision.

2.2.3 BIM and GIS Integration

As mentioned above, the collection of data at different scales is essential to the development of the concept of “smart cities" and “city digital twins”.A possible development could be the integrated use of GIS and BIM.Despite GIS and BIM having different operational scopes, they both describe real-world objects.Achieving a coherent collaboration between both domains will enable us to create a continuity of information on a multi-scale level that connects the building and it is environment (building in the urban context).BIM focuses on micro-level of building components, like walls, windows and MEP systems.Whereas GIS provides macro-level descriptions and exact geographic coordinates of an object, such as cities, land, and building landscape.Integrating information from different sources and different LOD is advantageous in the building assets management process.The integration of GIS and BIM allows designers to obtain information from both macro and micro level built environment data, and furthermore, enables the strengths of these two technologies to be exploited. Information from a GIS can facilitate BIM applications such as site selection and placement of materials on site, while BIM models can help generate detailed models in a GIS and lead to greater effectiveness in project management.In this framework, the creation of a spatial database able to describe the built environment by making a combined use of GIS and BIM could be a valid support for the achievement of more informed and effective decision-making processes in the management of building assets.Nowadays there is an increased association between BIM and GIS in construction projects for multiple use cases.Due to this collaboration, interoperability issues have appeared between both domains.Even though BIM and GIS can represent the same city element such as building, or infrastructure the context, model structure, vocabulary(semantic and geometric) are not the same for example, BIM uses GUID(Global Unique Identifier) while GIS uses ObjectID(object identifier) to identify elements.Also,GIS uses concepts such as inner and outer building installation whereas,BIM does not have these concepts.As result, multiple differences emerge in modelling environment, reference system, detail representation, application area, semantics and temporal aspect levels(Table 3).

	BIM	GIS
Modelling Environment	Focuses on the building model without taking into consideration its environment. In addition, BIM model is not grounded which means that you don't know which part is above or underground.Furthermore, it is presented as a single LOD.	Focuses on out-of-doors environment, where each element is connected to his surroundings. In addition, it contains multiple levels of development (LODs) and multiple layers(e.g.land use, elevation, etc.)
Reference System	Use local coordinate systems that have an arbitrary unit, covers limited scale, has no zone limitation, composed by small number, and has no projection and height distortion.	Use global coordinate systems such as Coordinate reference system that has linear unit as meter, covers the world, is fixed by zones limitation, has a large number of digits (7-8 before and 2-3 after the decimal point), and contains height and projection distortion.
Details of Drafting	Utilized to develop larger scales with a higher level of details	Builds upon existing information and objects. It covers a large area with less detail and in smaller scales.
Application Area	BIM is rooted in the building and its attributes, it is used in analysis, documentation, detailed design, renovation and construction process, operation, etc.	Used to represent urban and city areas, facilities management, planning and engineering, environmental resources, management, etc.
Tools	Revit, Autodesk, etc.	ArcGIS, QGIS, etc.
Semantics	Use IFCOWL to represent the building construction data, entities, concepts and properties of IFC schema with Web Ontology Language.It is updated with each new IFC version.	Use ISO TC 211 Ontologies to represent the UML models of ISO/TC 211 with Web Ontology language. This enables us to expose the ISO/TC 211 to other communities and connect different concepts.
Temporal aspects	Even though BIM contains attributes, and entities that represent building life cycle, there is no link between the different building life cycle phases.	Do define links between geometrical representations and geometrical properties, also it links and represents the element in different life cycle phases

Table 3. BIM and GIS Differences(Elio et al, 2020).

Therefore it is important to search the methodologies and instruments able to collect and harmonize different data sources mainly concerned with persistent interoperability issues between BIM and GIS.There are two main exchange formats between GIS and BIM: CityGMLand IFC.On the one hand, IFC has been developed as an ISO standard and it has been largely accepted for the building industry.On the other hand,CityGML has been recently adopted as an international standard for modeling cities in the Open Geospatial Consortium (OGC) and the EU.The two formats are related and share a number of similarities in terms of information about the attributes, but IFC contains much more detailed information than CityGML, and a complete "translation" between the two formats is not easy.There were mainly four methods being used for data integration as shown in Figure 16.

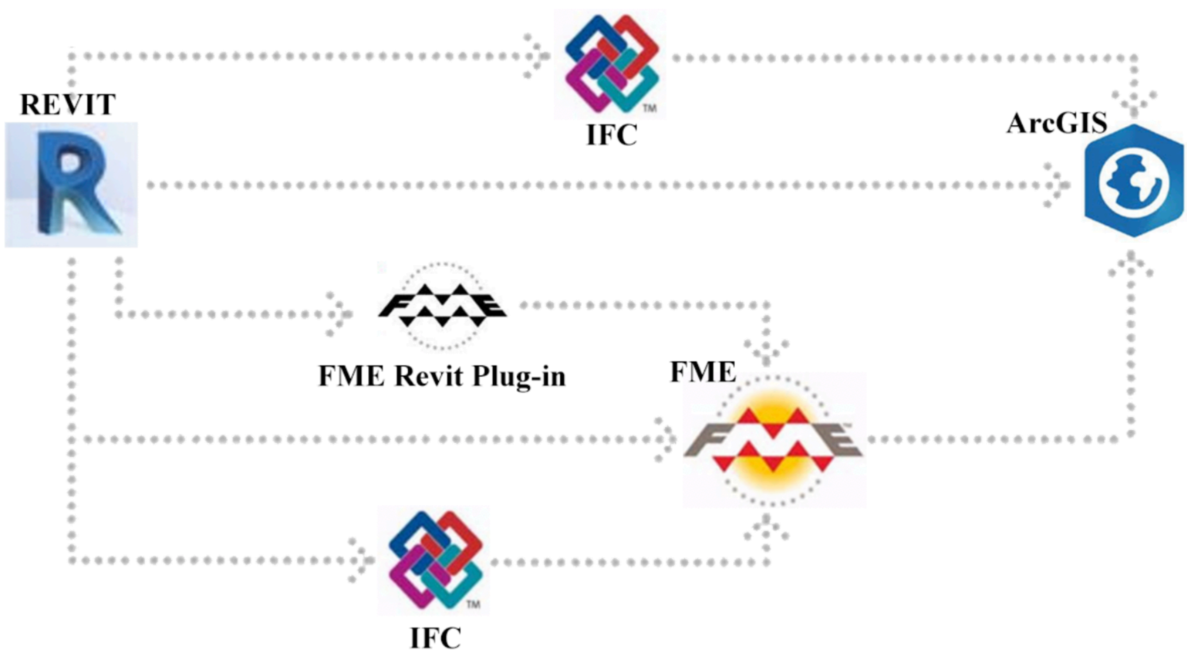


Figure 16. BIM-GIS Workflow.

Method 1: Revit (.rvt) to IFC (.ifc) to multipatch geometry (.shp)

For this direct integration method through IFC exporter, two elements were translated; boundary representation (B-rep) and sweep solid (SS) to represent 3D Geometry. B-rep represents a 3D object using its bounding surfaces. It is used for composite objects, such as doors (IfcDoor) and windows (IfcWindow). In SS, a 2D surface organized with a path is used

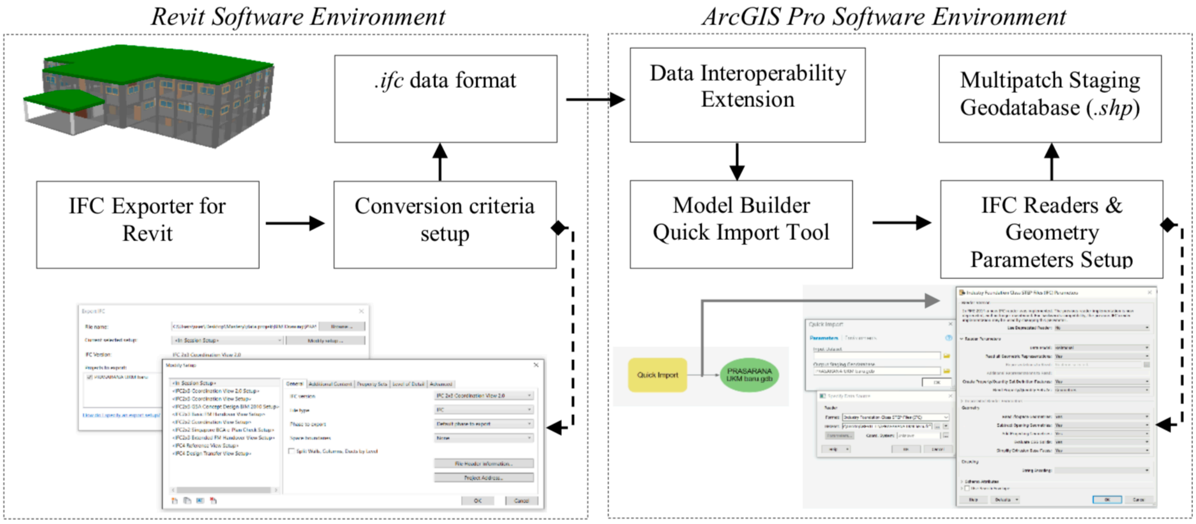


Figure 17. Integration Method 1 (Rahman et al. 2019).

to state a solid, the path outlines the route over which the surface is extruded. But it requires data interoperability extension on ArcGIS Pro for converting the .ifc format into multi-patch geometry. This method doesn't have the capabilities to generate room volume based on room boundaries. This become the limitation for the user who seeks for 3D analysis that relates to space and volume. By integrating the BIM data through this method, it is appropriate for LOD 300 and above as LOD 100 and LOD 200 does not attain any impact other than data visualization.

Method 2: Revit (.rvt) to multipatch geometry (.shp)

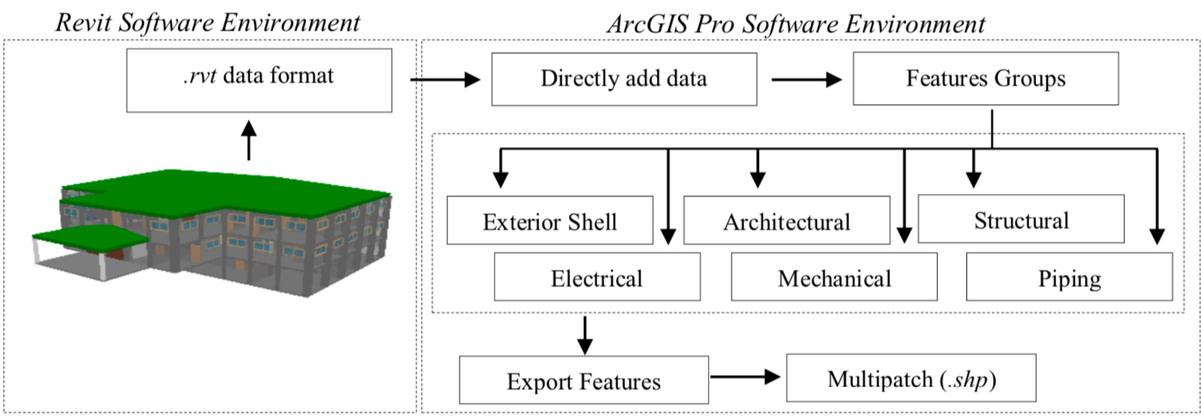


Figure 18. Integration Method 2 (Rahman et al. 2019).

This is second method that integrates BIM data directly into multipatch geometry and just currently developed in the last two years. The Revit file is translated on the fly to be represented in a data model, like CAD data, so that it is used as a direct input to many of the geoprocessing tools but also displayed on a map. To translate those data into the multipatch geometry format, it requires the user to export the data directly from the software. The advantages of this method is its practicality in data visualization as the data arranged in the default layer group consist of Exterior Shell, Architectural, Structural, Electrical, Mechanical and Pipping. This method has limited capabilities as only B-rep of 3D geometry is integrated from the BIM model. It unable to generate the room volume based on room boundaries but have enough content to run simple 3D analysis such as indoor pedestrian route network. This gives advantages for the user who seeks for 3D analysis that relates with visualization and spatial analyst. Other than that, the integrated data also can be used to preserve the asset database to monitor the energy consumption of the building as suggested by Fosu et al(2015). By integrating the BIM data through this method, it is appropriate for LOD 300 and above for advanced 3D analysis as LOD 100 and LOD 200 does not attain any impact other than data visualization.By adding the .rvt data into ArcGIS Pro, the data will be organized into several categories such as Architectural, Structural and so on. These data sourced Revit properties in feature classes and the parameter is defined as ArcGIS features attribute. In order to migrate those data into 3D multipatch geometry data format, the user can use the export features tool. The data products sourced Revit properties in feature classes but the parameter is defined based on ArcGIS features attribute.

Method 3: Revit (.rvt) to (.ifc/.rvz) to FME Workbench (.gml) to multipatch geometry (.shp)

For this indirect integration method, it is selected to be used in the integration phase because of its flexibilities in designing the semantic information which requires further analysis. The semantic information is important as there are plenty of information stored in the BIM model. The selection of data information based on the 3D analysis requirement for the project can help in reducing the unnecessary data besides can reducing the size of integrated data. The 3D Geometry elements such as B-rep, CSG, and SS can be extracted from this method.

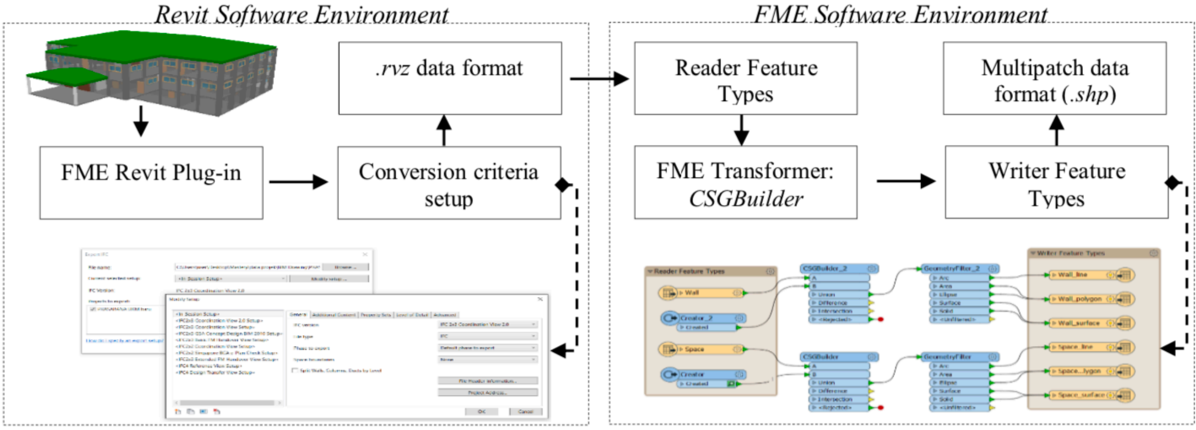


Figure 19. Integration Method 3 (Rahman et al. 2019).

For CSG, it used to represent the post- processing object for the operation of simpler objects such as the intersection of the wall in shape of cones, cylinders and so on. Besides that, there are numbers of geometry that can be translated from BIM models such as segments, path, simple area, simple surface, composite surface, simple solid, composite solid and so on. This method has the ability to generate room volume and gives advantages for the user who seeks for 3D analysis that relates to space and volume. By integrating the BIM data through this method, it is suitable for LOD 300 and above as LOD 100 and LOD 200 does not attain any impact other than data visualization.In order to integrate BIM 3D model from Revit using Method 3, the FME Revit Plug-in extension is needed. By enabling the extension, the conversion process from .rvt data format can be easily converted into .rvz data format by specifying several details information for conversions such as level of detail (low, medium, height) and property set (base quantity, common property set). After the model converted into .rvz, a workspace needs to be set (reader feature types, writer feature types). In order to make sure the converted data in CSG geometry form, CSGBuilder in FME Transformers must be used. If not, the converted data will act in b-rep geometry form. Since the target data format is in Multipatch Geometry, the writer format need to be set ESRI Shapefile while the reader data format is in Autodesk Revit. Run the Translation tool when the workspace has been confirmed.

Compare to convert .rvz, convert .ifc produce the same geometric information; the difference is in the complexity of the related tables.When converting from the .ifc format, a smaller number of tables is created; starting from .rvz, the database is more complex but all the added fields are empty.The .ifc file thus created was verified with the “FME Inspector” application in order to ensure that all the structured information from Revit was correctly exported. After verifying the .ifc file, the same was opened in the “FME Workspace” application and then converted into a .shp file, in order to manage the model and related information in ArcGIS.

Method 4: Revit (.rvt) to FME Workbench (.gml) to multipatch geometry (.shp)

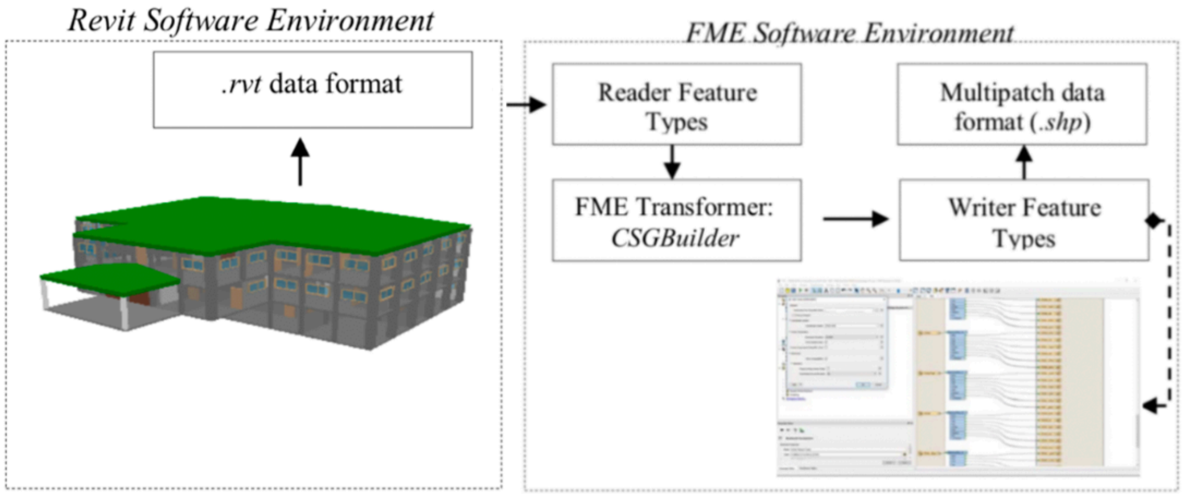


Figure 20. Integration Method 4.

In the release of FME Desktop 2019 it will be possible to read native Revit files(.rvt), without the need of export to IFC files or RVZ intermediate files.And the FME Exporter for Revit is no longer available for FME 2019.0+.The conversion of the .rvt file in .gml is realized with a script of FME and become easier than the original to be assigned a class related to the reachable LOD CityGML.

Above all, each of them starts (.rvt) and finish (.shp) with the same data format but it produces different characteristics of the final product. Each final product has its own capabilities to be utilized into a 3D analyst.At the geometry level of the integration process, the focus is more towards the translation of information between BIM and GIS. There are two major issues that can be seen in the translation phase namely; 3D Geometry and Geometry

Classification.For 3D geometry, GIS and BIM are using different approaches.For example, Method 3 integration BIM through IFC format contains a combination of CSG, SS and B-rep to represent 3D geometry while Method 1 and Method 2 integration do not translate the CSG. This is because generally, the GIS platform is only supporting B-rep elements. Due to the integration conducted on a GIS platform, the 3D geometry elements will fulfill the requirement based on its current platform. It is important to understand this matter because the geometry data level is playing a major role in 3D indoor mapping.The different in nature becomes a barrier for both platforms to be integrated automatically.

However, it depends on the requirement for integration and identify the 3D analysis research to be carried out.For example, to conduct dynamic factor analysis such as smoke simulation, CSG is important so the integration method must be able to produce the CSG element on the output integrated product for volume usage.But if conduct for larger-scale 3D analysis, such as district building sunlight analysis, in this condition it is not necessary to import CSG information.Follows as shown in Table 5 presents the different studies done in the previous years to combine BIM and GIS advantages in different scenarios and applications such as:enrich urban model with BIM information;Energy consumption and evaluation on building, district and city level;Facility scenarios (e.g. water facilities); navigation system and emergency response, environmental analysis (e.g. flooding).

All the presented studies tried to accomplish their objectives and applications by seeking a solution for the integration and coexisting of data heterogeneity between BIM and GIS.However, we have noticed that not all barriers and incompatibilities have been surpassed and only a small degree of interoperability has been achieved.Most of the approaches are oriented to specific use cases such as flood assessment, navigation system, etc.Most created models and approaches can only be applied to a specific use case.

Reference	Approach	Advantages	Limits
(Mignard & Nicolle, 2014)	Create an Urban Information Model (UIM) as a crossroads between building model and geographic information systems, which allows to integrate all the information about the city, including urban proxy elements, networks, buildings, etc. into an ontology.	• Allow facility managers to support the life cycle of urban environments • Improve the quality of knowledge models • Facilitates the volume of data • Friendly 3D interface	• Usage of database to store the instance of the ontology • Ontologies are not fully used • Unable to make logical reasoning or inconsistency checking of the model
(Floros et al., 2017)	Present a framework, where an IFC model is generated and converted to a LOD 3 CityGML Model, which is validated and evaluated on its geometrical correctness and semantical coherence.	• Time efficient • Improve existing converting tools	• Don't investigate a fully complex model • Convert only into LOD 3
(Deng et al., 2016)	Present a reference ontology called Semantic City Model and adopt an instance-based method to achieve automatic data mapping between IFC and CityGML at different levels of details (LOD).	• Bidirectional conversion of geometrical information • Capture all semantic information (semantic mapping) • Generates all LOD levels	• Misses some building components • Tackles only building model • Transforms only IFC BRep and swept solid geometries
(Sebastian et al., 2013)	Aim to enable an open information capture, exchange, sharing, comparison and storage of the relevant building and GIS models for designing energy-efficient buildings in healthcare districts.	• Generate semantic BIM + GIS typology models; • Interconnect the design, construction and facility management models • Design a decision-support tool which accommodates • Grab semantic and geometrical	• Tackle only building energy issues and models • Use only IFC and CityGML standards • Focus on BIM and GIS building model
(Wook Kang & Hee Hong, 2013)	Propose a BIM-GIS-based architecture model in which data were extracted from different heterogeneous systems such as BIM, GIS, and Facility Management database using ETL. The architecture is used for facility management, energy management, and design evaluation.	• BIM model can be checked by GIS tools • ETL provides a data warehouse for the heterogeneous systems, and can be used for information mining • BIM geometry information can be visualized into a simplified surface model	• Unidirectional integration from BIM into GIS tool • BIM object geometry can be viewed only in LOD 100 and 200 • Selection of BIM property information which indicates semantic data loss
(Vilgertshofer et al., 2017)	Achieve to connect a tunnel model represented in both CityGML and the IFC data model by applying semantic web technology to emphasize the important role of semantic technologies in allowing the coexisting and coherence between the entities of both standards	• Identify clashes between existing buildings/infrastructure and the planned tunnel • Execute queries that access both data pools • Connect IFC to each CityGML LOD • Achieve Semantic and geometric coherence between both models	• Connect only IFC and CityGML standards • Approach applied only on tunnel models • The mapping is not automatic (need for human intervention)
(Boguslawski et al., 2015)	Integrate BIM and advanced GIS analysis to improve 3D analytical model for emergency response. The objective is achieved by using Green Building XML (gbXML) and Industry Foundation Classes (IFC), and GIS analysis methods and data structure, as data input.	• Generate an automatic navigation model for complex interior based on BIM model • Reconstruct the navigable network and primal-dual representation. • Create indoor topology with their connection • Generate route calculation	• Based only on IFC geometrical information • Don't use GIS standards • No connection with the outdoor environment
(Amirebrahimi et al., 2016)	Present an integrated framework that allows for a case-by-case analysis of flood damage to a building and its components. In addition, it provides a comprehensive understanding of flood risks at different levels of the community.	• Shows quantitative and qualitative damage effect • Used for cost estimation, decision making and urban planning • Spatiotemporal parameters are taken into consideration	• Semi-automatic process • Unified model treats only flooding use case • Applicable only on new building or those in their pre-construction phase • Don't consider all flooding factors such as weather.

(Zhang et al., 2019)	Propose a new urban management method through the combination of the GeoSOT grid code and BIM technology, where a real-time 3D visualization earth platform was built by using the Cesium platform to achieve refined and efficient management of urban components	• 3D and real time visualization platform • Achieve urban component management and smart fire protection • Manage a variety of urban components with different granularities • Achieve multilevel precise management • Achieve the fusion of geographic information and building information	• Input data are transformed into Cesium file format • Used only for urban management scenario • Is not based on standards
(de Laat & van Berlo, 2011)	Describe the development of a CityGML extension called GeoBIM to get semantic IFC data into a GIS context.	• Consider IFC semantics and properties • Transform 60 to 70 classes from IFC to CityGML • Bidirectional transformation	• Support only IFC and CityGML standards • Generated geometry issues when transforming IFC to CityGML

Table 4. Previous work related to BIM-GIS integration(Elio et al, 2020).

Andrews (2019) recently exposed the future integration of BIM-models (digital representation of assets) and GIS knowledge, that integration must be adapted to rapidly changing technology, data collection and workflows.Integration workflows will change because previous file formats have certain limitations in ongoing technology development (no streaming, data loss, incomplete duplication, unidirectional).“In the push to true digitalization, digital representation of an asset needs to be accessible quickly in a distributed environment that can be updated and upgraded to adjust to more complex query, analysis, and inspection over time and across the lifespan of the asset. I expect integration technologies to continue to mature over time as BIM becomes richer in content and as the need to use BIM data in GIS context for lifecycle asset management becomes more critical to sustainable human habitation” (Andrews, 2019).Future integration efforts will evaluate aspects like extraction of common geometries like rooms, spaces, footprint of a building or data for navigation (indoor) because they can be useful for GIS applications or asset management. The approach of BIM and GIS workflows makes it necessary to define specifications for features in BIM models needed for GIS workflows before design and construction begins and which are also needed for use during lifecycle management(DR.A.Carstens, 2019).

3.Methodology

3.1 Case Study

The case study of the thesis is the Fiat Mirafiori industrial area, on the southern suburbs of Turin. The industrial complex, which covers an area of 2,000,000 m^2, was the largest Italian industrial area and is the oldest still operating car factory in Europe(ilmessaggero, 2019). Inspired by Henry Ford's Detroit model, local investors and entrepreneurs pooled their resources to found the Fabbrica Italiana Automobili Torino(FIAT) in 1899.And then FIAT Mirafiori was built in 1939 to replace the obsolete Lingotto structure, it was designed to employ over 20,000 workers(Figure 1).It became operational after the Second World War, during which it was hit seven times by bombings.In 1956 it was expanded with the construction of the Mirafiori Sud area and in the middle years of the "economic boom" it had 75,000 employees. It was during this period that Fiat formulated a new company policy, implemented its own real estate development plan.Between 1949 and 1971, a total of 1,681 houses were built, accounting for 75% of the total number of houses built in Turin during the same period.Over the years the development of FIAT Mirafiori has affected the entire surrounding area, and transforming the area into a real city(Figure 2).And in just over twenty years (1951-71) the population of Mirafiori Sud underwent an exponential growth passing from 3,000 artisans and farmers, up to over 40,000 workers(ISTAT).

Figure 21. FIAT Mirafiori 1942. (https://www.panorama.it/economia/lo-stabilimento-fiat-mirafiori-compie-80-anni-storia-foto)

Figure 22. FIAT Mirafiori 2020.(Google maps)

However, as in other “mono-industrial” cities, Turin’s economic model has declined since the 1970s due to several causes, such as the energy crisis of 1973 and deficiencies in the Fordist model.The production activity is now rarefied, today in FIAT Mirafiori only the “Levante” Maserati SUV is produced and less than 10,000 employees. On the other hand, with the economic transformation of Turin, innovative industrial activities (electronics, robotics, telecommunications, etc.) began to develop in Turin, towards a "knowledge economy"(Conti, Vanolo 2003).Mirafiori inevitable needs to make changes to adapt to the new economic model.

In fact renovation of factories and transformation between old and new functions have been in progress in recent years.Major institutional projects paint this part of the city as a potential space for re-industrialization, such as a university campus (etc.). Mirafiori is the first district of the Turin Metropolitan Area chosen for the experimentation of a social innovation and civic engagement project which involves inhabitants and administrators-re local in the process of planning and management of public space, with a view to building a renewed urban governance (De Filippi and Cosia, 2016).This provides an opportunity for community to improve the ability of urban building stock management which is also one of the goals of building a sustainable city under conditions of increasing urbanization.On the other hand, in response to rising energy costs and the impetus to reduce environmental impacts, upgrading the large building stock that is responsible for 40% of the total energy consumption to maximum energy efficiency is becoming an important task(Özgür et al., 2016).

The recently released European Parliament Report on the Energy Roadmap 2050 (EU 2012) stated that building renovations are essential to bringing economical and environmental benefits to public and private sectors. Moreover, there is a need to scale up the current rate of building renovations to mitigate climate change and achieve adaptation goals. This strategy sets the foundation for a transformation of existing building stocks and would drive significant improvements in developing minimum energy efficiency standards.

However, due to the multifaceted goals of retrofit projects, including expansion of facility capacity, incorporation of new green technologies, improvement of indoor environmental quality, and safety, these projects are becoming increasingly complex and usually involve many stakeholders and a substantial amount of professional expertise.Retrofit projects are still only slowly being implemented for several reasons such as (1) the complexity resulting from aging systems and changes that have occurred, (2) user involvement, (3) the involvement of multiple stakeholders at different stages of the building lifecycle, (4) additional challenges in financing retrofit projects, and (5) a lack of a comprehensive understanding of the financial benefits of retrofitting buildings (Yu et al. 2011; Miller and Buys 2008; Ma et al. 2012).Therefore, it is essential to provide new tools and methodologies to develop a comprehensive understanding of a building to be renovated.From this point of view, a query-based dashboard platform is proposed in which has the ability to summarize multiple forms of building's information on queries and dynamically show graphical representation to all different stakeholders and in this way optimize their decision(Figure 23).

Figure 23. The proposed flow of a dashboard to involve different stakeholders.

3.2 Overview of Workflow

As mentioned in the previous chapter, on the one hand, the concept of “Smart City” and “City Digital Twin” provides a holistic vision to integrate Communication Technology(ICT) and Internet of Things (IoT) solutions in a secure fashion to manage city and building assets.On the technical side, in building-scale,BIM can be used to create, manage and share the lifecycle data of vertical facilities such as buildings, while in urban-scale GIS can be used to store, manage and analyze data describing the urban environment, which is horizontally distributed.So integrating of GIS and BIM technologies could be a valid support for the achievement of concept of “Smart City” and “City Digital Twin”.

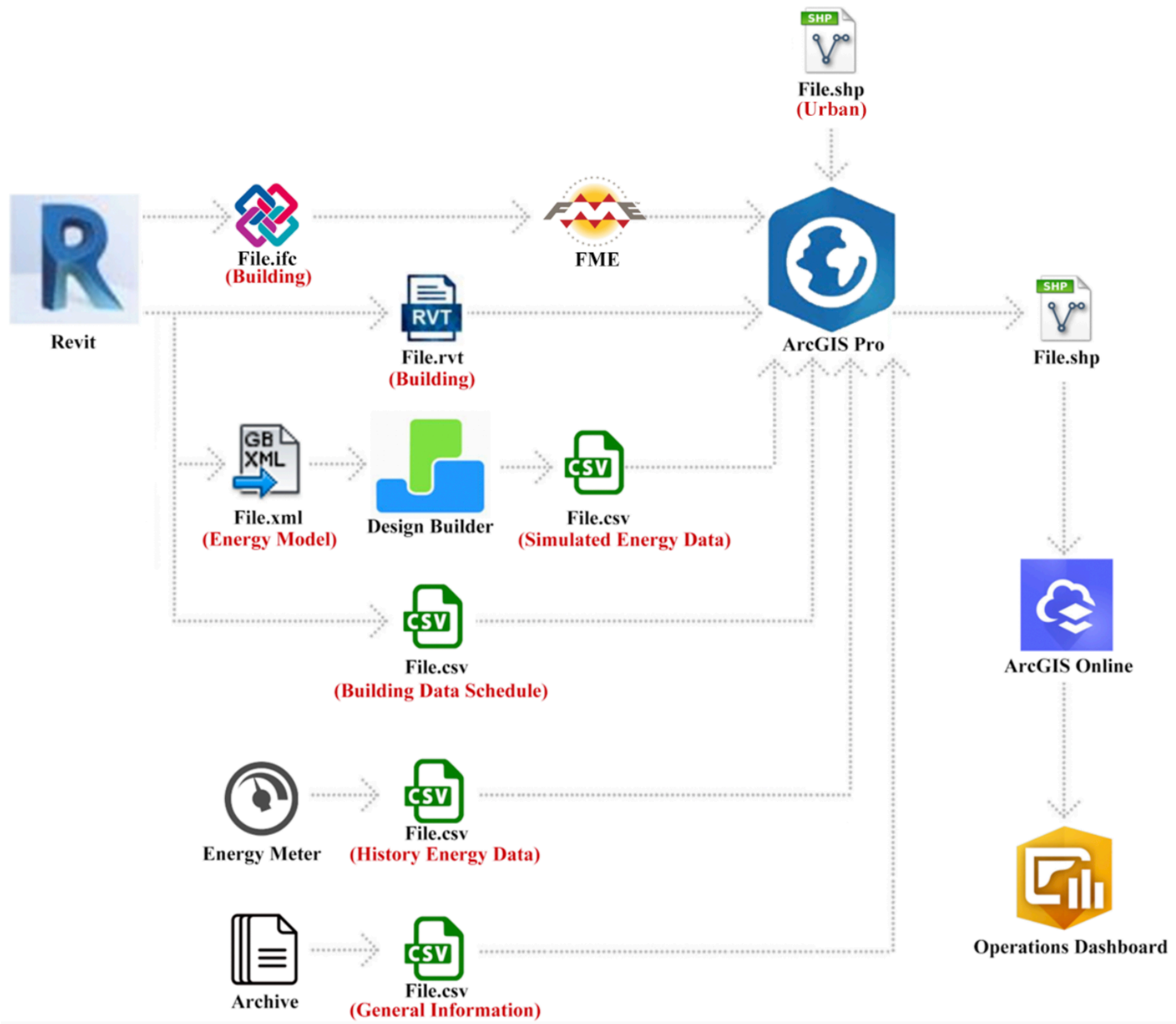


Figure 24. Schema Methodology of the thesis.

On the other hand, by studying the case study of FCA Mirafiori, a query-based dashboard platform is proposed to research in which has the ability to summarize multiple forms of building's information on queries and dynamically show graphical representation to different stakeholders and optimize their decision.On the basis of above research and considerations it is proposed to reach the objective by integrate BIM and GIS with a precise flow of activities. This methodology is schematized with the above workflow(Figure 24).

Briefly summarize the implementation process of the methodology which contains three main parts:(1)Data Collection,(2)Data Transformation and Integration,(3)Data Visualization(Figure 25).

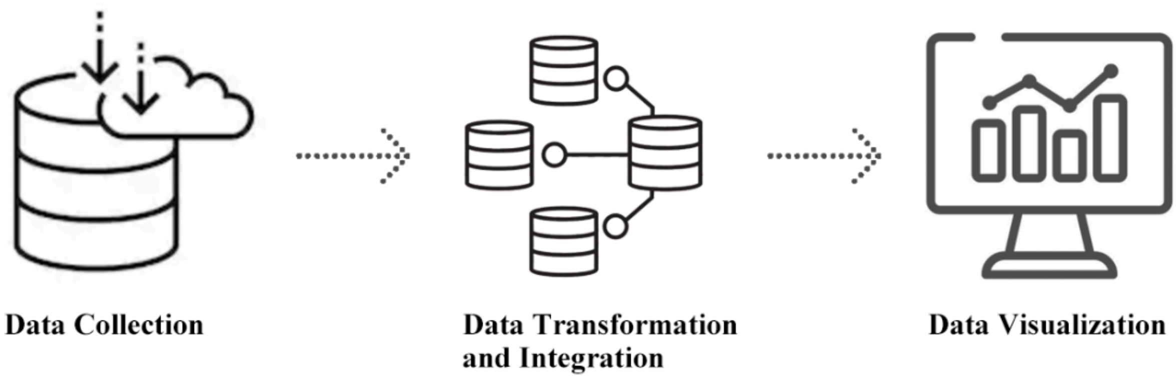


Figure 25. Implement process of the Methodology.

(1)Data Collection

First, we need to collect different type of data source.There are four main data categories: (a)Building data, which includes graphic building construction information such as walls, roofs, floors, doors, windows, partitions and also includes non-graphic information such as material thermal mass type, ratio and scheduling.(b)Urban data, which contains the information such as the existing conditions for parcels, zoning, land use, location, shape and other attributes of spatial entities that near the building.(c)Building energy data, which contains both the historical and simulated energy consumption of the building.(d)Generally information data, which describes the generally information of the building such as building name, sector, address, construction and renovation period.

(2)Data Transformation and Integration

Secondly, after collecting these heterogeneous datasets, we can use different kind of tools to transfer and integrate them into the same platform to obtain a single database.And there will be a dynamic connection between this integrated database and each of them, which is very convenient to modify if need. For example if one of the datasets is updated into a new version the integrated database will be automatically changed.

(3)Data Visualization

Finally, after uploading the dataset and their representation inside the web environment, we can obtain the Dashboard which able to store, handle, visualize and display these information on building assets.In this way we can have graphical and technical outputs that meet the demands of users and implement a 3D visualization and interactive platform oriented to public participation for building assets management.

3.3 Data Collection

(a)Building Data

The building data in this thesis comes from the Revit model of the case study—Lastratura of FCA Mirafiori(Figure 26,27).

Figure 26. Lastratura of FCA Mirafiori(Google Map).

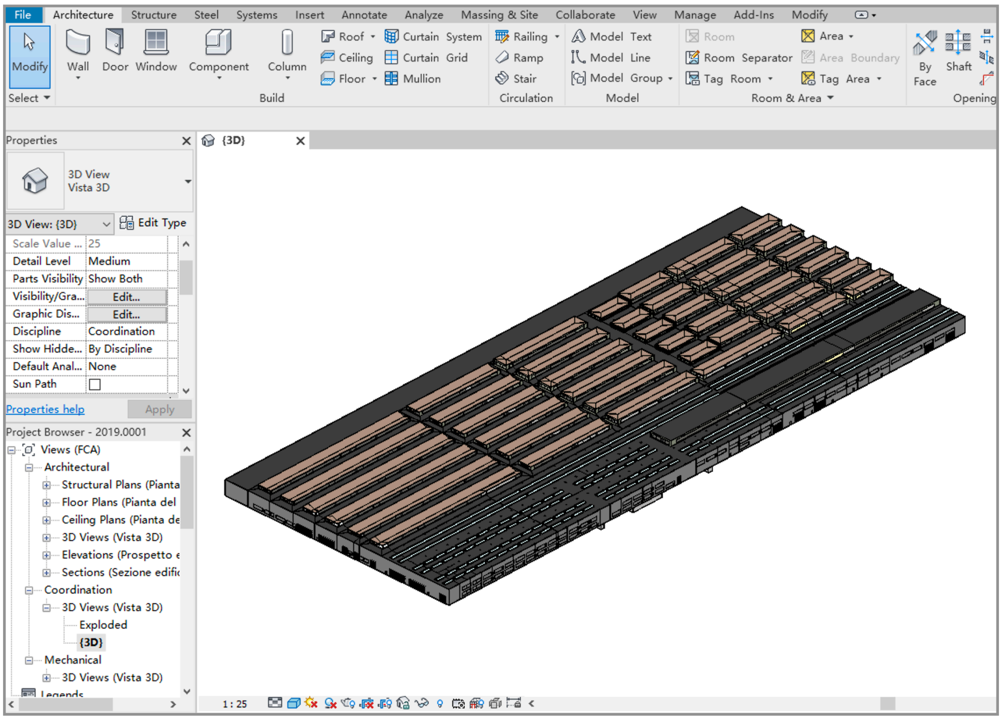


Figure 27. Lastratura BIM model.

In this stage we can export the .rvt and .ifc file, both of which can describe the geometry and semantic information of the building and in next step we will compare the advantages and disadvantages of each integration process.

In Revit we can also create schedule abacus(Figure 28) which count some basic building data such as the external surface area of the building—the transparent surface area(Windows, transparency roof) and the opaque surface area(opaque roof, wall, door).Export these schedules and stored in separate Comma Separated Value (CSV) file.Each CSV file has a common field of “Building_ID”.

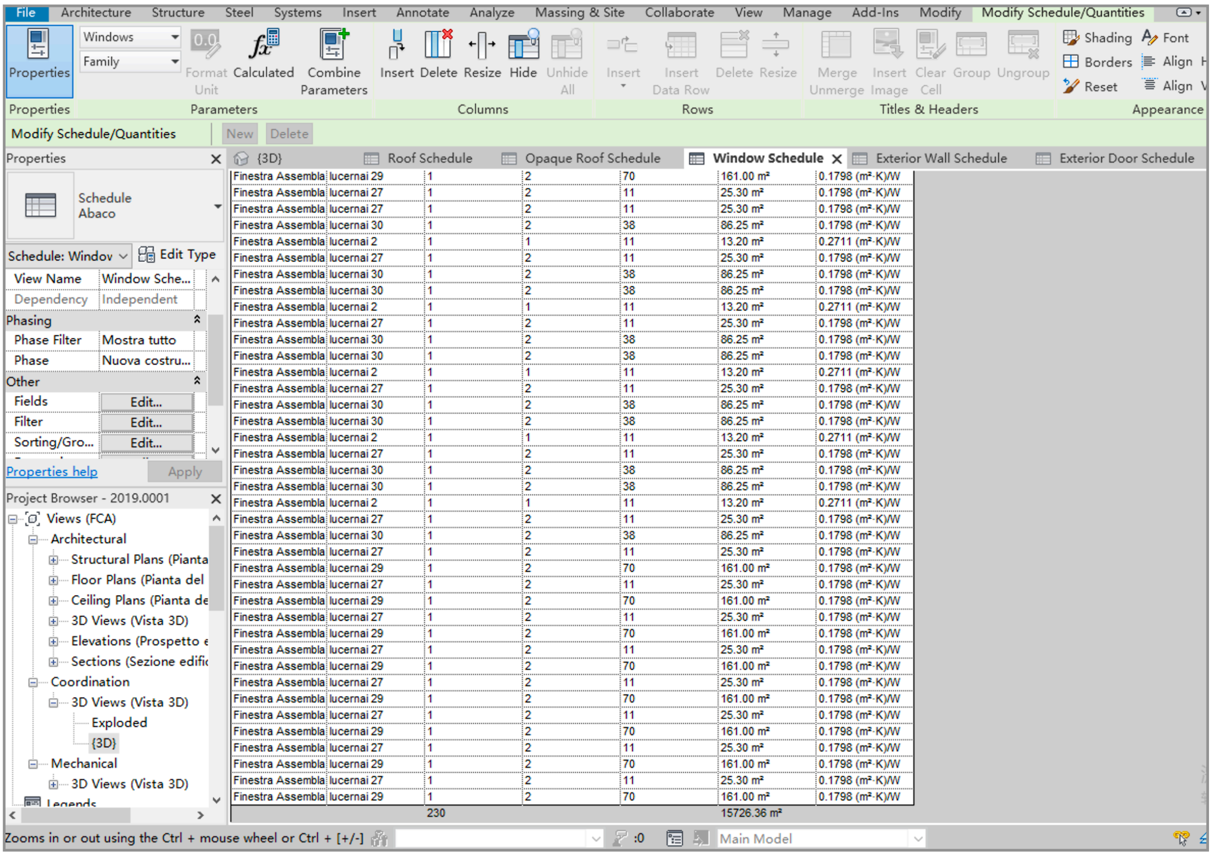


Figure 28. Schedules in BIM model.

(b)Urban Data

The urban data can be freely obtained from the Geoportale Piemonte online(Figure 29), where we can download the BDTRE files.It corresponds to the Territorial Database of Reference of the Entities and from 2014 is the reference cartographic base of the Piedmont Region, for all public and private entities.The vector data (the discrete geometries (points, lines and polygons) of the geographic objects and the associated alphanumeric information) of BDTRE are structured in accordance with the classification and nomenclature of the national specification and are published in shapefile format.Specifically, from the Geoportale site, by filtering the search with the BDTRE field, it is possible to select from an online map a reference area from which to obtain all the vectorial data.These data are collected in a .zip folder that contains all shapefiles divided into subfolders, by type (e.g. AMM,IMM,IND).

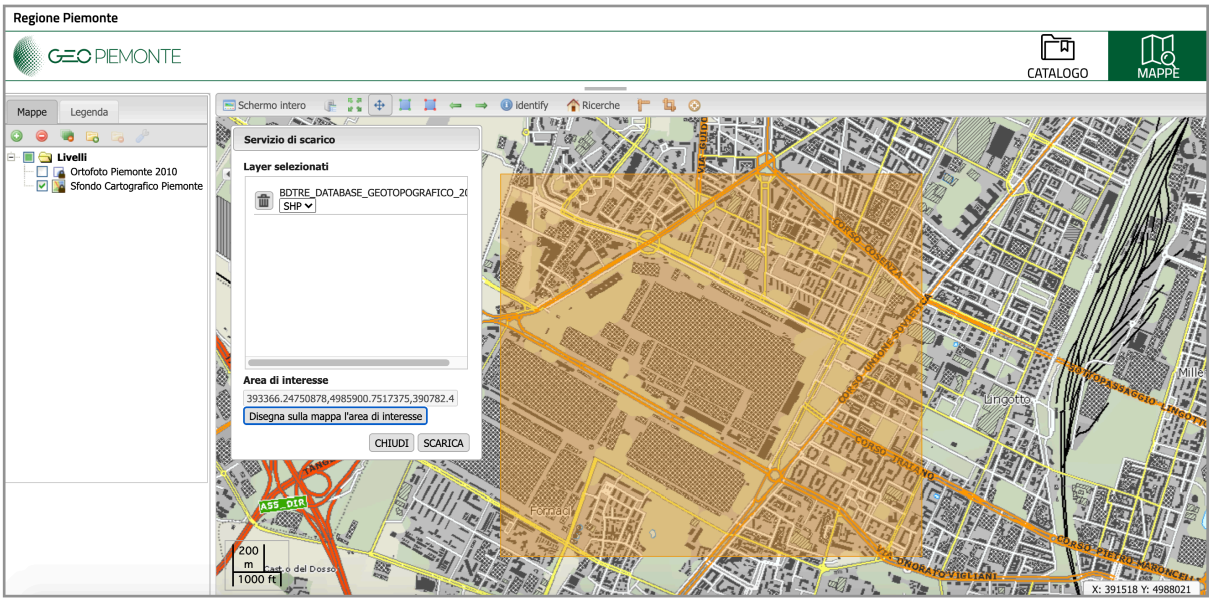


Figure 29. Download shapefile BDTRE from Geoportale Piemonte.

The shapefile “edifc_2019.shp”(Figure 30) we used is regard to the theme of the buildings, a massive update was carried out on the whole region on the basis of the buildings surveyed by the Cadastre in 2015. They are 2D polygons feature that delimits the geographical boundaries of each buildings in urban environment. This data has many fields which can be very useful in the GIS environment. For example the field “EDIFC_USO” corresponding to the building type such as industry, residential, commercial, etc. In ArcGIS Pro environment we can graphically filter different type of buildings, in order to create different symbology appearance.

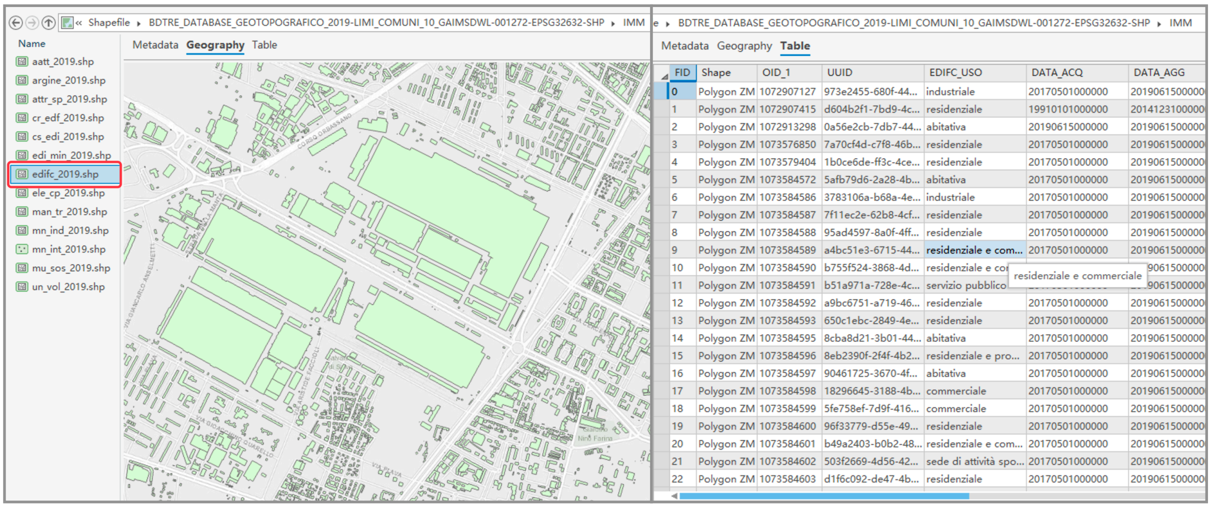


Figure 30. Geographic and field attributes of shapefile “edific_2019.shp”.

(3)Building Energy Data

Building energy data contains both the simulated and historical energy consumption of the building. Simulated energy data is related to the generation of the EAM model using the BIM model.This process can be used as a specific energy-saving retrofit scenario in the future. Through the interoperability process, the BIM model can be imported in a simulation engine such as DesignBuilder.Thanks to the development of interoperability currently many standard exchange format were tested such as green building eXtensible Markup Language (gbXML).The gbXML open schema helps facilitate the transfer of building energy properties stored in BIM models to engineering analysis tools.This model is composed of rooms and analytical surfaces so that the Energy Analysis Model (EAM) could be created showing all the analytical surfaces useful for the analysis.Below there is the export step from Revit, using gbXML format.

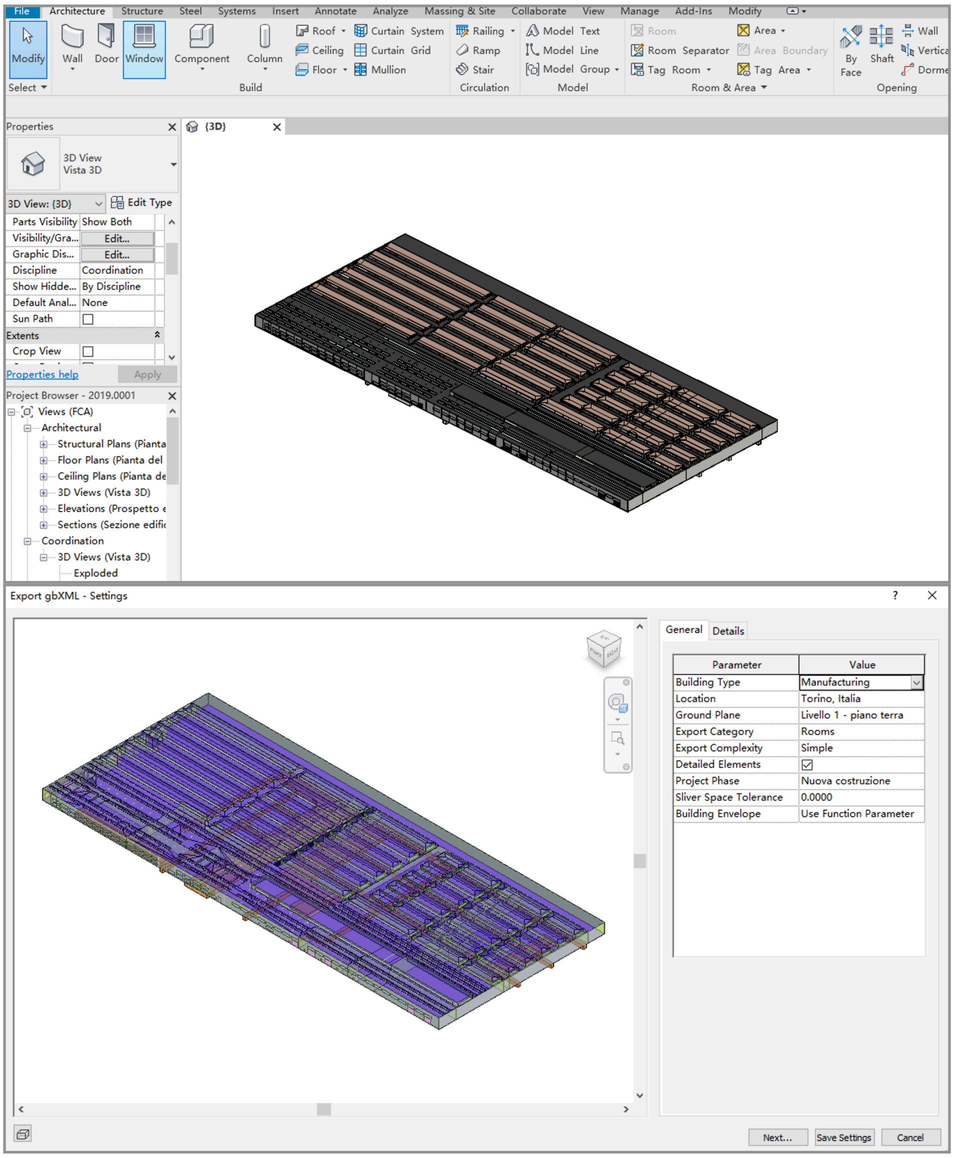


Figure 31. The EAM model generation with gbXML.

The next step is to proceed with the import model in DesignBuilder.DesgnBuilder has a hierarchical structure of the elements, which means that all information that set to the highest level are assigned to those elements start passing from the building to the block, to the zone and finally to the surface.DesignBuilder allows to manage the geometry of the building, the thermal properties of the construction elements and the configuration of the systems. The results that this software returns come from Energy Plus calculations run in background.The parameters to be defined are found in the Activity cards, Construction, Openings, HVAC(Figure 32).

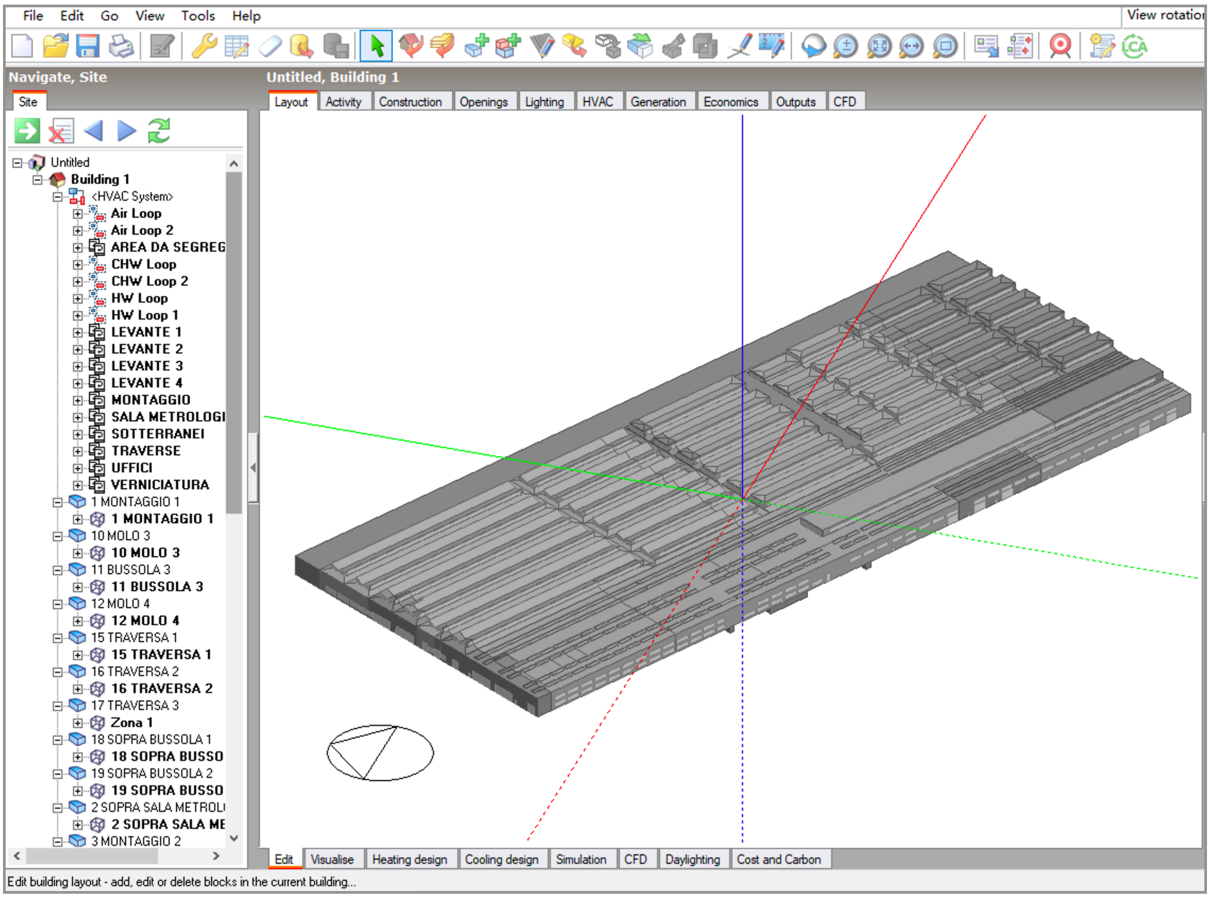


Figure 32. Design Builder Layout.

Setting of information on simulation is another very important card to energy analysis purposes.In this tab, we can fill the input data with respect to the period to be analyzed. In this case of study energy simulations of the model were made from October to April when the building is scheduled to start heating.EAM model is then completed in DesignBuilder considering the specific use of the building, adding the occupancy and activity profiles of the users, and editing the characteristics of the heating system.The figure below shows the simulation results obtained with the Simulation Engine(Figure 33).At the end of the simulations a set of data in .csv format is obtained.

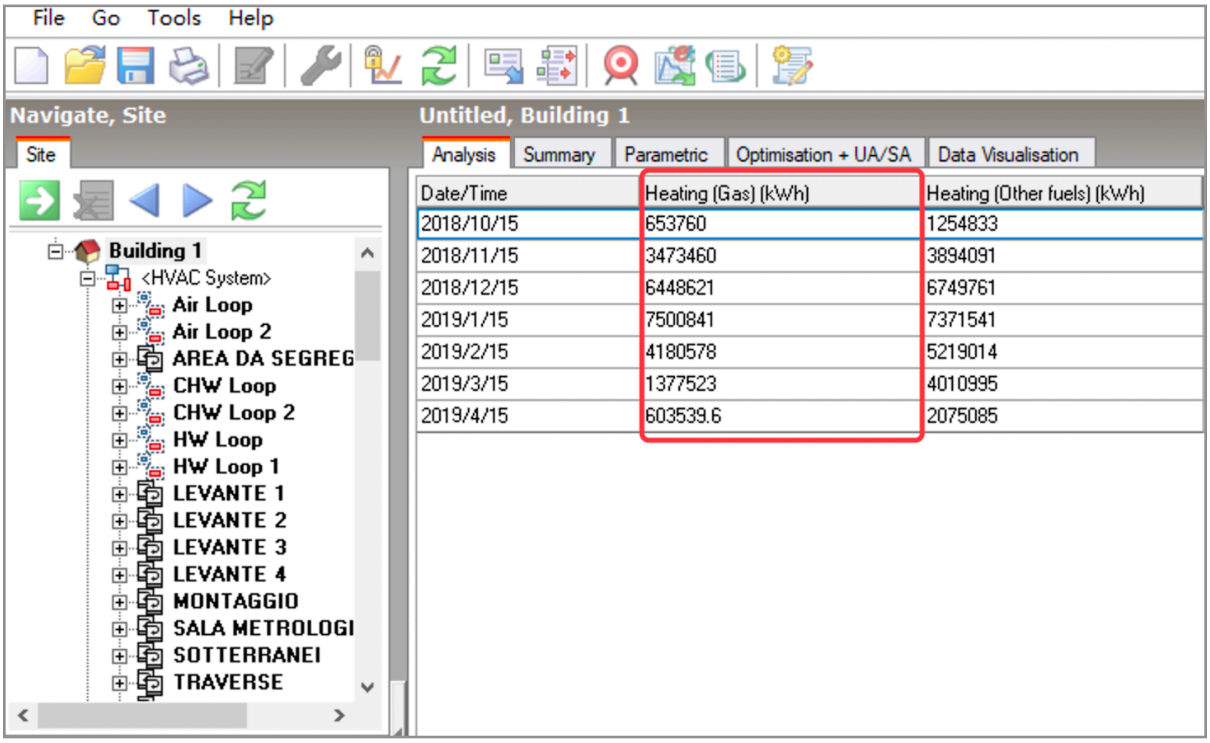


Figure 33. Design Builder Simulated Result.

On the other hand, the historical energy data is obtained from FCA Group's sensor data which are extracted and plotted using Microsoft Excel as visible in figure below(Figure 34).It shows the monthly and annual heating consumption data in 2017 and 2018 of Lastratura.In this way measured and simulated data can be compared in order to validate the design scenario with the reality concerning thermal comfort and energy consumption.

Consumi di Utilizzo - Mirafiori Carrozzeria Lastratura

Descrizione area	Ottobre'17	Novembre'17	Dicembre'17	Gennaio'18	Febbraio'18	Marzo'18	Aprile'18	Ottobre'18	Novembre'18	Dicembre'18	Gennaio'19	Febbraio'19	Marzo'19	Aprile'19
Lastratura 1	969,839	3,980,764	9,956,878	10,313,800	8,043,867	5,151,545	3,481,887	20,000	-21,104	-1,982,744	0	0	0	0
Lastratura 2	111,216	0	2,871,160	89,568	2,676,360	2,118,332	0	-20,000	21,104	1,982,744	3,610,304	464,832	0	346,832
Lastratura Levante	2,421,147	11,287,975	19,952,088	13,167,346	12,009,699	8,923,195	2,001,772	2,973,686	12,569,364	23,435,794	23,673,786	13,724,201	4,855,979	2,078,163
Lastratura	3,502,202	15,268,739	32,780,126	23,570,714	22,729,926	16,193,072	5,483,659	2,973,686	12,569,364	23,435,794	27,284,090	14,189,033	4,855,979	2,424,995
	3,502,202	15,268,739	32,780,126	23,570,714	22,729,926	16,193,072	5,483,659	2,973,686	12,569,364	23,435,794	23,673,786	13,724,201	4,855,979	2,078,163
	0.97	4.24	9.11	6.55	6.31	4.50	1.52	0.83	3.49	6.51	6.58	3.81	1.35	0.58
							33.20							23.14

Figure 34. Historical Heating Consumption Data.

(4)Generally information data

The generally information data corresponding to general aspects of the buildings such as building name, sector, address, construction and renovation period, occupancy number, etc.These data can be collected from web public source and then integrated into one .csv file.

3.4 Data Transformation

(1)Urban Data Transformation

After collecting all these heterogeneous datasets, the next step we need to transfer and integrate them into the same environment and platform to obtain a single database.The first data transformation is about the reconstruction of the three-dimensional map of the urban area near the FCA Mirafiori.As mentioned in the previous chapter a two-dimensional cartography edific_2019.shp collected from Geoportale Piemonte online can be imported into in the ArcGIS Pro environment by homogenizing its reference and projection system in WGS 1984 UTM Zone 32N (EPSG:32632).It was possible to extract the building solids with an automated process thanks to the use of tool of Extrusion made available by the software.Extrusion is the process of stretching a flat, 2D shape vertically to create a 3D object in a scene.We can extrude building polygons by a height value to create three-dimensional building shapes.A comparison of building footprints on the ground and building footprints extruded to three-dimensional shapes is shown below:

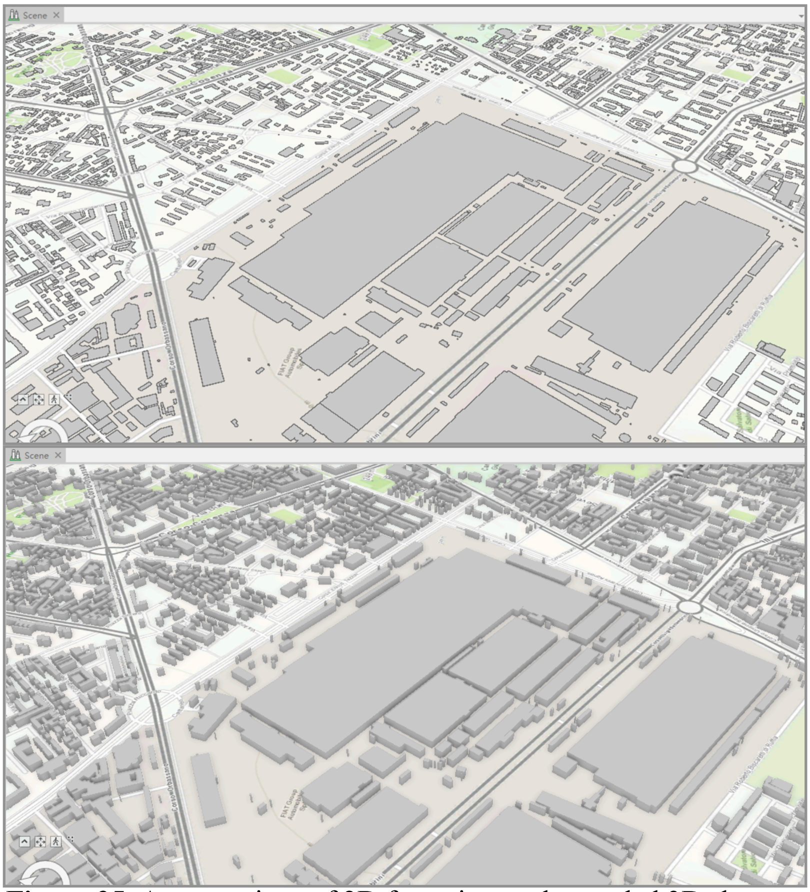


Figure 35. A comparison of 2D footprints and extruded 3D shapes.

Moreover, we can also change the way building is represented by symbolizing the feature layer thanks to ArcGIS Pro provides many different symbolization methods.It is a dynamic attribute change of symbology based tool, the data can be described by different colors.It would be useful for showing the distribution of different buildings function.For example, in this case study as the “building_type” data is contained in the feature, the different buildings typology of the city are shown such as industry, residential, commercial, etc.So the buildings can be color coded based on the function type.Below(Figure 36) there is the 3D model of the buildings with different functions(industry and others) around FCA Mirafiori district.We can clearly see the location and density relationship between the factory and surrounding communities and the important role of industrialization in urban expansion process.

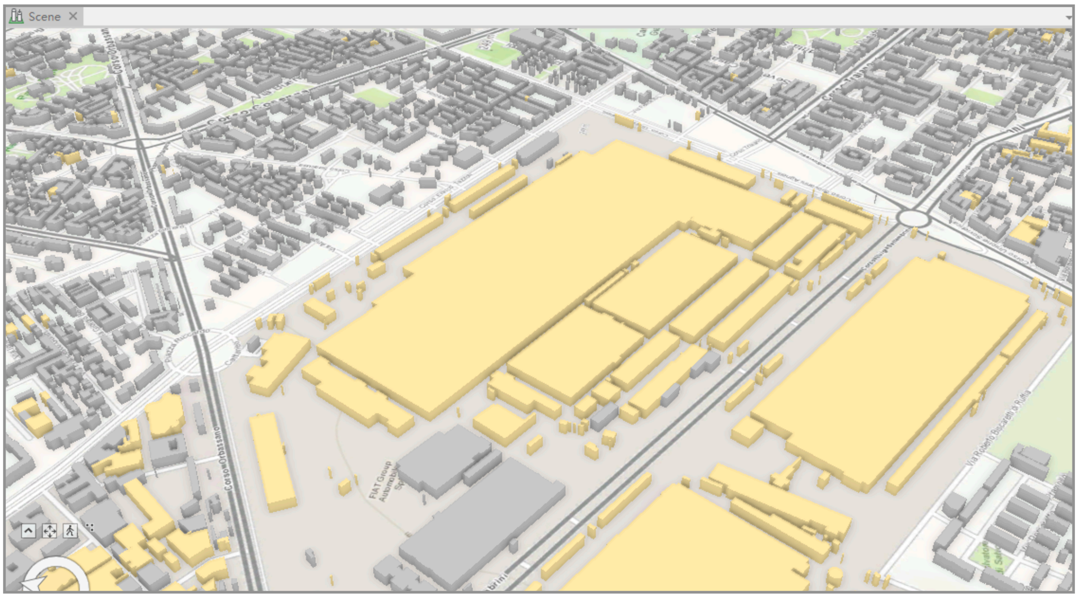


Figure 36. 3D models of the buildings with different functions around FCA Mirafiori district.

In fact, this analysis tool can provide many positive aspects in the urban planning process if there are more open source embedded in the feature.For example, it is possible to visually check the population density distribution in the neighborhood according to the number of building populations at the urban scale.This is very useful for the decision-making of urban infrastructure facilities planning. In addition, it can also be distinguished according to the construction year and energy level of the building, which provides a basis for macro analysis for planning and decision-making to improve the energy consumption of urban buildings. The ArcGIS Pro software provides great convenience for automatically processing and visualizing these massive data.

(2)Building Data Transformation

The second data transformation is about the process of importing the building data which comes from Revit model into the GIS environment.As some possibilities for interoperability between BIM and GIS have been already described and discussed in previous chapter 2.2.3, in this section we will test two of them around the case study in order to generate different LOD(from LOD1 to LOD4) models and then compare their differences.

Method 1: Revit (.rvt) to multipatch geometry (.shp)

The first step is that integrates BIM data directly into multipatch geometry which just currently developed in the last two years.The Revit file is translated on the fly to be represented in a data model.But at first we need set the geolocation data for the building model in the Revit software in order to get an incorrect positioning after imported into ArcGIS Pro.In Revit we can use the Specify Point Coordinates command to change the real coordinate values of the building(Figure 37).And place the .prj file which is renamed with the same name as the .rvt file in the same folder.

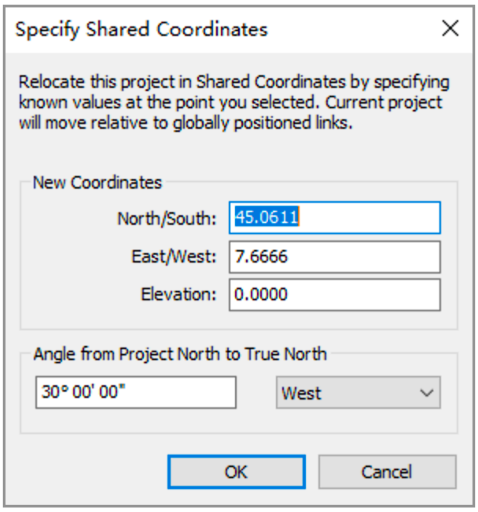


Figure 37. Specify coordinates in Revit.

Then export the .rvt file directly from the software and add into ArcGIS Pro, the data will be organized into several categories such as Exterior Shell, Architectural, Structural, Electrical, Mechanical and Pipping and so on.This provides many advantages of practicality in data visualization.We can use the export features tool to migrate those data into 3D multipatch geometry data format.The .rvt model is now correctly geolocated in ArcGIS Pro and each single element can be interrogated with the software's features(Figure 38).However, this method has limited capabilities as it unable to generate the a mass volume based on building boundary.But thanks to the ArcGIS Pro’s powerful capability of processing geographic and related data. Firstly we can use geoprocessing 3D analyst tool “Multipatch Footprint” whichcan create polygon footprints representing the two-dimensional area of three-dimensional multipatch features(Figure 39).

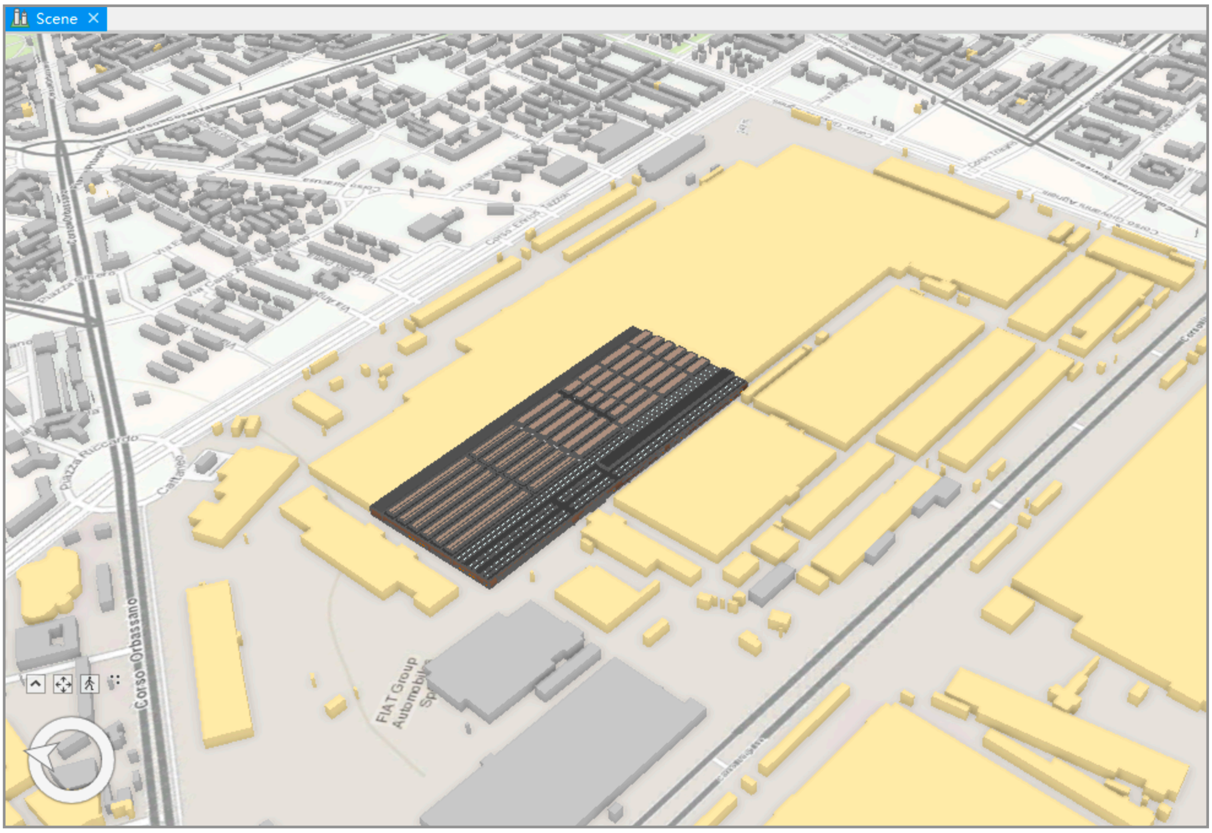


Figure 38. Import .rvt model(LOD3,4) directly into ArcGIS Pro.

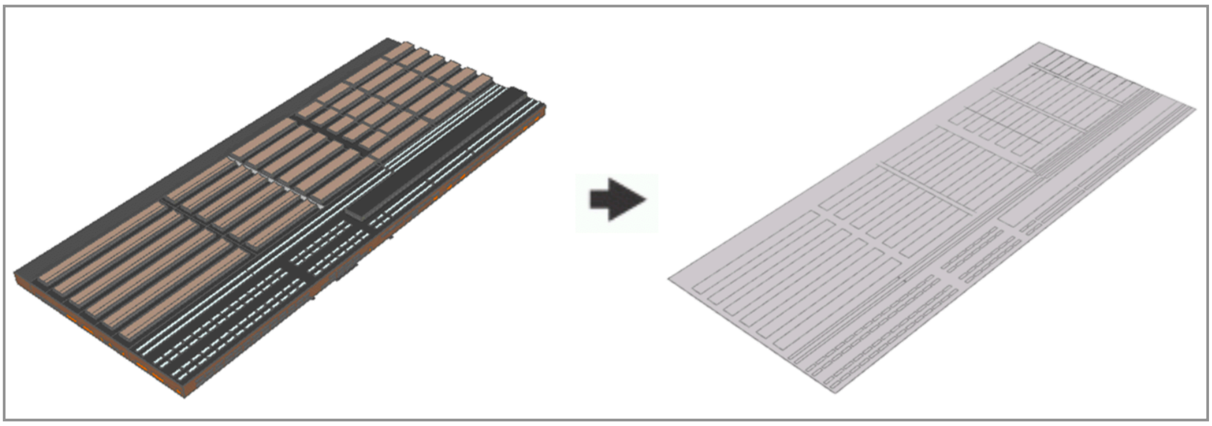


Figure 39. Using “Multipatch Footprint” tool create 2D polygon footprints.

After this transformation the new layer will be composed by group field parameter because the original 3D building is comprised by multiple features that share a common identifier in the attribute table.Then we can use another data management tool “Dissolve” in order to aggregate these group features.In this way all features in the layer are dissolved into one single feature.And finally extrude building polygon by the height value to create three-dimensional building mass(Figure 40, 41).

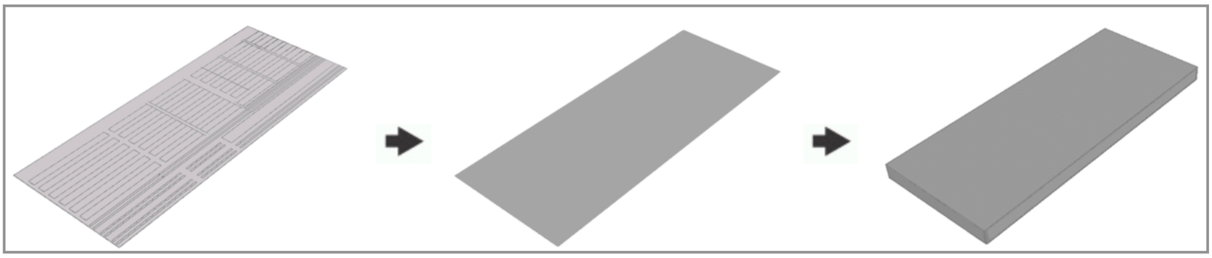


Figure 40. Using “Dissolve” and “Extrusion” tool create 3D mass feature.

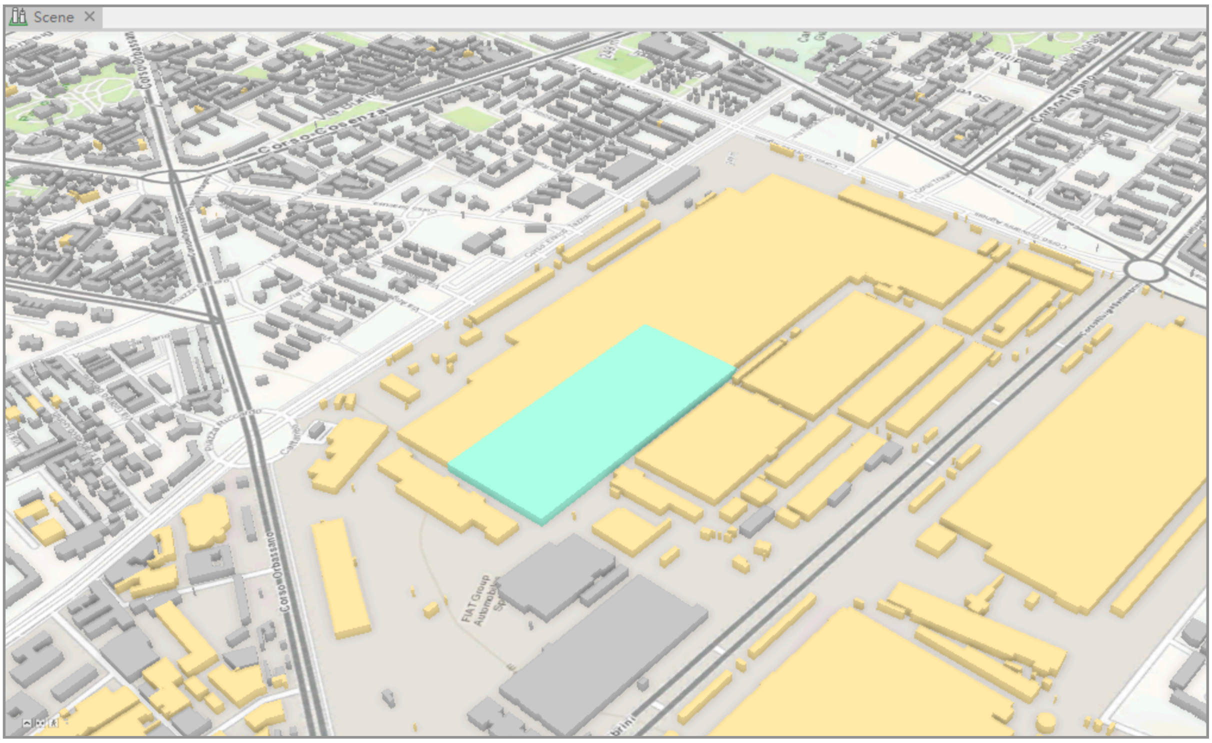


Figure 41. 3D mass(LOD1) model with urban environment.

So by adopting this method we can obtain different level of detail models from separate layers.On the one hand, models with high LOD3,4 which have complete exterior and internal view could be easily obtained after directly importing the .rvt file into ArcGIS Pro.On the other hand, models with low LOD1 which are basically referred to as the block model with flat roofs can also be transferred by using some geoprocessing tool in ArcGIS Pro.

However, using this method can not create precise LOD2 model which has differentiated roof structures and thematically differentiated surfaces.Although we can export the “ExteriorShape” feature by using geoprocessing tool “BIM file to Geodatabase”(Figure 42), the exported model would already have the openings given by windows and doors(Figure 43).This would not be correct because in LOD2 model we have not yet introduced the additional detail information of Windows.The perimeter wall of the building can be viewed in LOD2, while openings such as windows and doors only from LOD3.Therefore, another data transformation method which has the advantage for creating LOD2 model will be tested in the method 2.

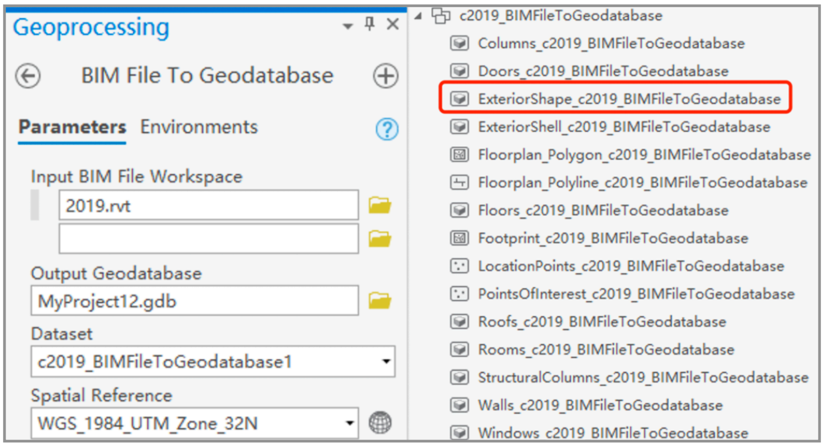


Figure 42. Using “BIM file to Geodatabase” tool import “ExteriorShape” feature.

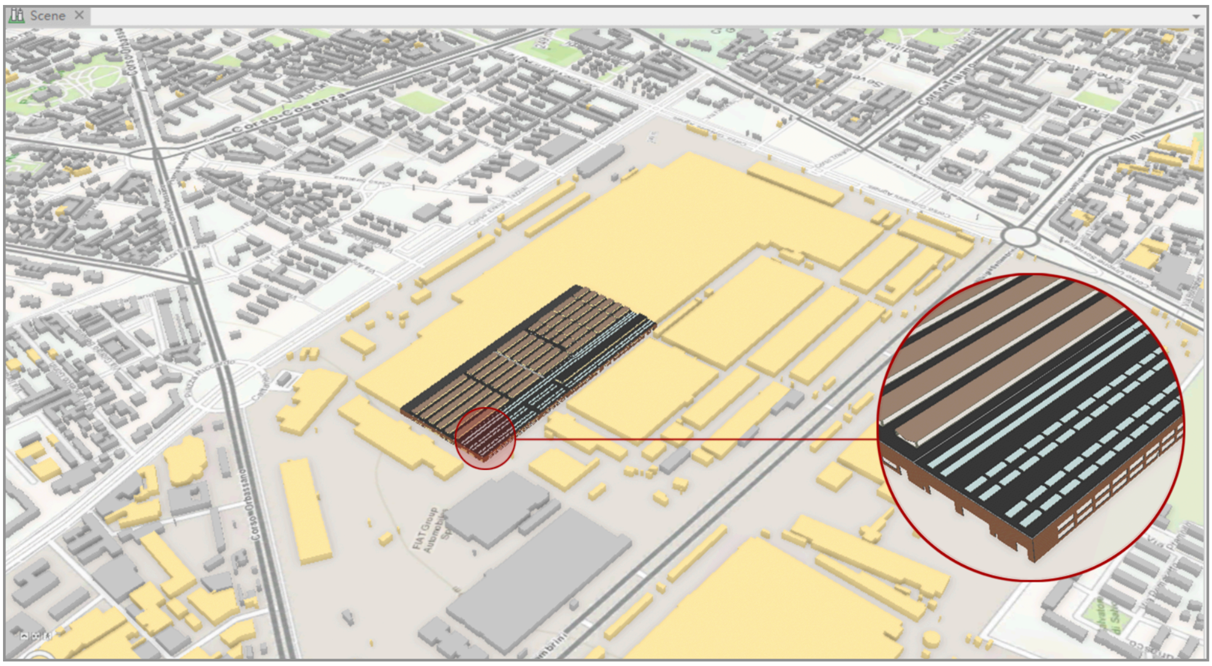


Figure 43. “ExteriorShape” feature viewed in ArcGIS Pro.

Method 2: Revit (.ifc/.rvt) to FME Workbench (.gml) to multipatch geometry (.shp)

For this method we need first convert the .ifc file to the .gml format.The FME "Feature Manipulation Engine" Workbench software is used for this method.FME was the first tool designed to be a spatial ETL application, focusing on translation of geographic data.It is a visual programming platform specialized in converting, sharing and integrating data. It has the capability to accomplish data integration by reading data from multiple sources (here A and B), using transformer tools to change or restructure the data to fit the users' needs, and writing it into a destination (C).While many data integration tools process only spreadsheet (i.e., tabular) data, FME can handle spatial data. It also uses a graphical interface, so no coding is required.The project file you create represents an executable file, where input data and the Reader is inserted.Using standard and editable tools called Transformer, we can create the sequence of operations that the Reader file must perform to generate the output file, the Writer.The basic workflow of FME workbench as shown below.

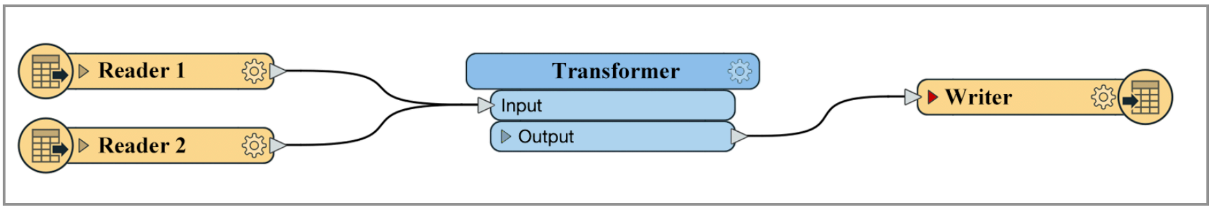


Figure 44. The basic workflow of FME workbench.

As mentioned in the previous chapter 2.2.2, the technical objects of the BIM with a significant feature of related virtual 3D models of the ground's surface which has different IFC classes that can transform to CityGML features.For example, "IfcRelSpaceBoundary" is geometrically described as a collection of planar polygon faces. Each face relates to a particular building element that is stored as a boundary attribute.Exporting IFC space boundaries at different levels can be provided by Autodesk Revit and transforming it into FME Workbench for the geometry of space boundaries in different IFC classes.

On the other hand, CityGML extends the GML standard with semantic and appearance aspects of 3D city models and introduces the concept of Levels of Detail (from LOD0 to

LOD4) in which objects become more detailed, both geometric and thematically, while the LOD increases.So this building data transformation method provides the possibility to produce a multi-LOD 3D model which has more potential to meet the requirements of different users.

As LOD0 model can be very easily obtained from open urban data source(.shp) and after using extrusion tool LOD1 model can also be easily generated(as there is no other floors in this case study), so following we will focus on testing the process that generate from LOD2 to LOD4 models which are BIM derived.

The Generation Process of LOD2 CityGML

The geometry proposed for this LOD involves the realization of a textured 3D model where the roofs are structured.The initial data is derived from BIM and corresponds to a 3D provided with geometric content related to walls, roof and floors.So after importing the .ifc file, in the Select Feature Types dialog we only select IfcSlab and IfcSpaces.These are the two layers needed to create a simple lod2Solid geometry.The IfcSlab represents the floors and roofs, and the IfcSpace represents the space between these floors.

Then the IFC features need to be merged into a single feature that represents the building.Add a Triangulator transformer to the canvas and connect it to both the IfcSlab and IfcSpace feature type.This transformer breaks the input geometry into a mesh for each of the flattened components.Now that the meshes have been created for each component we need to merge them together so we can work with a single mesh.Add a MeshMerger transformer to the canvas and connect it to the TINSurface output port on the Triangulator.This will merge all the individual meshes into a single mesh.CityGML has specific standards for attribute naming in order for the file to be readable. Thankfully there is a custom transformer to create these attributes.Add a CityGMLGeometrySetter custom transformer to the canvas. In the parameters set the CityGML Lod Name to lod2Solid and the Feature Role to cityObjectMember.Add an AttributeCreator transformer to the canvas and connect it to the

CityGMLGeometrySetter in order to set attributes we'd like to create such as Building_id and Building_name.

Next, add a LocalCoordinateSystemSetter transformer to the canvas Set the Origin X and Y.Next, re-project the data into the desired coordinate system. To do this, add a CsmapReprojector transformer to the canvas.In the parameters, set the Destination Coordinate System to EPSG:32632 and then change the Vertical Handling to Heights are relative to the ellipsoid(s) or geocentric.Finally, add a CityGML writer to the canvas and name the dataset Riverside_LOD2City.gml. Set the Feature Type Definition to Automatic and then connect it to the CsmapReprojector.After running the workspace we can inspect the output in the FME Inspector(Figure 46).

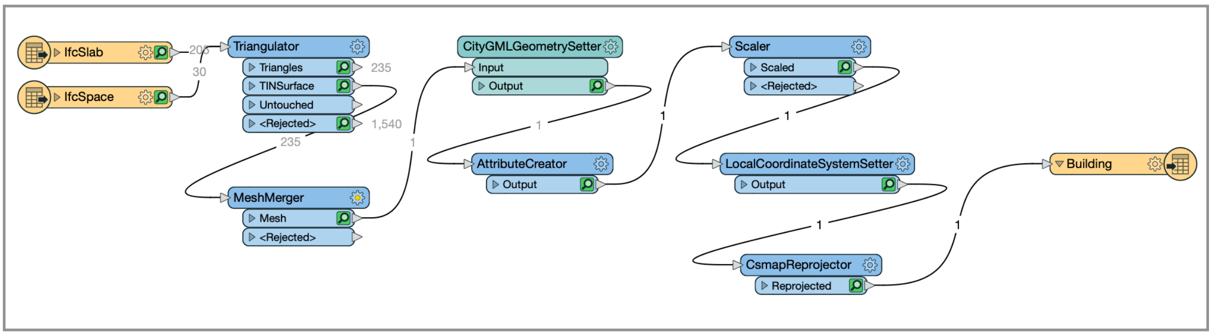


Figure 45. Complete workflow for creating LOD2 CityGML.

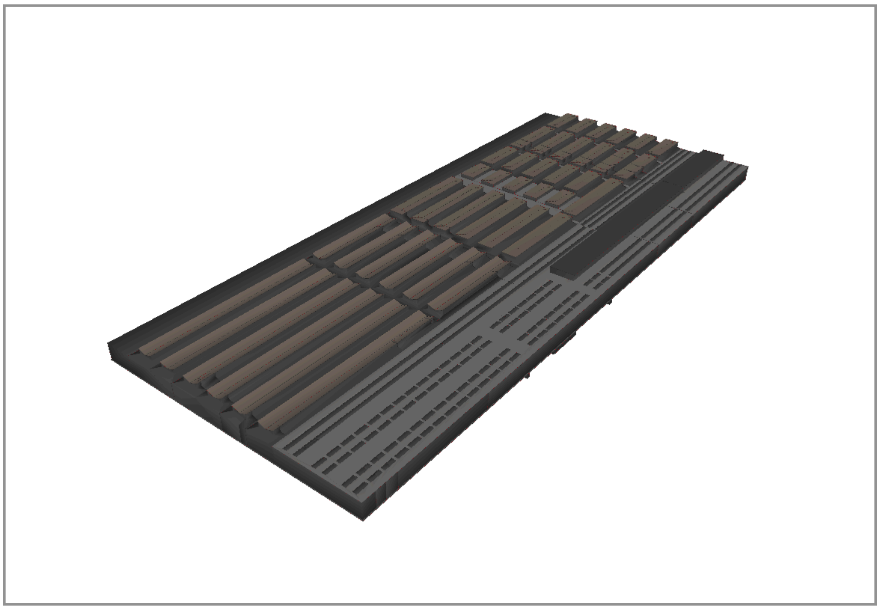


Figure 46. Output LOD2 CityGML viewed in the FME Data Inspector.

For the .gml formats it is not possible to proceed with their direct loading in the ArcGIS Pro. The files are converted to ArcGIS Pro in Geodatabase file format (.gdb) with the Quick Import tool in the Data Interoperability Tools function folder. The Type of geometry created is a Multipatch with only one feature.And further convert the Geodatabase file into a shapefile.The resulting LOD2 object is transferred into ArcGIS Pro as shown below.

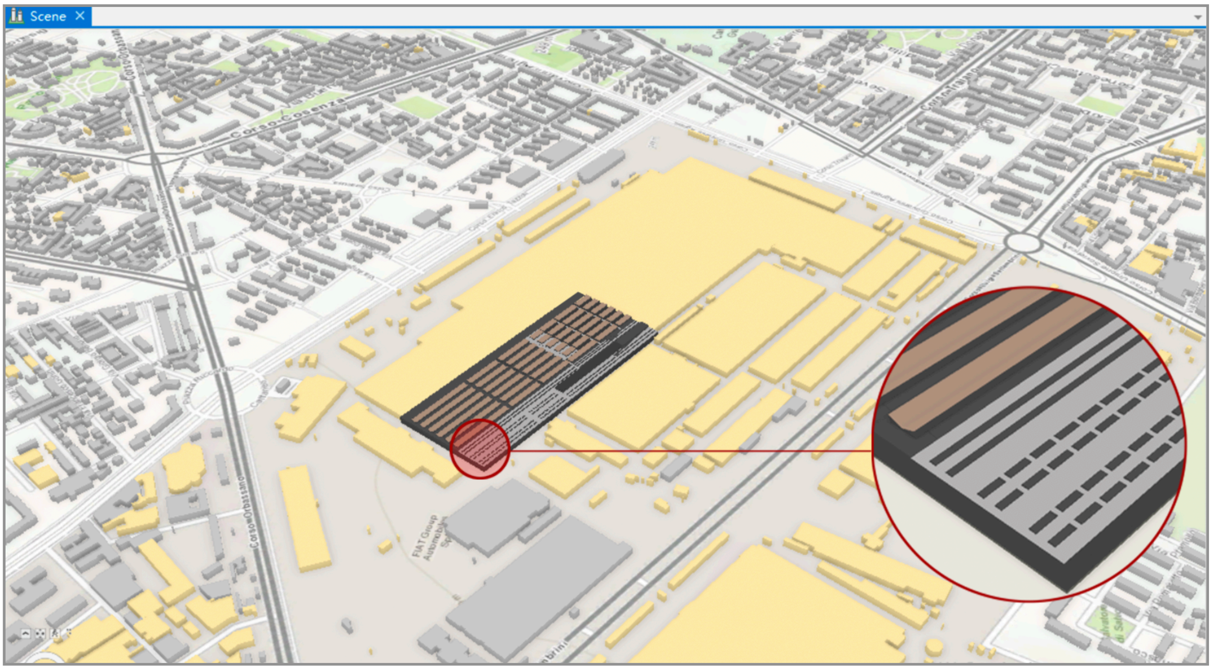


Figure 47. LOD2 model viewed in ArcGIS Pro.

The Generation Process of LOD3 and LOD4 CityGML

Unlike generating LOD2 CityGML model, the process of creating LOD3 and LOD4 is more complicated.For the IFC feature in this level is needed more details, for example, the opening is referred to the more details behind IFC format.Almost all features have their parent link set to the IFC Building Story, instead of the Building, so we need to move up one link to create the CityGML parent link to the Building, using the lookup tables stored in the variables.These separations and combinations can require several lookups of parent type and grandparent IDs from the variables created by the different IFC reader.The conversion of the .ifc file into LOD3 and LOD4 CityGML is realized with a script of FME, of which you can see an excerpt in the figure:

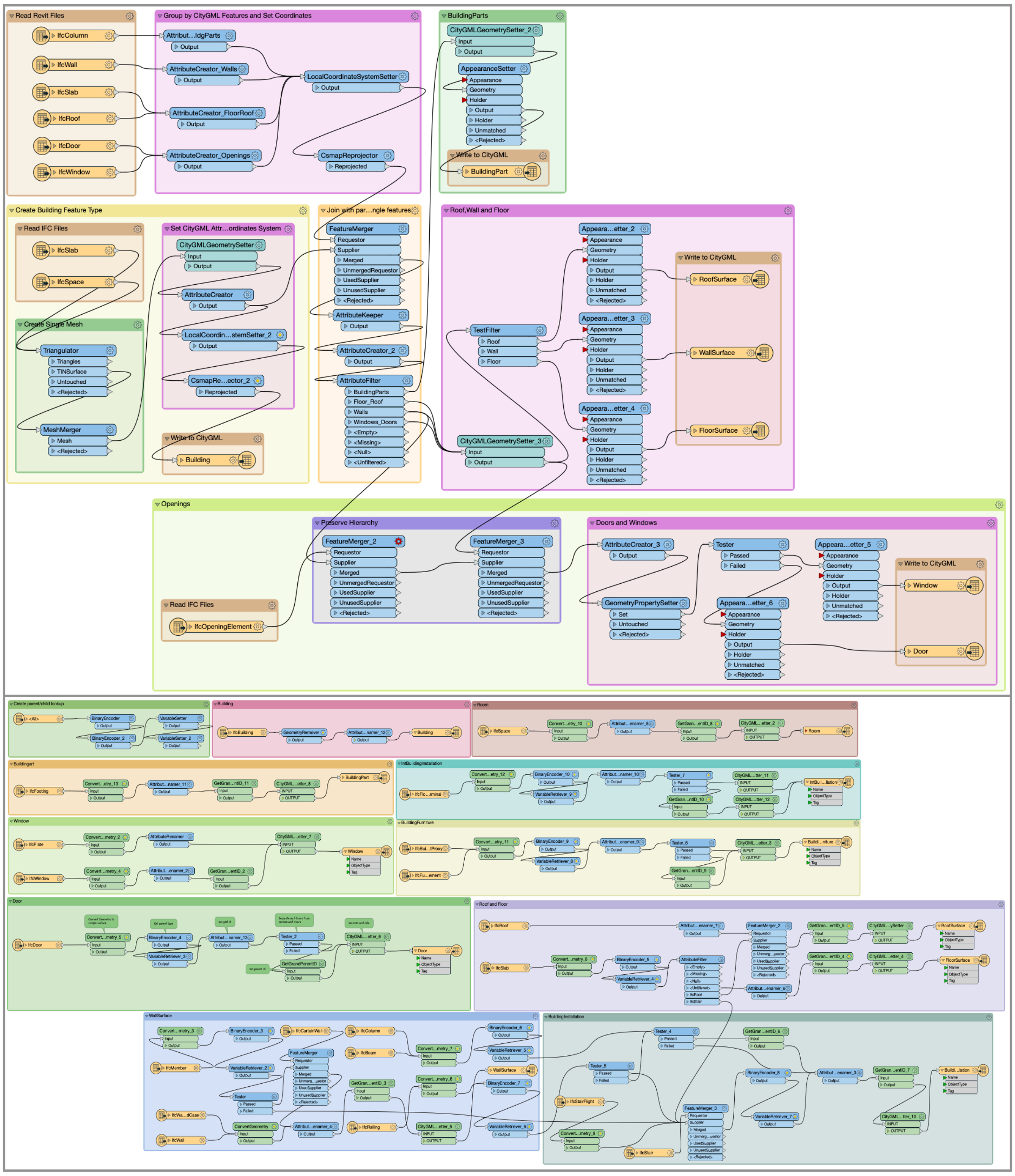


Figure 48. Complete workflow for creating LOD3 and LOD4 CityGML.

Finally, the complete LOD models are obtained after successfully transferred data between BIM and GIS environment.Each method has its own advantage aspects.Both of them able to create high LOD models but using method 1 is easier than method 2 for users.On the other hand, for low LOD models each of them has their areas of expertise.Method 1 provides possibility to generate LOD1 while method 2 is good at working on LOD2 models.

3.5 Data Integration

In the previous step we have transferred the urban data and different LOD building models into the ArcGIS Pro environment.This chapter will focus on the integration of GIS with building's energy data and other generally information, enables a more complete representation to reproduce the overall shape of the buildings with the aim of conveying information on them.In other words, the aim is to create the relation between geometry and information of the building in the urban environment by organized databases.

Thanks to the intrinsic characteristics of Geographic Information Systems, each geometry defined in the three-dimensional environment is linked to a row in a table, so that a set of user-defined information can be associated to it.In the specific case, in order to link building energy data and other information to the spatial elements representing the existing buildings, it is sufficient to exploit the presence of a common field between the spatial and the building data set.It is about the selection of a unique identifier such as the "Building_name" which labels each information to be used as key in the data integrate process.In ArcGIS Pro, we have two options to associate tables able to link between multiple entities:joining or relating tables temporarily in a map project or creating relationship classes in a geodatabase (more permanent associations).

First we need create the entity-relationship model before link these information.The entity-relationship(ER) model is based on following elements:objects, their properties, and the relationships between these objects.And there is cardinality defines the possible number of occurrences in one entity which is associated with the number of occurrences in another.For each entity, two cardinalities are specified: the minimum and the maximum number of possible occurrences.Normally there are three relationships defined by cardinality:Cardinality 1:1,Cardinality N:1(or 1:N),Cardinality N:M.A one-to-one relationship is a type of cardinality that refers to the relationship between two entities A and B in which one element of A may only be linked to one element of B.A many-to-one (or one-to-many) relationship is a type of cardinality that refers to the relationship between two entities A and B in which an element of A may be linked to many elements of B, but a member of B is linked to only one element of

A.A many-to-many relationship is a type of cardinality that refers to the relationship between two entities A and B in which many elements of A may be linked to many elements of B and vice-versa.Below is the a basic example of ER model.

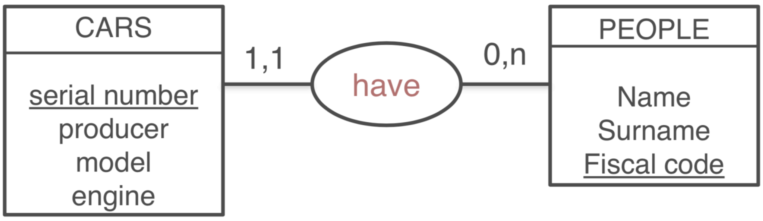


Figure 49. A basic example of ER model.

For our case study there are three data categories need to be integrated:Building energy data, which contains both the historical and simulated energy consumption of the building;Generally information data, which describes the generally information of the building such as building type, sector, address, construction and renovation period. And non-graphic building information drives from the schedules of Revit model.Below is the ER model for the data integration process.

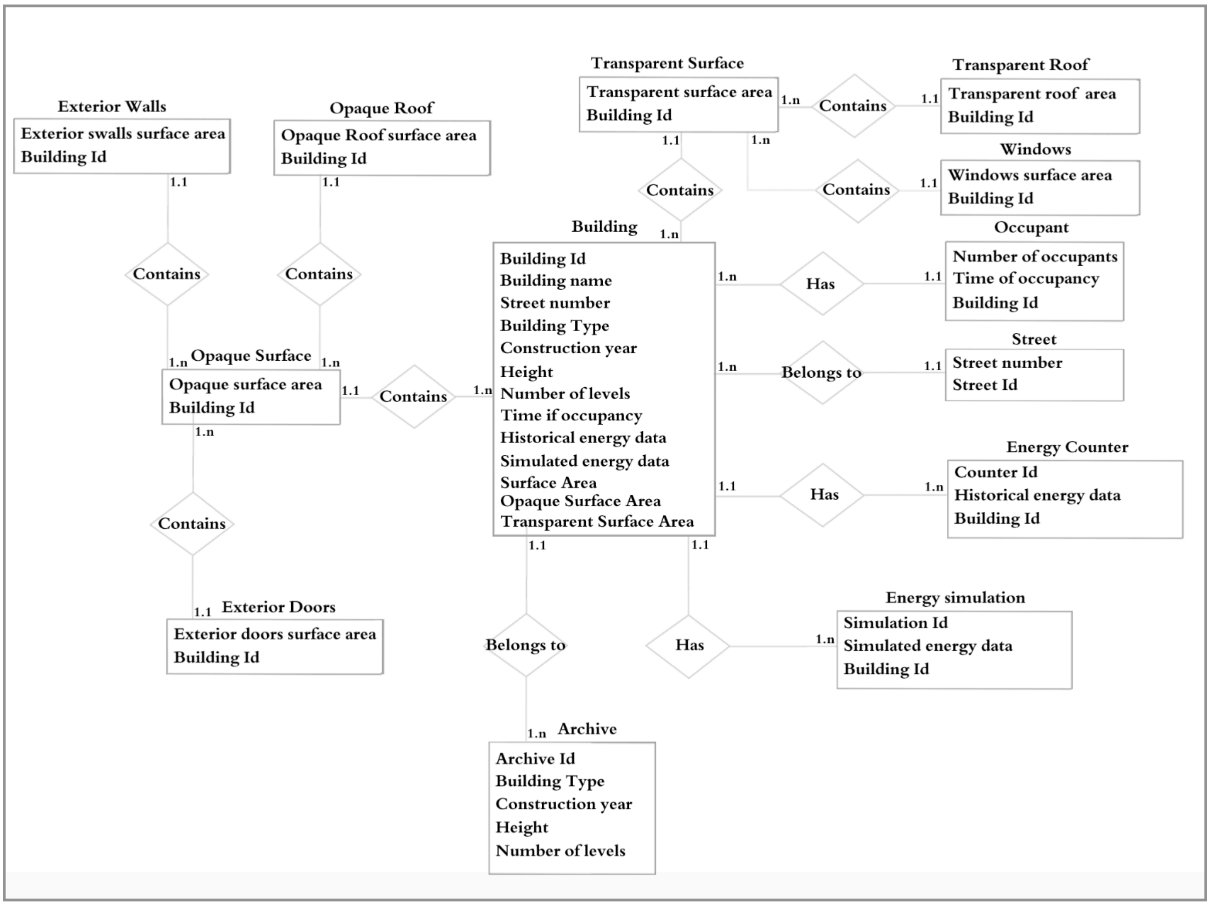


Figure 50. The ER model for data integration.

Specifically, we join these data tables to building layer based on the value of a field (Building_ID) which can be found in both tables.Notice that the name of the field does not have to be the same, but the data type must be the same.

When performing an attribute join, the joined fields are dynamically added to the existing table.Figure 51 shows the query results after joining data tables to the LOD1 building layer.This process which join massive data into one single feature can also be used for LOD2 building layer.In this way the complete data on building can be obtained through an informative pop-up simply by clicking on the desired geometry.

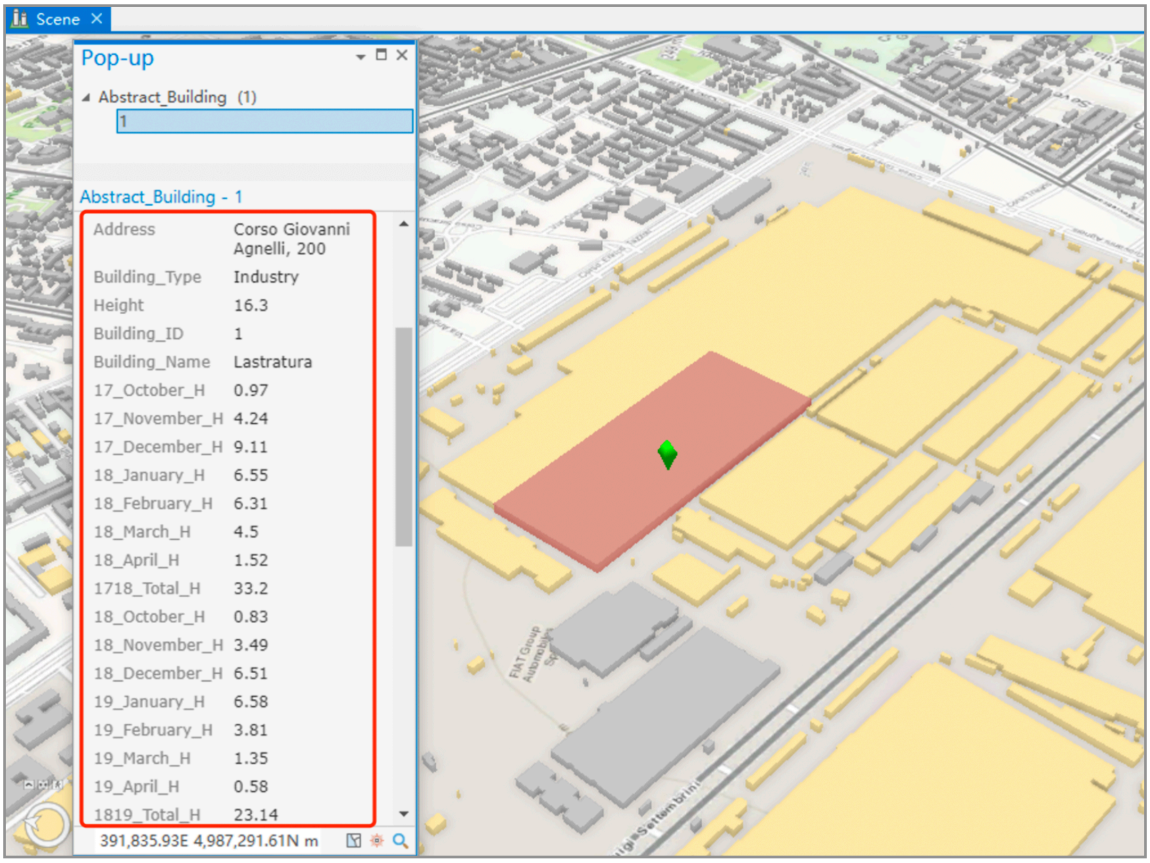


Figure 51. Zoom on LOD1 model with the pop-up containing all joined information.

On the other hand, for high detail model(LOD3 and LOD4) which are consisted of different features such as roof, wall, window, etc. Although it is not possible to merge them into a single feature, we can create a more accurate relation between each element and the statistic data.For example, the feature "windows" has field of "FamilyType" which defines each window's category.But we can not obtain from the ArcGIS Pro platform information about the area of windows surfaces.This value, however, is obtained by preparing a window

Abacus, as this screen allows the geometric properties of the windows and create calculated Values(Figure 52).This creates the possibility to join the data of window surface area into each window feature in ArcGIS Pro(Figure 53).

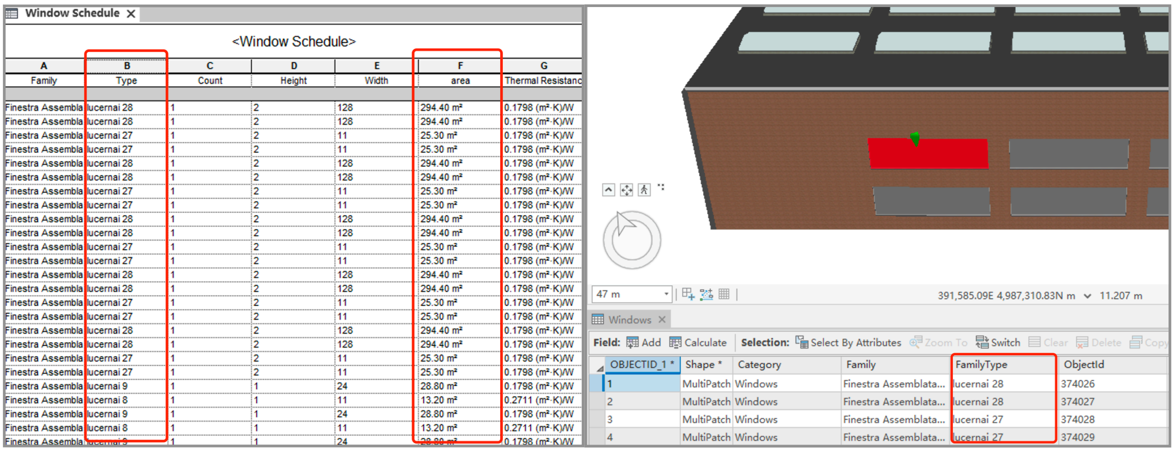


Figure 52. Calculated values in Revit Windows Schedule and GIS side window attribute.

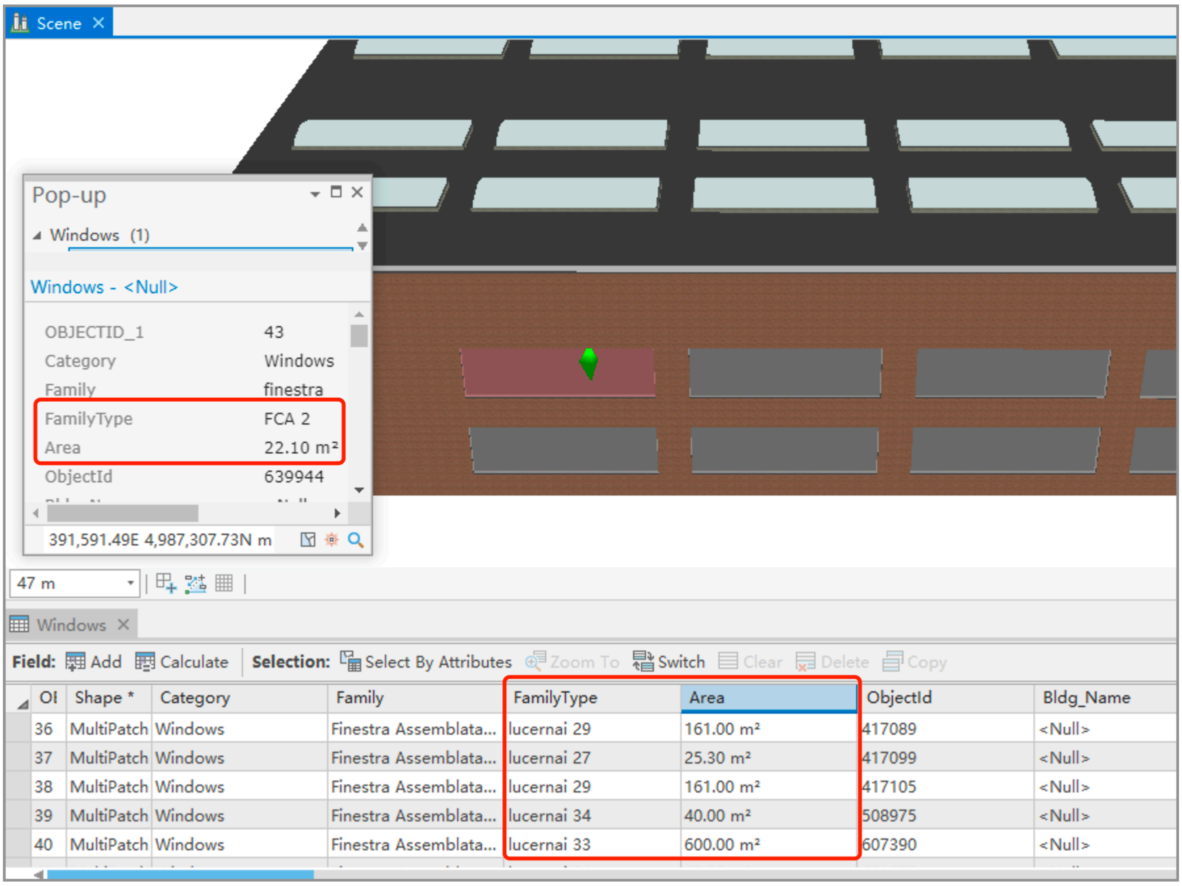


Figure 53. Zoom on feature of window with the pop-up containing joined window surface area.

This process can also be used for doors, roof, walls and other elements in the high LOD model.In sum, using join or relation options provides useful way for data integration between all LOD model. It depends on which kind of analysis we want to carry out.

3.6 Data Visualization

Once the model is completed in its geometrical and informative integration part, it is ready to be visualized and navigated through a graphic interface.Because of the widespread diffusion of the file format involved, some platforms were available even though, the use of 3D GIS is quite new and, therefore, there is still a lack of effective specific tools for its handling.For the aim of this study, a web-based tool was chosen in order to define a platform that is easily sharable among the actors involved in the management and the use of the building assets.In this direction the choice fell on the product offered by ESRI: ArcGIS Online.In this environment, a web scene can be defined by uploading various layers from the desktop software ArcGIS Pro, to be visualized and interrogated via web.Specifically, we can export all the features to .shp files and upload them to the online environment. And if need to append or update the file in the future, we can select the overwrite update data selection just ensure all field names and layers in the file we upload with the same as the original file(Figure 54).

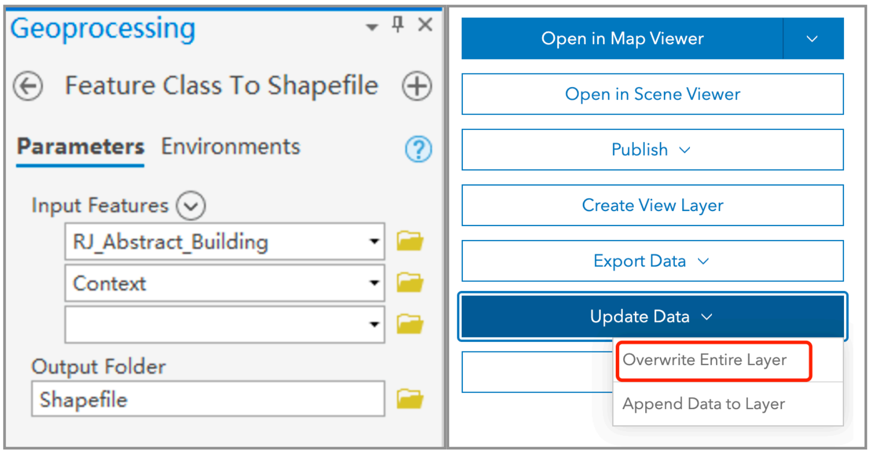


Figure 54. Export features to .shp files and overwrite the old version data.

Once uploaded the file, the sharing of the content is possible simply by the communication of the URL between the users that have access to the ArcGIS online platform.The graphic interface of the portal is intuitive and, coupled with the visualization of the three-dimensional shapes of the reference built environment, allows all kind of users to navigate and query the model.On the one hand, the qualitative assessment of the data, which is the main-feature of the online system, can be achieved thanks to the opportunity of representing ranges of attribute values with color scales.On the other hand, the accurate data on each building can be obtained through an informative pop-up simply by clicking on the desired geometry(Figure 55).

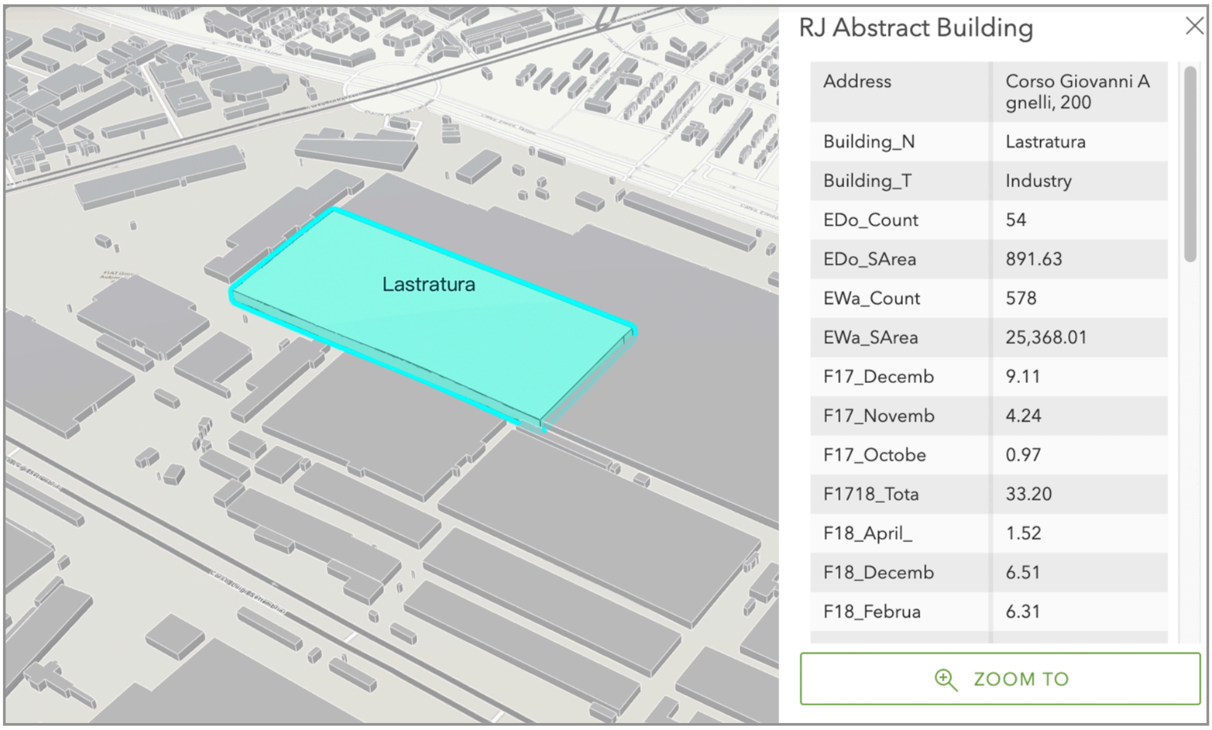


Figure 55. Query the model on ArcGIS Online.

However, as it was previously proposed, what we expected is the ability to summarize multiple forms of building's information on queries and dynamically show graphical representation to meet different user's needs.Obviously, at the present state, there is still need an effective specific tools for its handling the visualization and sharing of the open content.

Therefore a "Dashboard" is proposed which used to define a set of graphic objects that, structured and displayed in a certain way, allow to make accessible at a glance in real time a lot of information of different nature and complexity.Views in a dashboard may come from one or more data sets and reports, offering a consolidated view regardless of the location of the input data.The ability to view different data of the same process at the same time, make the dashboard a powerful decision support tool, especially in business and management in general.In the dashboard screen it is possible to select the chosen data inside a box and the navigation is updated in real time, filtering the data inside all the boxes.The dashboard is not born as a database but is a tool that contains only the data necessary to obtain specific information.Therefore, dashboards are created for a purpose and contain only the data necessary to fulfill the purpose.In this way the clicks on the filters allow to get to the information sought in a simple way.

Thanks to the development of Web Operations Dashboard for ArcGIS Online which is a fully configurable application that allows you to use charts, indicators, maps and other visual elements to show the status of static or real-time objects, services and events.Enables users to convey information by presenting location-based analytics using intuitive and interactive data visualizations on a single screen.The data that can be entered in an Operation Dashboard are GIS-derived and this is well suited to the management of real estate assets on an urban and territorial scale.It has a direct connection with the ArcGIS Online map and scene which can be created by uploading the .shp files.Therefore, in the final step we use this application in order to generate an interactive dashboard.

Firstly we need add the web layer which previous created in ArcGIS Online by importing the .shp files(Figure 56). The map layer will become data reference source and the cartographic format manageable in the Dashboard Panel.

Figure 56. Add Map Layer in Operation Dashboard.

Secondly is to display the building information which contained in the building layer.There are two categories information:Building object information which describes the different types surface area of building and Building energy information which describes the energy consumption.

The tool “Indicator” and “Gauge” are used for analysis of building object information.An “indicator” can be used to show the numeric attributes of individual features, and used to display a count, a sum, an average, a minimum, or a maximum summary statistic. Additionally, it can be configured to compare its computed value to a reference value and configured to show an icon or change its color only in response to conditional thresholds being met.This creates a very intuitive display for building object data.And “Gauges” are used to display a single metric within a quantitative context defined by minimum and maximum values.For example, we can show both the percentage of opaque and transparent area of building surface(Figure 57).

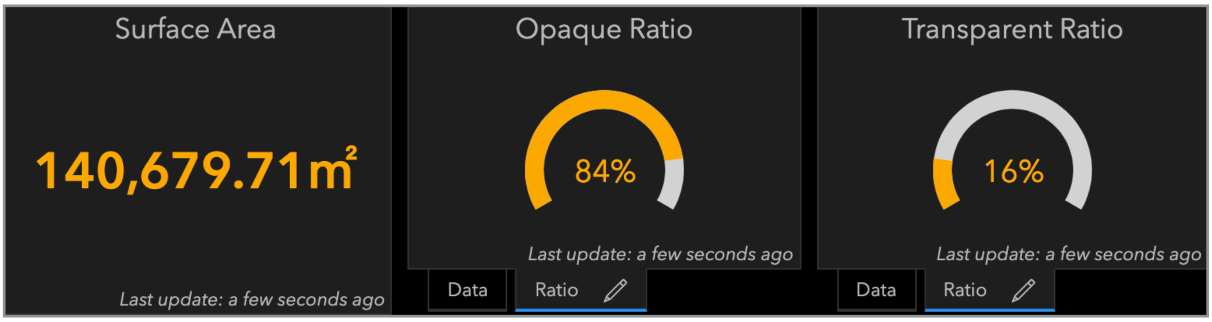


Figure 57. Use “Indicator” and “Gauge” analyze building object data.

Third, “Serial Chart” and “Indicator” are used for analysis of building energy information.A serial chart can visualize series of energy data along a horizontal (x) axis(time) and a vertical (y) axis(energy consumption).Both the historical and simulated annual and monthly energy data are created in order to examine the trends of building consumption(Figure 58).

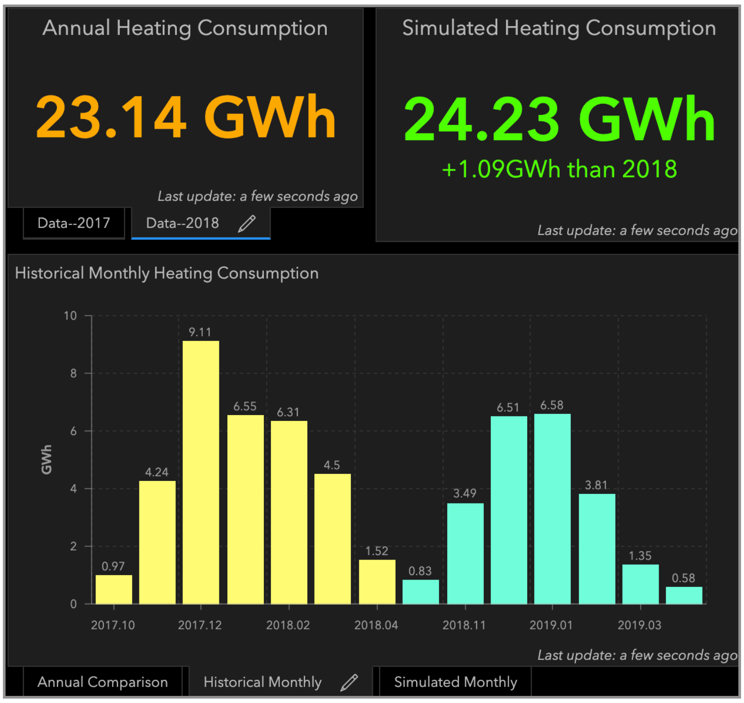


Figure 58. Use "Indicator" and "Gauge" analyze building energy data.

Next, the most important step is to create a "selector" in which can trigger actions.On the Selector tab, we can specify properties specific to the element, such as the selector's title and how it's displayed, as well as the data or values on which it's based. On the Actions tab, we can specify the actions to be triggered by the selector.Therefore we can choose a category selector which is characterized by "Building_Name"(Figure 59).

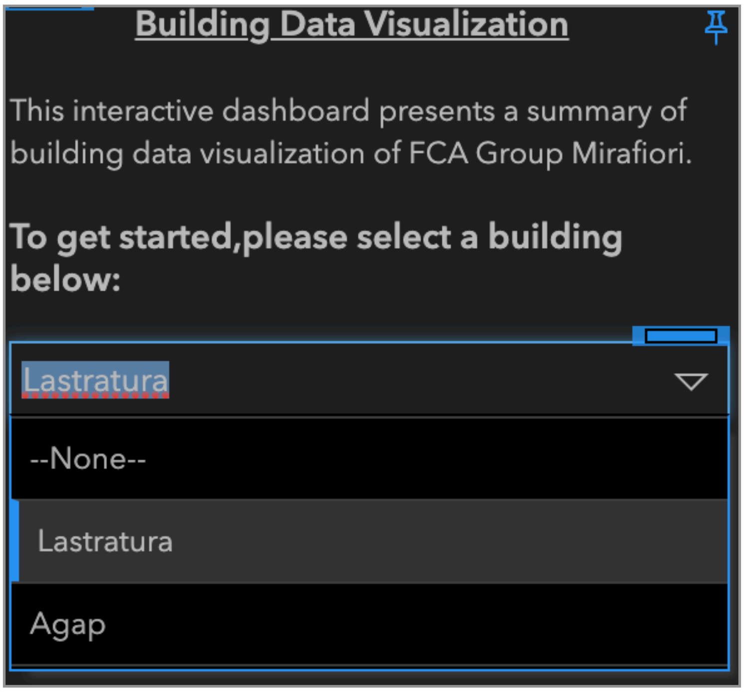


Figure 59. Create "Selector" characterized by "Building_Name".

Finally, after organizing positions of different data panels and embedded 3D map into the map panel, the dynamic dashboard for building information visualization is created as follows(Figure 60,61).In this query-based dashboard web platform, we can summarize multiple forms of building's information on queries and dynamically show graphical representation to all different stakeholders and in this way optimize their decision.

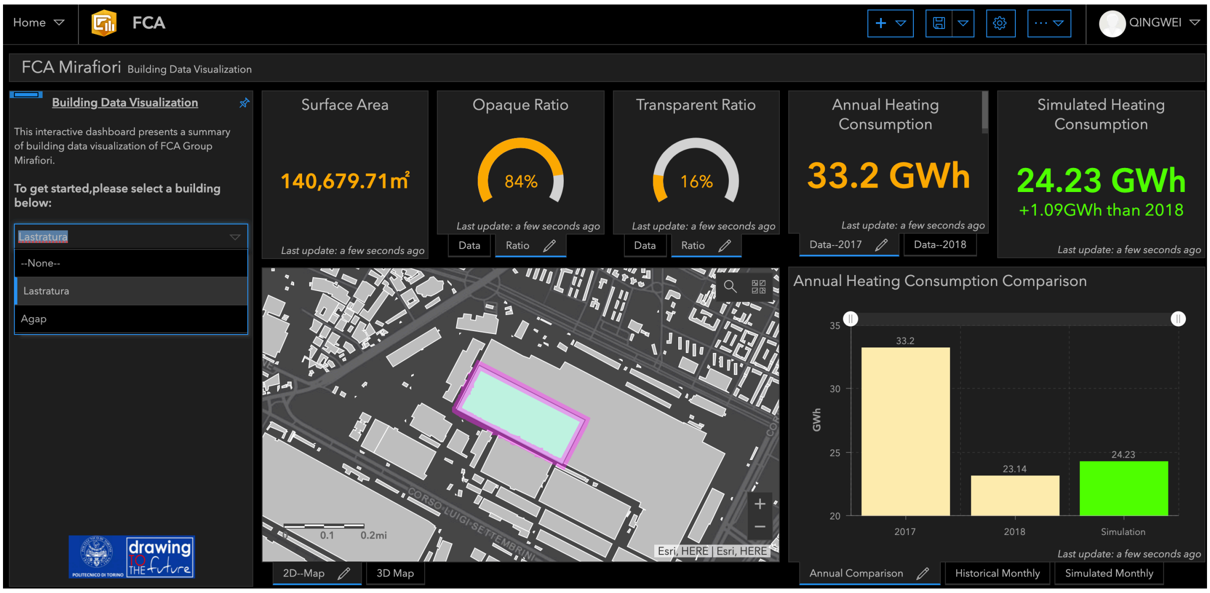


Figure 60. Query information based on the attributes of 2D map.

Figure 61. Embedded 3D map in Dashboard .

4. Results

The thesis work deal with the management of the real estate assets of FCA Mirafiori Lastratura through the analysis of two very distinct realities, BIM and GIS, evaluating the strengths of each to seek process optimization.Specifically, the research shows a workflow for the definition of a three-dimensional web-based environment able to support the visualization of building data(Geometry and information) on the built environment.

- **Building Geometry Visualization**

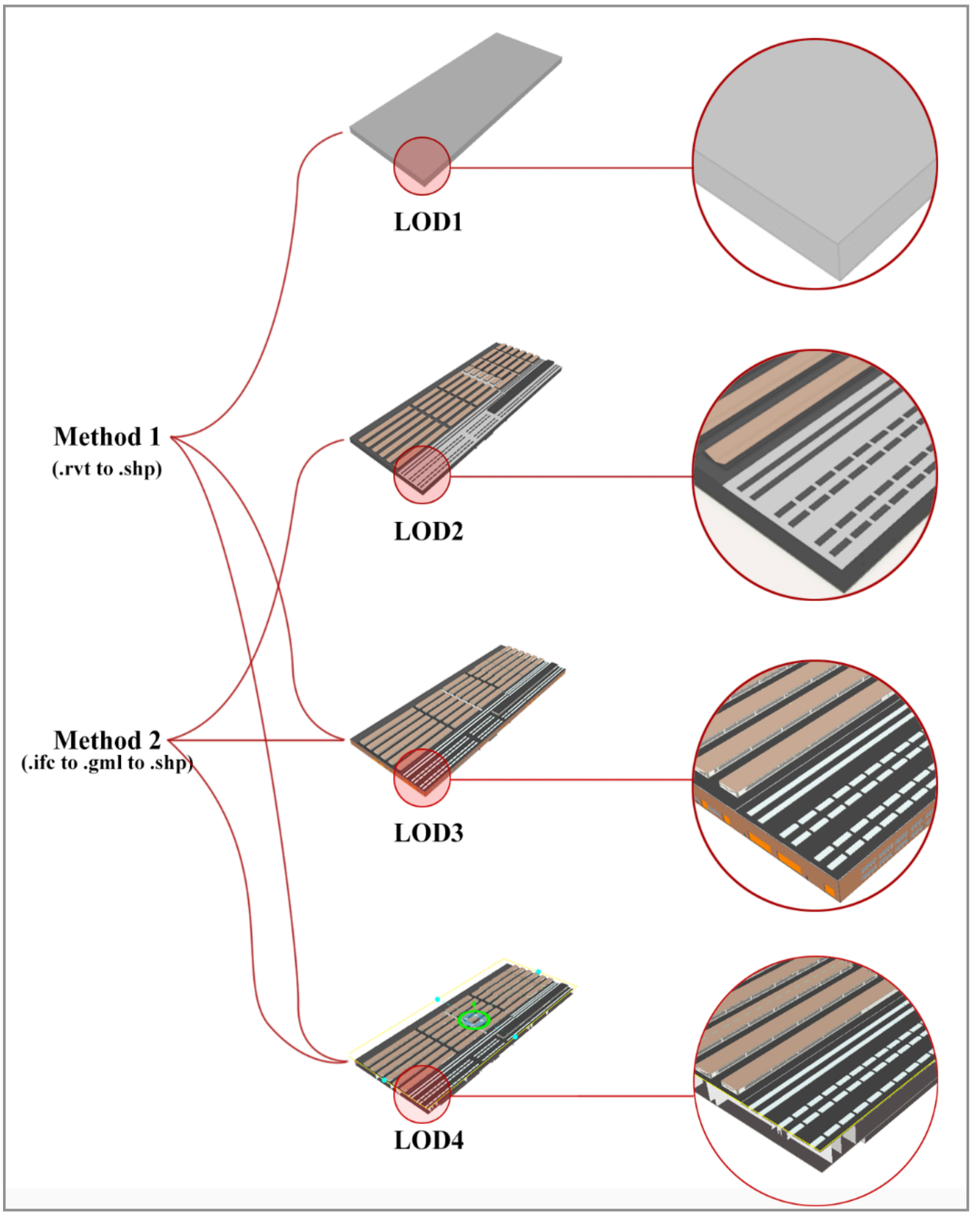


Figure 62. Comparison of creating different LOD models between two methods.

First aspect the thesis focus on is about the visualization of building geometry in different level of detail.In the case study, we test two different methods(Figure 62) to transfer the BIM domain data into GIS domain environment.This framework offers different detailed building models, acquired through .rvt and .ifc enrichment process.The method 1 which integrates BIM data directly into multipatch geometry so that it is used as a direct input to many of the geoprocessing tools but also displayed on a map.It The method 2 transformation system is developed using Feature Manipulation Engine (FME), by Safe Software.FME allowed us to restructure the data model (IFC) and transformed it to the destination data format (CityGML).

Each method has its own advantage aspects.Both of them able to create high LOD models but using method 1 is more convenient than method 2 for users.The deliverable of method 1 can be immediately used and easily adapted by the architect and building modelers who have limited knowledge of data semantics and data interoperability.On the other hand, for low LOD models each of them has their areas of expertise.Method 1 provides possibility to generate LOD1 while method 2 is good at working on LOD2 models.LOD1 and LOD 2 model could be used when we need regards building object blocks as generalized features for carrying out some macro-scale analysis in urban environment.LOD 3and LOD4 model is more suitable when we need regards building object blocks as real features or construction elements with openings for executing more precisely analysis between building and city.

- **Building information Visualization**

Second aspect the thesis focus on is about the dynamic visualization of building information. In this case study, the multi-domain information contained in the building, were implemented synthetically in ArcGIS Pro and a web platform founded on a 3D GIS.The implementation of LOD1 city models and the creation of Dashboard for the analysis such as energy use and consumption of building stocks offers benefits especially in terms of comparison and communication.The provision of a query-based dashboard makes the comprehension of huge set of data more spontaneous with respect to the traditional cases in which numerical information are presented in tables or, at best, with the support of two-dimensional maps.This leads to the possibility of including a wider range of stakeholders in the debates which touch the theme of building assets management such as energy demand and saving.The web-based tool allows to share a common platform between different kind of stakeholders with the aim of capitalizing in the best way the data collected and generated.For the end users, the understanding of the information on the energy behavior of the buildings may stimulate energy-aware consuming, while for the owners and the facility managers, an immediate representation of the energy demand and the thermal properties of the building stock could be used as a support for the decision-making.

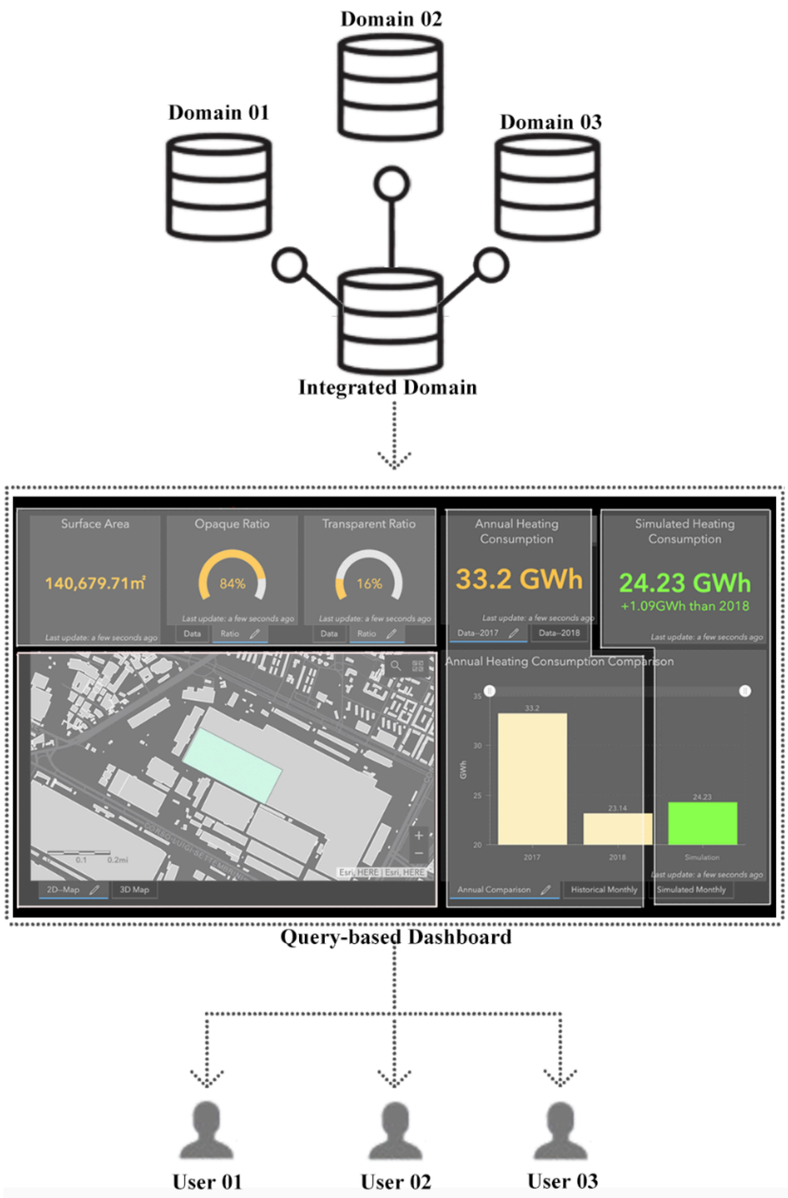


Figure 63. Query-based Dashboard integrated different domains data and share with all stakeholders.

5.Conclusions and Future Developments

A method of integrating GIS and BIM data to support management of building assets on the community scale is presented in this thesis. Through reviewing the city Digital Twin(DT) concepts for building assets management and existing information technologies, the author find that the integration of GIS and BIM can be very beneficial in this context.Therefore, this study attempts to address the data challenges in urban-scale building assets management by combining GIS and BIM technologies.The integration of BIM and GIS systems is developing in these days for data exchange of cooperation and interoperability in the capability of each system for simulation.Regarding the data integration approach, two transformation methods are used in the data integration process in order to achieve geometry and semantic integration between the GIS (Geodatabase) and BIM (RVT/IFC) models.

Furthermore, the output dashboard also automates the generation of the information required by different stakeholders through a data query process, and then provides useful visualizations of the simulation results.We expect that users who do not know BIM and GIS can also use our method to obtain building data and perform the simulation.The development of the query process on the integrated data to satisfy data requirements of stakeholders. Through the queries, stakeholders can rapidly retrieve design information for energy simulation from the integrated model.In this sense, different stakeholders can better manage and control different sources of data and different design scenarios in this way involved in a better decision-making process.Such work can alleviate the data incompatibility between GIS and BIM in the domain of urban-scale building assets management.

Future developments will involve the addition of other attributes to the city model, from the data on the building generally data to more sophisticated information about the facility management of the building stocks. By analyzing the Building Information Modeling (BIM) process of an industrial building through the management of the building's own data, integrated with those deriving from sensors for monitoring process variables. Specifically, this method will not only integrate BIM, GIS but also IoT technologies in order to develop a real digital twin of the building.

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