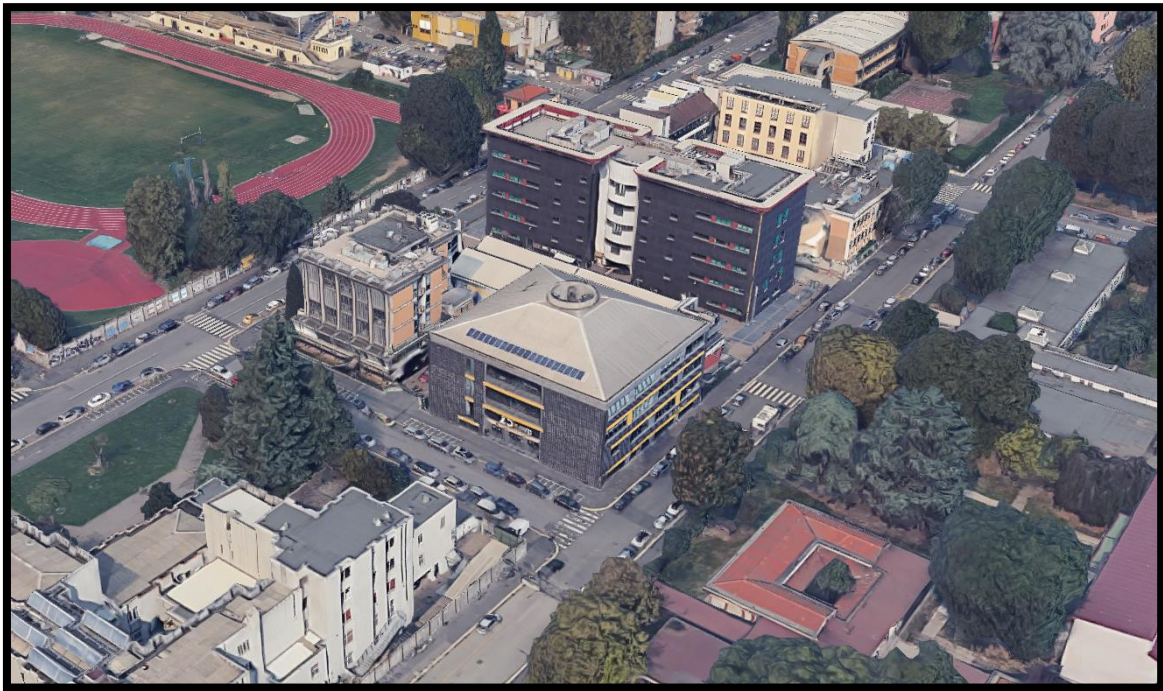


# MODELLING RULES FOR BIM AND GIS INTEGRATION FOR FACILITY MANAGEMENT



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## **Abstract**

### **English**

Acknowledged methodologies for Facility Management (FM) and Condition Inspection (CI) are time consuming and expensive. Furthermore, the use of new technologies within the final phases of a building's lifecycle is barely spread. Faster, cheaper and reliable procedures for assessing building stocks are needed for helping the building managers in decision making processes.

New tools have been used for many years to manage the information of the buildings during the design and construction phases, but FM needs to be harmonized in this digital process since we don't have tools to assess the built environment in an efficient way and the existing methods don't happen to be actually collaborative. The purpose of this thesis is proposing a methodology to increase the efficiency of CI processes using Building Information Modelling (BIM) and Geographical Information System (GIS) procedures for the assessment of the built environment, through a series of steps; after developing a BIM model of the building and its surroundings, the assessment was performed through the use of online surveys whose information the data manager introduced into the digital models (BIM and GIS integrated). This way, any change regarding the condition of a single element could be updated way faster than usual and the same with repairs or renovations (furniture, windows, etc.).

The methodology was tested in a case study (building 25 Politecnico di Milano). The results shown were positive and demonstrated that the methodology can be applied in the built environment, supporting the development of the digital model for CI. Therefore, it could be stated that the integration of BIM and GIS tools with FM procedures leads to a significant growth of the efficiency in the current methodologies used in CI.

## **Español**

La metodología utilizada actualmente en Facility Management (FM) y Condition Inspection (CI) consume mucho tiempo y dinero. Además, el uso de nuevas tecnologías en las últimas fases de la vida útil de un edificio está muy poco extendido. Se necesitan nuevos procedimientos más rápidos, más baratos y asimismo confiables, para evaluar el stock de edificios con el objetivo de ayudar a los gestores de la edificación en la toma de decisiones.

Desde hace muchos años se utilizan las nuevas herramientas de que disponemos para administrar la información de los edificios y el FM debe armonizarse en este entorno digital, ya que no tenemos herramientas para evaluar con eficacia el entorno construido y los métodos existentes no se muestran efectivamente colaborativos. El propósito de esta tesis es plantear una metodología para incrementar la eficiencia del CI utilizando la metodología Building Information Modelling (BIM) y Geographical Information System (GIS) para la evaluación del entorno construido, a través de una serie de pasos: tras desarrollar un modelo BIM del edificio y sus alrededores, la evaluación se realizó mediante el uso de formularios online cuya información fue introducida por el gestor del edificio en los modelos digitales (BIM y GIS integrado). De este modo, cualquier cambio respecto a las condiciones de un elemento concreto podría ser actualizado más rápidamente de lo habitual, igual que las reparaciones o renovaciones (mobiliario, ventanas, etc.).

La metodología se probó en un caso de estudio (edificio 25 del Politecnico di Milano). Los resultados mostrados fueron positivos, demostraron que la metodología puede aplicarse en el entorno construido y respaldaron el desarrollo del modelo digital para CI. Por lo tanto, se podría decir que la integración de las herramientas BIM y GIS con FM produce un aumento de la eficiencia de los procedimientos actuales utilizados en CI.

## **Valencià**

La metodologia utilitzada actualment per Facility Management (FM) i Condition Inspection (CI) requereix molt de temps i és costosa. A més, l'ús de noves tecnologies en les últimes fases de la vida útil d'un edifici està molt poc estès. Con l'objectiu d'ajudar al gestor de l'edifici amb la presa de decisions, es necessiten nous procediments més ràpids, econòmics i fiables per avaluar el stock d'edificis.

Des de fa molts anys s'utilitzen les noves eines de què disposem per administrar la informació dels edificis i el FM s'ha d'harmonitzar en aquest entorn digital, ja que no tenim eines per avaluar amb eficàcia l'entorn construït i els mètodes existents no es mostren efectivament col·laboratius. El propòsit d'aquesta tesi és plantejar una metodologia per incrementar l'eficiència del l'CI utilitzant procediments Building Information Modelling (BIM) i Geographical Information System (GIS) per a l'avaluació de l'entorn construït, a través d'una sèrie de passos: després de desenvolupar un model BIM de l'edifici i els seus voltants, l'avaluació es va realitzar mitjançant l'ús de formularis en línia i aquesta informació va ser introduïda pel gestor de l'edifici en els models digitals (BIM i GIS integrat). D'aquesta manera, qualsevol canvi respecte a les condicions d'un element concret podria ser actualitzat més ràpidament del que és habitual, igual que les reparacions o renovacions (mobiliari, finestres, etc.).

La metodologia es va provar en un cas d'estudi (edifici 25 Polimi). Els resultats mostrats van ser positius, demostrant que la metodologia es pot aplicar en l'entorn construït i va recolzar el desenvolupament del model digital per CI. Per tant, es pot dir que la integració d'eines BIM i SIG amb FM produeixen un augment de l'eficiència dels procediments actuals utilitzats en CI.

**Keywords:**

Building Information Modelling (BIM), Facility Management, Asset Management, Condition Assessment, Condition Inspection, Geographic Information System (GIS), GeoBIM





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## **Abbreviations**

BIM: Building Information Modelling

GIS: Geographic Information System

FM: Facility Management

AM: Asset Management

CA: Condition Assessment

FCA: Facility Condition Assessment

BCA: Building Condition Assessment

CI: Condition Inspection

ISO: International Organization for Standardization

EN: European Norm

UNI: Ente Italiano di Normazione

AEC: Architecture, Engineering and Construction

AEG: Architecture, Engineering and Geospatial

LoD: Level of Detail

LoI: Level of Information

LOD: Level of Development

IFC: Industry Foundation Classes

CityGML: City Geography Markup Language

GeoBIM: Integration of GIS and BIM



## 1. Introduction

Many different reasons have motivated the accomplishment of this thesis. A deep study on the construction market, the widespread use of new technologies and the need to obtain better methodologies to manage the building stock are the main motivations to address this enterprise.

### 1.1. Scope

Information and communication technologies (ICT's) have created an enormous impact on daily activities, including every social, economic and legal sector. They have also brought an industrial revolution in the construction process all around the world, as well as a comprehensive improvement in performance of construction processes in terms of time, quality and customer's satisfaction.

There are many phases of a construction project where information and communication technologies can be implemented:

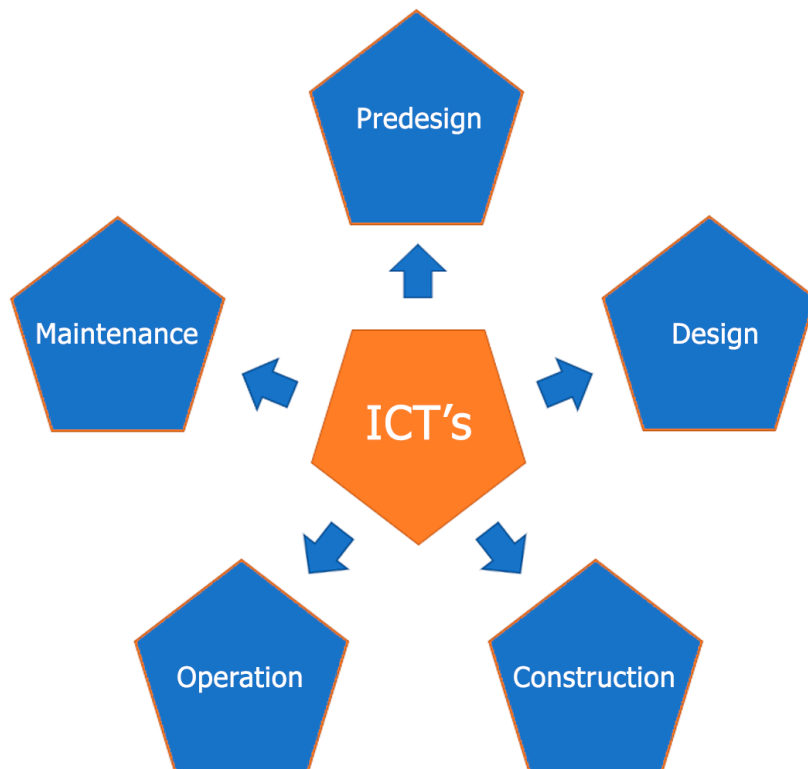


Figure 1. Construction phases and their relationship with ICT's.



During the preliminary phases, which mostly imply communication and information exchange, the use of emails and digital media is already common. The same happens for those design-oriented phases, where the use of specific software is widely spread. Computer Aided Design (CAD) is a must for engineering and architectural companies, although is being replaced more and more for the Building Information Modelling (BIM) methodology.

For construction phases, it is alike. There are many technologies that help reducing risk at work, optimizing material leftovers and ensuring that everything gets done in a proper way, and many documents that aim helping with this transition, as the 'Going digital' report (UKBIM Alliance, 2018). It is when the construction is over, that the implementation of new technologies and methodologies is lacking.

Operation phase must be considered specially in public structures like hospitals and shopping centres (Paudyal, 2012). Monitoring activities could be highly helpful in performance of normal functioning, as well as for maintenance purposes. Those two topics, which are closely related to Facility and Asset Management, need a better performance in terms of time and cost. The use of digital twins could help as well, especially if some kind of network with all the models could be created and shared among managers (Bolton *et al.*, 2018).

The ISO 55000 series provides an overview on asset management, its principles and terminology. Instead, the ISO 41000 and 15221 series handle the Facility Management part. There is a key element which will be the focus of this thesis: performance evaluation and improvement. More specifically, aspects concerning Condition Inspection of buildings and built environment, and the opportunities of implementing an efficient methodology.

## **1.2. Objectives**

In order to get to an efficient methodology, it is important to analyse the use of technologies, that help making people's lives easier. Lots of these technologies are focused on helping professionals with their respective jobs; this is because automatizing and systematizing those tasks which can reach such level of

autonomy implies huge levels of savings, regarding as much time as money (International Federation of Robotics, 2017).

For those processes that cannot be automated, there is still plenty of room for improvement. Applications and software for professionals also imply big cost and timing savings, for instance in the architecture field. Moving from handmade drawings to CAD was a big step in terms of efficiency (Techwalla, n.d.), as long as the initial struggles were solved (implementation of the software, training and learning how to use it). It has been many years since the Architecture, Engineering and Construction (AEC) area began to point at BIM as a matter of present and future.

In relation to facility management and asset management, there is software used to help managers in decision making (Technology Advice, 2020). A proper management software should have at least these features:

- Asset management: it should help users to differentiate and track physical assets, including equipment, inventory, costs... Allowing managers to make informing decisions about orders and budgets.
- Maintenance management: offers automated evaluations on preventative maintenance and scheduled maintenance for routine tasks. Regulatory compliance features store data to help managers stay current.
- Inventory and procurement: it ensures the upkeep of appropriate parts, tracks specific inventory locations, and allows built-in order purchasing.
- Administrative management: organize leases, real estate portfolios, purchase orders, and billing for your facility's team. Keeps track of tenant renewals, vendor contracts, and offers comparisons on financial data.
- Labour resource tracking: stores personnel skill profiles for future job-to-skill matching and forecasting of personnel gaps. Track employee labour and human resource paperwork, and make sure certifications and documents are up to date.

- Mobile capabilities: cloud-based platforms offer a real-time data exchange between maintenance supervisors and are accessible from any device. This allows office personnel and on-the-ground maintenance staff to stay in permanent communication and prioritize tasks. At minimum, a mobile web interface should be required.

BIM has a great potential for indoor inspection as well as Geographical Information System (GIS) for the outdoor part. However, there are some issues to solve and the main goal is to bring solutions to these problems. So, the **objectives** of this academic work are:

- Developing an efficient methodology for asset and facility management, focusing on the condition inspection of a building and an urban environment.
- Make the most of existing technologies regarding construction and management.
- Integrate facility and asset management concepts, specially, those linked to condition inspection, with BIM and GIS.

### **1.3. Motivation**

Talking about economy is always a matter of fact when it comes to justifying such an important thing as an investment. Why should it be interesting to take advantage on ICT's for asset/facility management purposes?

Construction market has a huge impact on economy. It is one of the most important sectors and brings stability to a country, along with other areas such as services and industry, which make the foundations of the financial system. For this reason, it is really important to make an analysis of European construction market, so the relevance of such an investment can be understandable.

For this purpose, some reports made by the **European construction sector observatory** have been reviewed. It is an initiative under COSME (a European programme for small and medium-sized enterprises) that regularly analyses and

carries out comparative assessments on the construction sector in all 27 EU countries and the UK. The results shown are displayed next.

The **Spanish construction sector** has been showing some signs of recovery since 2013 (although the 2017 values for production of construction and civil engineering were 5% and 16.9% below the 2010 levels respectively).

The total turnover of the broad construction sector grew by almost 27% between 2013 and 2017, while it was especially significant in the real estate activities and the manufacturing sub-sectors. Business confidence has been improving since 2010, in some cases surpassing the EU 28 average; the number of finished dwellings increased by 36% between 2015 and 2017. At the same time, the housing price has been increased by 11,1%.

The **Italian construction sector's** gross value added (GVA) accounted for 16.7% of Italy's 2018 GDP, proving it to be one of the most important sectors in the national economy. This happened despite the drop of 16.2% between 2010 and 2018 in terms of the sector's turnover, and the decline of 30.9% of production during the same period.

Sustainable construction and rising investments in R&D are prominent factors contributing towards the economic growth. A modest recovery in the construction sector is expected in 2020, although existing systemic bottlenecks such as employment decline in the sector, late payment by public administrations and **inefficiencies in maintenance of public structures** may discourage private investment in the future.

On the other hand, Euroconstruct, a Europe's construction market forecasting network, has also published reports on the European construction market and predictions on how it will be evolving that are interesting for the purpose of this thesis.

According to them, **European construction market** has reached a 3.1% of growth in 2018, with the forecast of a 2% in 2019 and a decreasing trend to an 1.5% in 2020 and 2021 (We Build Value, 2019). The construction industry in

Europe is seen relying on large infrastructure projects for a good part of its growth.

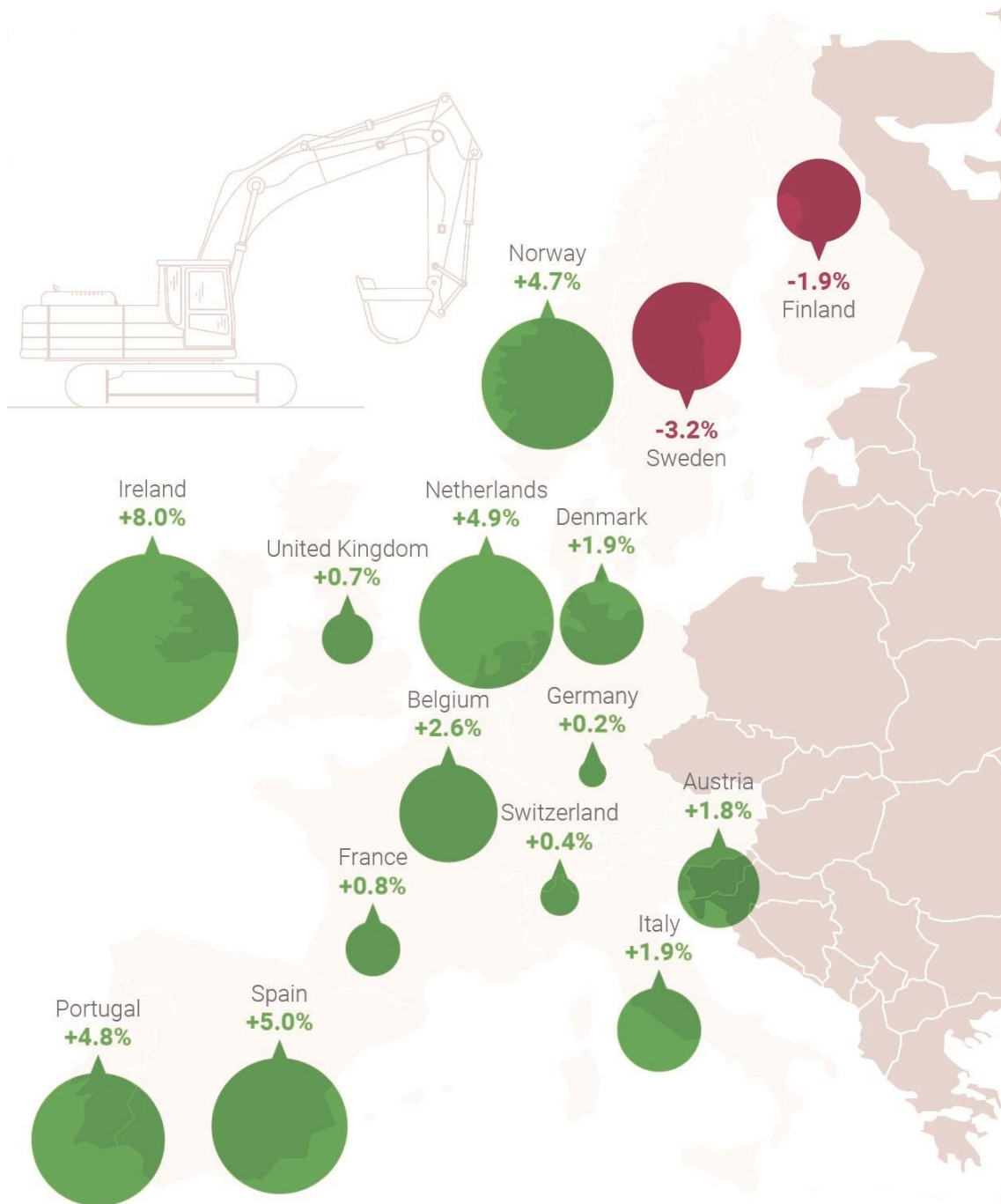


Figure 2. Construction industry in Western Europe (Euroconstruct, 2018).

Between 2019 and 2020, the construction industry in Italy should see moderate growth, underperforming other European countries. Ireland, Spain, Netherlands, Portugal and Norway should be the countries with a higher growth

in the whole continent. Particularly taking into account that this growth is mainly linked to large projects, the importance of facility and asset management is strongly increased. Saving costs can lead to better investment choices made by the countries' governments; if public assets are correctly managed, investment in maintenance can be refined, and the money not spent in this item can be used to build new infrastructures, which would result in a higher growth.

Asset and facility management technologies have a lot to say about this topic, as there are many benefits from applying them to the construction industry (8 benefits of asset management software for the construction industry, 2018):

- Inventory management: many details, including the brand, type, purchase date, current location, movements... can be stored.
- Maintenance and service scheduling: it can be used to set up maintenance and service reminders which help reducing the risk of unplanned breakdowns.
- Compliance: setting up licensing reminders to ensure that software always meets compliance requirements.
- Fuel usage: strictly managing fuel usage can be advantageous, specially with fuel costs ever rising.
- Asset utilization: daily tracking of assets can give a good idea of how many hours a piece of equipment is in action and which ones are underused.
- Insurance premiums: increasing security can lead to reduced deductibles and lower insurance premiums.
- Job estimation and billing: analysing data from previous projects may improve estimation on future tasks or jobs.
- Machine operator efficiency: tracking assets can help identifying bad habits on-site and eliminating them can produce safer worksites, reduce labour costs, etc.

Many other papers show the importance of construction market in Europe (Renonbill, 2020) and the advantages of adopting new technologies in this particular field (Building Smart Spain, 2019). For all these reasons, developing a proper methodology could result into an improvement for the construction industry and it would be really interesting to take advantage of these potential benefits.

## **2. State of the art on asset and facility management**

After introducing asset/facility management, the focus is going to be on two different topics, both related. First of all, condition assessment (which is a strong part of asset/facility management and is a matter of interest for this academic work), and the second one, its integration with BIM and GIS.

### **2.1. Asset/Facility Management and Condition Assessment**

It may be necessary to differentiate between Facility and Asset Management. Both concepts have converged when it comes to their professional functions; however, they still have a quite few differences when regarding daily operations.

The first difference is about what kind of assets are managed. Asset management considers all assets, while facility management is focused on those physical ones. The second difference is the purpose of the actions that managers must take; while the asset manager's main objective is to maximize the return on the business' assets, the facility managers search for an optimal work environment and improve overall productivity (Critical Systems Management, 2018). This work is made from an engineering point of view, thus, talking about physical assets.

#### **2.1.1. Asset management – ISO 55000**

Effective control of organization's assets is truly important to create value through managing risk, with the aim of achieving a successful balance of costs, risk and performance. In this direction, **asset management** translates the company's aims into asset-related decisions and plans, enabling the organization to realize value from its assets in the achievement of the objectives. Benefits can include some of the following:

- Improved financial performance
- Informed asset investment decisions
- Managed risk
- Improved services and outputs
- Demonstrated social responsibility



- Demonstrated compliance
- Enhanced reputation
- Improved organizational sustainability
- Improved efficiency and effectiveness

In order to understand these benefits, the first step should be to define what an asset is. An **asset** is an item, thing or entity that has some value for the company (this value could be potential or actual). It can be tangible or intangible, financial or non-financial and variable according to the stakeholders.

Asset management is based in a set of fundamentals. These are **value** (because it's not focused on the asset itself, but in the value that can provide to the organization), **alignment** (because they are used as a decision-making instrument), **leadership** (because it is used at a managerial level to improve the organization) and assurance (because it brings certainty that the assets will fulfil their purpose).

To coordinate and control asset management activities, companies normally use **asset management systems**. Nevertheless, some important aspects about asset management can be arranged outside this system. The relationship between them is shown in Figure 3.

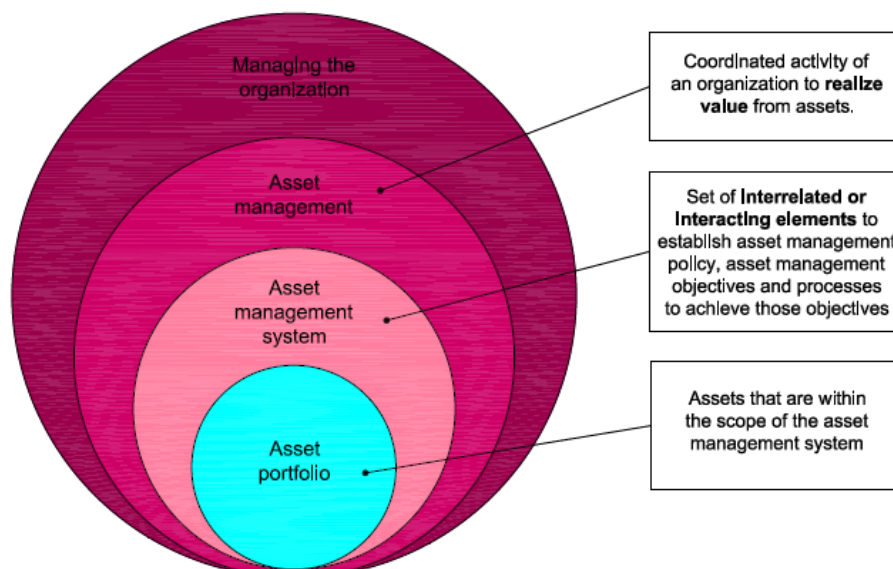


Figure 3. Relationships between key terms (International Organization of Standardisation, 2014).

Asset management system's **function** is to establish the asset management policy and asset management objectives, as well as the processes needed to achieve those objectives. The elements of the asset management system should be seen as a set of tools, including policies, plans and information systems. This information ought to be accurate, but the system is more than information; it interacts with many functions of the organization.

An asset management system can provide some **benefits** to an organization:

- The creation of the system itself: it can stimulate and improve organizational knowledge and decision making.
- New insights and cross functional integration: it enhances the understanding of assets, the risks associated, investment needs, etc.
- Financial functions benefit: integration of assets with long-term financial plans can enable balancing short-term financial needs.

Besides, there are some **elements** that define an asset management system:

- An asset management system has an impact on the **whole organization**, and the process itself of establishing an asset management system requires a thorough understanding of its elements and policies.
- When establishing an asset management system, an organization should consider its internal and external **contexts**.
- Top management and **leaders** at all levels are responsible for communicating the organization's asset management objectives and the importance of the asset management system to employees. This communication should be two-way, being open to receiving information aimed at improving the asset management system.
- The principles by which the organization intends applying asset management to achieve its organizational objectives should be set out in an asset management policy or strategy and this should be documented in a **strategic asset management plan** (SAMP).

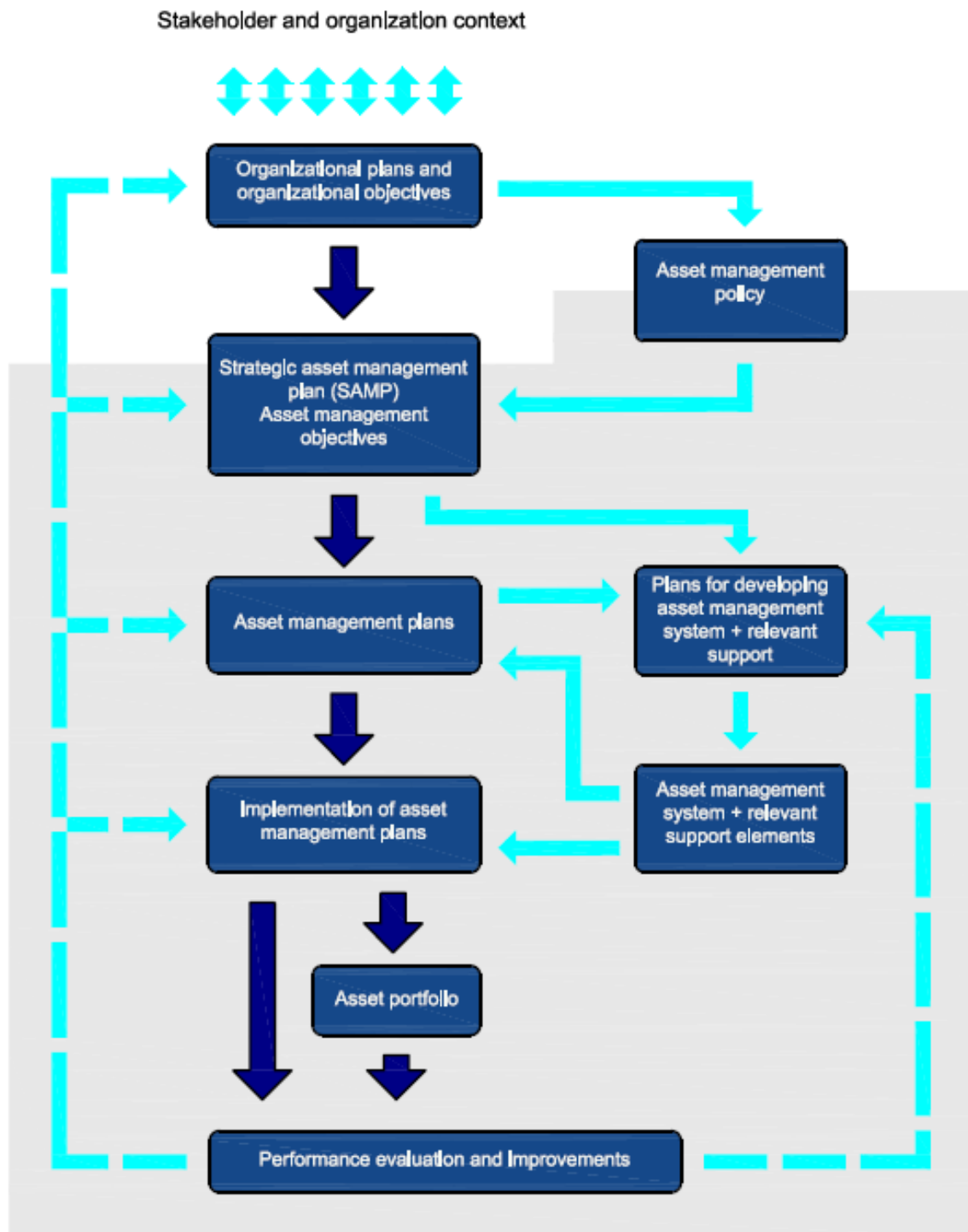


Figure 4. Relationship between key elements of an asset management system. The grey highlighted box designates the boundary of the asset management system (International Organization of Standardisation, 2014).

- The asset management system should specify the competency requirements for personnel involved in asset management. This normally

requires close cooperation with the organization's human resource management system. These two systems should be mutually **supportive**.

- **Operation** of the asset management system can sometimes require planned changes to asset management processes or procedures. Risk assessment and control in the context of managing change is an important consideration in operating an asset management system.
- Asset **performance evaluation** can be done through effective data management and its transformation into information. This should be evaluated against any objectives set specifically for the system itself.
- Continual **improvement** is a concept that is applicable to the assets, the asset management activities and the asset management system.

Relationship between these different key elements can be seen in Figure 4.

### **2.1.2. Facility management – ISO 41000**

**Facility Condition Assessment (FCA)**, on his behalf, involves the analysis of the condition of a facility in terms of age, design, construction methods and materials. It can be done in several ways, one of which is the Condition Inspection (CI). Condition Inspection would be a set of operations needed to verify the condition of a given element. For instance, visual inspections of a building part should be registered and stored into some kind of support (ideally a digital one), and it can be as simple as a Google Form (that has been used in the study case), or specific software.

According to a report made by Woolpert, an Architecture, Engineering and Geospatial (AEG) services company with +100 hundred years of history, FCA should be organized as follows (Przybyla, 2011):

- **Project preparation:** establishing the team, reviewing facility documents, defining the scope of the assessment.
- **Data gathering:** interviewing the staff, collecting facility data and identifying facility deficiencies.

- **Data analysis:** prescribing corrective actions for each deficiency, preparing cost analysis for each action and grouping tasks into projects.
- **Reporting and delivery:** summarizing data, preparing final report and finalizing the correction database.
- **Program planning:** prioritizing objectives, developing working schedules, assisting client in project implementation.

In this report, there is also a recommendation about how to divide deficiencies into categories attending not only to the nature of the systems (envelope, HVAC, plumbing...) but also to the significance of its consequences: building integrity (equipment, physical damage), health/life safety (those elements related to the integrity of users) and functionality (energy, accessibility...). For this purpose, a proper scale should be established.

All these tasks have been traditionally done with manual means such as hand notes, photographs and as much office automation. In the aforementioned report, Woolpert introduces the use of GIS to FCA; nevertheless, this is limited to outdoor facilities. In the same way, there is some evidence of the use of BIM for FCA of indoor elements. The integration of these two methodologies is a challenge that will be analysed as it is part of the scope of this work.

There are other important regulations regarding Facility Management, each of them focused on particular aspects of its implantation. The ISO 41001 describes the importance of giving a context of the organization, understanding the needs and expectations of interested parties and determining the scope of the FM system. After that it focuses on the stakeholders, that discusses leadership, policies, roles, responsibilities, and authorities, to eventually get to planning and support actions. This planning is played during operations and it has to be permanently monitored to evaluate its performance, looking after constant improvement.

This regulation has been written in image of the UNE EN 15221 and it's replacing it since 2017, as new documents are being released.

### 2.1.3. Condition assessment of existing buildings

There are many purposes to undertake condition assessment of an existing building: planning for maintenance or repair, code compliance, durability, etc. There are three main types of assessment ('Guideline for condition assessment of the building envelope', 2000):

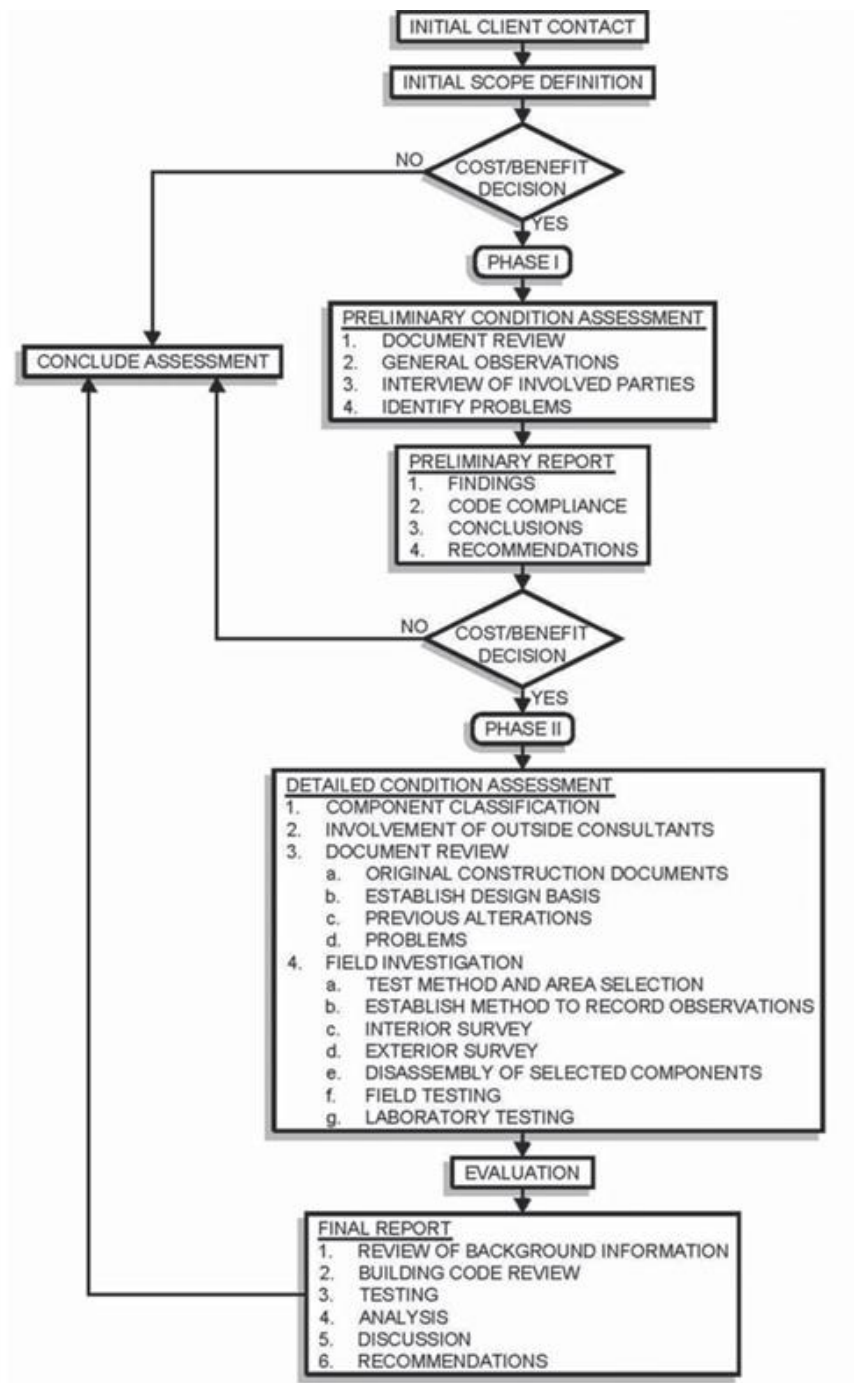


Figure 5. Condition assessment of a single building envelope ('Guideline for condition assessment of the building envelope', 2000).

- **Cursory assessment:** visual overview of the general condition of the building envelope. Often used for screening multiple buildings and establishing priorities for maintenance.
- **Preliminary assessment:** it is limited in scope and consists on a site visit for familiarization: identifying problem areas, setting a preliminary report and recommendations.
- **Detailed assessment:** expansion of the preliminary assessment; includes a review of documentation, analysis and report.

The generic procedure is a sequence that can be applied to the entire building or to discrete component systems, such as roofing, walls, windows...

### 2.1.3.1. General approach

It is divided into two initial phases: a preliminary condition assessment to identify user concerns, key components, typical problem areas... and a detailed condition assessment to review background information and to assess the condition of the systems and components.



Figure 6. Facility level program ('Guideline for condition assessment of the building envelope', 2000).

Neither of those phases should be initiated without defining in a proper way the scope of work. Each of them should be terminated with a written report detailing the findings, providing conclusions and recommendations.

Preliminary CA could be periodically repeated for each similar type of building or system. Once the condition falls below a previously defined baseline, a more intensive assessment can be initiated. An approach for such a facility-level condition assessment program is shown in Figure 6.

#### **2.1.3.2. Cursory Condition Assessment**

A quick approach is useful for screening multiple buildings for an owner or agency and establish, therefore, relative priorities for unit assessment (this could be done by a checklist with a numerical rating system). The results of these reports may be used for planning and budgeting of maintenance and repair.

#### **2.1.3.3. Definition of scope**

For properly doing this, it is necessary to define the problem, as this may vary the scope of the assessment from a general one, to an evaluation of individual or selected component systems. It is often necessary to increase the scope of a narrowly defined assessment if it indicates problems with systems and/or components beyond the initial scope.

It is important to make the client aware that other kind of problems that are not part of the defined scope, are not going to be evaluated. Also, often, the scope is not determined initially but is developed during the preliminary evaluation based on the investigator's observations.

#### **2.1.3.4. Preliminary condition assessment**

This is a **limited step** since the amount of time available for a site visit usually defines the scope of the preliminary assessment. It is an opportunity for the investigator to familiarize with the materials, details, systems... and to establish the scope for the detailed assessment, if necessary.



It is also important to make a quick **document review**, including plans, elevations and a few details. After that, a general observation may help making a rapid evaluation of which components require a more detailed evaluation during the future phases of work. There is the potential risk to judging systems as acceptable while they may have underlying distress or deterioration.

In any case, the **general observations** typically include the following:

- Walk-around survey. Taking general photos or video tapes are good ways to register information, highlighting those obvious and/or potential defects, cracks, bulges, misplacements...
- If any significant damage is noted, it could be interesting to make additional observations proximate to the damage.
- Identifying any components that appear to pose an immediate safety risk.

**Involving the property** with regular interviews when possible is a way to keep them aware of the building's problems and repairs. When applicable, asking the involved parts about the history of alterations and repairs may help.

#### **2.1.3.5. Preliminary report**

The goal of this phase is to conduct future investigations back to the client. As a minimum, it should include the following data:

- Preliminary findings. Clearly identifying and presenting all observed problem areas, including all concerns raised by the clients. Presenting each observed problem area and its potential for building distress.
- Identification of legal and/or code compliance issues.
- Preliminary conclusions.
- Preliminary recommendations.

#### **2.1.3.6. Detailed assessment**

Once the preliminary assessment is finished, it needs to be expanded with a more detailed one. This implies more reports, or at least extending those already made. The nature of the new documentation will depend on the type of the assessment and the requirements of the clients.

Many guides for Condition Assessment can be used as guidelines, with different approaches such as real-estate (Astm, 2008) or even regarding particular aspects, like roads and parkings (Systems and Management, 2011). Other interesting concept regarding Building Condition Assessment are the Key Performance Indicators or KPI (Dejaco, Re Cecconi and Maltese, 2017), considering them as useful decision-making helping tools.

## **2.2. Information management process according to BIM approach**

The main document that must be reviewed from a BIM approach is the BS EN ISO 19650, that replaces the British PAS 1192. Nonetheless, this new regulation is based on the previous one.

### **2.2.1. The BS EN ISO 19650**

The **BS EN ISO 19650** is the current standard for information management using BIM. It has five parts, being the third one the last to come out this year (and the fourth one is still under development). In its **part 1 (2018)**, it defines some principles of asset management based on purposes which could come from the appointing party itself or from other third parties. These **purposes** should be defined for better understanding what are the requirements about information deliverables. They can include, but not be limited to:

- Setting a **register** of assets to support accurate auditing and reporting; this should include both spatial and physical assets and their groupings.

- **Support** for compliance and responsibilities: information required to support the maintenance of the health and safety of the users of the asset.

- **Risk management**, especially to identify and review the risks that a project or asset can be exposed to, for instance natural hazards, extreme weather events...

- Information required to support the **review of the business case** for ownership and operation of the asset; this should include continuous development of the following impacts and beneficial aspects:

- Management of utilization to support comparisons of actual use.
- Management of security and surveillance (security requirements);
- Support for renovation of each space or location, supported with detailed information about the capacity, in terms of areas, spaces, occupancy, environmental conditions and structural load bearing.
- Information relating to environmental effects.
- Information necessary for the normal operations, to help the appointing party anticipate the cost of asset operation.
- Maintenance and repair: information on the recommended maintenance tasks, including planned preventative maintenance.
- Replacement: recycling of the physical assets should be supported with detailed information relating to the principal materials.
- Information on the recommended decommissioning should be provided to help anticipate and plan for end-of-life costs.

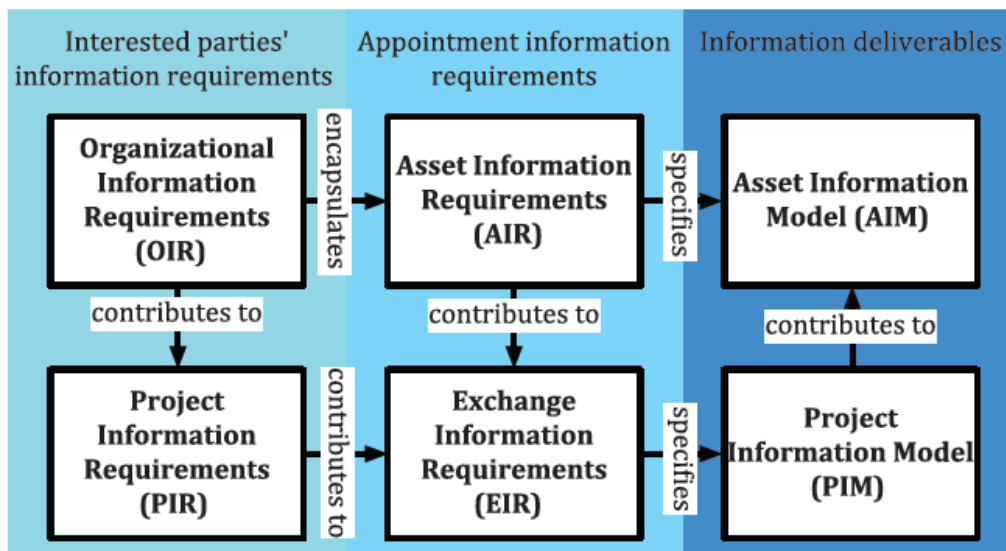


Figure 7. Hierarchy of information requirements (BS EN ISO 19650-1:2018).

The different types of information requirements and information models are shown in Figure 7 and explained next, according to this regulation.

#### **2.2.1.1. Organizational information requirements (OIR)**

This includes the information needed to answer or inform high-level strategic objectives. These requirements can arise for a variety of reasons.

OIR can exist for reasons other than asset management, for example in relation to submitting annual financial accounts.

#### **2.2.1.2. Asset information requirements (AIR)**

AIR set out managerial, commercial and technical aspects of producing asset information. The technical aspects of the AIR specify those detailed pieces of information needed to answer the asset-related OIR.

Across an asset management strategy and plan there can exist several different appointments. The AIR from all these should form a single coherent and coordinated set of information requirements.

#### **2.2.1.3. Project information requirements (PIR)**

PIR explain the information needed to answer or inform high-level strategic objectives in relation to a particular built asset project. PIR are identified from both the project management process and the asset management process.

Repeat clients may develop a generic set of PIR that can be adopted, with or without amendment, on all of their projects.

#### **2.2.1.4. Exchange information requirements (EIR)**

EIR set out managerial, commercial and technical aspects of producing project information. The managerial and commercial aspects should include the information standard and the production methods and procedures to be implemented by the delivery team.

The technical aspects of the EIR should specify those detailed pieces of information needed to answer the PIR. EIR should normally align with trigger events representing the completion of some or all project stages.

Across a project there can exist several different appointments. The EIR from all these appointments should form a single coherent and coordinated set of information requirements, sufficient to address all the PIR.

#### **2.2.1.5. Asset information model (AIM)**

The AIM supports the strategic and day-to-day asset management processes. It can also provide information at the start of the project delivery process. For example, the AIM can contain equipment registers, cumulative maintenance costs, records of installation and maintenance dates, property ownership details and other details regarded as valuable to manage in a systematic way.

#### **2.2.1.6. Project information model (PIM)**

The PIM supports the delivery of the project and contributes to the AIM to support asset management activities. The PIM should also be stored to provide a long-term archive of the project and for auditing purposes. For example, the PIM can contain details of project geometry, location of equipment, performance requirements during project design, method of construction, scheduling, costing and details of installed systems, components and equipment, including maintenance requirements, during project construction.

### **2.2.2. The PAS 1192**

This is the document used as a guideline for the ISO 19650. It has six parts, being the first couple of them abolished by this new regulation. Part 3 is a specification for information management for the operational phase of assets using building information modelling. It is a complement for the part 2, which is focused on the delivery phase of projects. Part 3 specifies information about the discipline of asset management, which allows organizations to optimize the cost of managing portfolios of assets which can be complex and varied in nature, distributed over extensive geographical areas and may be subjected to differing utilization requirements. Integrating the management of information across the longer-term activity of asset management with the shorter-term activity of asset

construction for a portfolio of assets should deliver real savings. These come about in a variety of ways, including:

- Reduced costs as a result of the automated transfer of accurate, complete and unambiguous information at asset handover and during transfer of operation from one service provider to another.
- Better awareness of the operational and maintenance needs of assets.
- Better decisions regarding operation and maintenance expenditure based on actual asset performance and status.
- Dynamic measurement and condition-sensing enabling poor energy performance, faults and impending failure to be identified.
- Better organizational and strategic planning from complete and more accurate asset information, for example in the development of the health and safety file required by the Construction Regulations.
- Better information quality as a result of automation enabling an increased amount of verification.

#### **2.2.2.1. General considerations**

However, there are some issues to consider. The management of portfolios of assets will typically involve an almost continuous cycle of assets being created, operated, maintained/overhauled and then decommissioned or demolished prior to more asset creation activities. This is about the operational phase.

Also, an interesting point is that this PAS provides mechanisms for existing assets to enter the asset management process without necessarily relying on a project information model, this means, even if the capital/delivery phase has not been managed following the standards of the PAS 1192-2.

There are three different entry points to the information management processes set out in PAS 1192-2 and PAS 1192-3, and these are cross-referenced to the stage numbers shown in green ovals in Figures 8 and 9:

- 1) Stage 7 and n, operation and end of life – PAS 1192-3 information management in response to a trigger-related event (e.g. minor works).
- 2) Stage 6, handover and close-out – PAS 1192-3 information management in response to a capital/delivery project that has followed PAS 1192-2.
- 3) Stage 0, strategy – PAS 1192-2 information management in response to a major works trigger-related event.

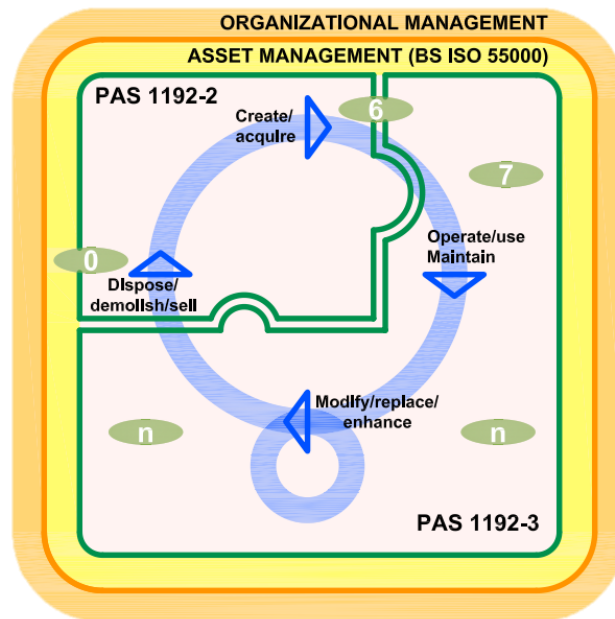


Figure 8. Relationship between asset management, PAS 1192-2 and PAS 1192-3 (British Standards Institution (BSI), 2014).

It should be noted that the inclusion of the disposal stage of the lifecycle within PAS 1192-2 covers the situation where demolition of an existing asset is part of the construction of a new asset. Also, this PAS applies across a mixture of planned and unplanned events in the life of an asset that can happen in any order between the points of asset handover and asset disposal.

PAS 1192-2 and PAS 1192-3 both support what has become known as BIM Level 2. The wedge diagram in Figure 10 is often used to describe what is meant by the different maturity levels of BIM, from Level 0 to Level 3. The levels were defined in 'A report for the Government Construction Client Group – Building

Information Modelling (BIM) Working Party Strategy Paper’, with BIM Level 2 defined as:

‘Managed 3D environment held in separate discipline ‘BIM’ tools with attached data. Commercial data managed by an enterprise resource platform. Integration on the basis of proprietary interfaces or bespoke middleware could be regarded as ‘pBIM’ (proprietary). The approach may utilize 4D programme data and 5D cost elements as well as operational systems.’

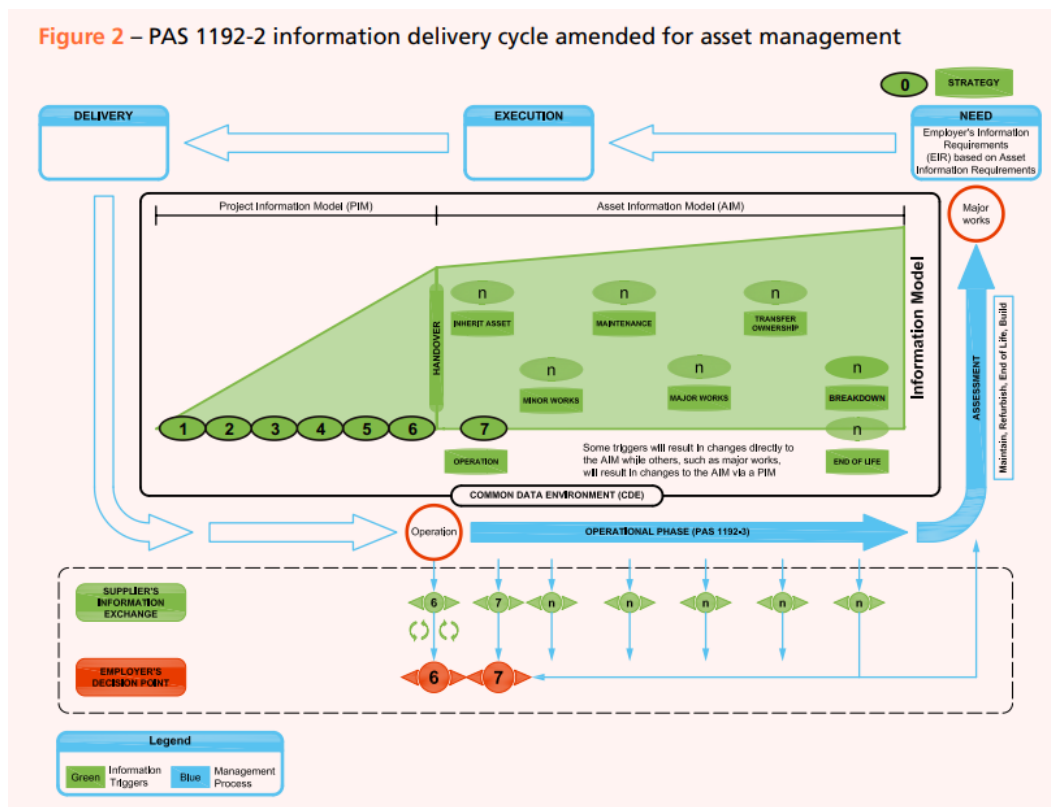


Figure 9. PAS 1192-2 information delivery cycle amended for asset management (British Standards Institution (BSI), 2014).

In addition, collaboration at BIM Level 2 is file-based as opposed to paper-based (BIM Level 0) or through integrated web services (envisaged as BIM Level 3 at the time of writing).

The purpose of the asset information model (AIM) is to be the single source of approved and validated information related to the asset(s). This includes data and geometry describing the asset(s) and the spaces and items associated with it, data about the performance of the asset(s), supporting



information about the asset(s) such as specifications, operation and maintenance manuals, and health and safety information. This duality geometry-information is key to understand the way BIM works, because both aspects can have different treatments and levels of detail.

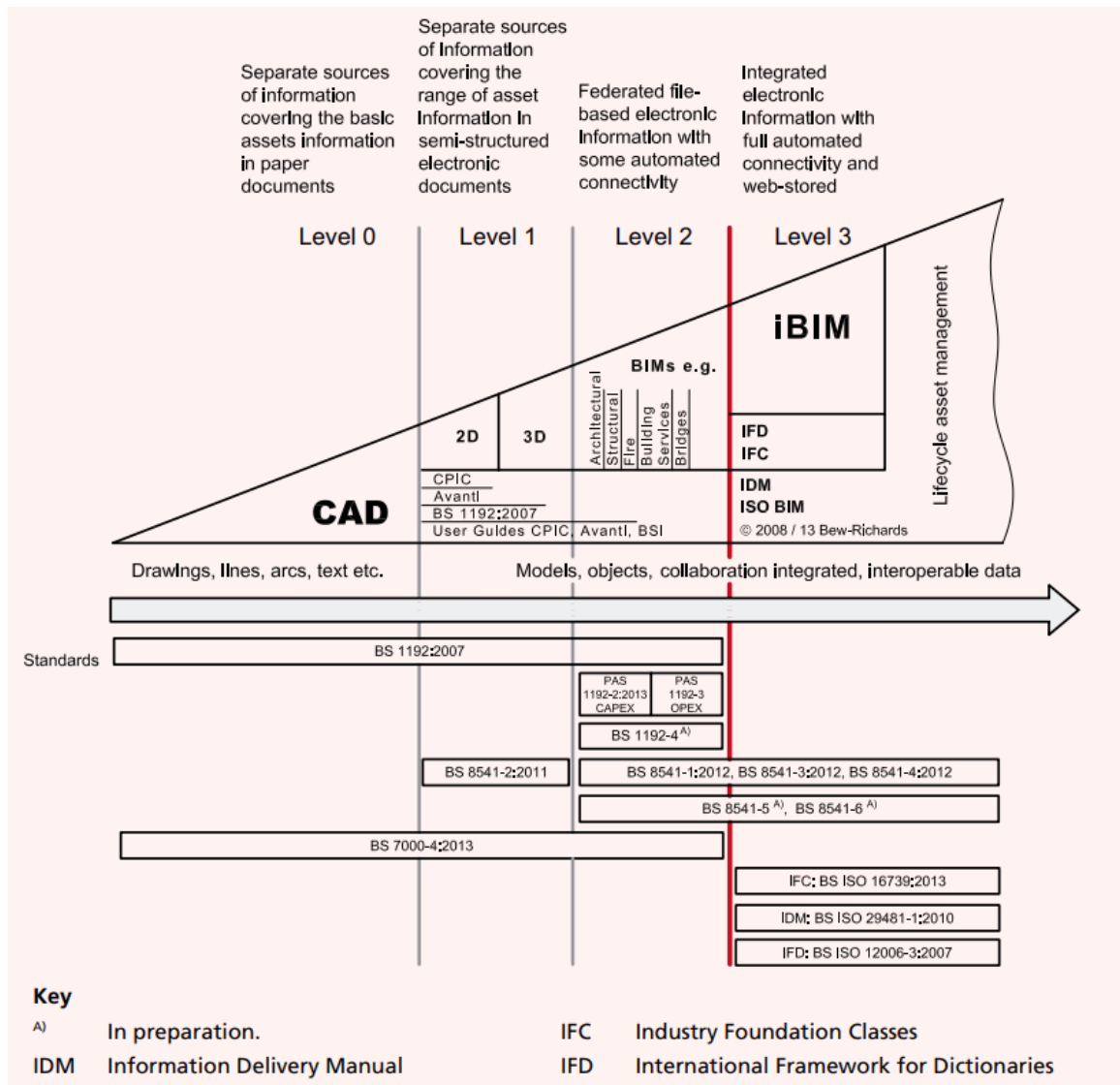


Figure 10. BIM maturity levels extended to asset information management (British Standards Institution (BSI), 2014).

### 2.2.2.2. Information Management Process (IMP)

The organization shall establish, document, implement and maintain an **information management process (IMP)**. The IMP shall cover the operational lifecycle of the asset including, but not limited to, handover from design and construction, day-to-day operation of the asset, planned and reactive

maintenance, minor works, major works, decommissioning, and dismantling or demolition.

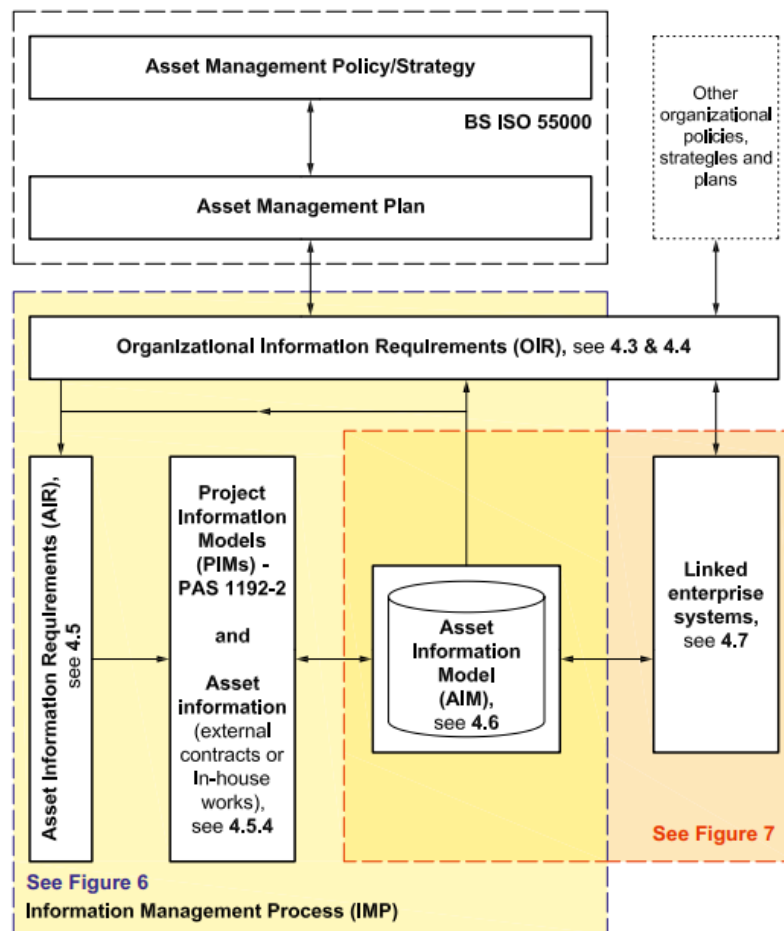


Figure 11. High-level asset information process map.

The IMP shall operate within or link with such enterprise systems or organizational functions as necessary to optimize the capture, processing, storage and analysis of the data and information specified in the asset information requirements (AIR) for the purposes of satisfying the organizational information requirements (OIR).

On the other hand, the purpose of the IMP should be maintaining the integrity of asset information to support the following activities:

- Defining asset management strategies and plans.
- Implementing asset management plans.
- Managing the asset lifecycle.

- Acquiring and maintaining asset knowledge.
- Managing the organization and its human resources.
- Managing and reviewing risk.

The AIM process shall comprise the following **steps**:

- a) Establish information governance processes to direct, control and assure that asset information is managed effectively as an organizational resource, with reference to any asset management strategies and plans.
- b) Establish the OIR based on the asset management activities identified in the policy, strategy and plan, which are developed through BS ISO 55000.
- c) Define the AIR that shall be met, in order that the OIR can be satisfied, and the information exchanges by which data and information is transferred to and from the asset information model (AIM).
- d) Define the mechanisms for the creation, receiving, validating/verifying, storing, sharing, archiving, analysing and reporting on the information and data to be held in the AIM.
- e) Define the interfaces for exchange of data and information between the AIM and other information systems used by the organization.
- f) Define the mechanisms for maintaining the AIM and for monitoring the quality, including referential integrity, of data and information within the AIM.

### **2.2.2.3. Asset Information Model (AIM)**

The AIM shall be created in accordance with the organization's requirements. This shall be achieved through a variety of management activities, including some or all of the following:

- a) Transfer of information from existing organizational systems into the AIM.
- b) Recognizing or relabelling an existing data store as part of the AIM.
- c) Collection of new or updated information from surveys of the physical asset.

d) Exchange of information and data with project information model(s) generated as a result of BIM Level 2 capital/delivery.

Asset information shall not be considered as the AIM until it has been authorized and accepted according to the information management process.

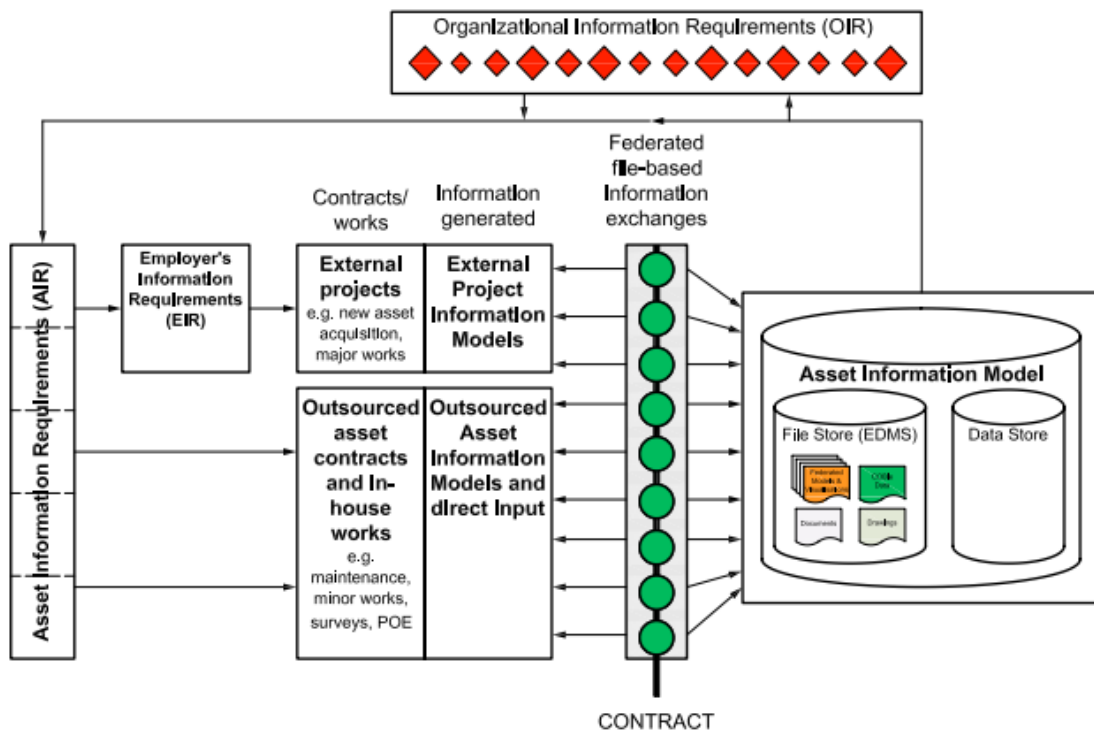


Figure 12. Exchange of data and information with the AIM (British Standards Institution (BSI), 2014).

### 3. State of the art on BIM and GIS

Once the big picture on asset and facility management, and its applications on building and construction management is done, it is time to get into the use of BIM/GIS and its integration with those disciplines.

#### 3.1. Asset/Facility Management with BIM and GIS

There is bibliography regarding integration methods for BIM and GIS. First, some introduction about BIM methodology will be given; then, the same concept with GIS and finally, some cases of integration for both technologies.

##### 3.1.1. Building Information Modelling (BIM)

Building Information Modelling or BIM is a concept that exists for 50 years. However, it has become particularly popular in the last 2 decades, since the use of new technologies has allowed it to be a useful tool.

The fundamentals of BIM methodology are the use of management of information related to the building, in real-time and from several different users. Thus, the building is no longer a set of lines to which a value is attributed (walls, doors, etc) but a set of components that actually include the necessary data. This implies a sort of duality since objects have two kinds of information.

- **Geometric data:** this is, the object itself. It can be as simple as a box acting as a table, a table with just a wooden plank and four legs, or even a certified model from a commercial house with every detail.
- **Information:** a list of attributes that vary on the kind of object; for instance, a door has properties relative to the dimensions (width, height), to the position on the wall, how is it opened (left or right), the material, insulation coefficient, the brand and model, and so on.

This methodology allows to store a big amount of information that can be used in several ways. As it has been said before, the use of BIM is widely extended in the design phases, and even the construction ones. This is a concept connected to the BIM dimensions (BIMnD, 2019):

- First dimension (**1D**): Concept, establishment of the bases for collaborative projects. Setting of the BIM Execution Plan (BEP).

- Second dimension (**2D**): Vectorization of the Sketch, establish the workflow and organizational procedures (templates) around BIM of the different work areas involved.

- Third dimension (**3D**): Modelling, parametric and spatial requirements for the construction of the digital twin of the element with the chosen software. Coordination of the different disciplines (architecture, structure and facilities), quality control and constructive viability and the preparation of documentation for commercialization.

This dimension is usually seen as the main target of using BIM, but having a 3D model with all the information stored and when the construction begins, it is not useful anymore. From now on, design phases are over, and some concepts connected to the process of the construction itself start to be put on the table.

- Fourth dimension (**4D**): Planning, refers to the temporal dimension with the objective of establishing the execution deadlines and ensuring that they are met. It often considers the logistics of the work, planning what and when the auxiliary means are needed, defining the time, duration and the determined phase of use. The usefulness of 4D is its dynamism and the training to anticipate possible conflicts, clash detection, that may arise on site, to be corrected in the design phase, where the cost is significantly lower than in the execution phase.

For this step, there is software that make realistic simulations on how the process is going to be done, to help managers organizing the site into as many parts as it is necessary to optimize the work.

- Fifth dimension (**5D**): Costs, the estimation and control of costs affects the profitability of the project. In the fifth BIM dimension, budgets are generated, economic feasibility studies are carried out, offers and contracts are managed, as well as related to the return on investment and benefits in general.

- Sixth dimension (**6D**): Energy Sustainability. It refers to everything related to eco-efficiency, sustainability certifications (LEED, BREEAM, Passivhaus ...), simulations on energy behaviour, or the so-called green BIM.

- Seventh dimension (**7D**): Monitoring / Maintenance. Defines the guide to lengthen and maintain the quality of the project once built, includes what refers to inspections, repairs, etc. For owners, it is one of the most important BIM dimension, since it affects its usefulness and the management of conservation costs. Everything needed for space management and maintenance must be documented. Here the goal is to know what, when and how much. This is the dimension which **Asset and Facility Management** is connected.

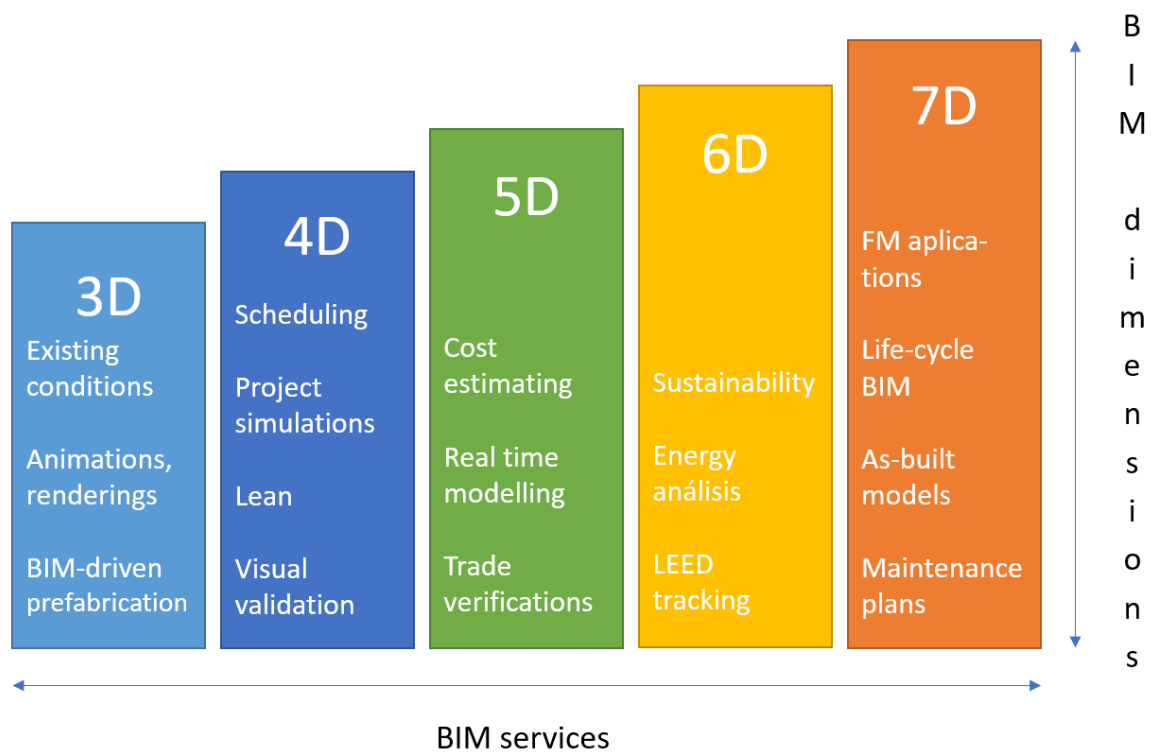


Figure 13. BIM dimensions and the services implied (Prepared by the authors).

Since BIM methodology is focused on the building, for the outdoors it is just limited. There are tools for creating built environments, but it is not possible to create, for instance, a whole neighbourhood as it would be too big, and the software would not be able to carry with all the information. For public spaces there is another tool that fits better; the Geographic Information System (GIS).

### 3.1.2. Geographic Information System (GIS)

A Geographic Information System is, essentially, a database designed to store, analyse and manage geographic data. Its use is widely extended in many kinds of Engineering and it is also capable to display visual information, but in a less detailed way than BIM.

Nevertheless, it is a tool with a high potential to manage big amounts of information, because it is oriented to be used for large surfaces. There is also this duality geometry-information, usually in the form of tabular data known as 'attribute data'. Attribute data can be generally defined as 'additional information about each of the spatial features'. An example would be schools: the actual location of the schools is the spatial data; additional data such as the school name, level of education, student capacity would make up the attribute data. It is the partnership of these two data types that enables GIS to be such an effective problem-solving tool through spatial analysis (Caitlin Dempsey, 2019).

GIS can be used as tool in both **problem-solving** and **decision-making** processes, as well as for visualization of data in a spatial environment. This information can be analysed to determine:

1. The location of features and relationships to other features (mapping): spatial location of real-world features can be mapped so, in that way visualizing the spatial relationships among them is possible. An example is figure 14.

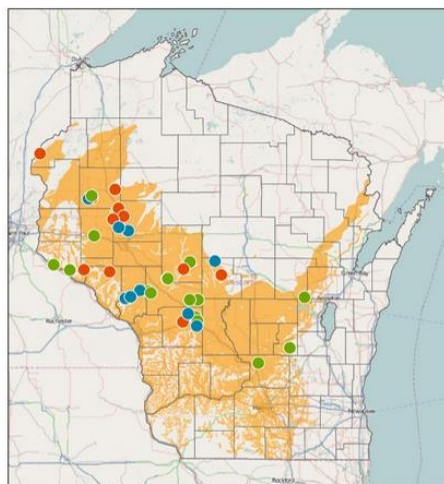


Figure 14. Sand mine locations and sandstone areas in Wisconsin (Caitlin Dempsey, 2019).



2. Mapping quantities or densities: such as where the most and least are, to find places that meet some criteria or to see the relationships between places.

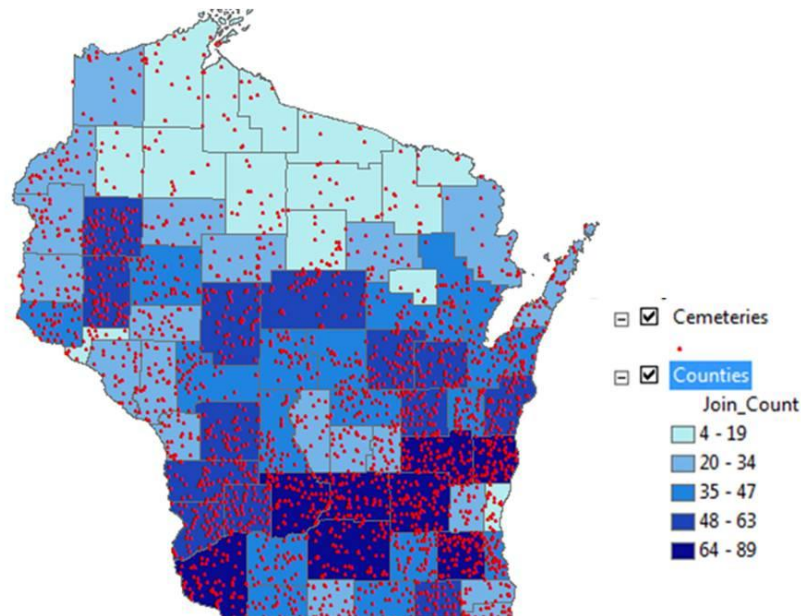


Figure 15. Cemetery locations in Wisconsin. Colours show the global amount per county (density), and dots show the frequency (Caitlin Dempsey, 2019).

3. Finding what is inside an area of interest or nearby: what is happening or what features are located inside a specific area/region or its surroundings. This can be done by creating specific criteria to define an area of interest (AOI).



Figure 16. Flood event and buildings in the floodway. This can be used to determine which parcels fall inside the flood event, to determine potential costs of damage.

4. Mapping change in a specific geographic area over time to anticipate future conditions, decide on a course of action, or to evaluate the results of an action.

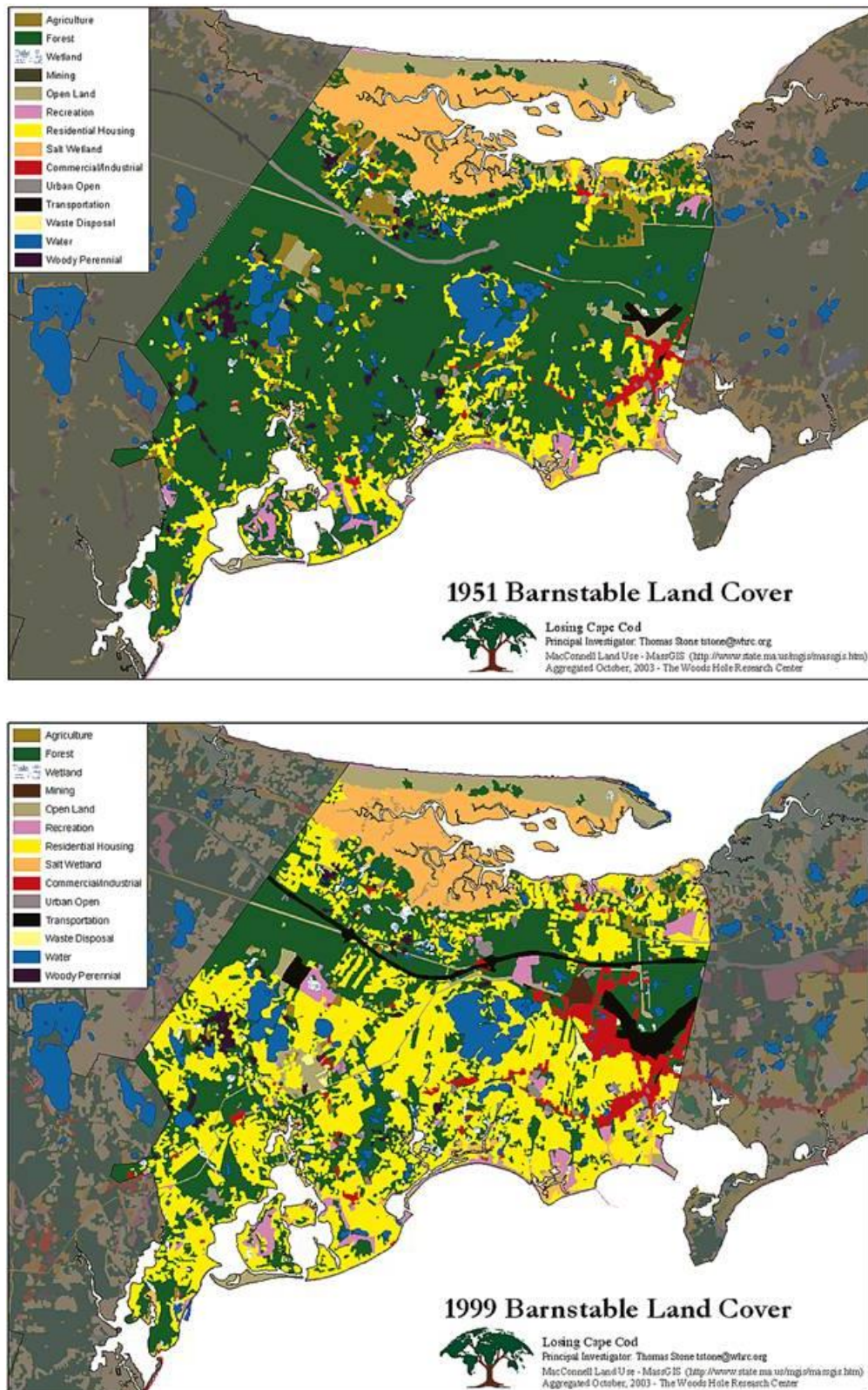


Figure 17. Changes in residential development in Barnstable from 1951 to 1999 (Caitlin Dempsey, 2019).

### 3.1.3. Integration of BIM and GIS

An appreciable amount of literature about the integration of BIM and GIS has been written. For instance, (Sani and Rahman, 2018) reviewed the existing information regarding this topic. GIS and BIM are different domains but have common things such as the use of 3D models to manage data. Each one has its strong and weak points, as they have been described. BIM focuses on the building, its internal and external components (with a high amount of detail not only at data level, but also on the geometry). On the contrary, GIS stores information of a wider dimension range; its models contain topographic data, which is important for the spatial planning of the urban landscape. The relationship between GIS and BIM can be understood as depicted in the Fig. 18.

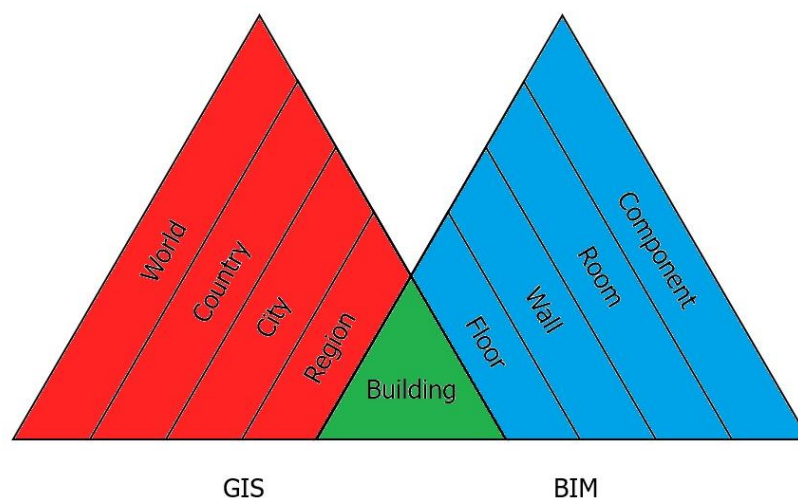


Figure 18. Overlap between GIS and BIM (Prepared by the authors).

To make possible the interoperability between GIS and BIM, it is necessary for their stored data to speak a common language. Most extended file formats are CityGML for GIS and IFC for BIM:

**CityGML (City Markup Language):** it is an open standard data-model and exchange format that stores information of 3D models and it is based on Geography Markup Language (GML). It defines the basic attributes, relations and entities of a city and it is divided into two parts: the schema that describes the document and the document itself that contains the data. The levels of detail (LODs) help understanding the amount of information contained in the model:

- LOD0: 2D footprint of the building
- LOD1: basic block, a prism with the height of the building
- LOD2: a block with the true form of the roofs
- LOD3: more detailed external parts (windows, etc)
- LOD4: also includes information of the inside

**IFC (Industry Foundation Class):** it is the primary open BIM standard. It was developed and defined by BuildingSMART, formerly the International Alliance for Interoperability (IAI). This format allows to store a great quantity of detail and it is classified into four levels of development (also LODs):

- LOD100: only the volume of the building
- LOD200: more accurate shape of the façade and roof
- LOD300: windows, main partitions
- LOD400: every indoor element is defined

Actually, BIM LODs (level of development) would be the sum of LoD (level of detail) and LoI (level of information) as the following figure shows.

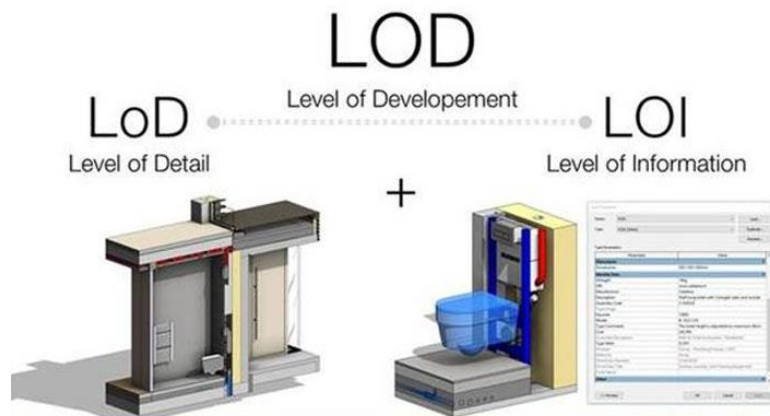


Figure 19. Level of Development = Level of Detail + Level of Information (SrinSoft, nd).

One of the biggest challenges is, therefore, the harmonization of those LODs which differ from one system to another, as shown in Fig. 20. LOD0 has not an equivalence in terms of BIM, since it is referred to the 2D print of the building and this clashes with the concept of BIM itself.

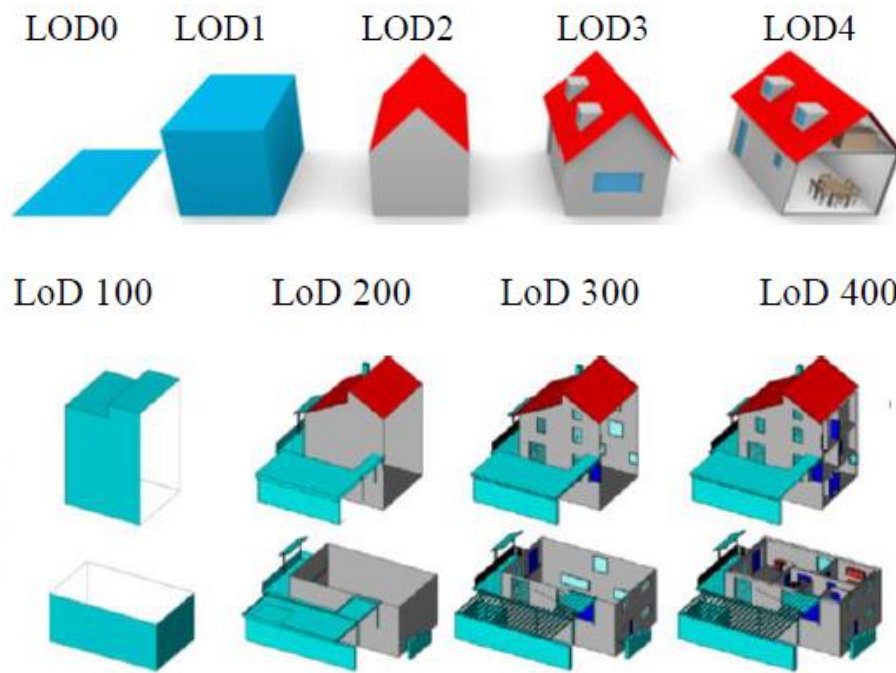


Figure 20. Differences between GIS and BIM LODs (Sani and Rahman, 2018).

Nevertheless, the BS EN ISO 19650 'Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling', in its Part 1: Concepts and principles, introduces the 'Level of information need' which is defined as 'the level of information need for each deliverable that is determined according to its purpose and includes the appropriate determination of quality, quantity and granularity of information'. This regulation just mentions this classification and relates it to the 'definition of information requirements and resulting information models', as well as its principles, which is furtherly developed in the recently released ISO 17412.

Another gap to fill is the creation of the models. In terms of FM, usually there are not BIM models of existing buildings, so it would be more efficient if there was the possibility to automatize its creation. (Dehbi, Haurert and Plümer, 2017) propose a method for deriving BIMs from sparse observations.

BIMs for existing buildings must be derived from observations like 3D point clouds and the necessary measurements are both cost and time extensive. However, for the creation of these models, it is easier to verify or falsify

hypotheses than to reconstruct them from observations. With this aim, statistical relational learning (Markov Logic Networks or MLNs) has been used together with specific Support Vector Machines (SVMs) to learn and generate a weighted attributed context-free grammar. Besides, uncertain projective geometry is used to deal with the uncertainly observations. Another proposed method is an approach using Constraint Logic Programming (CLP) for solving a multi-linear problem. Nonetheless, the first method showed better results.

When designing, as humans, there are certain trends that apply to most buildings, like rules that can be described and quantified. The same is with regulations, they can be helpful to predict some design constraints (such as dimensions). There is an example to understand this shown at Figure 21.

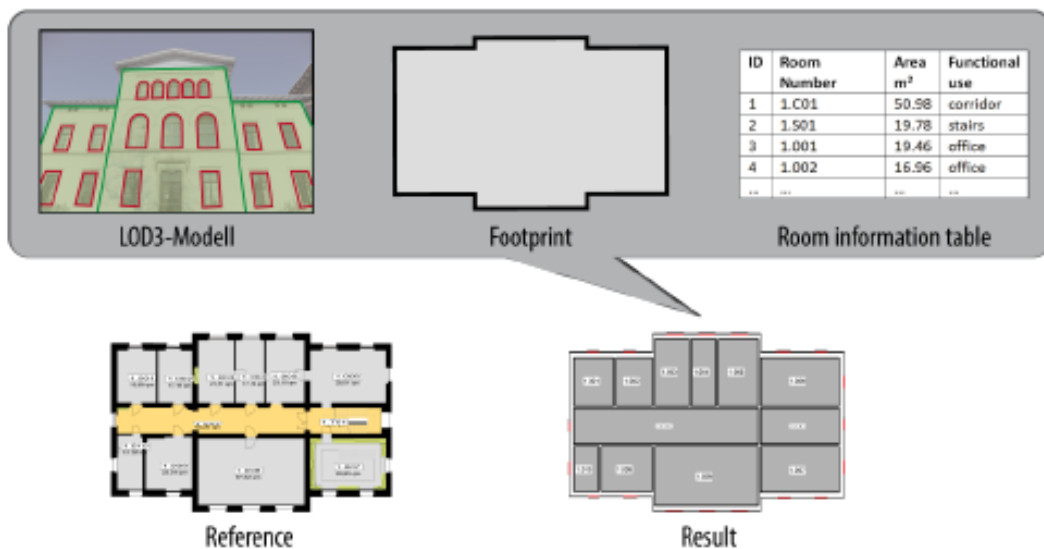


Figure 21. The results of the simulation have been proved to be lookalike the actual building (Dehbi, Haurert and Plümer, 2017).

Once the integration is done, the possibilities are enormous. Since architectural drawings are not always useful for non-professionals, cartographical presentation of BIM data can be very important to many users. This is because BIM is popular not only in AEC industry, but also for end users of many kinds.

There are many potential uses of this information, such as Facility Management or navigation systems. Anyway, particular attention should be paid to the user's perception of interiors to adjust the cartographical message

accordingly. Appropriate visualization of BIM data may help to present building-related data in an understandable form for non-professionals (Gotlib and Wyszomirski, 2018). Examples of demands for this use could be the following topics:

- Indoor spaces by type/user/attributes.
- Types of cable by type/voltage.
- Computer network by speed.
- Pipes by type/functionality.
- Outdoor spaces by type/attributes.



Figure 22. Example of geovisualisation of function of rooms and spaces (Gotlib and Wyszomirski, 2018).

Data taken from tenants may be used as a base for FM reporting. Presentation of distinct values is the most common in FM, because it gives a good overview about object on given drawing.

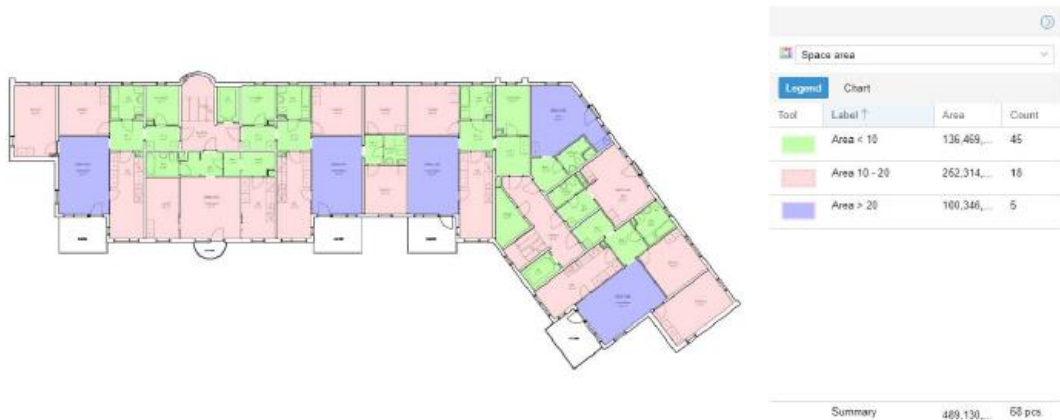


Figure 23. Example of geovisualisation presenting spaces divided into intervals by their area prepared on floor plan in BIM model (Gotlib and Wyszomirski, 2018).

Besides, merging BIM and GIS data together can add new value to BIM presentations (for instance solar study, since BIM model exists in local coordinate system and GIS has absolute coordinates). Standard BIM model analyses available in Revit software are:

- Energy Analysis: expected energy use based on geometry and location.
- Solar Analysis: visualize and quantify the distribution of solar radiation.
- Light Analysis: analysis for illuminance.
- Heating and Cooling Loads: analysis to size HVAC equipment.
- Generate Insight: varies building design inputs resulting in high and low possible annual energy costs. Inputs can then be adjusted, e.g., glazing properties, to see instant feedback on performance impacts.

These analyses base on approximate location and orientation of building model. When BIM model is located with high accuracy in GIS model, then additional analyses are possible:

- Sun light operation through windows in indoor spaces.
- View from the window (availability of sunlight, nearest buildings).
- Propagation of cellular signal inside the building.



### 3.2. Integration of BIM and GIS for Asset and Facility Management

Contemplating all the information described above, it is time to consider the different aspects about the integration of BIM and GIS with Asset and Facility Management. First, some review about BIM uses in AM/FM has been done. After that, the same with GIS models and finally, the integration of them all.

#### 3.2.1. BIM for Asset and Facility Management

Which are the possibilities for AM/FM considering that the problems mentioned before are solved? Most benefits can be obtained from the design phase rather than construction and facilities, operations and maintenance phases. But this only happens with low LOD's (Ibrahim, Hashim and Ahmad Jamal, 2019). Until LOD 200, post construction phases do not benefit since the amount of information and detail is irrelevant for facilities, operations and maintenance. But this changes in LOD 300, 400 and specially 500 (as built).

The integration of Facility Management and BIM systems has carried multiple reviews and publications, creating guidelines for a successful integration (Dixit *et al.*, 2019). For instance, a reference model for assessing BIM capability of Architecture, Engineering and Construction Facility Management was developed grounded on the meta-model of ISO/IEC 330xx family of standards (Yilmaz, Akcamete and Demirors, 2019). In fact, a scientometric study reviewed global BIM research and showed valuable information (Liu, Lu and Peh, 2019):

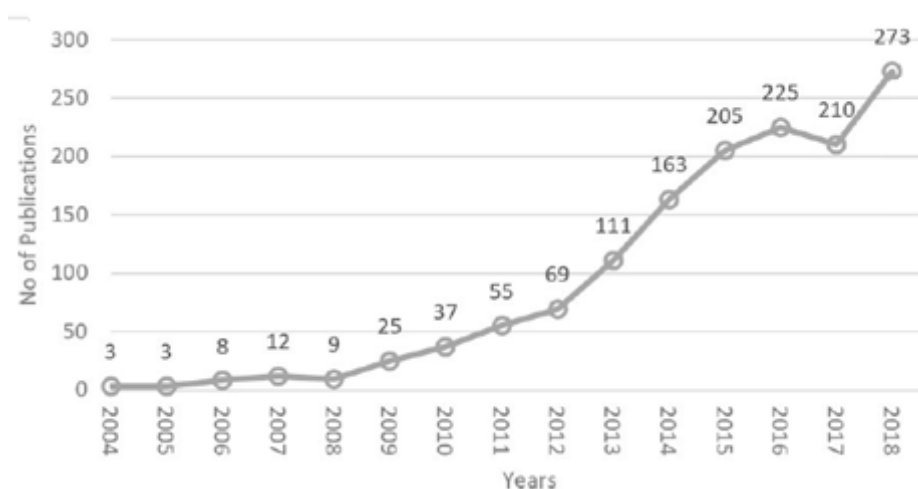


Figure 24. Distribution of BIM publications with times (Liu, Lu and Peh, 2019).

The PAS 1192-3 suggests the use of BIM models to store and access facility information. Nevertheless, there's still the problem of providing every stakeholder with the required information that varies depending on the purpose of each of them (Re Cecconi, Maltese and Dejacco, 2017).

According to this regulation, the BIM model has the same life as the physical building, which implies a great use of the model during building operation. In this way, the first step would be the implementation of model-oriented tools and workflows. This is extremely difficult because current AM/FM procedures are process-oriented, but in a BIM environment, diagnostic forms must cope with the organization of the model. However, BIM methods can be efficiently used to support daily AM/FM processes.

Existing AM/FM processes can be classified into a) maintaining an inventory, b) planning asset maintenance, c) supporting the previous elements implementing an information system. Since it is all about making decisions, it is also important to categorize these decisions. There are three kinds: strategic (long term, complex decisions), tactical (medium term, less complex decisions) and operational (day-to-day decisions). Managing an asset or a facility implies making operational, tactical and strategic decisions.

BIM for existing buildings gets often clogged up by the fact that it is seen as an end itself, instead of thinking of BIM models as a starting point for managing information about assets and portfolios in real estate. This has many advantages; to begin, information is stored in a database, so the use of paper is dramatically reduced, which helps with updating data as well. A BIM model can also be productively used to manage e.g. spaces, furniture, materials etc., so that maintenance operations and refurbishment are related to a space and not a component.

There is still a lot of work to do in order to provide stakeholders with tools that allow them a successful access to this data contained in the digital model. Assessment methodology could vary depending on the level of detail needed too. In addition, evaluation techniques should give as output some mark to enable decision makers to prioritize maintenance works. One way could be a two-step

approach: a preliminary survey on the whole building (to compare it with other buildings), and a detailed survey focused on the more critical buildings. These reports are connected to the drawings, but it is difficult to associate them to quantities and repair works.

Existing web tools have been developed to help with some of these tasks, through the following schema: the BIM model is created, non-graphical data are exported to a database which is published on the web and finally clients use web services to create reports. This has been tested by a case study (building 25 in Politecnico di Milano) with a low level of detail (LoD) but a high level of information (LoI) through four aspects:

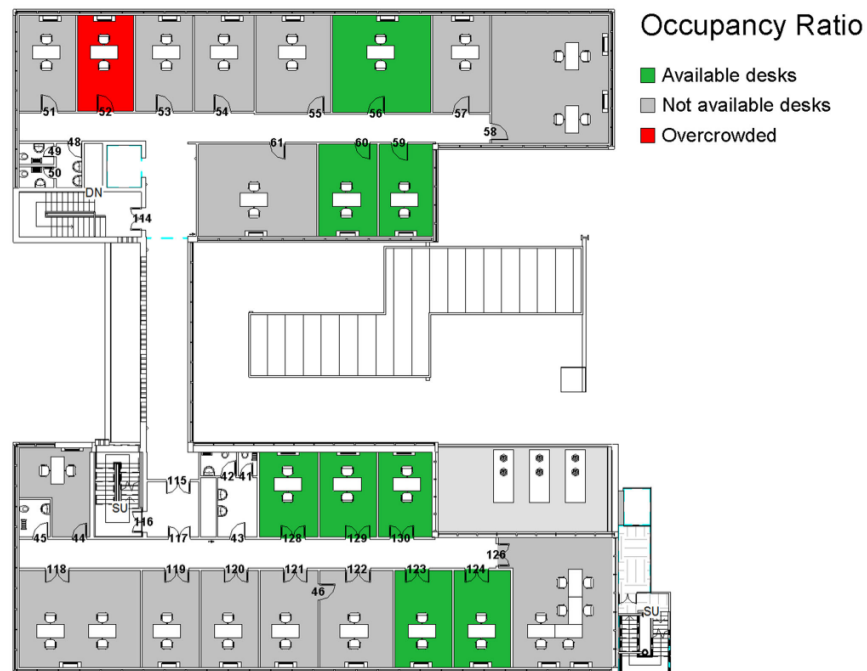


Figure 25. Plan with occupancy data (Re Cecconi, Maltese and Dejaco, 2017).

- Space management: entering occupancy data, the user can obtain a plan with empty rooms, desks and computers (Fig. 25).
- Mechanical equipment status: the plan shows all mechanical components working (green) or not working (red).
- BCA tool: the web interface allows to see indicators about the condition of the building, as well as updating them.

- Service life planning: it helps to control the lifecycle of the building.

Other work focused on the Politecnico di Milano is the research recently made by (Di Giuda *et al.*, 2020), that aims to provide a methodological approach to set the guidelines to structure BIM and IMM procedures at a public university. This was first tested on the ABC department, as the previous article, to be gradually extended to the whole institution.

About the use of BIM for Asset and Facility Management processes, there is a lot of literature written. (S. Matarneh *et al.*, 2019) lay the basis for research studies using the developed framework context to enable the identification of specific data outputs for FM systems inputs; (Chen and Tang, 2019) proposes an innovative management workflow design which integrates BIM with digital programming to implement efficient schedule and cost planning of building fabric maintenance. This allows to narrow the knowledge gap between maintenance theories and practical maintenance management by a consistent and sustainable building information flow. On their behalf, (S. T. Matarneh *et al.*, 2019) concludes, through a bibliometric and content analysis, that the process of information exchange between BIM and FM is not a straightforward process, as software interoperability remains a significant challenge.

Other approaches are, for instance, the system designed to automatize image-classifying data from a smartphone, for inspection-repair processes in FM (Zhan *et al.*, 2019); the two case studies of FM digitalization in hospitals (Koch, Hansen and Jacobsen, 2019) and the theory of CDM, that combines active data with BIM in Facility Management (Halmetoja, 2019). Not to forget about Construction Operations Building Information Exchange (COBie), a system created to guarantee that the data collection from design phase to construction phase is ensured, from a FM point of view (Alnaggar and Pitt, 2019). In addition, there is a platform called VisualCOBie which provides an user interface for Information Management (Yalcinkaya and Singh, 2019).

Several authors address this topic with a more specific line. (Wanigarathna *et al.*, 2019) did a research demonstrating that the implementation of BIM during

the in-use phase of hospital buildings is different to that in the design and construction phases. At the in-use phase, BIM needs to integrate and communicate information within and between the estates, facilities division and other departments of the organisation. This poses a significant change management task for the organisation's information management systems. Thus, a strategically driven top-down organisational approach is needed to implement BIM for the in-use phase of hospital buildings.

Also, (Guzzetti *et al.*, 2019) proposes a methodology for modelling open spaces, analysing related questions about detail and accuracy on the BIM model; (Shrivastava and Akhtar, 2019) explores the current state of interoperability among architecture, engineering and construction software utilized in BIM for green sustainable buildings; (Wu and Lepech, 2020) presents a framework that uses the Application Programming Interface (API) with BIM to integrate physics-based durability performance models of a reinforced concrete structure.

There are other papers that focus on the automation of creating a model. For instance, an automated process using 2D floorplans and elevations to generate semantically rich BIM's with good geometry for energy simulation and Facility Management operations (Bortoluzzi *et al.*, 2019). A Lean-Agile approach to FM-BIM has been developed to guide the development of new models without pre-existing BIMs, as shown in Figure 26.

This methodology has the following key characteristics:

1. A base model with a minimum of geometry (rooms placed by level) is created and new geometric elements are added only where necessary to support a specific use-case; focus is instead on semantic information from the Computer Aided Facility Management and other systems.

2. The model is expanded to incorporate new BIM use cases iteratively using 'sprints', consulting the end-user of the FM-BIM after each to evaluate sprint success and set priorities for the next sprint.

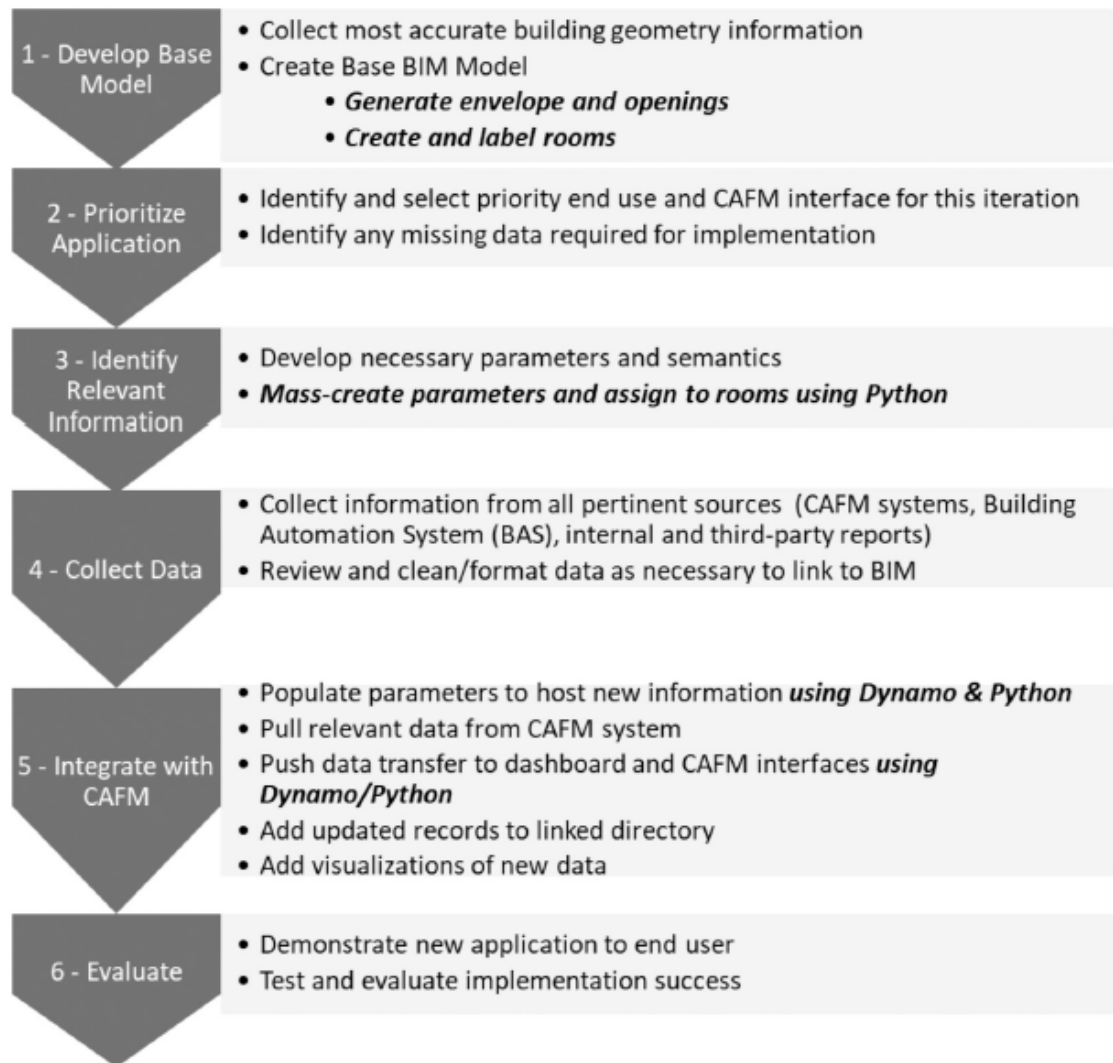


Figure 26. Lean-Agile process to develop new FM-BIM (Bortoluzzi *et al.*, 2019).

The automation process is outlined at a high level in Fig. 27. These FM-BIMs represent a reduced version of the complete BIM and encodes visible building and spatial elements rather than integrating non-visible elements. Further, these are not intended to contain the necessary level of detail to support restoration or construction projects but rather contain a simplified envelope.

In the same line, (Tang *et al.*, 2020) present smart buildings as the trend of the next generation's commercial constructions that link different building systems together with the Building Automation System (BAS). Since previous research has explored BAS and BIM integration for energy management, but it is still rarely seen to design BAS or exchange BAS information in different project stages using BIM tools, this research sets a fundamental step to facilitate

information exchange for BIM assisted BAS design and operation using one of the BAS open communication protocol named Building Automation and Control Networks (BACnet) and open BIM standard Industry Foundation Class (IFC).

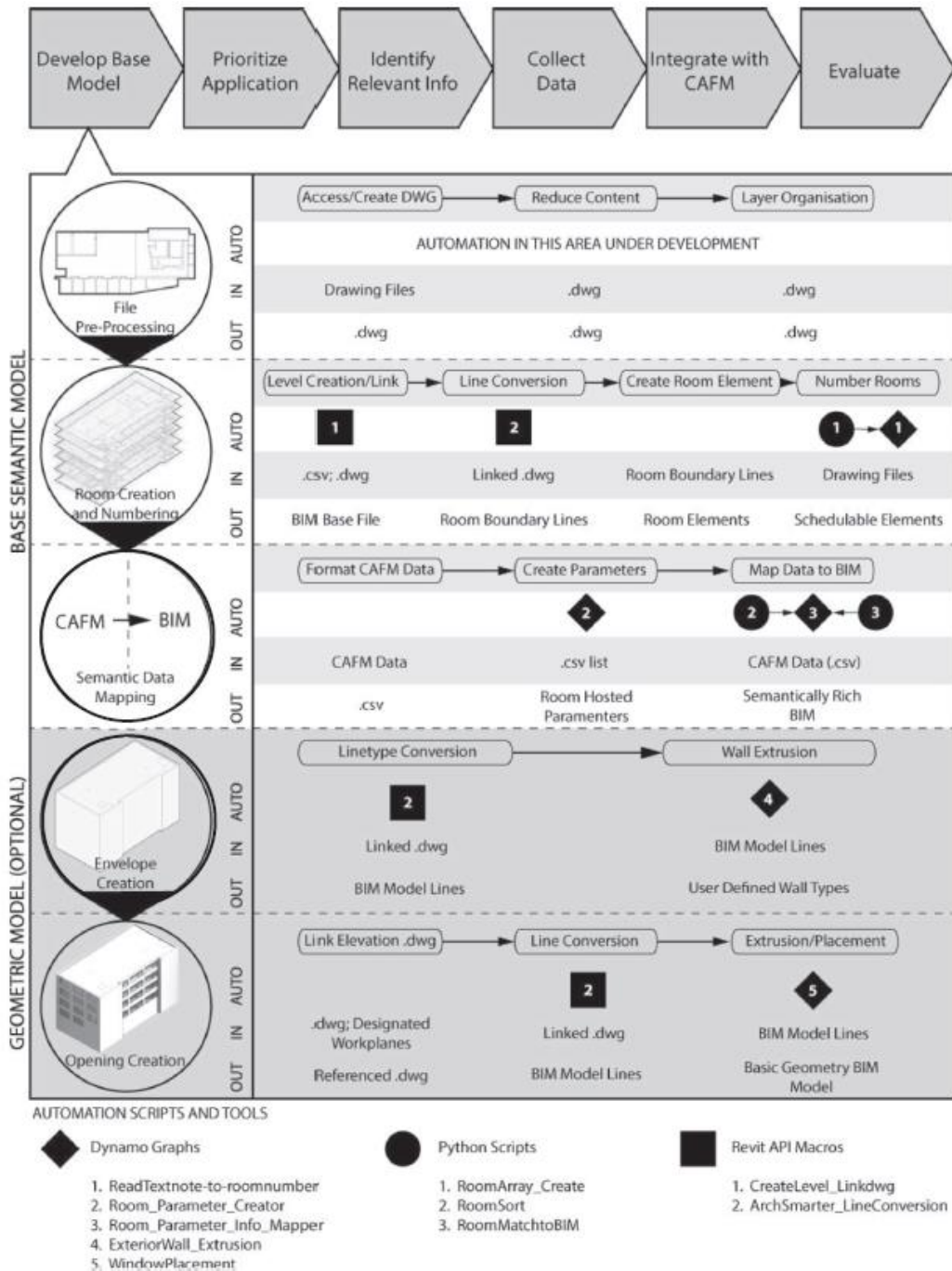


Figure 27. FM-BIM creation process overview showing python and dynamo algorithms.

### 3.2.2. GIS for Asset and Facility Management

The use of GIS in asset and facility management is also widespread. For instance, it is useful for considering spatial aspects in construction planning process, such as the impact of site topography and existing facilities in the surroundings on a construction plan (Bansal, 2020). The use of GIS in the construction planning process facilitates location-based analysis, modelling site constraints as well as spatial and non-spatial analyses on a single platform.

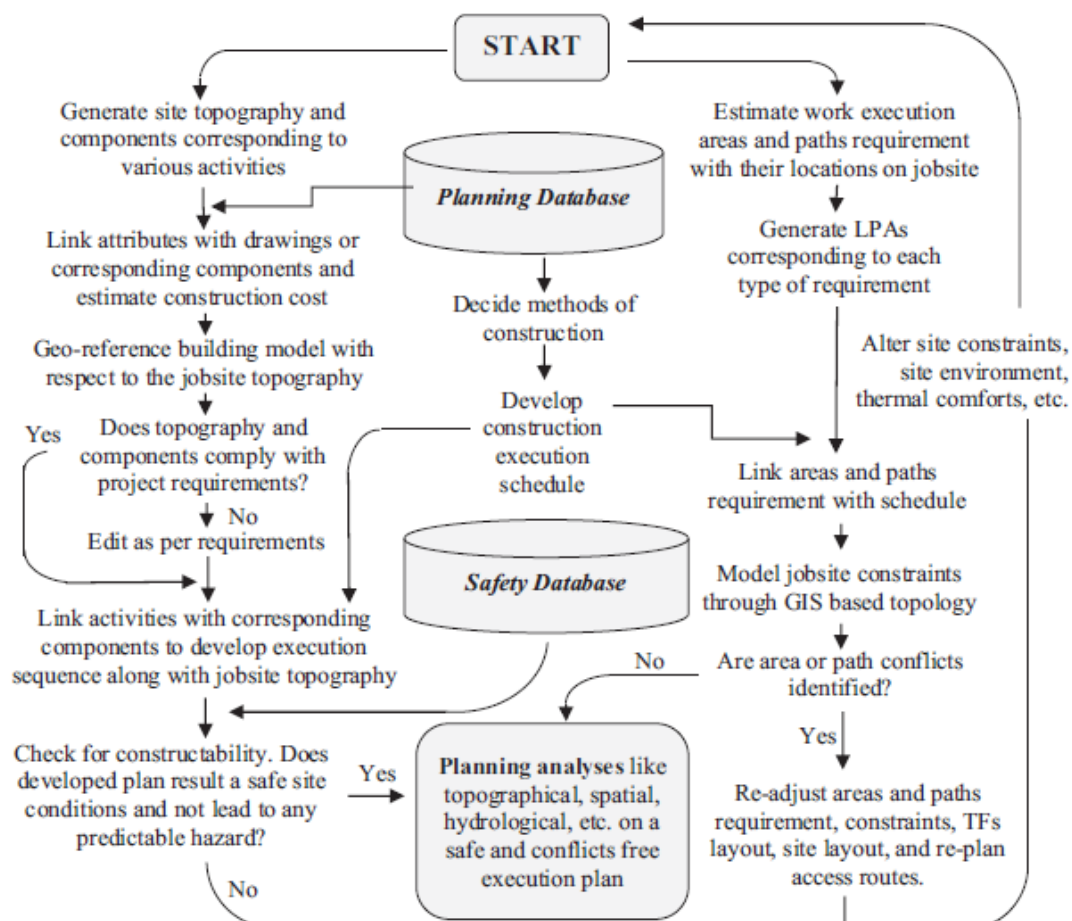


Figure 28. The GIS-based construction planning process (Bansal, 2020).

There are tools meant for scheduling a construction work, but activities have no direct link with 2D/3D components in drawings. The solution could be 4D modelling, but BIM-based software has some limitations. GIS, instead, uses a CPM scheduling and can link its activities with the corresponding components of a 3D model developed (Bansal and Pal, 2011).



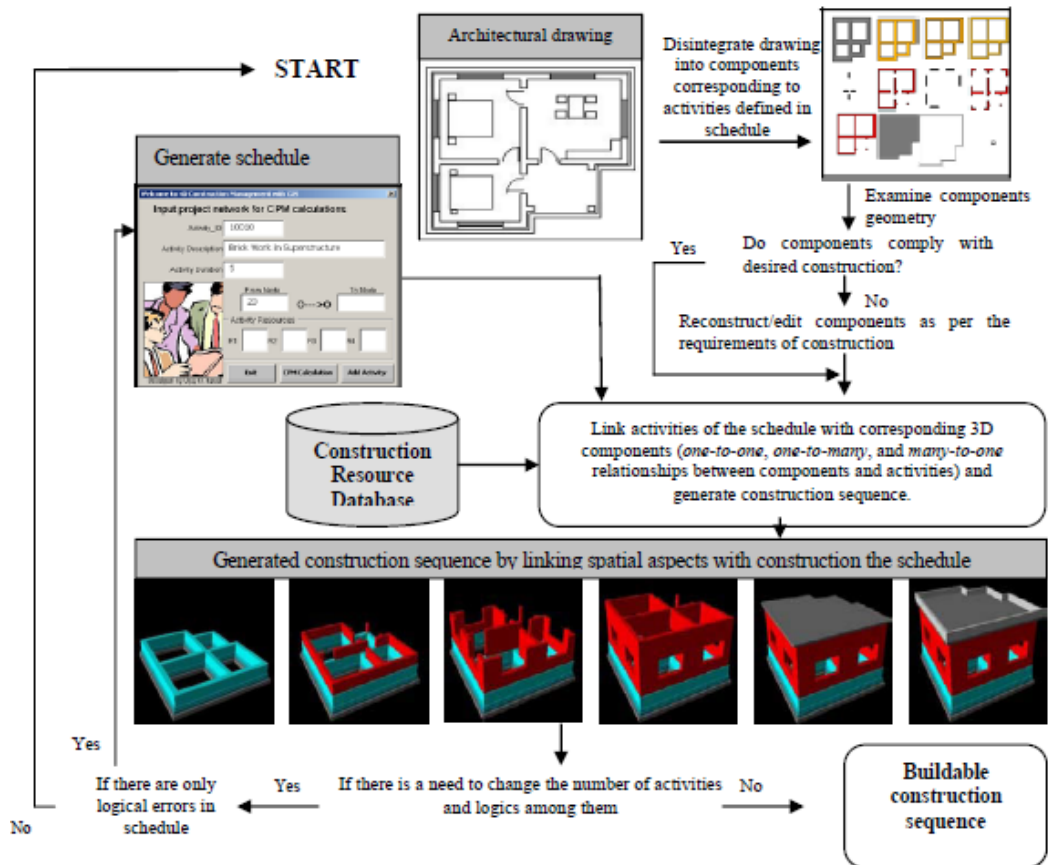


Figure 29. The architecture for generation, linking, visualisation, evaluation and correction of a construction schedule (Bansal and Pal, 2011).

It is also a powerful tool for disaster management. The evaluation of potential damages under different flood scenarios through quantification of their ability to provide relative short, medium and long-term risk reduction, supports decision makers in discrimination among alternative mitigation actions (Albano *et al.*, 2018). As well as project management, which is an interesting discipline in which apply GIS methodologies to improve the costs and scheduling (Albrecht, 2017).

### 3.2.3. BIM and GIS for Asset and Facility Management

At this point there is the problem of the integration. Several authors have addressed this issue from a generic approach (Joklova and Budreyko, 2019) or from a more specific one. (Kang and Hong, 2015) proposed and BIM/GIS-based information Extract, Transform and Load (BG-ETL) architecture that separates geometrical information from that related to the relevant properties, applied to facility management.

This method searches to integrate these two heterogeneous datasets, automating both models. This data is divided into two categories:

- **Geometrical information:** the geometry of the BIM object presented to a GIS viewer as a surface model.
- **Property information:** desired properties should be selected and displayed by the BIM viewer, according to user's necessities.

The workflow is designed to map BIM objects to GIS objects in a CityGML model. It also allows to see the FM information stored, which is basically the aim of the methodology. It is important to underline that this system allows users to decide what information they want to see, because when exposed to unnecessary and incomprehensible data, managers are susceptible to make mistakes.

For the development of the BG-ETL architecture, the first consideration was the scalability and flexibility of the data integration method in order to support interoperability. Thus, the BIM/GIS middleware consists on an IFC converter to represent GIS model and then the FM data is extracted. Then, the information is stored in a dataware (DW), which basically is a digital database typically used to connect and analyse data from heterogeneous sources. Following this, the data stored in the DW is connected to the BIM object of the IFC.

From this point, the data modelers and FM staff need to perform manual tasks. So, if possible, the workflow of the elements between set of heterogeneous data models are mapped needs to be automated. The definition of this workflow consists on the following elements:

- Extraction: the necessary data from the perspective of each use case.
- Transform: this takes two steps; binding (the dataset is integrated by linking it to the relevant BIM object) and map rule setting (to semantically map the integrated BIM object to the GIS object).
- Load: the format is represented in CityGML. Some post-processing may be needed, for example data converting for optimal visualization.

This mapping workflow may vary from according to the use case (the algorithm changes). A mapping table is generated to automate semantic mapping when objects are defined by naming the source and the target. This whole process was tested on a case study and showed excellent results:

- Higher efficiency compared to manual data integration.
- Benefits: to analyse the quantitative benefits, eight items were established (data integration, flexibility, extensibility, effectiveness, reliability, reusability, maintenance and portability). A survey was taken to several BIM-related professionals and 36 out of 37 respondents considered that the system had improved the performance of these eight items, comparing them with manual data integration.

Another system is proposed by (Mignard and Nicolle, 2014). In this case, they use ontologies to combine BIM and GIS through a FM platform called ACTIVE3D. With this approach, they consider that BIM is no longer limited to the building but also to the interactions with its environment. This emerging discipline is called Urban Facility Management (UFM).

Graphical representations of processes to generate urban spatial structures can be described as urban models. The idea is to manage urban facilities in an interoperable way; to reach this goal, it is needed to set up mechanisms on semantic modelling of urban objects. The quality of the information depends on the person who is inputting the data and the software used. Consequently, the models substantially change from one person to another.

This can be homogenised by semantic BIM. The particularity of the semantic BIM is that it uses ontologies to manage models, which unifies the knowledge generated during each step of the building's lifecycle. The management of the building's lifecycle requires another management level; all the elements, their states and their interactions have to be validated. These interactions are defined as links. The IFC standard uses files that are made of objects and connections between these objects.

There are 3 types of IFC classes: object classes, relationship classes and resource classes. The ACTIVE3D semantic extension allows new elements to be added as well as relation elements and resources to the IFC management system. It is possible to merge two files, extract partial data, visualize, store...

Despite IFC and semantic BIM give a good answer to the problem of building management, their environment's modelling is more difficult. Although IFC 4 allows users to define geographical elements, GIS seems to be the solution.

Three areas of research involved in the definition of an Urban Information Model (UIM) have been identified: BIM axis, GIS axis and contextual axis (ontologies). There are many solutions dedicated to the implementation of one or more fields that can be identified on this multi-axis system. Some approaches are positioned on two axes, yet many of them allow dealing with all three dimensions. UIM is positioned in the centre of the system.

In order to work towards this new axis, the ontology should be then capable to merge data from IFC and CityGML. This process is divided into two parts: modelling and contextualization. The first one is referred to geometric and spatio-temporal entities. The second one refers to the relations between such elements.

Finally, the process has been tested through the ACTIVE3D platform. The implementation took three steps: the first one, defining the process itself; the second one, the development of the software architecture required, and the third step is the industrial implementation of the ontology mechanisms.

It works like this: first, it is needed to extract the data, and this can be done from several sources like BIM, CAD, etc. Then, this data must be exported and later stored. After that, the model is done, and the final step is to visualize this information depending on the user's profile.

Within this methodology, both semantic and geometric data are stored distinctly, so they need to be linked. This happens in the DB; the purpose of this links is to recover, from each geometry the related information or vice versa.

Other approaches are, for instance, linking the integration of these two methodologies with smart cities (Shahrour, Alileche and Alfurjani, 2017). This integration requires first the development of digital modelling for the City, urban infrastructures and buildings, which should include the asset data, the operating data and the environmental data all over the lifecycle of concerned systems. It should also guarantee the interoperability between the different modelling tools.

There is a study on management of 3D digital building based on BIM and GIS, which objective is to create a low-cost tool for storing building and city data, visualize it in a 3D model, and use it to perform spatial analysis in customized open source web-applications. A drone is used to obtain a photogrammetry of the building, in order to get an elevation. With this and a cloud point, the 3D model of the building is created. The geometry of the area was created as well using a drone. Later, data was stored in the web application CMD Build.

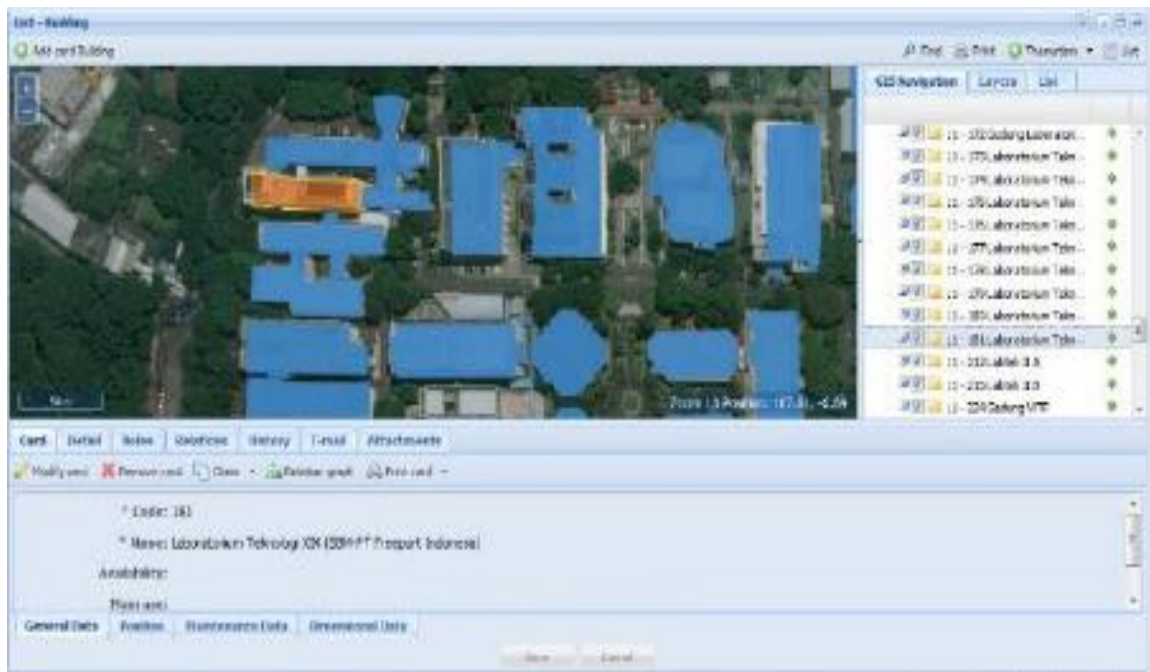


Figure 30. CMD Build for private user visualisation: 3D map with GIS (Trisyanti et al., 2019).

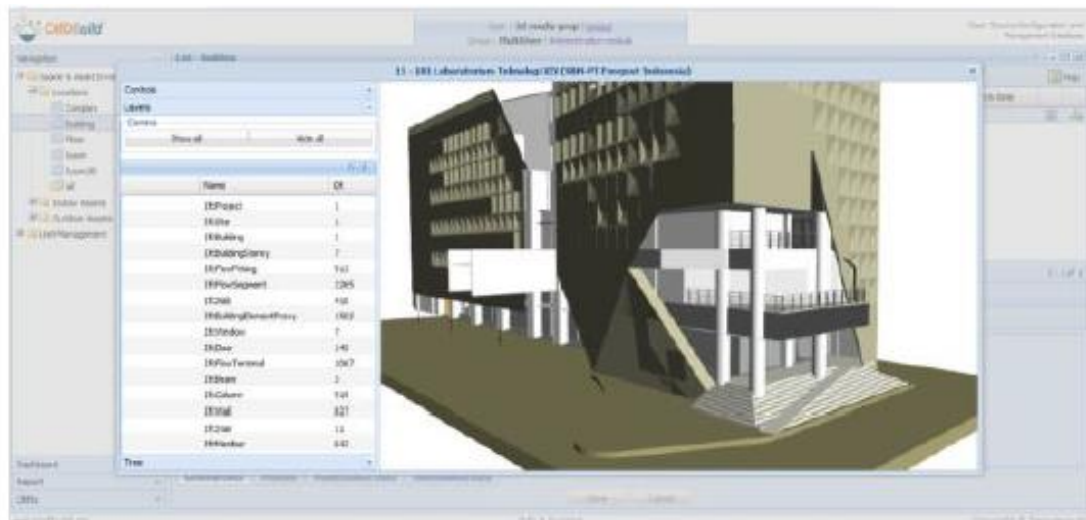


Figure 31. CMD Build for private user visualisation: 3D model of each building through BIM (Trisyanti et al., 2019).

On their behalf, (Boyes, Ellul and Irwin, 2017) focus on the potential for improved Asset Management by the integration of BIM and GIS and make a preliminary report on how 3D spatial queries can be used to establish a two-way relational link between two information systems through the ESRI 3D analyst toolbox, which identifies the location of objects by reference to a space.

### 3.3. Problem statement

Considering the integration of BIM and GIS with Asset & Facility Management (specially Condition Inspection) purposes, it is important to discuss a few aspects that come from the following questions:

- How much detail does the BIM model need? And the GIS?
- What are the steps in which the assessment is structured?
- How is the necessary information going to be collected?

It is a must to keep in mind that the process is part of a decision-making support system. For this reason, the Condition Inspection will produce a series of results (information) that will have to be managed and displayed in an effective way, this means, with appropriate tools. This is also part of the scope of the work.

## 4. Methods and tools

To establish a proper Condition Inspection process, integrating both Building Information Modelling -BIM- (for the building itself) and Geographic Information Systems -GIS- (for the built environment), the interrelation of the three main topics must be complete and mutual. Thus, the process has to reach several goals: first, the BIM model of the building and the GIS map of the area must work together as a whole, and after that, the integration of this ensemble has to be useful for Condition Inspection purposes.

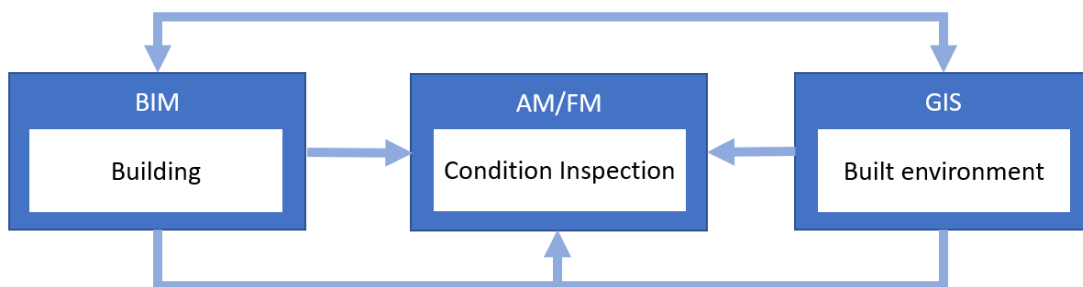


Figure 32. Interrelation of the different systems (Prepared by the authors).

A methodology has been developed for supporting the integration of BIM and GIS in a Facility Management context, which is based on the following topics:

- **Information requirements** and everything related to the 3D modelling of the building and the built environment, in terms of Facility Management. Definition on how these rules are set: what level of detail, what parts to model/not to model, how are the parameters going to be set, etc. How is the process for data exportation to a GIS environment, and how is this environment modelled and prepared for the Condition Inspection?
- **Condition assessment** of the building and built environment. A series of survey forms have been designed in order to achieve this objective. For the built environment, some data has been collected and modelled. Later, the information outcoming from the inspection is stored in the digital model and it can be displayed through the GIS viewer, as well as different analysis can be done in the same platform for decision making.

- **Procedure for data collection** and survey campaign implementation. Detailed guidelines on how this process should be done, to properly obtain the required information for the Condition Inspection.

The next figure shows the general process of the implementation of the GeoBIM model (integrated GIS + BIM) in a Facility Management context. It shows how the built environment (the real one) is inspected with Condition Assessment procedures (this is, the surveys for Condition Inspection); the results of this inspection are stored in the Digital Built Environment (DBE), that is made up of the BIM model, the GIS model and the results of the inspection (database); it is used as a source of information for accomplishing the Facility Management Strategy, by the visualization of the data integrated. In the end, this strategy helps with decision making for managing the actual built environment.

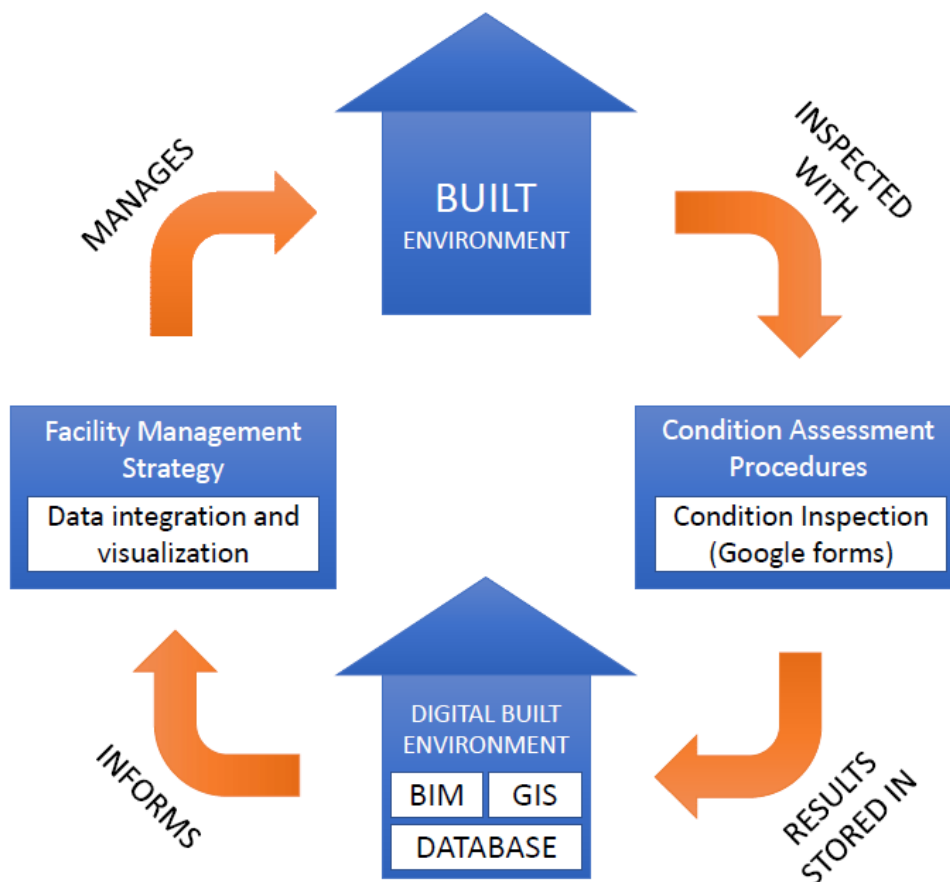


Figure 33. GeoBIM based Condition Inspection of the Built Environment (Prepared by the authors).



## **4.1. Condition Inspection of the building and built environment**

In order to set the requirements for the model, first it is necessary to set the requirements of the inspection. This normally happens during a meeting with the client, but for this case, some general requirements will be set to fit better into the average case and make it scalable.

The assessment is done by a Condition Inspection. The premise is to do it in a digital built environment and for this purpose, several things are needed:

- A digital model of the building.
- A digital model of the environment.
- The integration of both models (GeoBIM).
- A document to fulfil with data from the inspection.
- The proper personnel able to do it.

## **4.2. Requirements for the GeoBIM model**

As the model has two kinds of data (information and geometries), requirements have been divided into these two categories, for an easier comprehension of the process.

### **4.2.1. Requirements regarding information**

As there are two different entities (building + built environment), it is needed to set a division for inside/outside parts. The proposal is:

- Indoor: every single room inside the building.
- Outdoor: common parts (elevators, stairs...) and envelope.
- Outdoor: the immediate surroundings, if the building has a private urban space (such as a garden or a private entry).
- Outdoor: public areas (the neighbourhood).

This itemization could be subject to the particularities of every building; it could have no public areas surrounding it, or to the contrary, not private areas. But this is a universal index to follow for a first screening.

#### 4.2.1.1. Indoor parts

Then, all the elements are divided into categories, both for external and internal spaces. For the indoor part, this division is much clearer; it will coincide with the different kind of elements, systems and partitions that can be found inside an average building:

- Windows
- Walls
- Doors
- Furniture
- Ceiling
- Pavement
- Lightning/switchers
- Sockets
- Radiators (heating system)
- HVAC

Some of them could not exist (for instance, there could be not a HVAC system, or radiators, or it could be a small room without windows), but for most of the rooms there will be all of them. This seems a fair way to categorize the elements, since it allows to separate different kind of problems that will probably have to be solved by different technicians. For instance, if the problems are focused on lightning and sockets it is a matter of an electrician; if the windows or doors present issues, it's the carpenter who has to fix it; and so on.

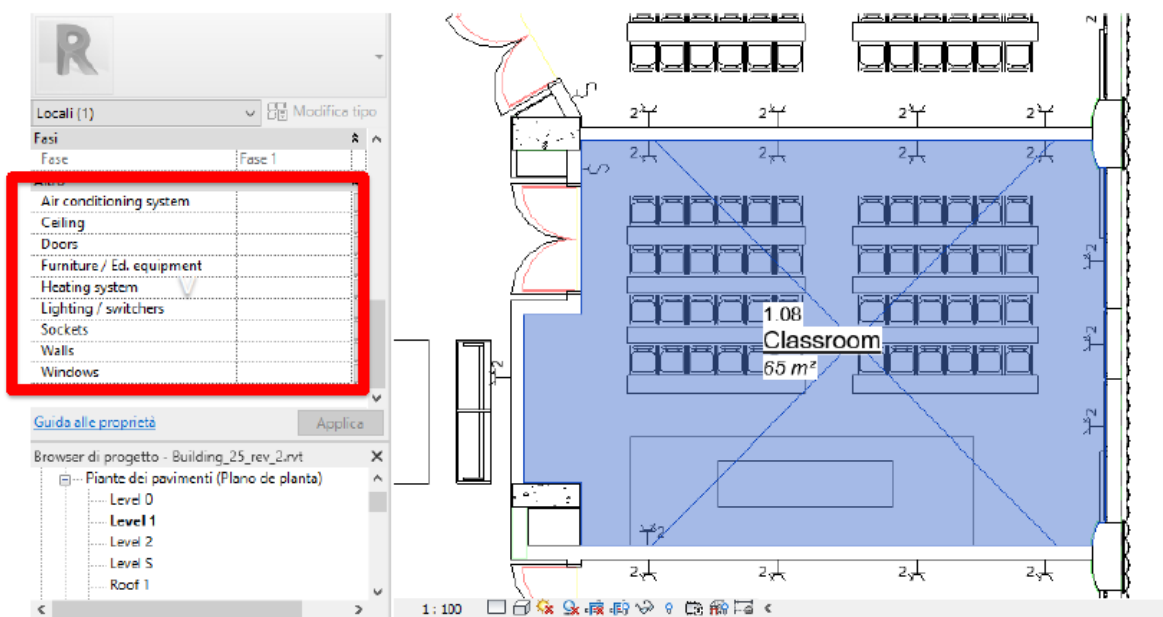


Figure 34. How it looks like when parameters and rooms are created and assigned.

Then, they will be assigned as 'shared parameters' to every room. A Revit Room is a three-dimensional volume that represents an actual architectural space. It allows several features, such automatic scheduling of parameters. In this case, rooms are created and then the shared parameters are linked to them.

Figure 34 shows how the final results once the shared parameters have been created and assigned to the current room in the options menu.

#### 4.2.1.2. Outdoor areas

As the outdoor areas are divided into 3 different types, there have been different categories, all of them are displayed in the table 1.

Table 1. How outdoor parts are divided.

Section	Elements/categories	
Envelope & common parts	Façade opaque	Elevator
	Façade transparent	Stairs
	Roof	Disabled access
	Doors	
Outdoor – private areas	Footpaths	Irrigation system
	Driveways	Fences/separations
	Vehicular ramps	Stairs
	Outdoor lighting	Ramps for disabled
	Green areas	Furniture/decoration
Outdoor – public areas	Kerbs	Vertical street signs
	Ramps	Fences/separations
	Manholes and drains	Horizontal street signs
	Urban furniture	Trainways
	Public lighting	Public transport stops

Again this is a general categorization, so it could happen that there were public transport stops in the private areas, or kerbs (because the private areas include pavements and not only roads), or any other situation; so the classification above is susceptible to be adapted. But still, it is the most feasible

situation, as having street signs at the private areas is less likely than at the public ones, and quite the opposite happens with stairs.

#### **4.2.2. Requirements regarding geometry**

There are also two separate procedures regarding geometry. First one will be the building and the immediate surroundings (private parts), that will be modelled in a BIM environment. Second one will be the outdoors, which will be stored and represented with GIS. After everything is completed, they will be integrated.

##### **4.2.2.1. Indoor parts**

Like any other BIM model, the first step should be getting some CAD template of the building to model, if possible. As this academic work's scope is oriented to institutions, public services and mainly medium-to-large entities, it's likely that they have some kind of maintenance service, a building managing service or any department responsible for building that can provide the CAD file. If this is not achievable, some visits to the building will be necessary and draw up the template in order to make easier the modelling process.

The elements do not need to be modelled in a high detail, for example it's not necessary to set all the layers that compound a wall, it can be just a generic type with the corresponding width. The table 2 sets the generic requirements for each element present in the model and some examples of unnecessary information that would increase the size of the file.

In a general way, it is desirable to have the overall look of the elements, hence the finishes (that can be simply a painting on Revit). Actual dimensions of each element are necessary data, as well as some details of systems, but in a typical basis the main part of the exhaustive information is not necessary.

Nevertheless, depending on the particular case, these determinants could change, and some information could become important or vice versa.

Table 2. Minimum requirements of modelled elements.

Element	Minimum requirements	Unnecessary information
<b>Walls</b>	Width, height, length	Composition of layers
<b>Floors</b>	Width, height, length	Composition of layers
<b>Ceilings</b>	Width, height, length	Composition of layers
<b>Doors</b>	Position, dimensions, opening systems (hinged-slide), cover plates	Exact geometry of accessories, structure of the board
<b>Windows</b>	Position, dimensions, opening systems (hinged-slide), cover plates	Exact geometry of accessories, structure of the glass
<b>Furniture</b>	General dimensions, quantities, location inside the rooms	Exact geometry (too heavy)
<b>Radiators</b>	General dimensions, quantities, location inside the rooms	Exact geometry (too heavy)
<b>HVAC</b>	Location inside the rooms, dimension	Exact geometry (too heavy)
<b>Sockets &amp; Switchers</b>	Location inside the rooms, height	Exact geometry (too heavy)
<b>Lightning</b>	Location inside the rooms, height	Exact geometry (too heavy)

The aim of modelling the geometries is to support visual inspection. Therefore, as previously said, a high level of detail is not needed, and this helps with the whole integration process with GIS (that the less polygons, the better result). F.i. a table could be just a box, which also would help a lot in terms of BIM-GIS interoperability (reducing polygon number hastens the process).

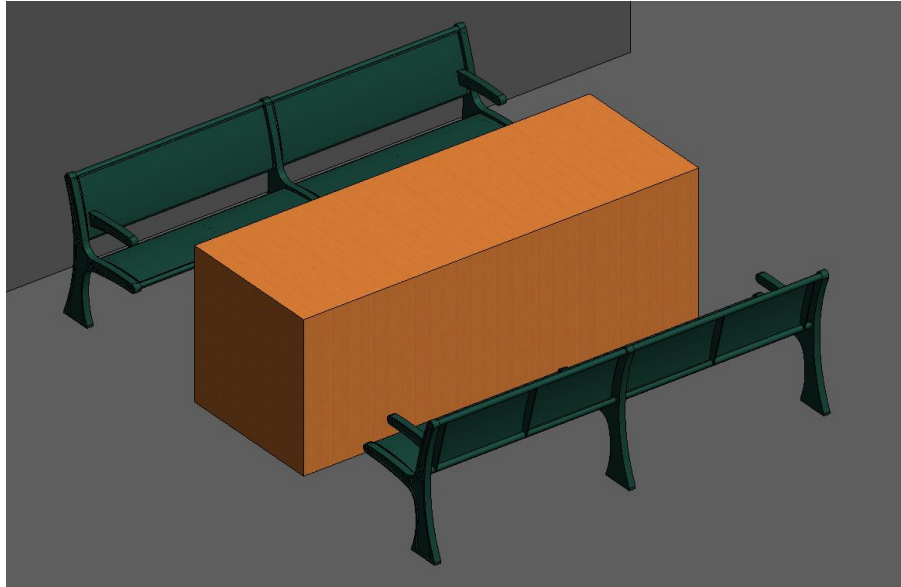


Figure 35. Simple geometry (a box that plays the role of a table) vs. more complex families (a generic yet very detailed workbench).

After reviewing the process, the agreement achieved is that the level of development appropriate for the assessment is LOD200. This implies approximate geometry of the elements and includes non-graphic information.

Still, there is an arrangement to be reached about the consistency of the necessary detail. The fact is that during the preliminary assessment, which is the scope of this academic work, the given mark corresponds to the entire group of elements in each room. For instance, there is a score for all the furniture in a given room, or for all the lights, or all the doors, so, what is the point of modelling every single one of them? Because during the detailed assessment, there will come the moment to analyse every single element and since this methodology aims to be scalable to a further development, this is a work that must be considered.

Summarizing, since it will be used with other purposes, the level of development of the model may be higher than the level required for the assessment intended in this work.

Table 3. Examples on preliminary vs. detailed assessment.

Element	Preliminary assessment	Detailed assessment
<b>Furniture</b>	Global mark for all the furniture in the room	Mark on every desktop, chair, workbench...
<b>Lightning</b>	Global mark for all the lights in the room	Mark on every light, so it's important to set the type
<b>Radiators</b>	Global mark for all the radiators in the room	Mark on every radiator

Regarding the envelope & common parts, the categories are more or less the same of the indoor parts. The only difference is that it includes elevators and stairs, which are rooms themselves, and the roof. Again, the detail required for each element is not high (at the same level that the indoors).

The immediate outdoors (private areas) are modelled with BIM as well. It may include pavements, roads, public lights and many other elements. All the categories that imply surfaces (for instance, green areas), do not need to include all the layers (as for the walls or the slabs in the indoors), just the corresponding finish (asphalt, soil, etc). All the categories that imply single objects (for instance, public lights) do not have to include all the elements, just general shapes or families of similar elements.

#### **4.2.2.2. Outdoor areas**

The outdoor areas are displayed and stored in a GIS database. This database can be downloaded from public sources, usually governmental websites. Once it is opened, geometries must be created. There are three kind of geometries allowed in a GIS environment:

- Points. This is valid for manholes, public lights, traffic signs...
- Lines. Appropriate for kerbs, fences, separations...
- Polygons. Suitable for roads, pavements, green areas...

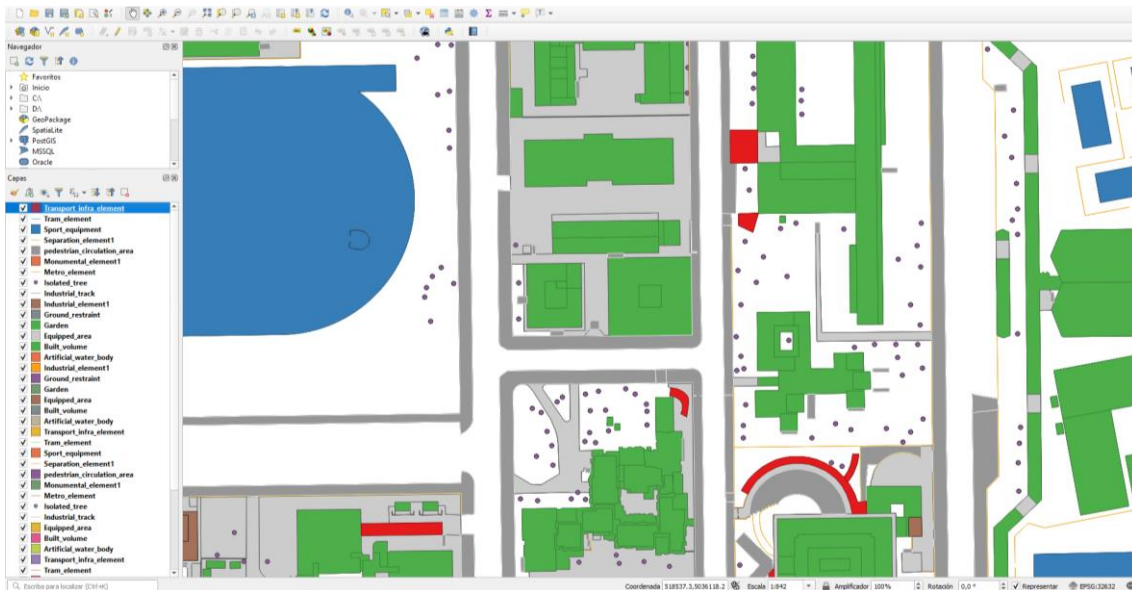


Figure 36. General view of the GIS map once downloaded.

This is how it looks like when the database is opened with a GIS platform. The different layers are displayed on the left, but as it can be seen, there are many elements that are not displayed but still are necessary for the assessment. So, that is the reason there is some modelling to do in GIS, despite having the database from an official source. This is achieved through a campaign, where the people who are going to do the assessment, take notes on these elements while doing the CI. Later, they are modelled whereas introducing the data into GIS.

#### 4.2.3. Integration of the BIM model inside GIS environment

Many approaches for this purpose have been described in earlier sections. For achieving the goals of this project, the defined process is the following one:

1. Georeferencing the BIM in Revit to fit the map coordinates.
2. Export the Revit data as IFC, so it can be integrated with GIS.
3. Use the FME 'quick translator' to create shapefiles of the IFC.
4. Import those shapefiles into the database using QGIS software.

Other additional steps would be:

- Simplifying the geometry for GIS: this strongly depends on how single elements are modelled, but there is the option to convert every solid into a point so it can be easier to work with it in GIS.



- Joining the room information and the spaces to create 3D rooms.
- Stitching together the IfcWall, IfcWallStandardCase, Slabs and Roof to create the LoD2 building.

In the next figures it can be seen how shared coordinates are set in the BIM model (top left), how the model is translated for GIS integration after being exported as a IFC file (top right), and how is introduced into GIS (bottom).

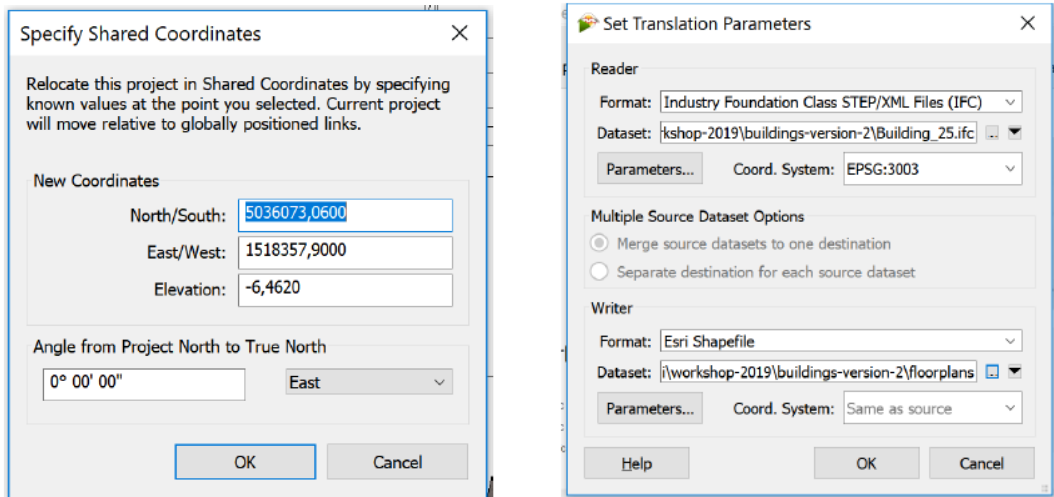


Figure 37. Setting coordinates of the project in Revit (left) and the FME quick translator (right).

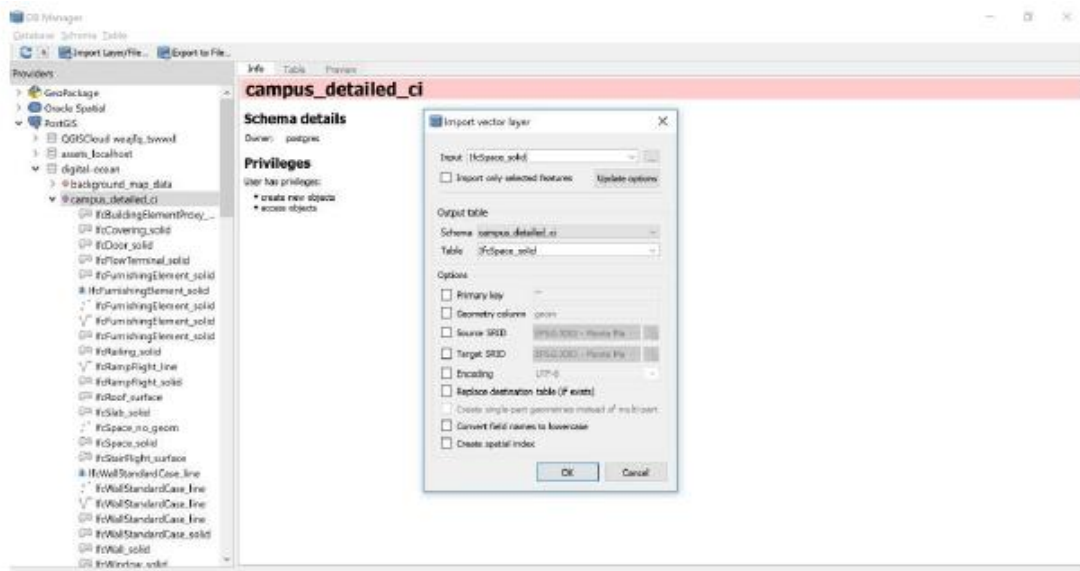


Figure 38. QGIS data import.

### **4.3. Data collection and analysis**

Once these rules are set, the following step is the assessment itself. The idea is that the users can assess the building through an easy via, a fully accessible media. After that, the building manager can assign its mark to every element. For this purpose, one easy way was using Google Forms. Every person with a Google account can access them and can make the assessment quickly through a cell phone, a tablet or a laptop, at any moment. For instance, if the building is an academic/scholar space, the students can rate the classrooms where they take the lessons during the day. If it is a public institution, workers can do the assessment; if it is a hospital, it could be done by the staff...

A campaign was created, via an academic workshop about GeoBIM, where PhD students participated and helped through the assessment and definition of external parts of the building and the CI of the internal rooms. It was organized in a way so that the building could be accessible for the students and the classrooms were available.

It lasted three days, so the first steps were giving some context and information necessary to properly fill the forms and use the proposed software, and then some free time was given to do the 'in situ' work.

#### **4.3.1. Surveys – contents and shaping**

The surveys were set following the rules mentioned above. There are four different forms, one per each part in which is divided the assessment:

- Indoors (general)
- Outdoors: envelope & common parts
- Outdoors: private areas
- Outdoors: public areas

Every survey has an option to implement notes and/or pictures.

## Indoors - Building

Room code \*

Tu respuesta

1 = Very good condition  
5 = Very bad condition

Condition \*

	1	2	3	4	5	Not visible	Not present
Walls	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ceilings	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Doors	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Windows	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Furniture/Equipment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Heating system	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Air conditioning system	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sockets	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lighting and switchers	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Notes

Tu respuesta

Pictures

[📎 Añadir archivo](#)

## Outdoors – Building envelope & common parts

Título

1 = Very good condition  
5 = Very bad condition

Pregunta \*

	1	2	3	4	5	Not visible	Not availa...
Facade (op...	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Facade (tra...	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Roof	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Doors/gate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Elevators	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Stairs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Access for ...	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Notes

Texto de respuesta larga

---

Pictures

Añadir archivo

### Abbreviations:

Façade (opaque)

Façade (transparent)

Roof

Doors/gate

Elevators

Stairs

Access for disabled

## Outdoors – Building’s surroundings

**Título**

1 = Very good condition  
5 = Very bad condition

---

**Condition \***

	1	2	3	4	5	Not visible	Not present
Footpaths	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Driveways	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ramps for ...	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Outdoor lig...	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Green areas	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Irrigation s...	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fences an...	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Stairs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ramps for ...	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Furniture / ...	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

---

**Notes**

Texto de respuesta larga

---

**Pictures**

### Abbreviations:

Footpaths

Driveways

Ramps for vehicles

Outdoor lighting

Green areas

Irrigation systems

Fences and separations

Stairs

Ramps for disabled

Furniture/Decoration

## Outdoors – Public areas (section 1)

OBS code \*

Texto de respuesta corta

---

Detection Code \*

Texto de respuesta corta

---

Entities \*

1. 1. Defects of the pavement
2. 2. Kerbs
3. 3. Ramps
4. 4. Manholes and drains
5. 5. Urban furniture
6. 6. Public lighting (poles and lamps)
7. 7. Vertical street signs
8. 8. Fences and separations
9. 9. Horizontal street signs
10. 10. Tramways
11. 11. Public transports stops and equipment

Type of surface where the entity is located \*

Permeable

Waterproof

## Outdoors – Public areas (sections 2-4)

Sección 2 de 4

### Condition of the element

Descripción (opcional)

Condition \*

	1	2	3	4	5	
Very good	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Very bad

Después de la sección 2 Ir a la sección 4 (Notes and pictures) ▼

Sección 3 de 4

### Degradation intensity

Descripción (opcional)

Degradation \*

	1	2	3	4	5	
Aesthetic	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Hazardous for users

Después de la sección 3 Ir a la sección 4 (Notes and pictures) ▼

Sección 4 de 4

### Notes and pictures

Descripción (opcional)

Notes

Texto de respuesta larga

Pictures

For this last survey, some extra steps were added since it is not only about singular entities, but a new concept is introduced: **defects on pavements**. There is an option to introduce the OBS code, which is a code attached to every surface. It was defined before starting the assessment, so pavement of street 1 could be OBS 1, road of street 1 could be OBS 2, pavement of street 2 could be OBS 3, etc. Also, the detection code is referred to the defect itself that is being described. This way, any crack or fissure can be located using these 2 codes.

There is an option to write whether it is a permeable or a waterproof surface, and then the mark. In this case, it is made of two parameters: one is the mark itself, and the second one is the degradation intensity, based on how much dangerous it is for users if it is not repaired (full explanation in the next page).

One decision to make is how to assign a general rating for any category. It could be conditioned by the element with the worst condition or be an average of the general picture, but, since there is the option to give particular marks to those elements in a worse condition, it makes sense to give an average mark and not to detriment the general condition for some exception/exceptions.

As the inspection will be, essentially, visual, it was decided to use a **semiquantitative inspection** This is, assigning a numeric scale from 1 to 5 to every element assessed (Likert scale). The scale goes like this:

- 1 (Very good): Very good condition of the element
- 2 (Good): Some aesthetic defect, needs minor repair
- 3 (Fair): Functional degradation of some parts, needs maintenance
- 4 (Bad): Not working and maintenance must be done as soon as possible
- 5 (Very bad): Not working and needs immediate maintenance

Also, there are other two feasible marks:

Not visible / Not present

The reason is that an element may not be present in every single room or outdoors space, and 'not visible' implies that something may be or not but the



fact is that this kind of inspection is focused on visible elements, so it does not really affect if it is present as long as it can't be seen.

For the outdoors, the marking system is the same, a 1-5 scale with the possibility that some elements were not present or visible. Defects on pavement's surface, may be also located and given a mark considering the magnitude of the flaw, differing a bit from the scale used before:

- 1 (Very good): Some aesthetic defect, needs minor repair
- 2 (Good): Some degradations as micro cracks, minor detachments
- 3 (Fair): The defect (crack, holes, etc.) affect the functionality of the surface
- 4 (Bad): Major degradations (cracks, holes, etc.) and need to be maintained
- 5 (Very bad): Major degradations (cracks, holes, etc.) and need to be maintained as soon as possible since it could be hazardous for users

#### **4.3.2. Campaign – procedure for data collection**









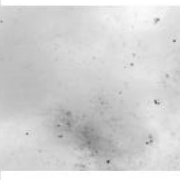


























The required data can be collected from many ways, depending on the use of the building. The best option would be having people in charge of this kind of things, being used to the scale and trained to successfully detect which is the best mark for a given element. Also, there have been collected some examples to make this work easier, which are displayed next.

There is one particularity that comes when talking of walls and ceilings; marks 3-5 are set depending on how much surface is damaged, like it is presented on table 4. Façades follow the same constraints as walls and ceilings for the indoors.






















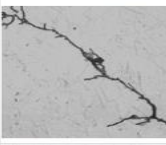




























Table 4. Relation between % damage and mark.

<b>% damaged surface</b>	<b>Given mark</b>
Less than 25%	3 – Fair
From 25	4 – Bad
More than 50%	5 – Very bad



Value	Survey forms	Description	Façade opaque	Façade transparent	Roof	Doors	Elevators	Stairs	Disabled access
1	Very good	Very good condition of the element							
2	Good	Some esthetic defect, needs minor repair							
3	Fair	Functional degradation of some parts, needs maintenance	 <25% of total surface	 <25% of total surface					
4	Bad	Not working and maintenance can be postponed	 <40-50% of total surface	 <40-50% of total surface					
5	Very bad	Not working and needs immediate maintenance	 >50% of total surface or	 >50% of total surface or					
100		Not visible							
200		Not present							



Value	Survey forms	Description	Kerbs	Ramps	Manholes and drains	Urban furniture	Public lighting	Vertical street signs	Fences / separations	Horizontal street signs	Trainways	equipment
	1 Very good	Perfect conditions										
	2 Good	Some aesthetic defect, needs minor repair										
	3 Fair	Functional degradation of some parts, needs maintenance										
	4 Bad	Not working and maintenance can be postponed										
	5 Very bad	Not working and needs immediate maintenance										
	100	Not visible										
	200	Not present										

The examples above were taken for the purpose of making everything more standardized, so the deviations for personal criteria are minimized and the valuations are as homogeneous as possible.

So, in general, the examples have been selected following the next principles:

- 1 - Very good: elements that are almost new, like they have been just built.
- 2 - Good: usually present dirtiness, or minor aesthetical defects.
- 3 - Fair: contain defects that need a reparation but still can be used (for instance, cracks on pavements, walls or ceilings).
- 4 - Bad: have bigger problems that could need a quick maintenance.
- 5 - Very bad: degraded elements that need an urgent repair.

It should be pointed out that during the process, all the assessment could be done with the mobile phone, tablet or any mobile device, which makes the inspection much more approachable.

This is because the whole procedure is intended to be easy to fulfil, especially considering that the condition of the elements could change quickly (some maintenance issues, or for instance when something is repaired and needs to be updated, so it's not urgent anymore).

#### **4.3.3. Tools for decision making**

GIS works with layers. Features are set on these layers and divided in separated floors. Each one contains information regarding one category for that floor. Also, it is needed to set another layer for the assessment, because it allows the manager to introduce into the model the mark registered in the forms.

Now both models are created and integrated, the assessment is done, and it is integrated in the GeoBIM model. From now on, there is the possibility to manage this information in several ways, all of them including visualization.

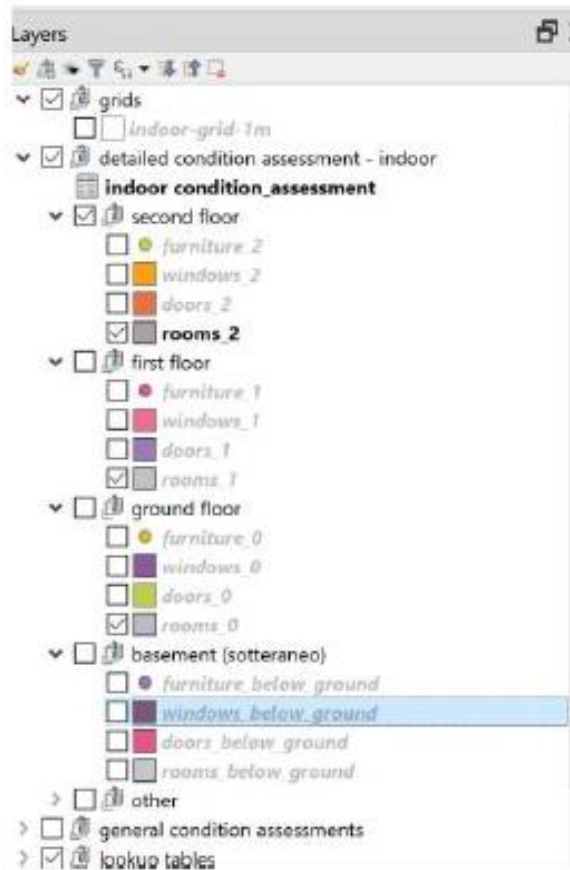


Figure 39. Examples on layers of the floors and the CI layer.

The first and more obvious option is to display a map of every existing asset. This is an easy thing to do, it just takes to set every layer on. Nevertheless, this must be done floor by floor, as it is a 2D map and otherwise floors would overlap.



Figure 40. Map of all the assets.

Another option, useful for FM purposes, would be to display those assets whose condition is poor or lower than a given mark. It is possible to create a map where every asset is displayed in a different colour depending on its condition.

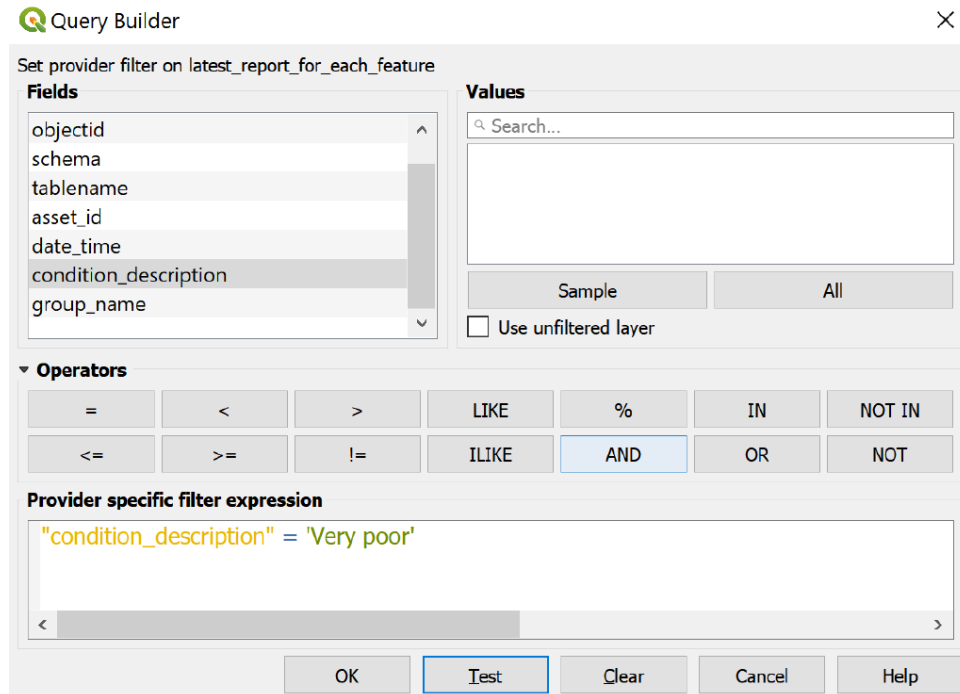


Figure 41. Filters for displaying only certain values on the condition inspection.

Pavements and roads are displayed as polygons and it is possible to put them with different colours depending on how much defects have.

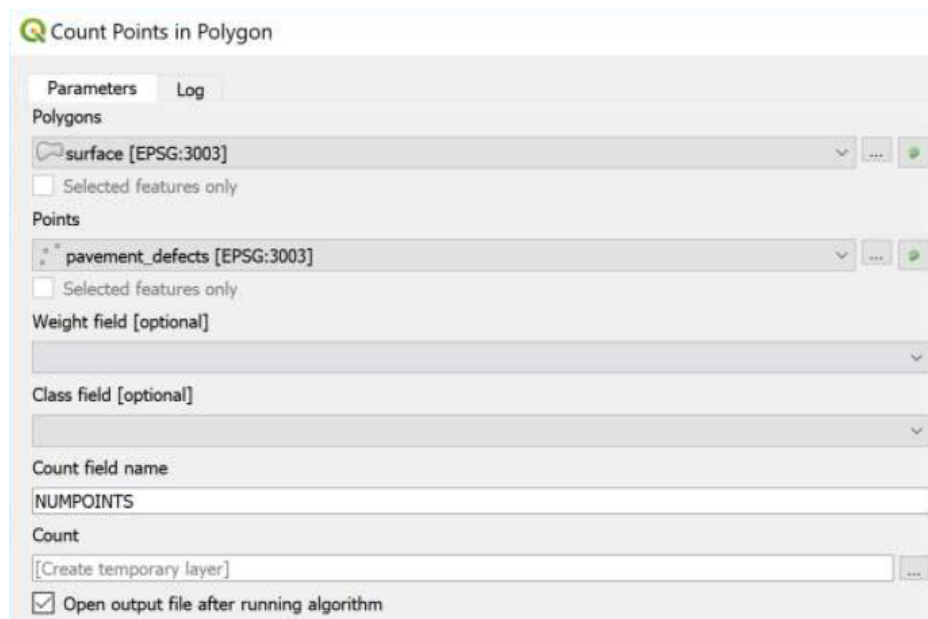


Figure 42. Colouring surfaces by number of defects.



A last example (but there are many other options) is to map floors/rooms by its general condition, with different colours or just displaying some of them.

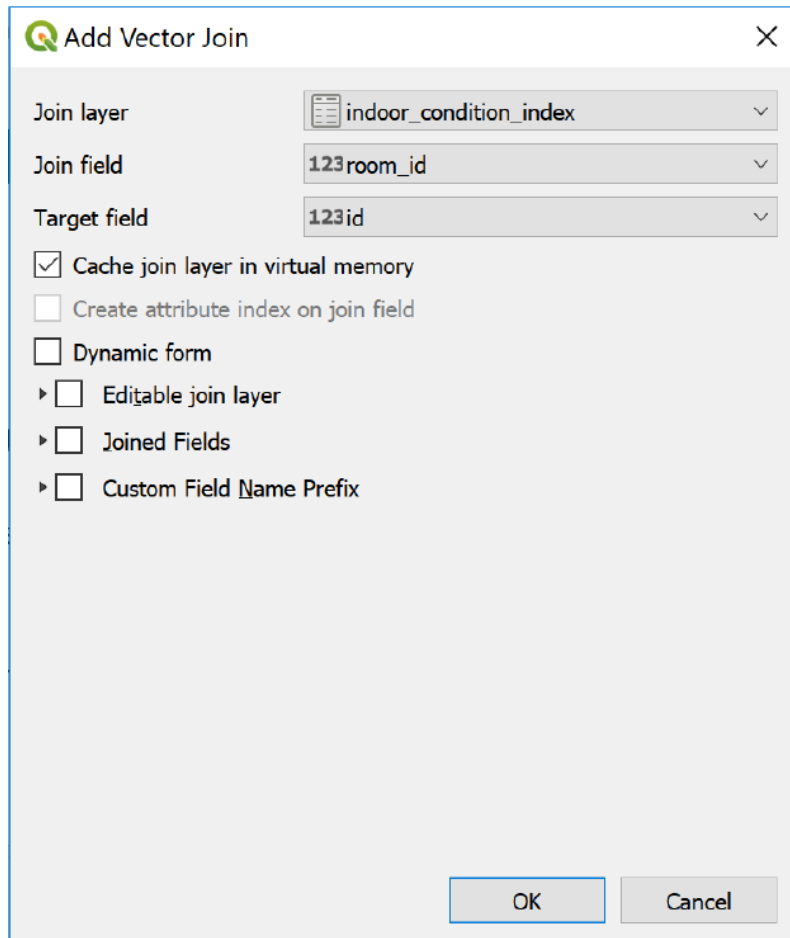


Figure 43. Displaying rooms by its condition.

## 5. Case study and results

The methodology previously introduced has been tested in a case study. After discussing some options, the choice finally adopted was Building 25 in Politecnico di Milano. It is an educational building, part of the Campus Leonardo in Città Studi, used mainly for teaching purposes in the sphere of design and engineering.

### 5.1. Introduction to the case study

The building has been selected because we have access to the information, through the building manager who will provide us with all the information that is within his reach. Another important aspect is the fact that making this study case in a university environment makes it scalable in a gradual way, as intended: starting from this building and its surroundings, it can be extended to a piece of the street, after to the whole neighbourhood and finally to the entire campus.

#### 5.1.1. Location and external parts

The selected case study is located in Via Golgi 40, Milano (MI), Italy. It is part of a complex of 4 buildings (22, 23, 24 and 25) in the same location, all of them property of the Politecnico di Milano.

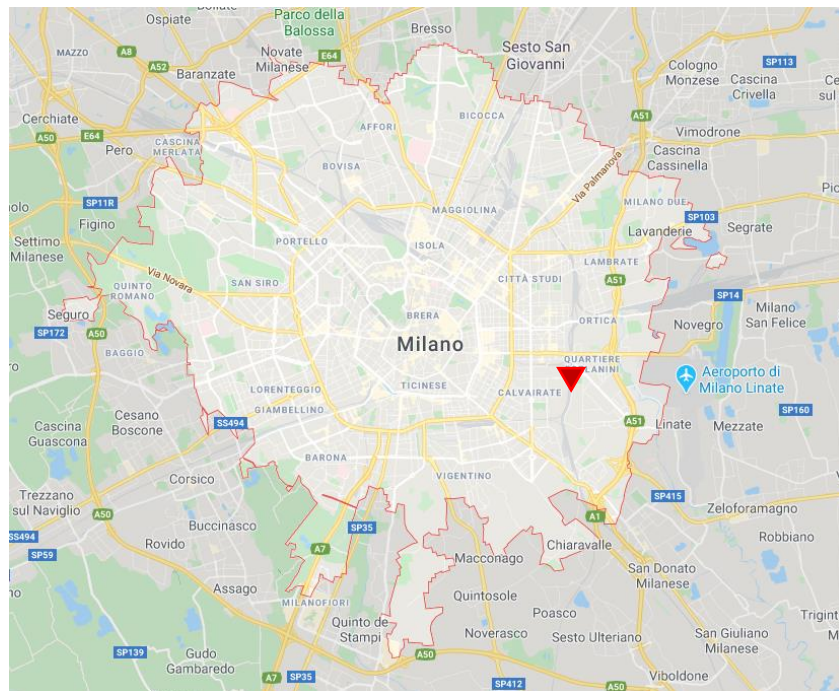


Figure 44. Location of the building inside Milano.

There are several elements in the surroundings. South side faces to the Via Bernardo Ugo Secondo, east side faces the Via Celeste Clerincetti, west side faces to building 24 and north side faces to building 23.

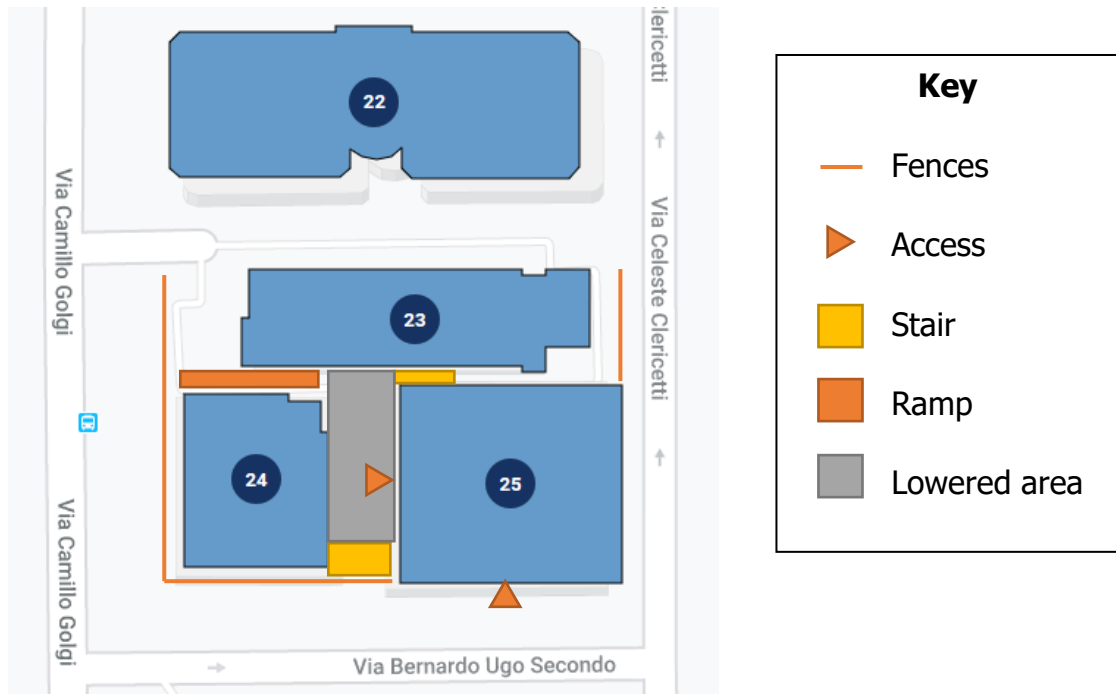


Figure 45. The building and its surroundings.

Fences demarcate the boundary between public and private areas. As it can be seen in the figure, there are two stairs: one of them in the west side that leads to an entry located in the basement and other one in the north side, much smaller. There is also a vehicular ramp which bring access to a private lowered area, in which there are two benches and tables.

Next there are some images of the external parts of the building, for a better understanding of the built environment. The first image (Fig 46) shows the lowered area with building 25 at left and building 24 at right, also the stairs that connect with Via Bernardo Ugo Secondo. Fig 47 displays the vehicular ramp placed between building 24 and building 23. Fig 48 illustrates the stairs sited between building 25 and building 23.



Figure 46. Lowered area between building 25 (left) and 24 (right).

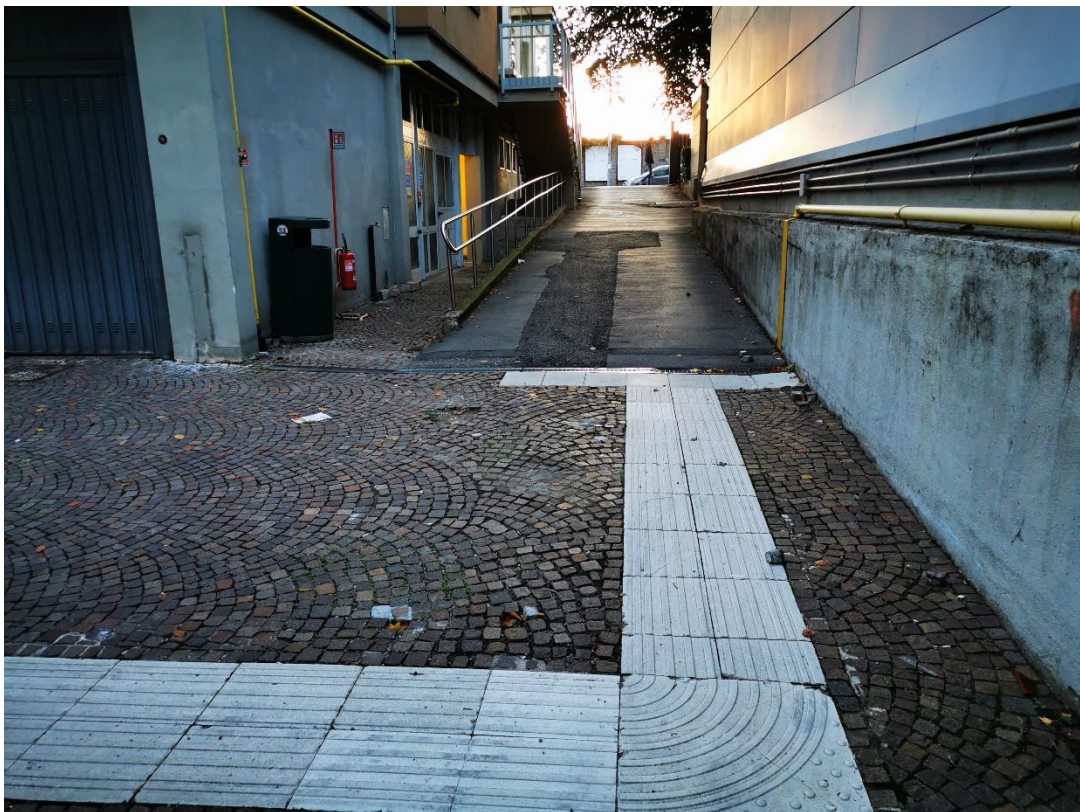


Figure 47. Vehicular ramp between building 24 (left) and 23 (right).

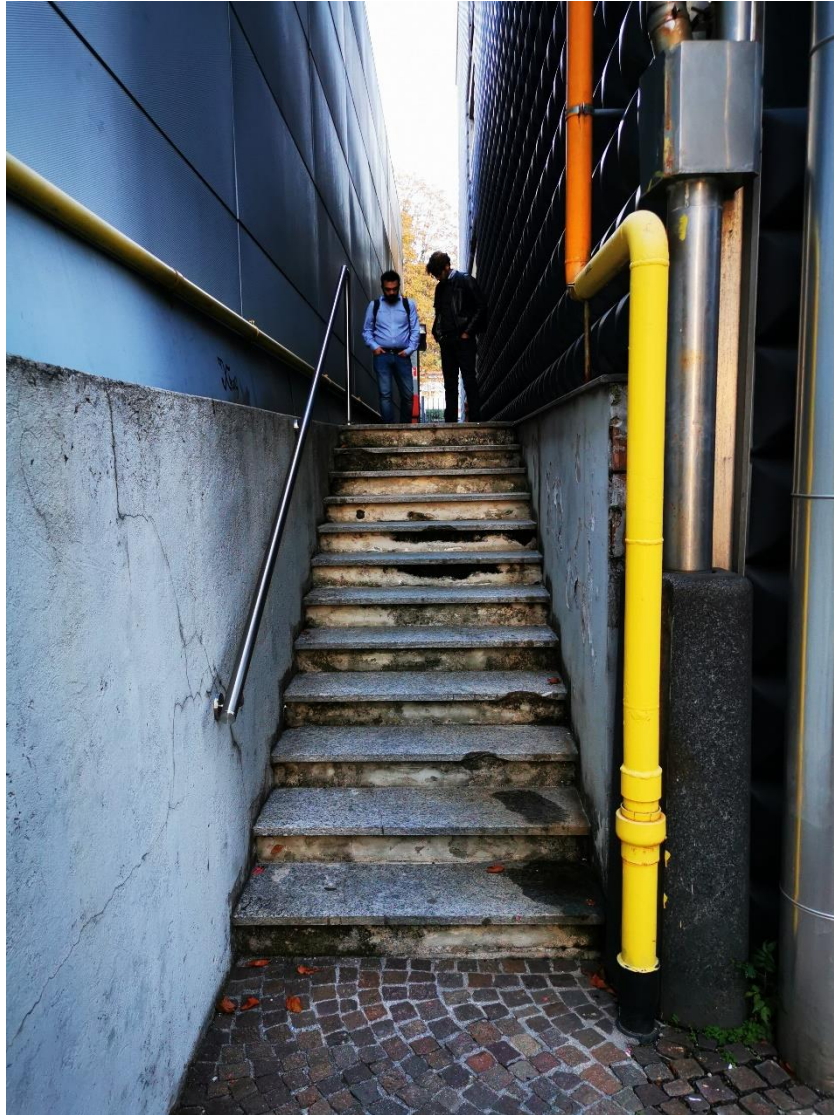


Figure 48. Stairs between building 23 (left) and building 24 (right).

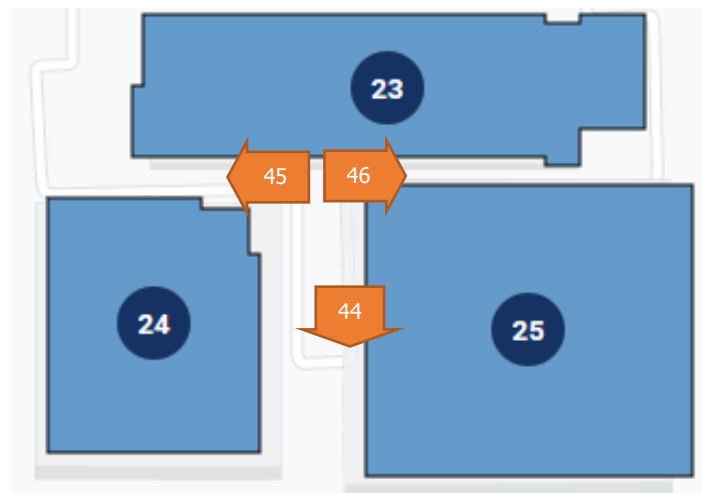


Figure 49. Location from where the photos above have been taken.

### 5.1.2. Building (Emilio Massa)

It's a four store building, with all its façades perfectly oriented to north-south and east-west. Below, there is a drawing of all the prospects.

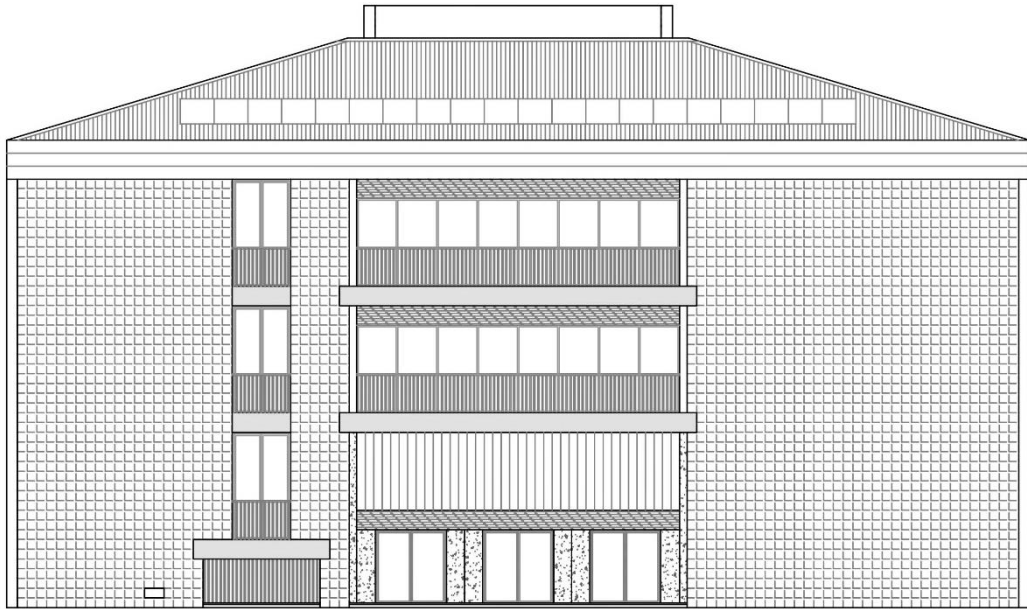


Figure 50. South façade.

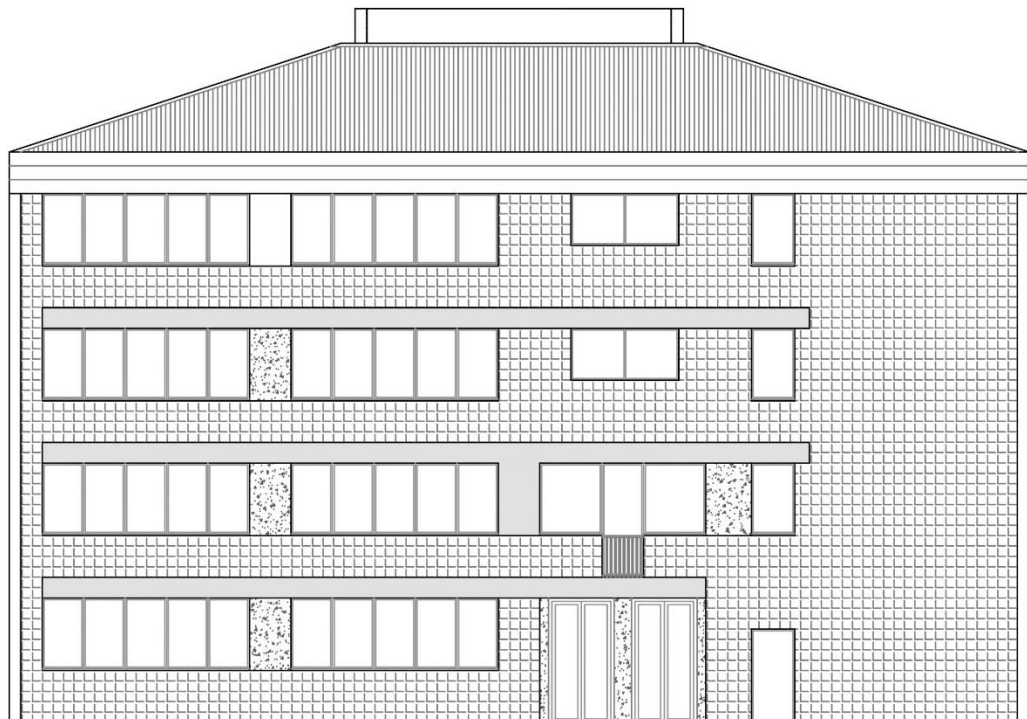


Figure 51. West façade.

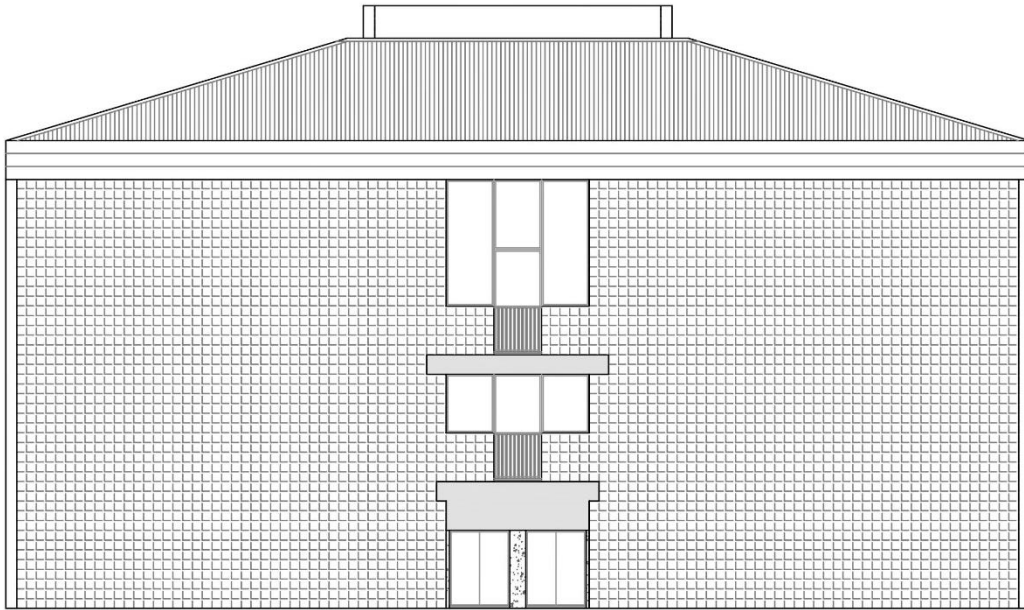


Figure 52. North façade.

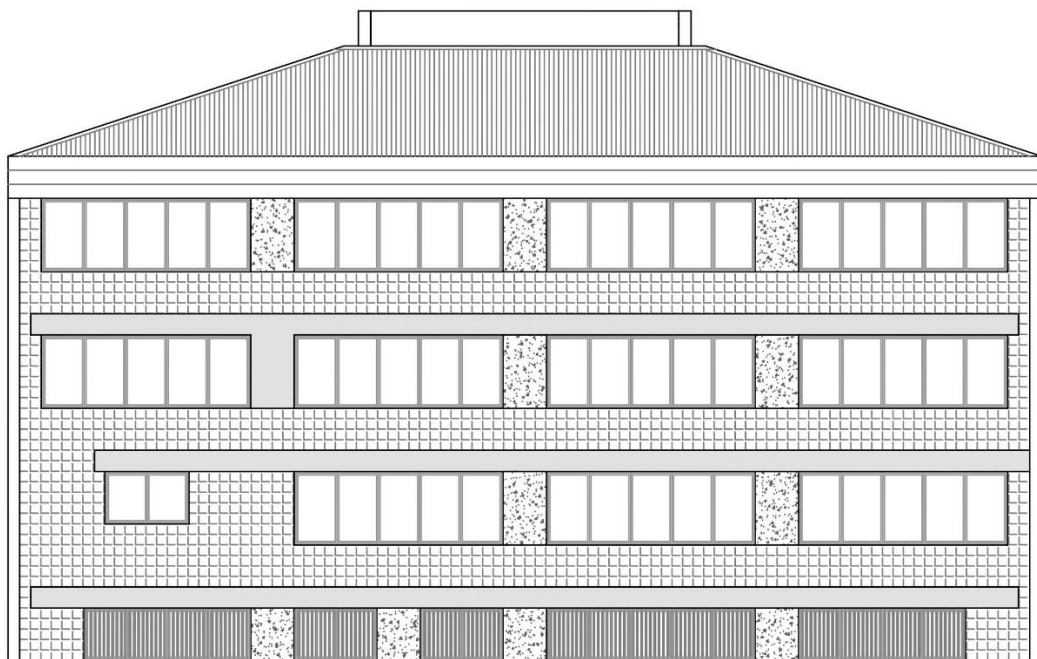


Figure 53. East façade.

An access at the south face (from ground floor) and the access at the west face (at the semi-basement level) can be seen in the prospects. There is also another entry at the north side, but it faces a little passage and brings access to the stairs, which implies that it's not a main gate.

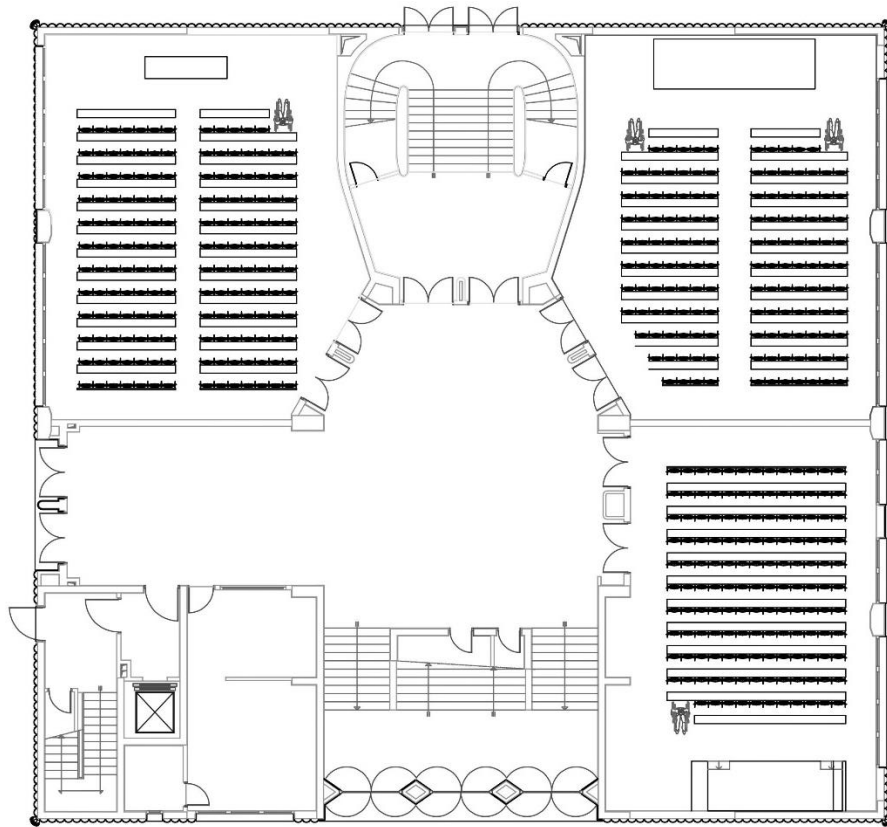


Figure 54. Semi-basement.

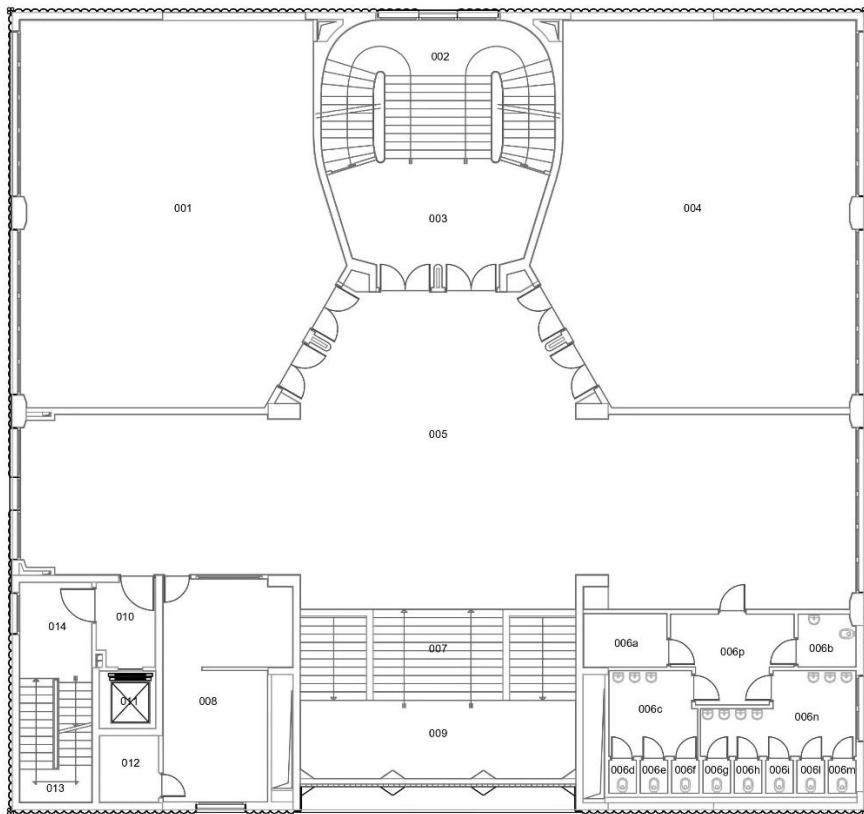


Figure 55. Ground floor.



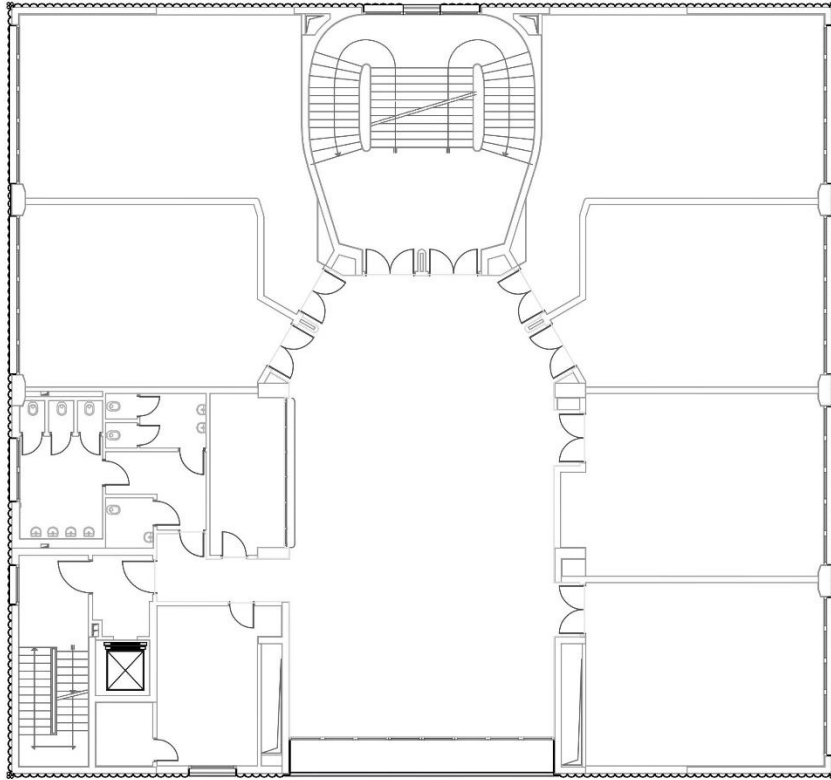


Figure 56. First floor.

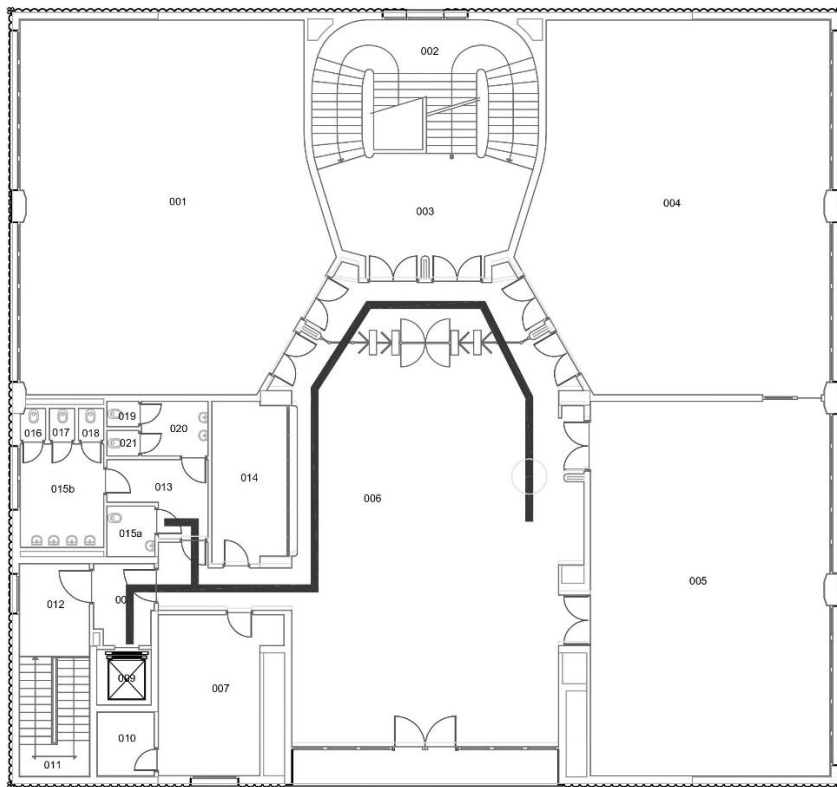


Figure 57. Second floor.

In the previous pages, there are drawings of the several building's floors. Every one of them is compounded of the following rooms:

- The **semi-basement** consists of 3 classrooms with a capacity between 140 and 150 students each one, the Erasmus Student Network headquarters and a couple of technical rooms. It has an open access from the lowered area in the west face.
- The **ground floor** comprises 2 classrooms with a capacity of 144 students each one, the bathrooms, the caretaker's cabin, and a technical room. Technically it is not a ground floor since its lower face is not at ground level, but a bit raised from it.
- The **first store** is made up of 5 classrooms with a capacity of 50 students each one, two service rooms, the bathroom, and a technical room. There is also a balcony accessible from the hall.
- The **second floor** consists of 3 classrooms with a capacity of 68 (one of them) and 134 (the other two) students, two service rooms, the bathroom, and a technical room. There is also the balcony.

Besides this, every floor has a central hall which works as a distributor (horizontal communication) for the classrooms and the other spaces. For the vertical communication systems, it has two stairs that cover all the floors: one in the centre of the north side with a central flight, a landing and two lateral flights; and one in the south-west corner, some simple stairs with two straight flights. There is also an elevator, and other stairs in the south face that connect the basement with the ground floor. These stairs have an intermediate landing that works as an actual a zero level and it is leveraged for the main entry.

Below, there are some examples of internal spaces of the building. At the images, the classrooms, the public spaces and the bathrooms are displayed, and even some technical spaces placed at the top level over second floor (only accessible for maintenance purposes).



Figure 58. Semi-basement access from the indoors.



Figure 59. Ground floor hall.



Figure 60. Inside of the S.01 classroom.



Figure 61. Technical floor over the second store, with the systems.

## 5.2. Modelling process

The whole modelling process has been divided into three steps: first the building itself, after the outdoors and, finally, the integration of both.

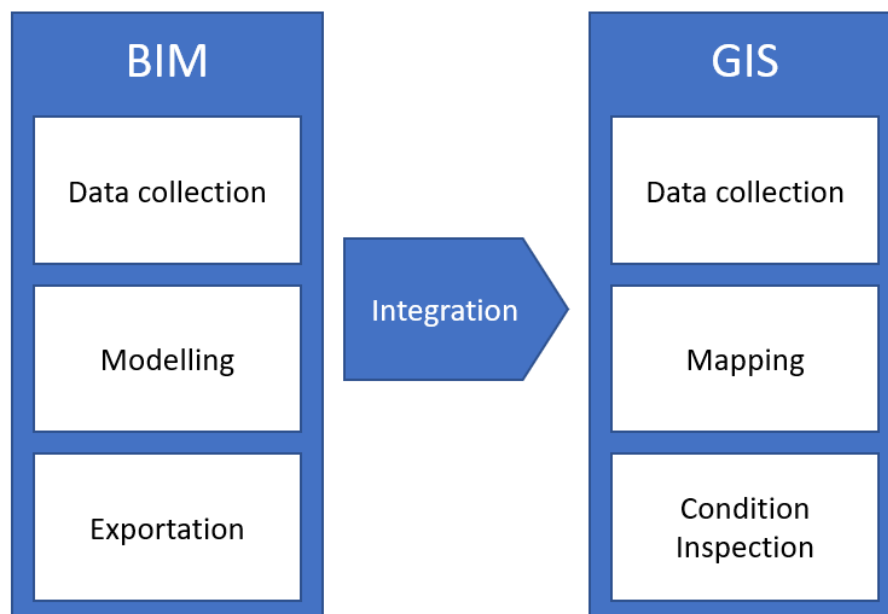


Figure 62. General schema of the process.

For this purpose, the software used has been the next one:

- Revit 2020 – for the building and the immediate surroundings.
- QGIS 3.4.13 – for the management and the integration of the GeoBIM model, as well as the introduction and visualization of the CI results.

### 5.2.1. The building (BIM)

First, the CAD drawings of the building were obtained from the building manager; as none prospects or sections were available, it was necessary to obtain the height of the different floors on-site in order to draw them. Once the building was ready to be modelled, there was still necessary to identify, measure and place all the elements pertaining the systems and furniture (like HVAC grills, radiators and lights). This information was obtained in the same visit.

With all the necessary data obtained, the modelling process started. The order was: slabs, external walls, and roof. Then, the envelope was finished and the

indoors modelling started (internal walls, stairs and ceilings). After that, the windows and doors were placed, and the building was finished. There last step was modelling the systems and the educational equipment (furniture).

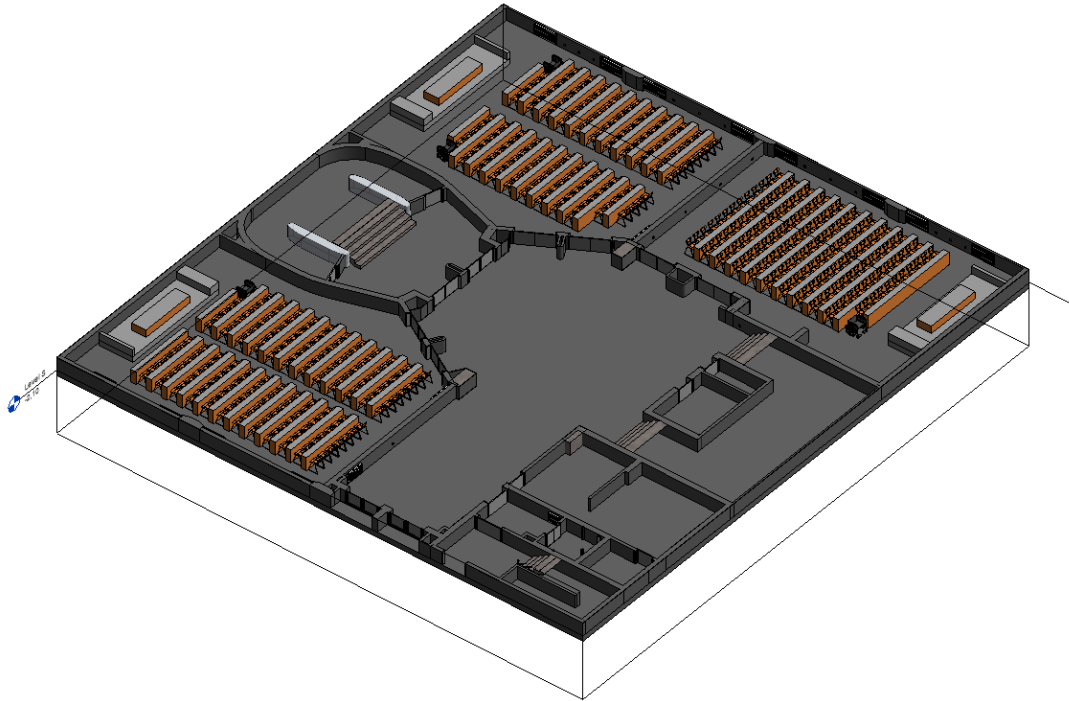


Figure 63. Semi-basement floor.

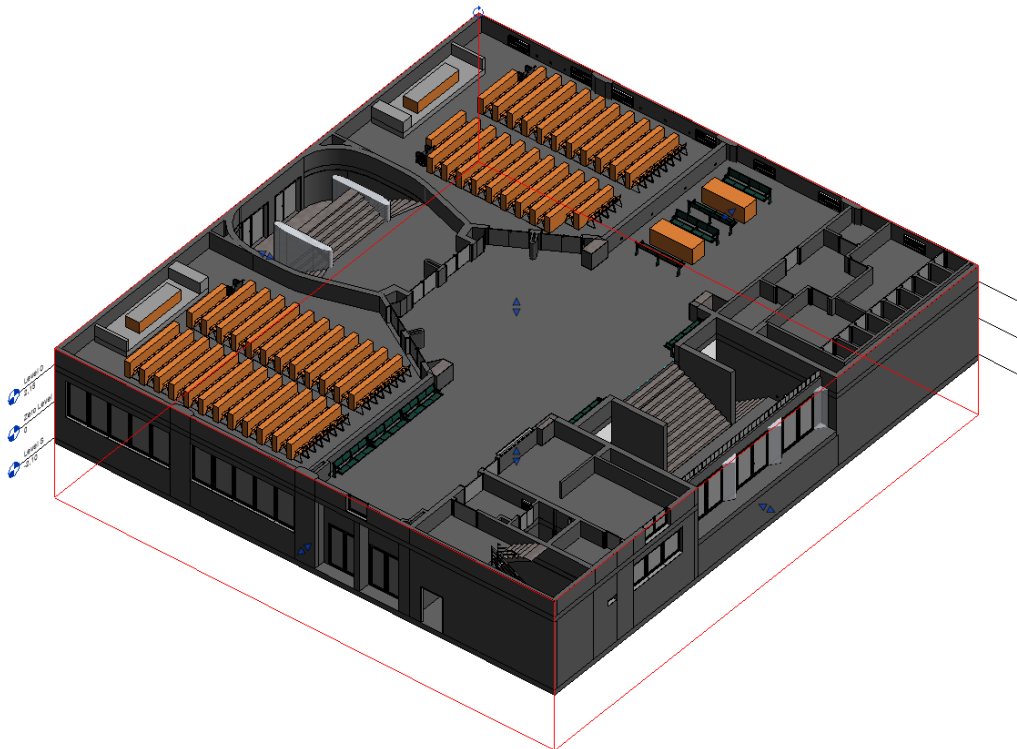


Figure 64. Ground floor.

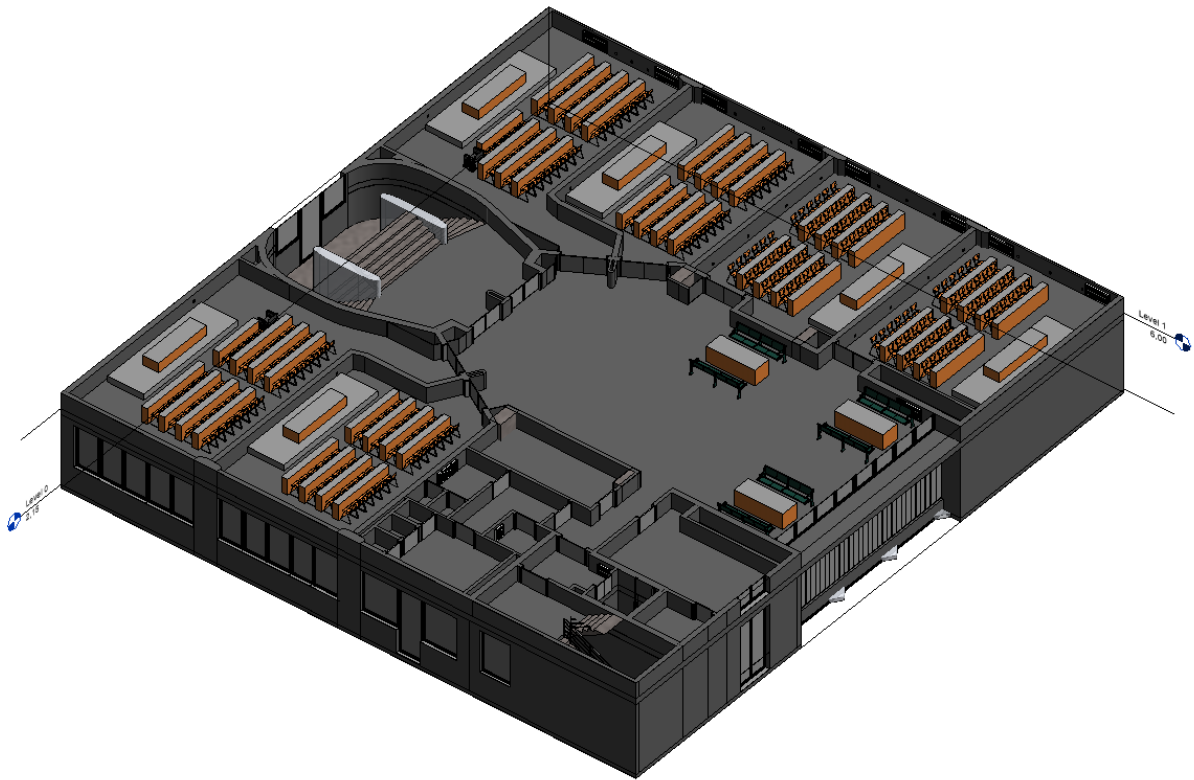


Figure 65. First floor.

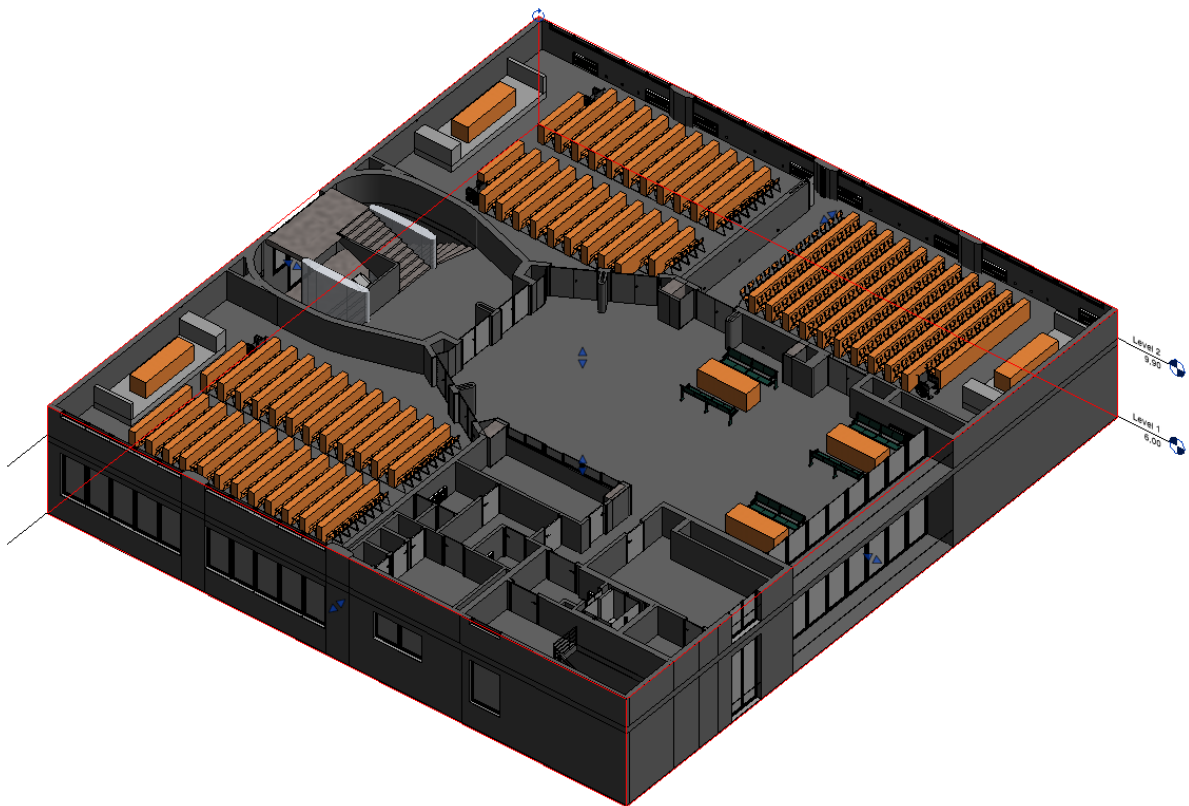


Figure 66. Second floor.

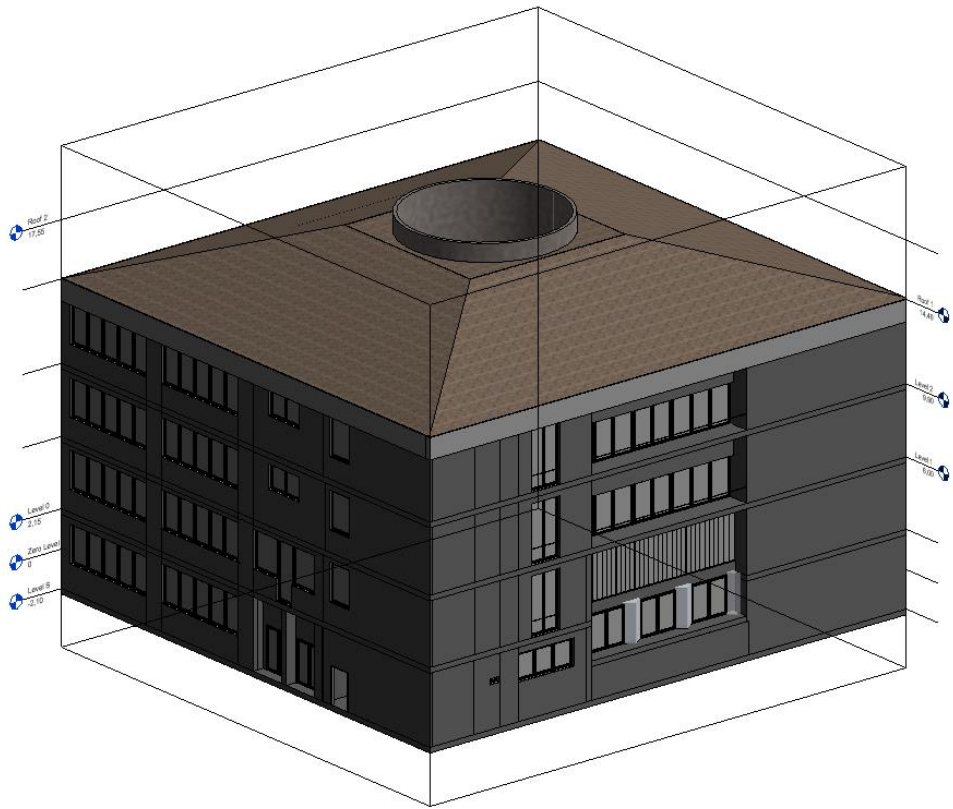


Figure 67. West and south façades.

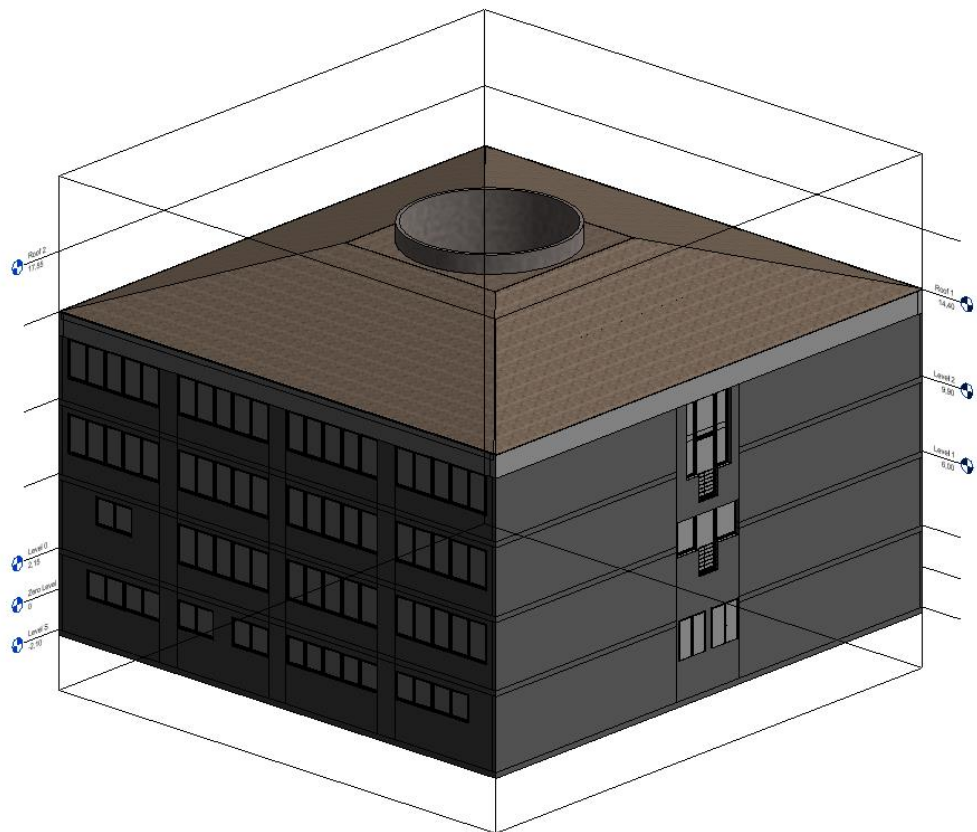


Figure 68. East and north façades.





Figure 69. Section by the south-east stairs.

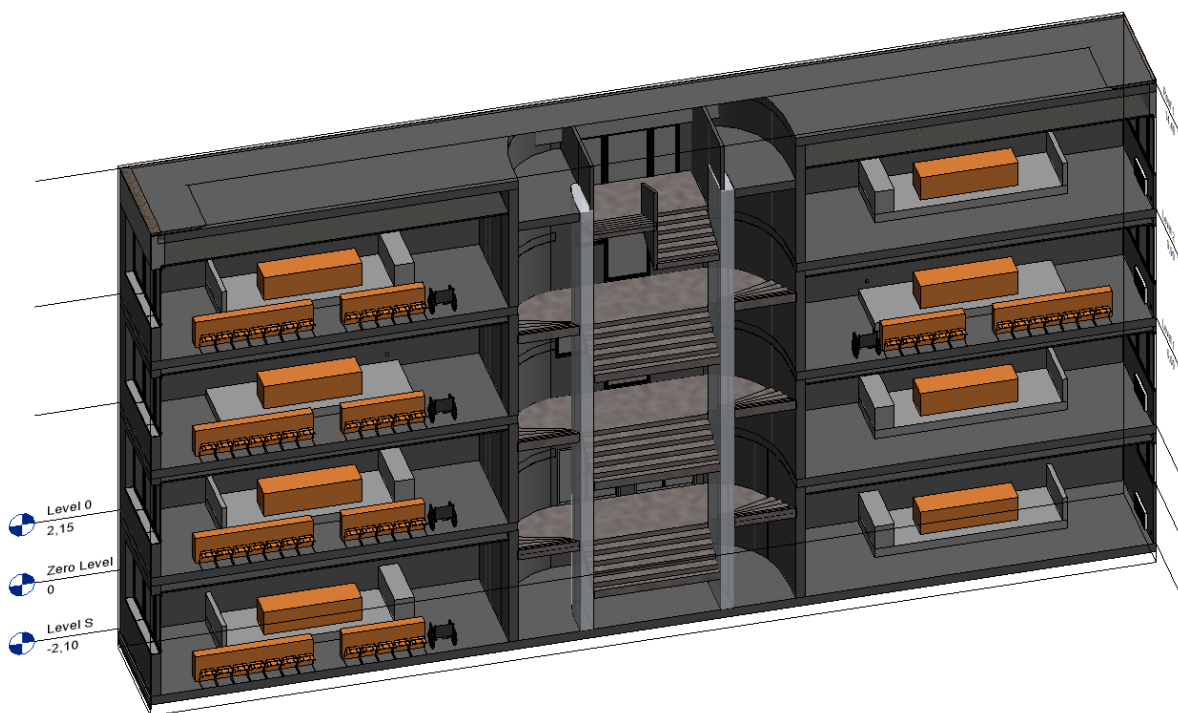


Figure 70. Section west to east, the northern stairs can be seen.

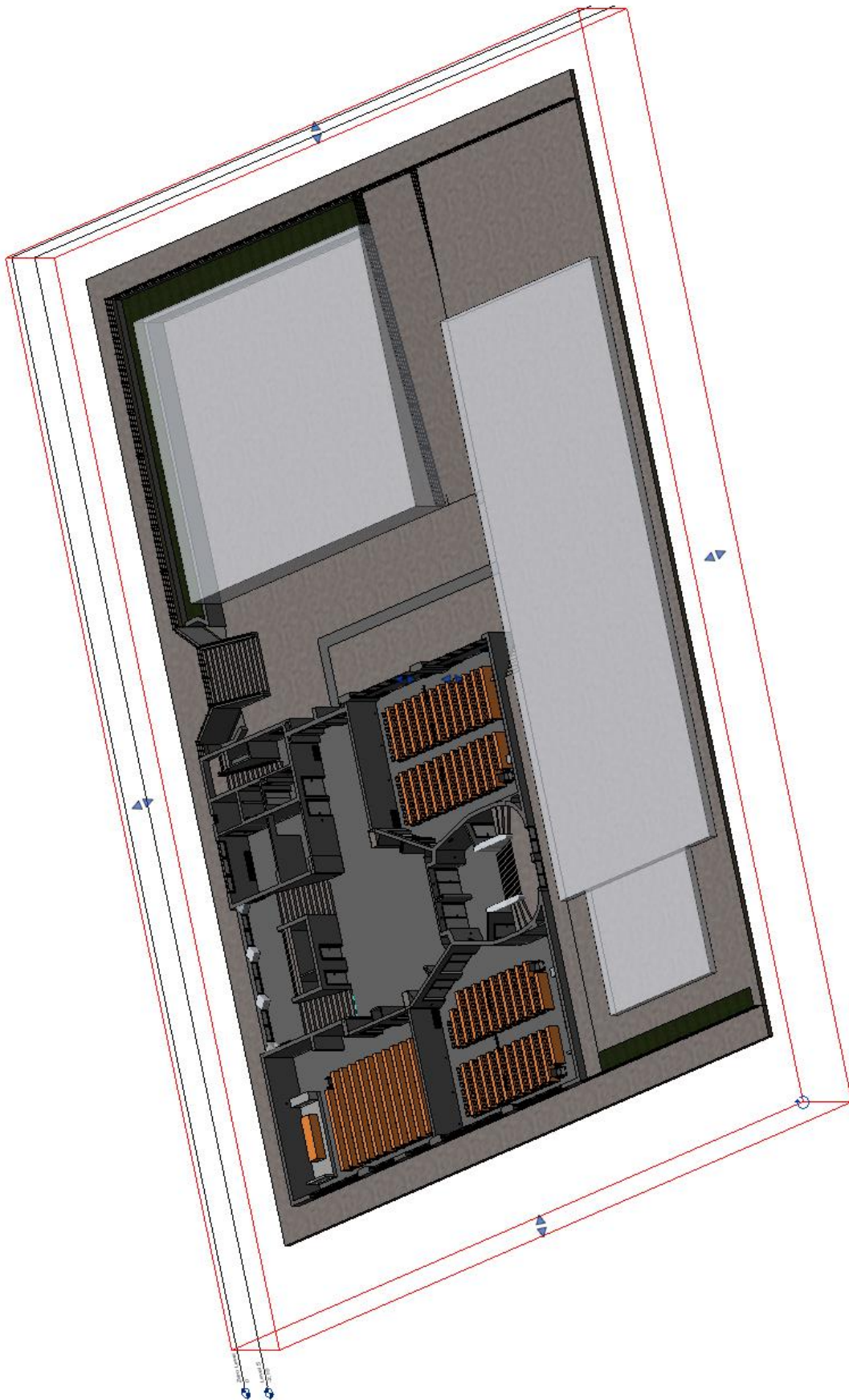


Figure 71. View of the building with its surroundings and the closest buildings.

Above, there are horizontal sections of every floor as they are once the building is finally modelled; after that, some perspectives of the façades, and vertical sections by the main stairs can be seen. It is possible to check the level of detail of the elements, both structural ones and systems/equipment.

The LOD200 implies simple geometries, but as this is expected to become developed in further stages, some elements have been modelled with a higher detail as a way to experiment. Nevertheless, they are still generic models that not necessarily are the exact representation of the real element; anyway, that would be an ultimate phase in the development of the methodology, at a further level than it is intended for the current project.

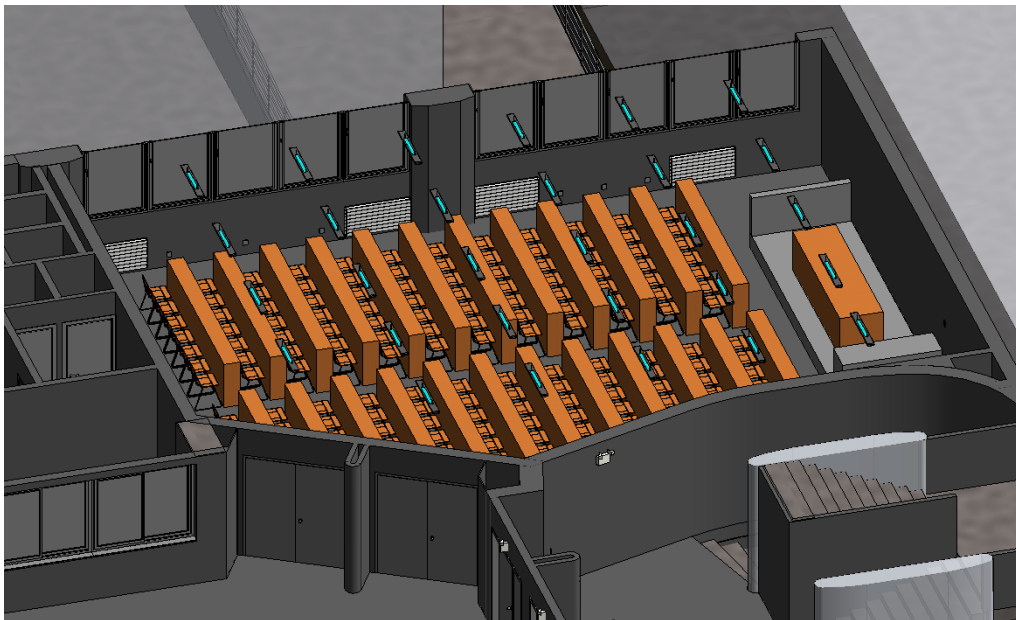


Figure 72. Examples of furniture and systems.

In Figure 72, some desks and the risen bases of the lecturer's tables are simple boxes with the dimensions and the materials of the actual elements. Instead, the chairs and the lights are approximate models.

Once the model is finished, it needs to be exported. Before doing this, there is one thing to take into consideration:

- Preparing the BIM model to be exported and integrated. This implies setting the appropriate coordinates to fit the GIS map. This is done in the

tab Manage > Project Location > Coordinates > Specify Coordinates at Point. Then, a window appears which looks like the next one:

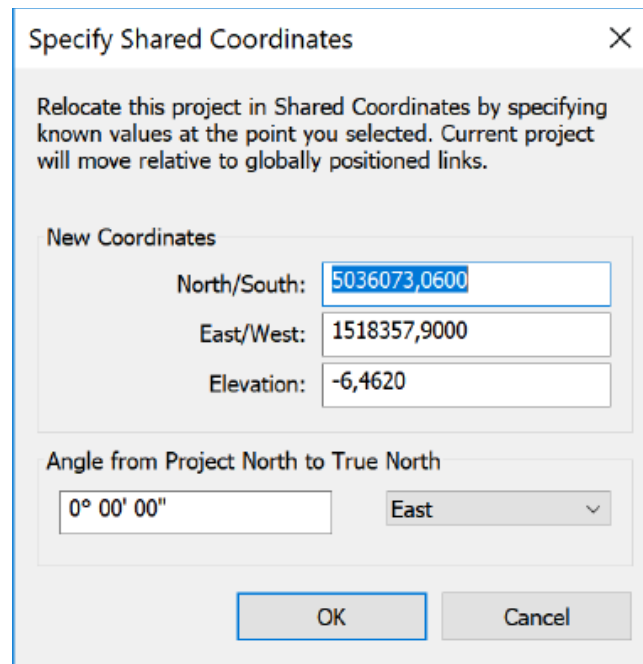


Figure 73. How coordinates are specified in Revit.

- After, the model has to be exported as an IFC file. This can be done directly in Revit, through the following path: File > Export > IFC.
- FME exporter. This is a software that allows the translation of many data types, in this case it is the IFC model to the GIS format.

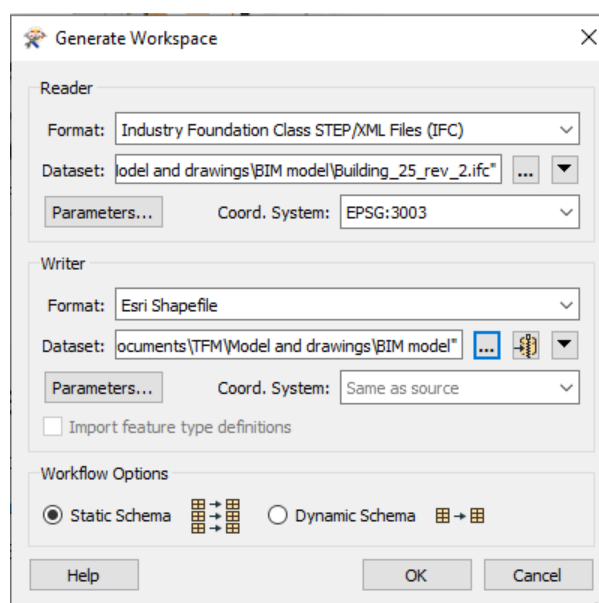


Figure 74. FME translation window.

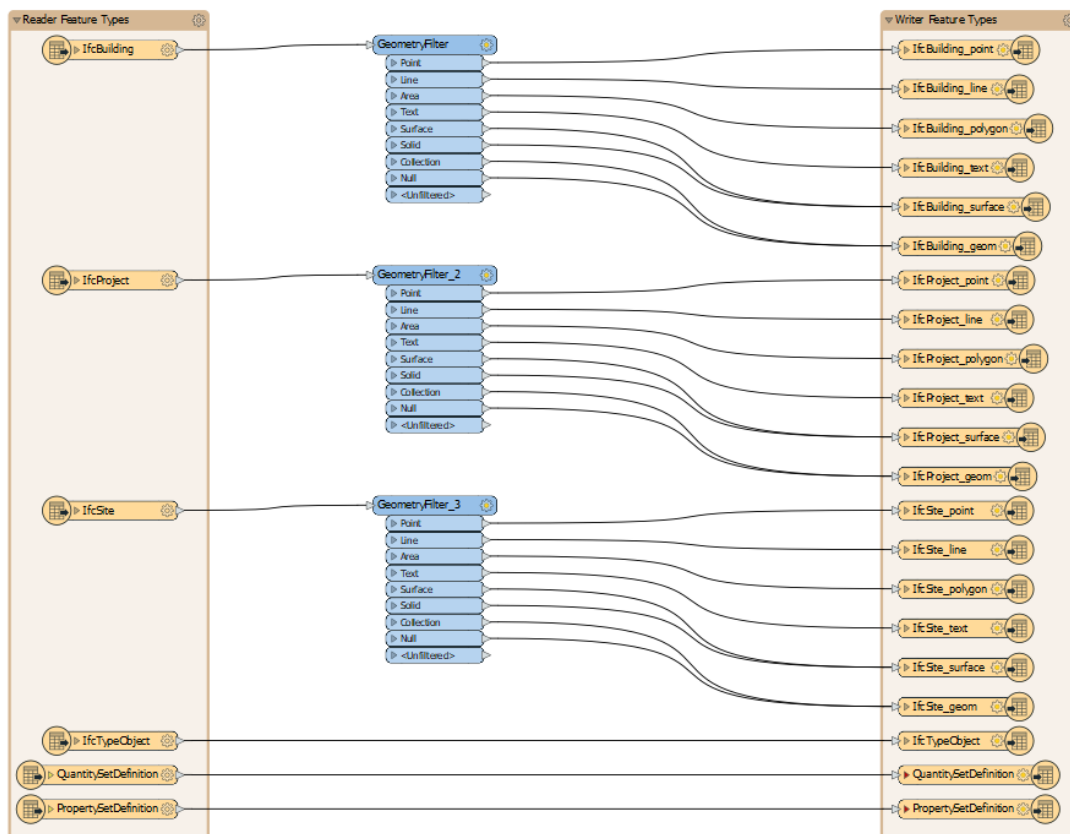


Figure 75. Structure of data once translated.

What figure 75 shows is the structure of the data once it is translated from the IFC model (reader features – left) to the CityGML file (writer features – right). The blue boxes are the transformations applied and the arrows show the actual workflow that data is following.

### 5.2.2. GIS and data integration

Regarding the GIS software, the steps to follow were:

- Downloading the database of the intended area from the official site of the 'Regione di Lombardia': <http://www.geoportale.regione.lombardia.it/>
- Integrating the IFC data (already transformed) importing it into GIS map.
- Modelling those external elements that are not present in the map.
- Eventually, when the condition inspection is done, adding the results.

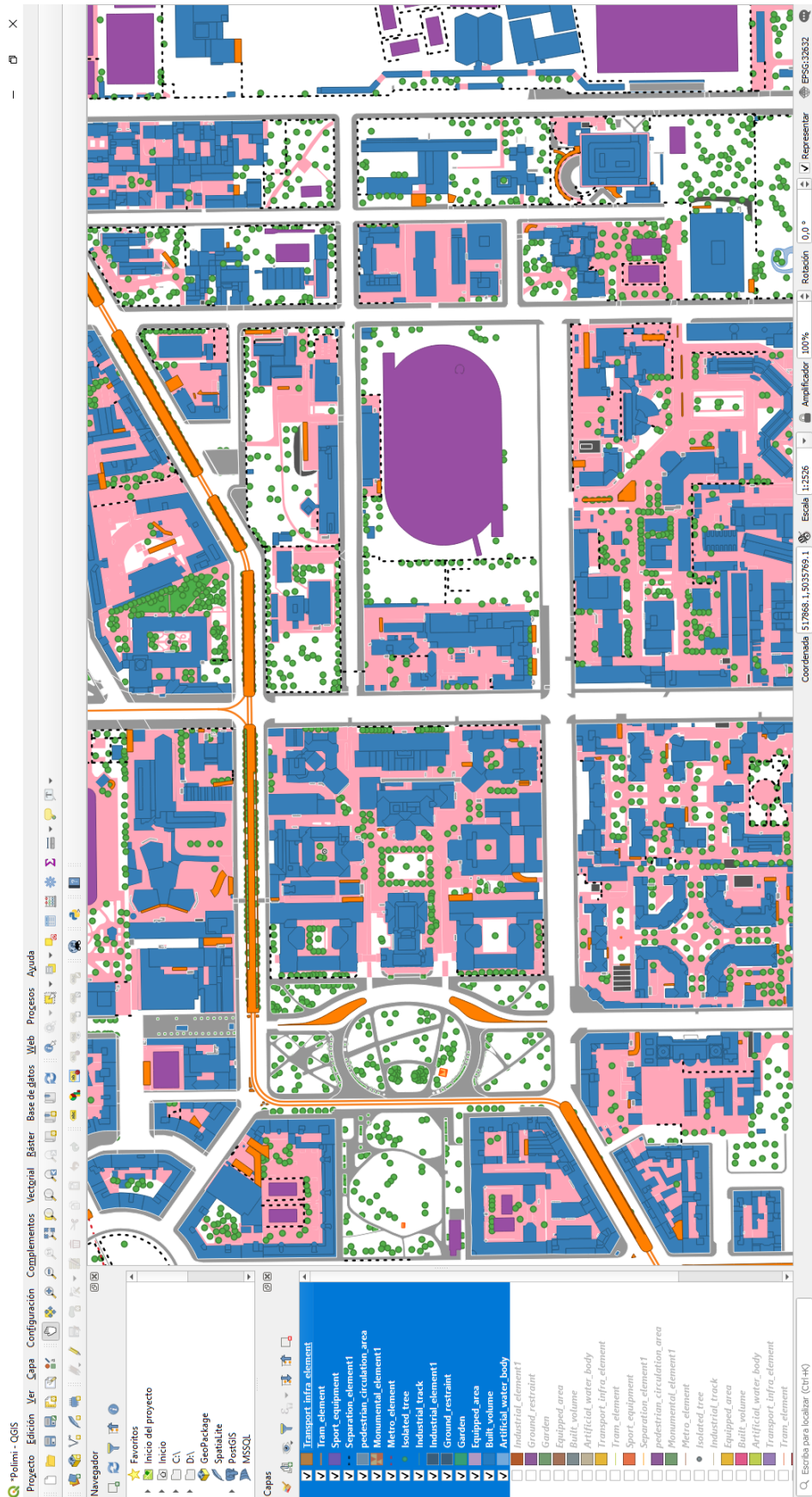


Figure 76. General interface of the GIS map of the area.

Figure 76 shows the general interface of the QGIS software. Besides the map, at left there are the tables (or layers) that correspond to the different kinds of elements present in the model (such as floors, buildings, etc.). These elements can be surfaces, lines or points (as aforementioned) but some are duplicated or even three times, and they need to be simplified. Also, it needs to be completed with several items that are not present, such as lighting, signs, etc.

Before that step, the data extracted from the IFC model was imported. This implied that the information was merged, and some new tables appeared, containing the IFC imported elements:

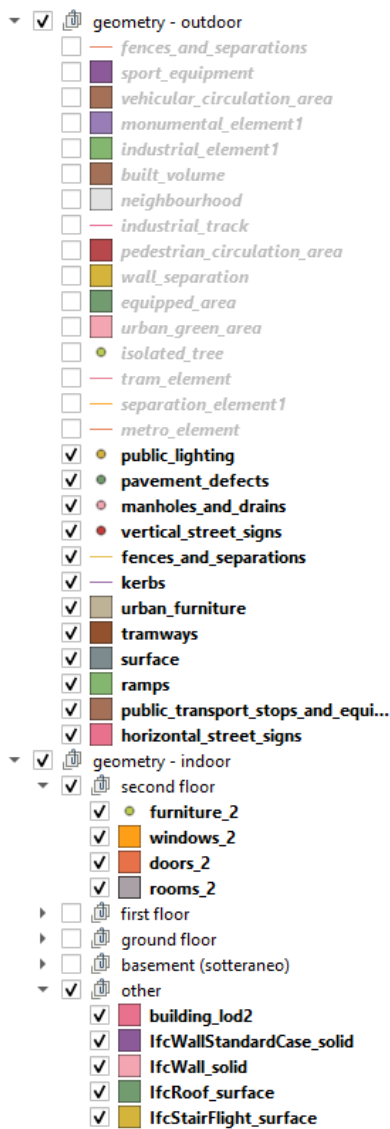


Figure 77. New tables.

## Geometry – outdoor

The first rows show the original tables contained in the map, but at this moment all of them shut down. Also, the duplicities have been fixed.

Right under that, there are the new layers/tables created to insert the new objects that will be added to the map.

## Geometry – indoor

Elements obtained from the IFC model have been grouped into the several floors, so there is a furniture, windows, doors and rooms table for each of them.

At the end, those elements that do not belong to a specific floor have been grouped as 'other' (stairs, roof, etc.).

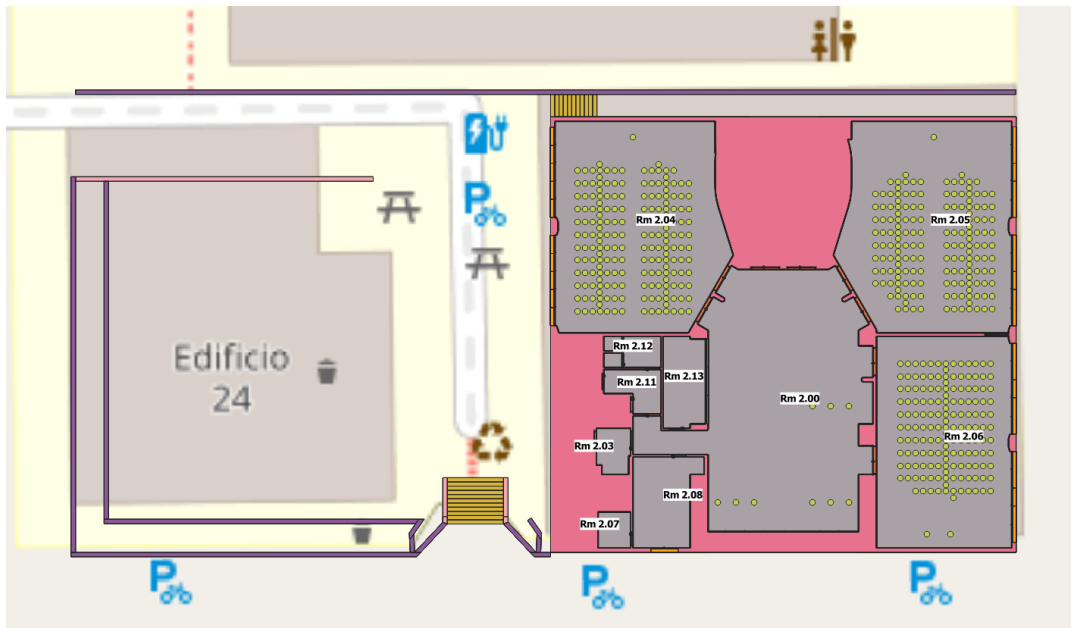


Figure 78. Map with the new imported elements.

As it can be seen at figure 78, the first general layers are not displayed, and an image placed underneath those elements is now visible. Besides that, the new imported elements are present (walls as lines, rooms as surfaces, windows as lines and furniture as points). However, since this is a 2D view of the building, layers overlap, and it can only be displayed one floor at each time.

One last step before initiating the condition assessment survey campaign is to add some layers to introduce the condition to the elements. Figure 79 shows a list of these, and Figures 80-85 display the tables themselves once opened.

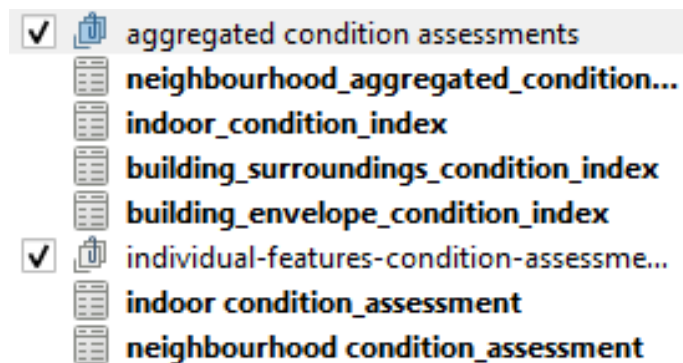


Figure 79. Index of new tables created to add the condition.



neighbourhood\_aggregated\_condition\_assessment - Atributos del objeto es...

Acciones

id	ted_condition_assessment_id_seq::regde
kerbs	
ramps	
manholes_and_drains	
urban_furniture	
lighting	
street_signs_poles	
street_signs_suspended	
tramways	
public_transport_stops_and_equipment	
pavement_condition	
road_condition	
date_time	CURRENT_TIMESTAMP

Aceptar Cancelar

Figure 80. Neighbourhood aggregated condition assessment table.

indoor\_condition\_index - Atributos del objeto espacial

Acciones

room_id	S.04
building_id	25 Emilio Massa
wall	Very good
ceiling	Very good
door	Very good
windows	Very good
furniture_equipment	Very good
heating_system	Very good
airing_system	Very good
sockets	
lighting_and_switches	Very good
date_time	NULL
group_id	Group 1
notes	NULL

Aceptar Cancelar

Figure 81. Indoor condition index table.

building\_surroundings\_condition\_index - Atributos del objeto espacial

Acciones

building_id	25 Emilio Massa
footpaths	Very good
driveways	Very good
vehicle_ramps	Very good
outdoor_lighting	Very good
green_areas	Very good
irrigation_systems	Very good
fences_and_separations	Very good
stairs	
disabled_ramps	
furniture_decoration_elements	Very good
date_time	NULL
group_id	Group 1
notes	NULL

Aceptar Cancelar

Figure 82. Surroundings condition index table.

building\_envelope\_condition\_index - Atributos del objeto espacial

Acciones

building_id	25 Emilio Massa
facade_opaque	Very good
facade_transparent	Very good
roof	Very good
doors_gates	Very good
elevators	Very good
stairs	Very good
disabled_access	Very good
date_time	NULL
group_id	Group 1
notes	NULL

Aceptar Cancelar

Figure 83. Building envelope condition index table.

indoor condition\_assessment - Atributos del objeto espacial

Acciones

condition\_id

date\_time

group\_id

asset\_details\_code

Aceptar Cancelar

Figure 84. Indoor condition assessment table.

neighbourhood condition\_assessment - Atributos del objeto espacial

Acciones

condition\_id  ✓

date\_time  ✗

group\_id  ✓

asset\_details\_code

Aceptar Cancelar

Figure 85. Neighbourhood condition assessment table.

These tables are designed to add attributes to an object, or group of objects.

- Figure 80 works as a summary for the outdoors condition assessment.
- Figures 81-83 are set to add the index to the indoors (79), the common parts & envelope (80) and the surroundings (81) of the building. Every table has the categories previously defined, with a drop-down menu which allows to set a condition (1-5) to each of them. Plus, there are three other cells to include the date of the inspection, the group number (this will be explained in the survey campaign part) and some notes. For the indoors, there is also a drop-down menu to choose the room.
- Figures 84-85 are created to add the condition of individual elements, both for the indoors and the outdoors. This is meant to mark objects that differ widely from the general condition of a room (table 82) or to spot something that needs to be highlighted in the outdoors (table 83).

Summarizing, the first four tables will be used to set a general mark on the categories described in the methodology for the indoors and outdoors, and the last two tables will be used for specific or individual conditions.

### **5.3. Condition assessment**

With the model finished and integrated, the following steps will involve the assessment itself. As aforementioned, a workshop for PhD students was organized between Politecnico di Milano and the University of London. The main topic of this workshop was GeoBIM, so the model was delivered to the students and a few ideas about BIM, GIS and Condition Assessment were discussed. The final part consisted on a practical exercise where the students had to assess the building and the built environment to later introduce this data into the CityGML file, as well as modelling all the elements that are not present.

#### **5.3.1. Survey campaign**

This workshop had place in November 2019. It lasted three days, where theoretical lessons and practical sessions were combined. Three groups were formed, and the whole process was divided as follows:

- **Common part:** all three groups assessed the envelope and common parts of the building, as well as the private surroundings (in order to have different data sources and get more reliable results).
- **Specific work:** each group had to assess a different floor (as there are four of them and just three teams, one of the groups had to perform the condition inspection for two floors).

In addition, the outdoors space was divided into three parts, and each group had to work on one of these pieces.

All three groups made a visit to the area, to perform a visual inspection and data gathering. Regarding the **condition inspection**, the information was introduced via the mobile devices into the google forms, in real time. Later, they were allowed to access the database to add them into the GIS model.

For the **elements** that were lacking and had to be modelled, the groups drew the objects on a graph paper (using a grid), so that they could easily get the coordinates of each element to transfer it to the GIS environment.

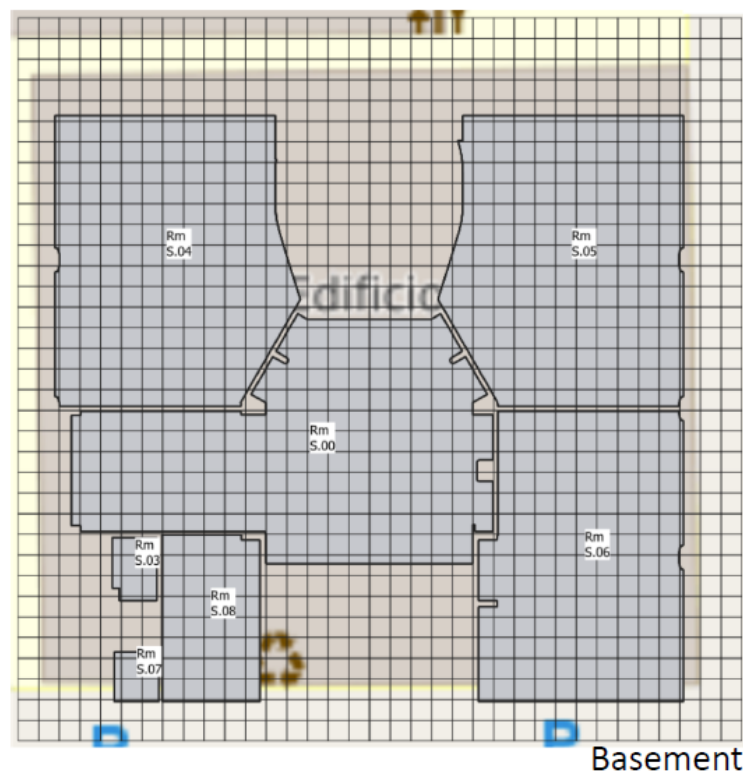


Figure 86. Grid used for taking notes and drawing elements.

### 5.3.2. GeoBIM model enrichment (database)

The data filled in the Google Forms, and the elements drew into the graph paper had to be added to the GIS database.

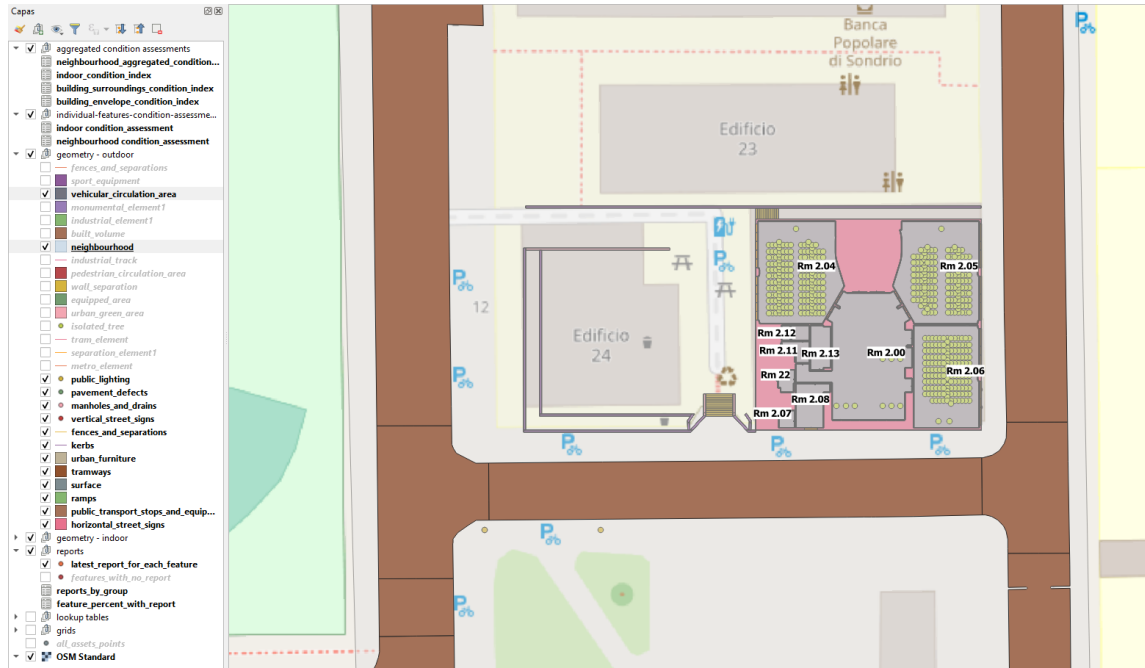


Figure 87. Map with imported features and existing layers.

To work on pavements and roads, the layers 'vehicular\_circulation\_area' and 'neighbourhood' were switched on (brown and grey). At this point, the map has all the data imported from the BIM model as well as the information already contained in the GIS workspace itself.

- public\_lighting
- pavement\_defects
- manholes\_and\_drains
- vertical\_street\_signs
- fences\_and\_separations
- kerbs
- urban\_furniture
- tramways
- surface
- ramps
- public\_transport\_stops\_and equip...
- horizontal\_street\_signs

Figure 88. New layers created in order to add the outdoors' elements.

These tables are used to create the elements (as points, lines or surfaces). Every team had to model a different area of the surroundings:

- Group 1: Via Camilo Golgi
- Group 2: Via Bernardo Ugo Secondo
- Group 3: Via Celeste Clericetti



Figure 89. The model with all the outdoors' features created.

For the assessment itself, the tables created and shown at Figures 81-83 were used to introduce the data taken from the Google Forms. The results of the Condition Inspection are shown and analysed in the next section.

#### **5.4. Results and Facility Management decision support tools**

The data outcoming from the inspection was exported as CSV files, so it could be easily visualized with a spreadsheet. These CSV files are connected to the surveys and if they are updated, it is needed to import them again. Right now, it is a semi manual process, but for the ultimate assessment methodology it is intended to replace it for a fully automatic procedure.

# Assessment outcome

Table 5. Indoor condition assessment.

Group n°	Room code	[Walls]	[Ceilings]	[Doors]	[Windows]	[Furniture/Equipment]	[Heating system]	[Air conditioning system]	[Sockets]	[Lighting and switchers]	Notes	Pictures
1	Rm0.05	2	2	1	3	3	Not present	2	2	2	Windows cannot be open manually.	https://drive.google.co
3	S.05	3	2	2	3	1	3	1	2	1	no	https://drive.google.co
2	S.05	3	2	2	1	2	4	2	1	1		https://drive.google.co
1	RM 2.04	2	1	2	1	2	2	3	2	1		
1	RM 2.05	2	1	2	2	3	2	2	2	2		
1	RM 2.00	1	3	2	2	3	3	3	2	2	Ceiling damaged, see photo	https://drive.google.co
1	RM 2.00	1	3	2	2	3	3	3	2	2	Ceiling damaged, see photo	https://drive.google.co
1	2.13, 2.08, 2.07	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Utilities rooms, locked, impossible to access.	
1	Rm22	2	2	2	Not present	Not present	Not present	Not present	Not present	2		
1	Rm2.11	2	3	2	2	4	2	2	2	2	Not visible	
3	S.00	2	2	2	Not present	Not present	2	2	2	2		
3	S.04	2	2	2	2	3	2	2	2	3		
3	S.05	3	2	2	2	3	2	2	2	2		
3	S.06	2	3	2	2	2	2	2	3	3		
3	S.08	2	2	1	2	Not present	5	2	1	2		
3	S.03	2	1	2	Not present	Not present	2	2	1	2		
3	0.00	2	3	2	2	2	3	2	2	3		
3	0.03	2	1	2	Not present	Not present	2	2	1	2		
3	0.06	2	3	1	2	Not present	2	Not present	2	2		
3	S.09	2	2	3	Not present	Not present	2	Not present	4	2		
3	S.10	2	3	1	Not present	Not present	2	Not present	4	2		
3	S.12	2	2	2	2	Not present	3	Not present	3	4		
1	Rm2.06	3	2	2	2	2	2	2	2	2		
2	1.02	5	3	4	5	4	5	5	5	5	good conditions, except to two quadrats ceiling	https://drive.google.co
2	1.01	1	3	2	1	2	1	1	1	1	good conditions, except to two quadrats ceiling	https://drive.google.co
2	1.02	1	3	2	1	2	1	1	1	1	good conditions, except to two quadrats ceiling	https://drive.google.co
2	1.00	1	4	2	1	1	1	1	1	1	good conditions, except to two quadrats ceiling	https://drive.google.co
2	1.03	1	1	1	1	2	5	Not present	Not present	Not visible		https://drive.google.co
2	1.05-08	3	1	1	Not present	3	Not present	Not present	Not present	Not present		https://drive.google.co

Table 6. Outdoor condition assessment - Building.

Group number	Facade (opaque)	Facade (transparent)	Roof	Doors/gate	Elevators	Stairs	Access for disabled	Notes
1	2	2	Not visible	3	2	2	3	Access for disabled only at basement floor and arriving by car (the portion of Street is damaged)
2	3	1	2	2	Not visible	Not visible	Not visible	
3	2	2	2	2	2	2	2	Facciata est 3

Table 7. Outdoor condition assessment – Surroundings.

Group number	Footpaths	Driveways	Ramps for vehicles	Outdoor lighting	Green areas	Irrigation system	Fences and separations	Stairs	Ramps for disabled	Furniture / decoration elements	Notes
2	1	1	1	1	2	Not present	2	2	1	1	4
1	3	4	1	Not present	1	Not present	2	2	3	4	2 Ramps are on a damaged street
3	2	Not present	2	2	3	Not present	3	3	3	Not present	2



Table 8. Outdoor condition assessment – Neighbourhood.

Group n°	OBS code	Detection Code	Entities	Type of surface	Condition	Degradation
2	1	3	1. Defects of the pavement	Waterproof		3
2	2	1	4. Manholes and drains	Waterproof	1	
2	3	1	4. Manholes and drains	Waterproof	1	
2	4	3	1. Defects of the pavement	Waterproof		3
2	1	1	4. Manholes and drains	Waterproof	1	
2	5	1	4. Manholes and drains	Waterproof	3	
1	1	1	7. Vertical street signs	Permeable	2	
1	1	2	4. Manholes and drains	Waterproof	2	
1	1	4	4. Manholes and drains	Waterproof	2	
1	1	5	4. Manholes and drains	Waterproof	1	
1	1	6	4. Manholes and drains	Waterproof	2	
1	1	7	7. Vertical street signs	Waterproof	4	
1	2	8	6. Public lighting (poles and lamps)	Waterproof	3	
1	2	9	6. Public lighting (poles and lamps)	Waterproof	3	
1	2	10	6. Public lighting (poles and lamps)	Waterproof	3	
1	2	11	3. Ramps	Waterproof	3	
1	2	12	7. Vertical street signs	Waterproof	5	
3	1	0	1. Defects of the pavement	Permeable		4
3	2	0	1. Defects of the pavement	Permeable		3
3	3	0	1. Defects of the pavement	Permeable		4
3	4	0	1. Defects of the pavement	Permeable		2
3	5	0	1. Defects of the pavement	Permeable		3
3	3	1	6. Public lighting (poles and lamps)	Permeable	2	
3	3	2	6. Public lighting (poles and lamps)	Permeable	2	
3	3	3	6. Public lighting (poles and lamps)	Permeable	2	
3	5	4	4. Manholes and drains	Permeable	1	
3	3	5	4. Manholes and drains	Permeable	1	
3	3	6	4. Manholes and drains	Permeable	2	
3	3	7	4. Manholes and drains	Permeable	1	
3	3	8	4. Manholes and drains	Permeable	3	
3	3	9	4. Manholes and drains	Permeable	2	
3	3	10	4. Manholes and drains	Permeable	2	
3	3	11	4. Manholes and drains	Permeable	3	
3	2	12	4. Manholes and drains	Permeable	1	
3	2	13	4. Manholes and drains	Permeable	1	
3	1	14	4. Manholes and drains	Permeable	3	
3	1	15	4. Manholes and drains	Permeable	2	
3	1	16	4. Manholes and drains	Permeable	3	
2	6	2	4. Manholes and drains	Waterproof	2	
3	1	17	4. Manholes and drains	Permeable	2	
3	1	17	4. Manholes and drains	Permeable	2	
3	1	17	4. Manholes and drains	Permeable	2	
3	1	18	4. Manholes and drains	Permeable	2	
3	1	19	4. Manholes and drains	Permeable	2	
3	3	30	5. Urban furniture	Waterproof	2	
3	3	31	5. Urban furniture	Waterproof	3	
3	3	32	5. Urban furniture	Waterproof	2	
3	1	33	5. Urban furniture	Waterproof	2	
3	2	34	9. Horizontal street signs	Waterproof	2	
3	2	35	9. Horizontal street signs	Waterproof	3	
3	4	36	9. Horizontal street signs	Waterproof	1	
3	4	37	9. Horizontal street signs	Waterproof	2	
3	1	38	9. Horizontal street signs	Waterproof	3	
3	3	39	9. Horizontal street signs	Waterproof	3	
3	3	40	8. Fences and separations	Waterproof	3	
3	3	41	2. Kerbs	Waterproof	2	
3	1	42	2. Kerbs	Waterproof	2	
3	5	43	2. Kerbs	Waterproof	2	
3	3	44	7. Vertical street signs	Waterproof	2	
3	3	45	7. Vertical street signs	Waterproof	1	
3	3	46	7. Vertical street signs	Waterproof	2	
3	3	46	7. Vertical street signs	Waterproof	2	
3	3	49	7. Vertical street signs	Waterproof	2	

This is the harsh data, but to make it more understandable and graphical, some visualization tools have been used and are described as follows.

#### 5.4.1. Visualization tools

The decision-making tools used are intended to be exportable to another contexts. Also, it is expected to bring a geometric reliability/conversion (so it is more trustworthy) and, eventually, to enrich the model's semantic. It is helpful,

therefore, to use some tools that make easier the visualization of the different elements in the database. GIS allows to do this in many different ways.

Some of the analysis made with the inspection data are shown as follows:

The first and obvious classification that we may need to use is a map where all assets are shown as points, and also classifying them with colours based on what kind of element is being displayed. It has been shown in Figure 89.

Other interesting analysis could be creating a map where depending on how the general condition is, for instance just showing those assets with a condition equal to 'Very poor'. It can be done through the use of filters.



Figure 90. Map of all assets and just those with 'Very poor' condition after using the filter.

*Note: the colours and location of some assets could vary from earlier images of the model, due to the existence of other projects that work with the same databases and information, which implies that it is in constant change. Also, the name of the 'Poor' and 'Very poor' condition were replaced by 'Bad' and 'Very bad' respectively.*

It is also possible to create a map with a different colour based on the number of defects contained in each one. For instance, in Fig 91, a colour scheme (RAG report) has been established so it can be easily and quickly seen how much defects there are on each surface. Additionally, it is possible to divide the number of defects by the area to get a significant value.



Figure 91. Different surfaces coloured depending on how many defects there are.

Further analysis are, for instance, colouring rooms by the number of furniture elements using the 'count points in polygon' feature, or calculating the average rating for the rooms (with a virtual field) and joining this information with the geometry, creating a table with the average ratings.



Figure 92. Rooms categorization based on how many furniture elements there are.

On its behalf, BIM also allows some analysis of this data. It is needed to say that, in order to do this, the condition of the elements should be also introduced

into the BIM model. Nevertheless, as it is a resource that can be useful for the topics here explained, next there are examples of how **colour schemes** (again RAG report) could be used in Revit to filter rooms based on its condition.

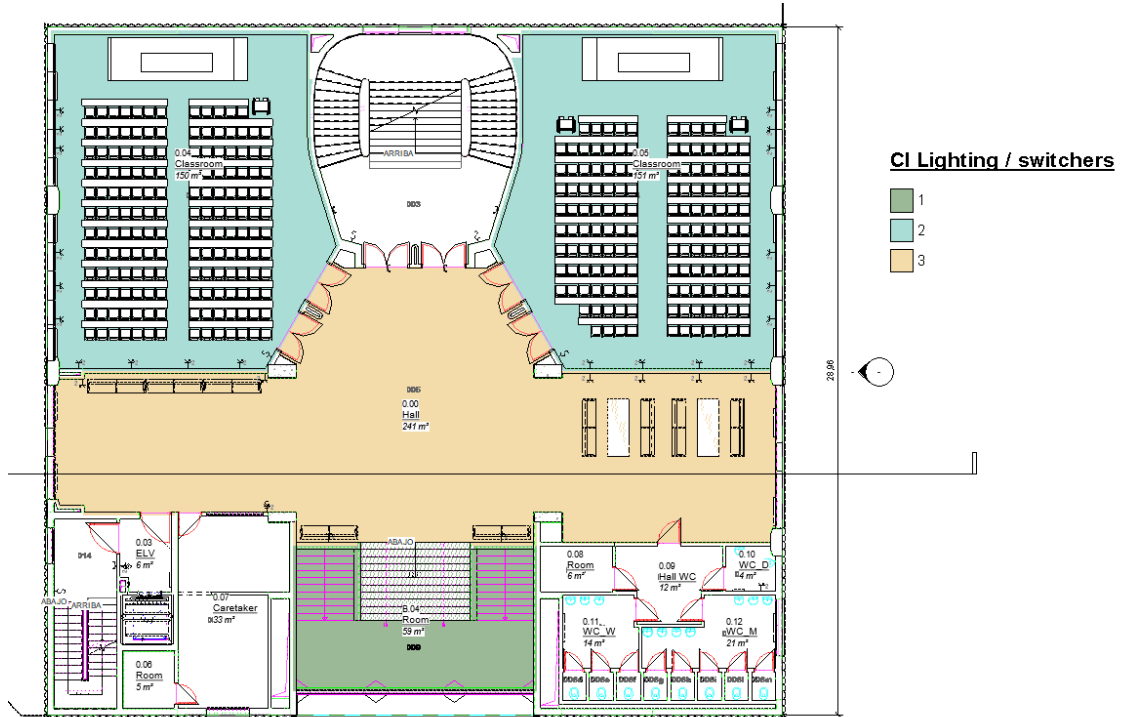


Figure 93. Colour scheme according to lighting / switchers CI.

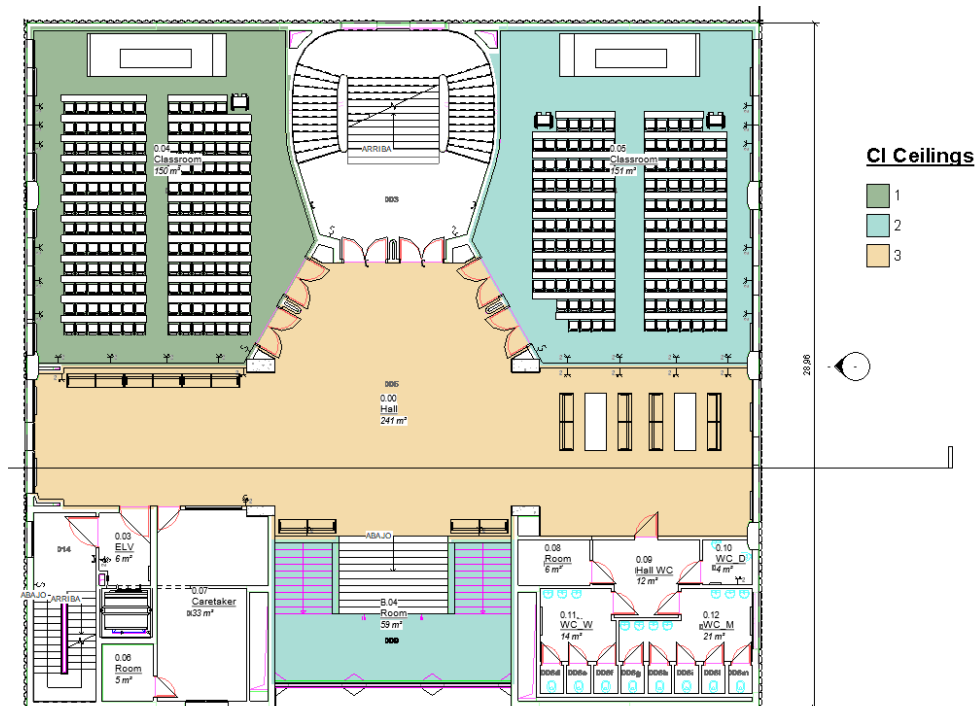


Figure 94. Colour scheme according to ceilings CI.

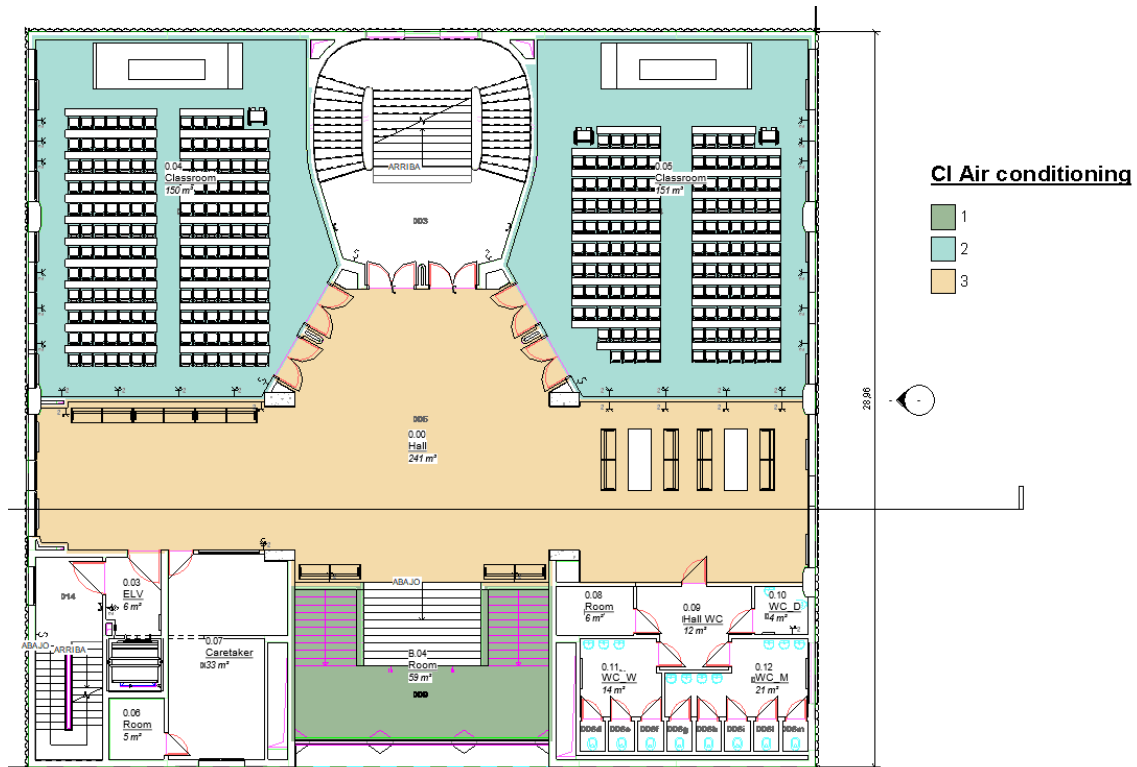


Figure 95. Colour scheme according to air conditioning CI.

All these tools allow us to have a better understanding of the data, through a visual interpretation rather than the bare database.

#### 5.4.2. Quantitative analysis

With all the information introduced in the model, many analyses can be made to understand the data and to improve decision making. It can be visualized in a more graphical way to better understand the outcome.

Some of this information can help focus on which parts require a deeper maintenance, or which is the part in the worst condition.

The analysis is structured like this:

- Indoor Condition Inspection Data Analysis
- Outdoor Condition Assessment Data Analysis – Envelope & Common parts
- Outdoor Condition Assessment Data Analysis – Surroundings
- Outdoor Condition Assessment Data Analysis – Neighbourhood

### 5.4.2.1. Indoor Condition Assessment Data Analysis

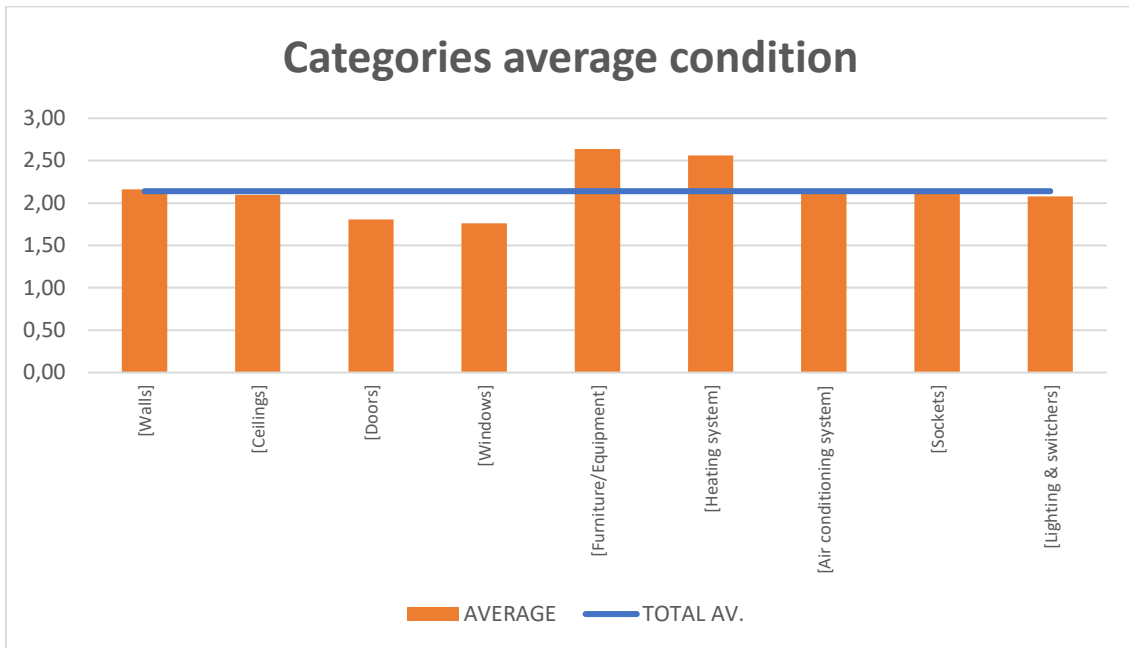


Figure 96. Average condition of each category for Indoor CI.

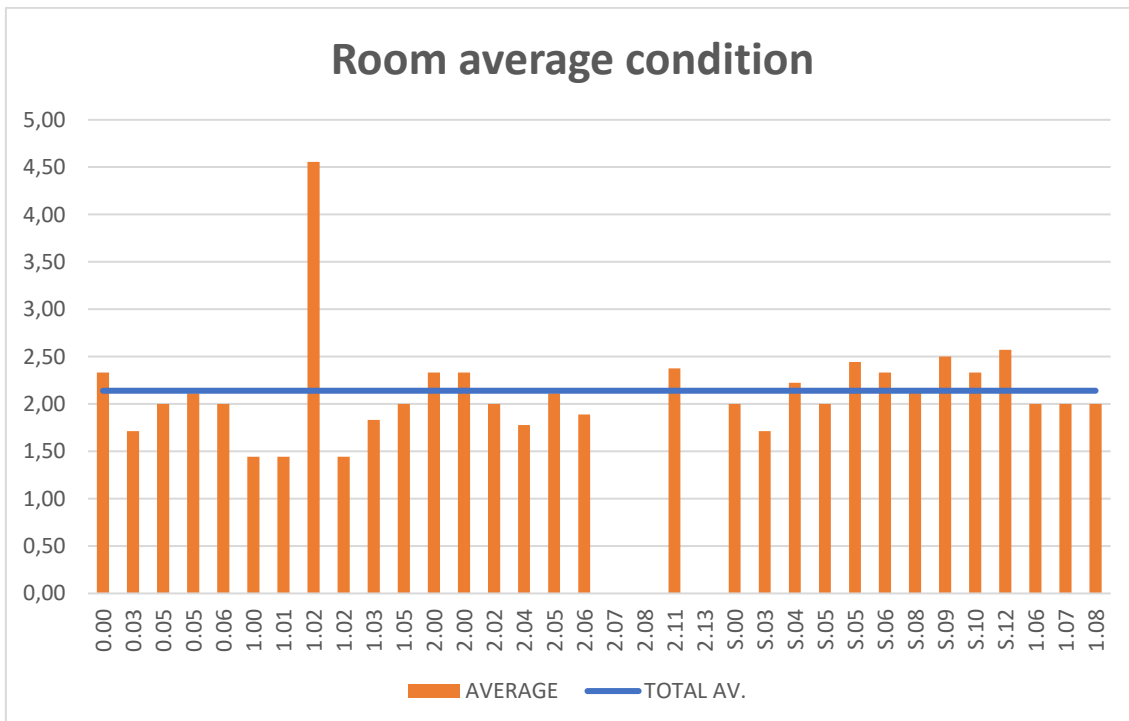


Figure 97. Average condition of each room for Indoor CI.

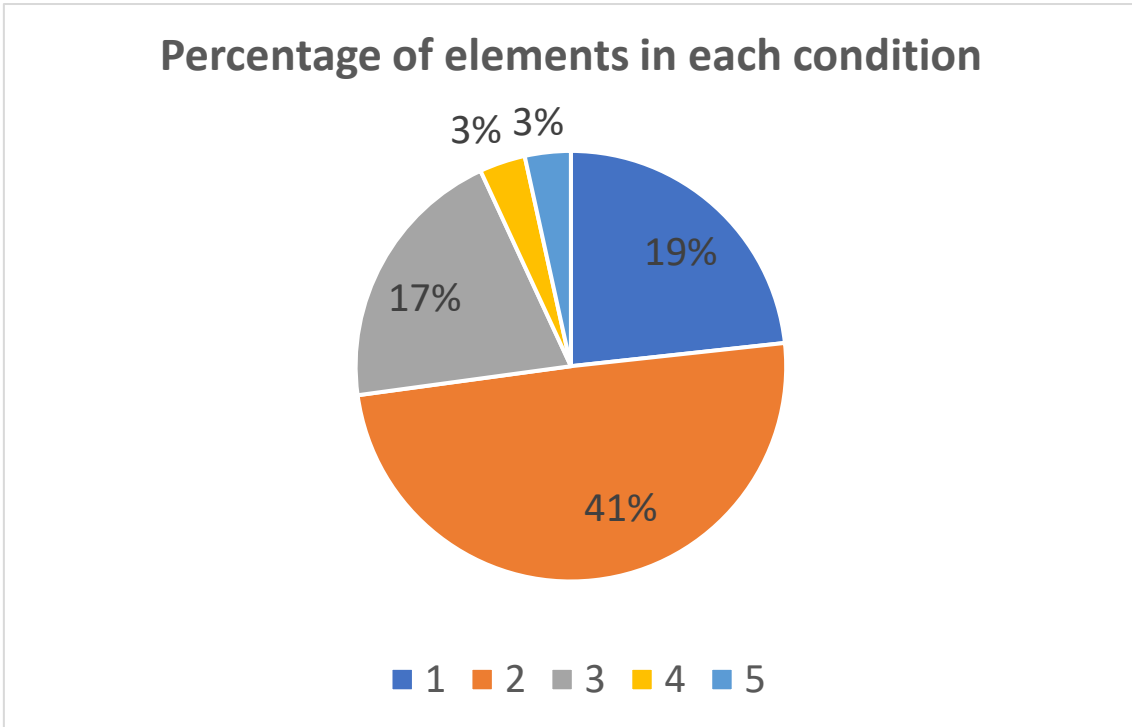


Figure 98. Percentage of elements in each condition (1-5) for Indoor CI.

#### 5.4.2.2. Outdoor C.A. Data Analysis – Envelope & Common parts

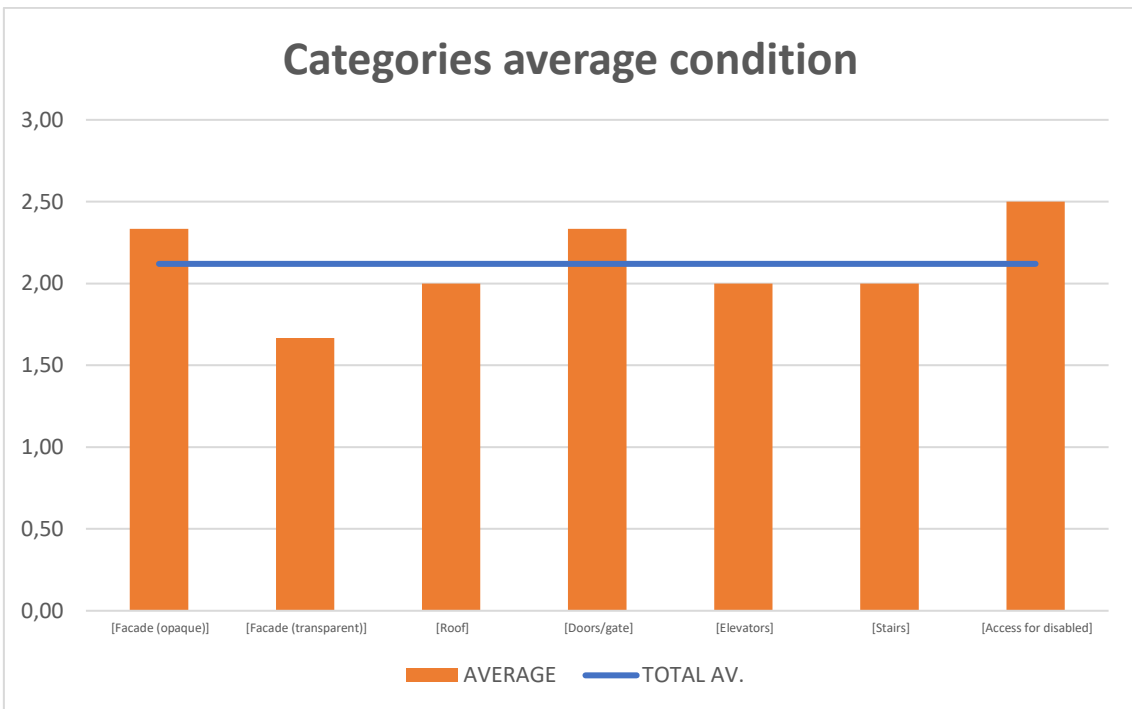


Figure 99. Average condition of each category for Outdoor – Envelope & Common parts CI.

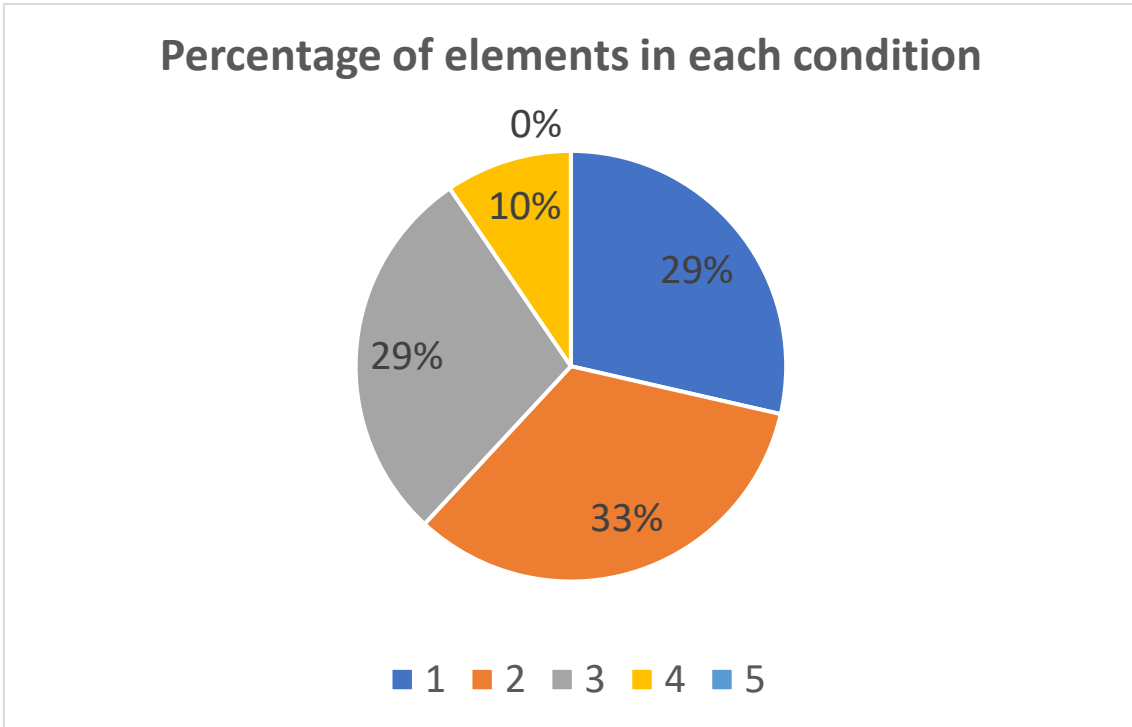


Figure 100. Percentage of elements in each condition (1-5) for Outdoor - Envelope CI.

#### 5.4.2.3. Outdoor C.A. Data Analysis – Surroundings

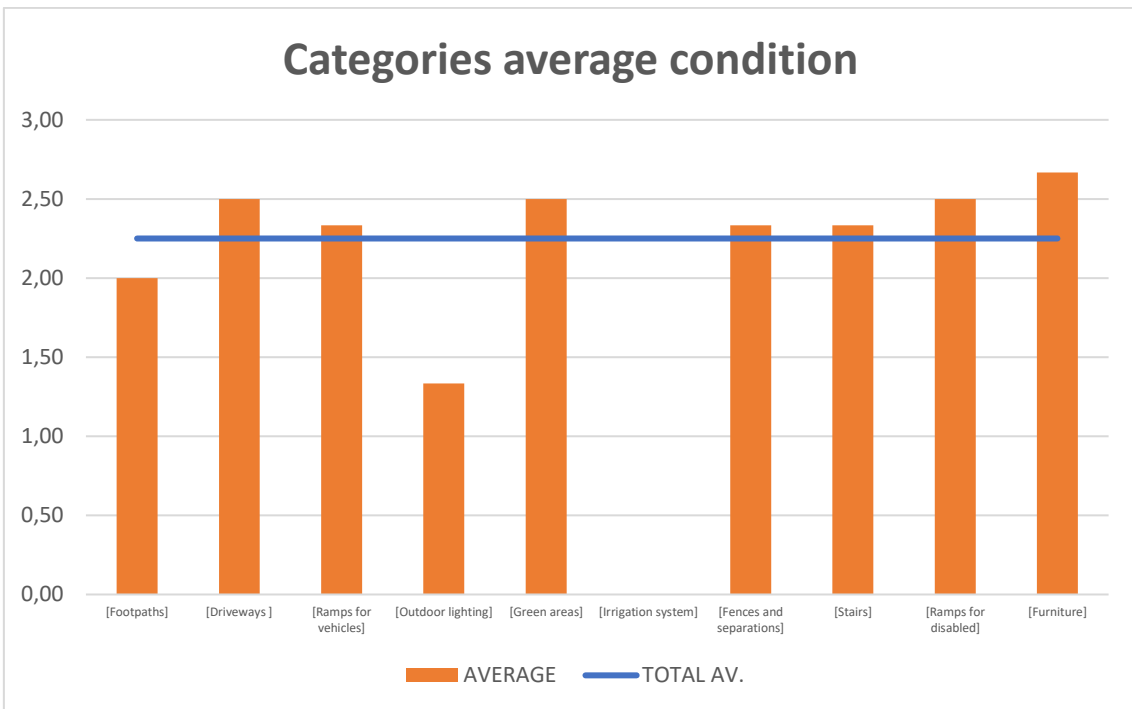


Figure 101. Average condition of each category for Outdoor – Surroundings CI.



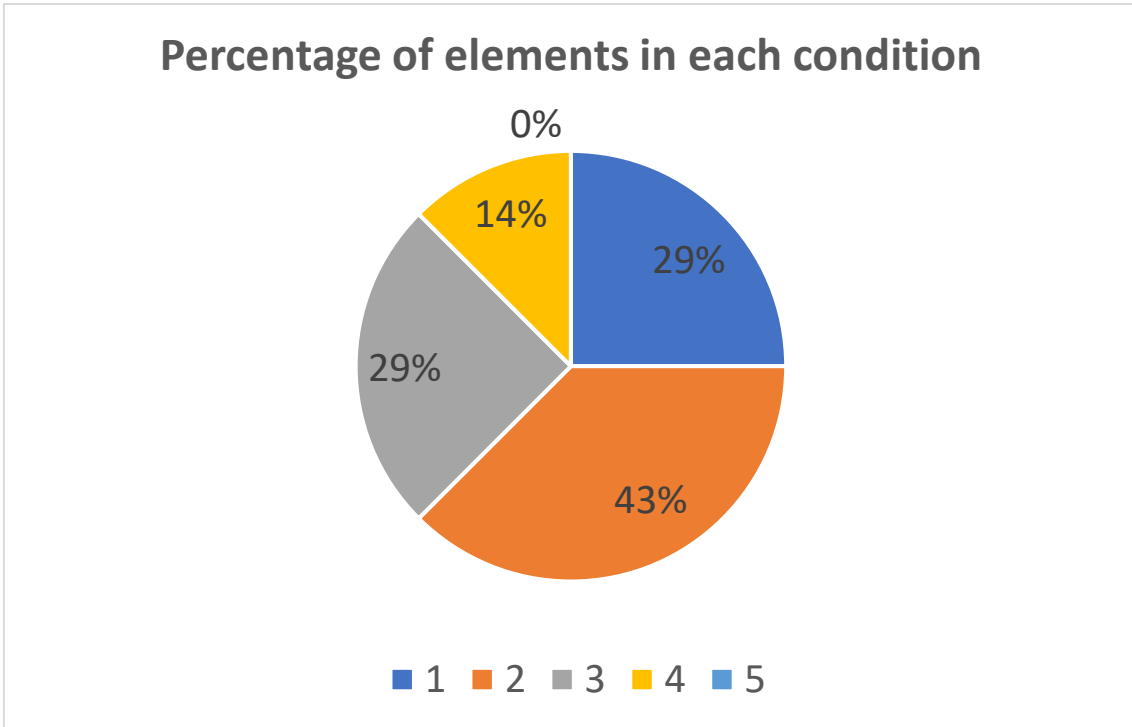


Figure 102. Percentage of elements in each condition (1-5) for Outdoor - Surroundings CI.

#### 5.4.2.4. Outdoor C.A. Data Analysis – Surroundings

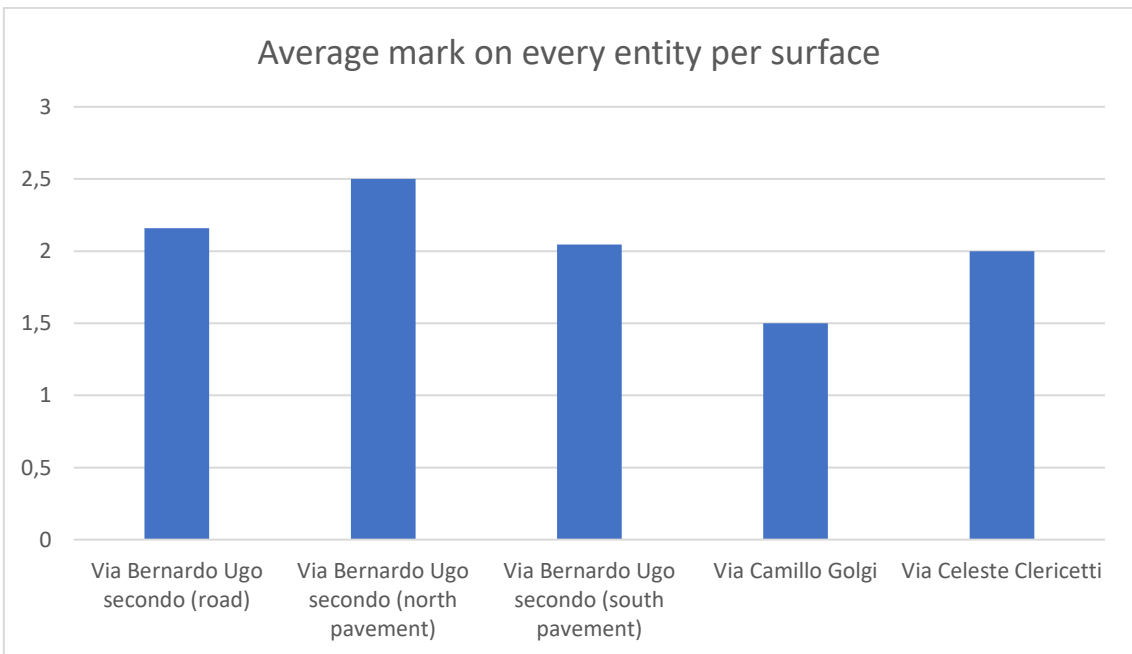


Figure 103. Average mark on every entity per surface for Outdoor – Neighborhood CI.

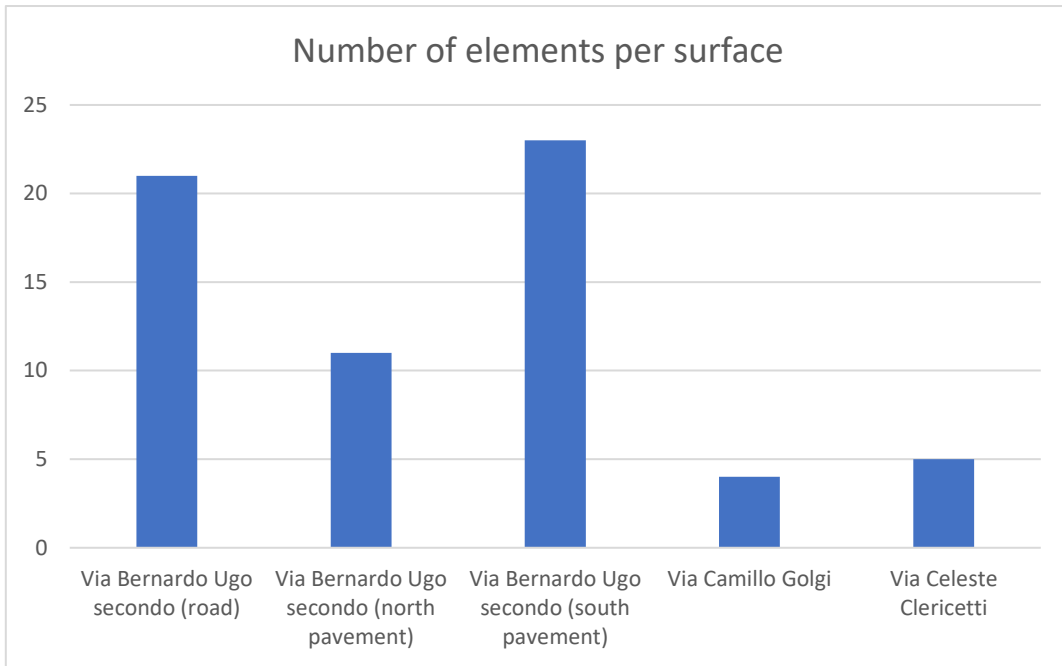


Figure 104. Total number of elements per surface – Neighborhood CI.

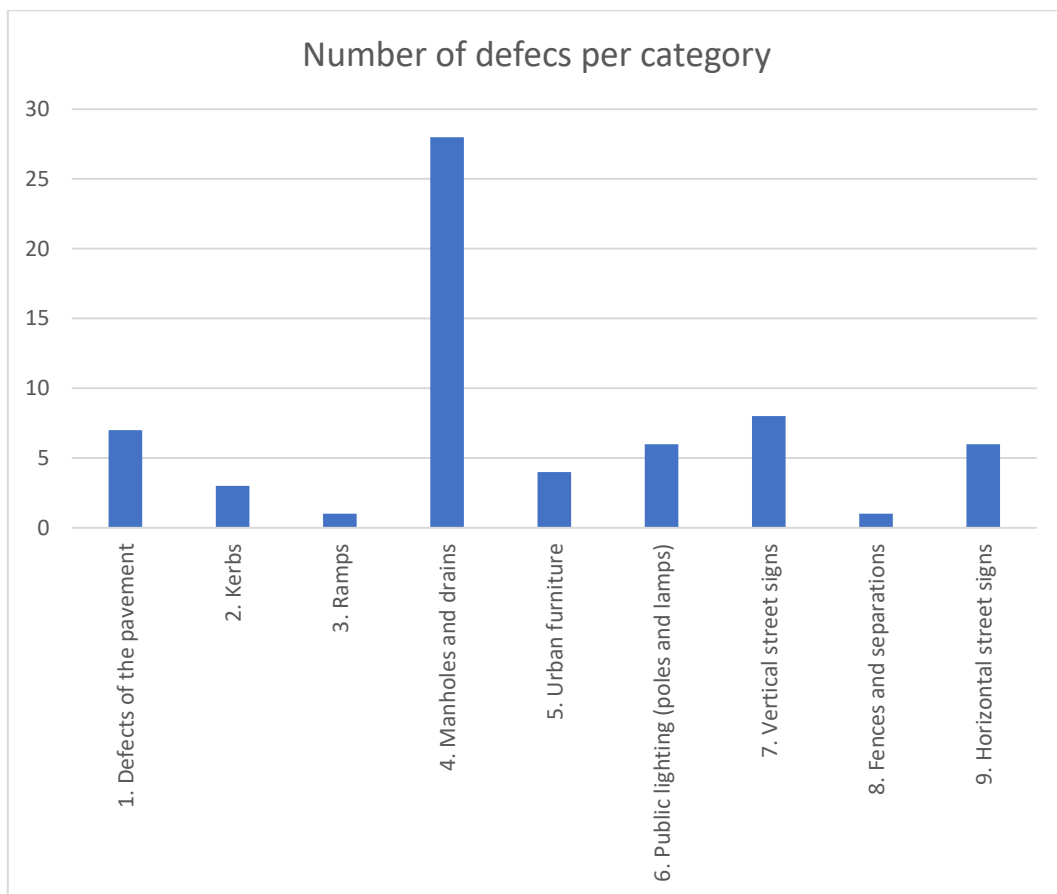


Figure 105. Total number of defects per category – Neighborhood CI.

## 6. Conclusions

In the course of this project, we have analysed the need of an efficient system for asset and facility management. This question has been addressed considering the subsequent factors:

- We have developed a methodology that allows us to do a proper Condition Inspection of the built environment.
- Also, we did it making the best of the Information and Communication Technologies, thus, using BIM for modelling the internal parts of the buildings and GIS for the external areas.
- After that, we integrated both models into a common environment, using international exchange formats.
- The assessment itself was done through the use of surveys that could be filled directly from a device such a smartphone or a tablet.
- Once the data was collected, some tactical parameters were set both for the BIM and the GIS model and the Asset & Facility Management data was integrated as well in the same environment.
- Out from this information, some visualization tools, data management resources and decision-making instruments were used to properly analyse the outcome and support the management team.
- All of this was tested on a case study.

What has been found is that this methodology increases efficiency of the whole process by providing a higher control of the information. Better tools make more precise diagnosis of both potential and current problems that a building or group of buildings could undergo.

However, some limitations have been identified during the process as opportunities for implementations and improvements to be considered for further developments. They are:

- For the BIM part, elements were modelled according to a LOD200, but as this methodology is meant to be used for general inspection and not for a more detailed one, there may be necessary a higher level of information in case of extending the procedure for more analysis.
- The use of laser scanners for the internal parts was considered, like some sort of automation, might be helpful. Some examples of this have been reviewed in the bibliography and in any case, it could be interesting to evaluate if this implementation could fasten the process.
- The integration of BIM and GIS into the GIS environment still presents a series of boundaries. A specific tool called 'Cesium' has been tested with optimal results, but it is still being developed by the University College of London. Nevertheless, it appears to be a useful tool regarding this topic.

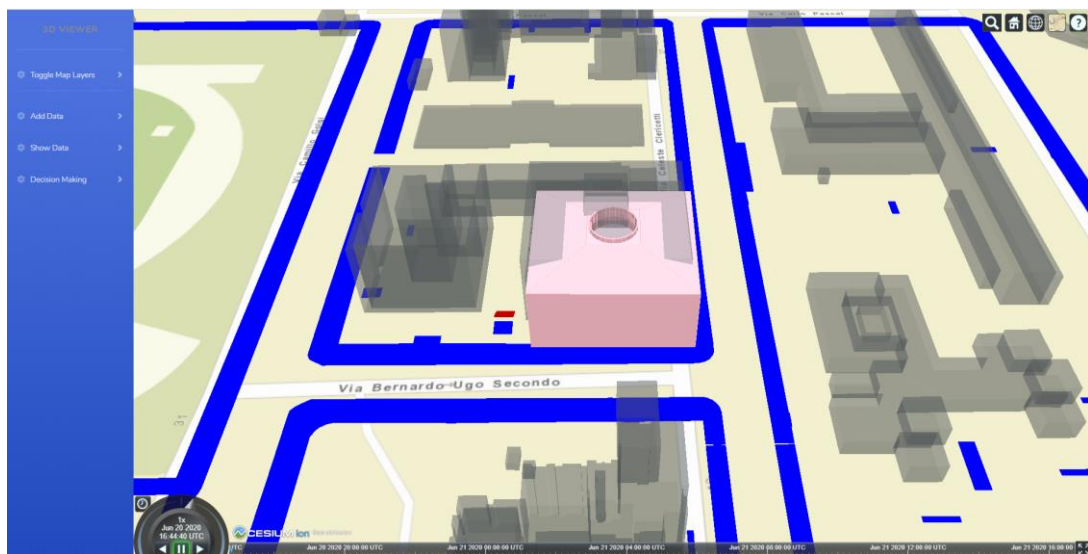


Figure 106. Cesium interface.

As final conclusion, it has been proved that the use of new technologies can be really helpful and developing strategies that allows users to take profit of their use can be critical in the next years for reaching a proper level of automation in the construction market, which will allow the professionals being more competitive and final users having a better-quality service.

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