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# Digital building management through Digital Twins and Data Science technologies

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## Preface

The research activity illustrated in this document was born by the interest of the Department of Public Works of the local administration of the Municipality of Trieste in topics regarding the management and maintenance of buildings.

This research activity is included in the protocol agreement “Trieste Città della Conoscenza”, which establishes the collaboration between the local administration of the Municipality of Trieste and the scientific institutions of Trieste. In particular, the collaboration between the local administration of the Municipality of Trieste and the University of Trieste enabled funding a Ph.D scholarship in the public contract sector.

The funding of the research path exploits the article 113 of the “Codice dei Contratti Pubblici (D.Lgs. 50/2016)”, which established a capital to be used for specific purposes. In particular, this capital can be exploited both for buying tools and technologies to support innovation projects and promoting Ph.D programmes in the public contract sector by exploiting agreements with Universities and educational Institutes.

On the whole, this research path was carried out in agreement with the two organisations in order to create and preserve a collaborative relationship which brings benefits to the two involved institutions.

# Premessa

L’attività di ricerca illustrata nel presente documento ha origine dall’interesse del Dipartimento dei Lavori Pubblici del Comune di Trieste sui temi di gestione e manutenzione di patrimoni immobiliari.

La ricerca si inserisce all’interno della convenzione Protocollo d’intesa “Trieste Città della Conoscenza”, che prevede la collaborazione tra il Comune di Trieste ed Enti scientifici del Sistema Trieste. Nello specifico, la collaborazione tra l’Università degli Studi di Trieste e il Comune di Trieste ha permesso il finanziamento da parte del Comune di Trieste di una Borsa di Dottorato di Ricerca di alta qualificazione nel settore dei contratti pubblici.

Il finanziamento del percorso di ricerca sfrutta l’innovativa disciplina del nuovo Codice dei Contratti Pubblici (D.Lgs. 50/2016), che nell’art. 113 stabilisce un apposito fondo dove destinare risorse finanziarie per particolari scopi di utilizzo. Nel particolare, il fondo può essere usato, sia per l'acquisto da parte dell'ente di beni, strumentazioni e tecnologie funzionali a progetti d'innovazione, sia per lo svolgimento di dottorati di ricerca di alta qualificazione, nel settore dei contratti pubblici, tramite apposita sottoscrizione di convenzioni con le Università e gli Istituti Scolastici Superiori.

Pertanto, il percorso di ricerca si è svolto in accordo tra i due enti al fine di creare e mantenere un rapporto costruttivo di collaborazione che porti benefici alle due realtà istituzionali coinvolte.

**Ringrazio il Comune di Trieste** finanziatore della Borsa di Dottorato, con particolare riferimento alle figure del **dott. Enrico Conte** e **l'arch. Lucia Iammarino**, e **l'Università degli studi di Trieste**, con particolare riferimento alla **Professoressa Ilaria Garofolo**,  per l' opportunità di crescita personale e lavorativa.

## Abstract

The management of buildings has been currently gaining momentum in the construction industry. Public and private organisations which deal with managing facilities are interested in and needy to use any means to run their business as best as possible. Indeed, the life cycle of buildings is distributed in an asymmetric way, where the longest part regards the operational phase, leading to a huge importance to this stage. Traditionally, buildings used to be managed by using paper-based documents, personal experience, and manual analysis approaches. This implied loss of data and separated data silos, insights potentially biased in favour of knowledge, and time-consuming tasks. With the advent of the fourth industrial revolution, technology has boosted the opportunities to exploit disruptive tools to effectively manage buildings in a digital way and data has been put in the centre of attention. Although the digital building management can be extremely useful to manage the usage of data, organisations need appropriate methods, tools and skills to handle it. Nevertheless, most of organisations are not ready or capable to embrace innovations and still use old and traditional practices, even if error-prone and less efficient. As a result, the digital building management is not conducted at a reasonable and effective level. In addition to it, not only the abundance of data might be problematic, but also its format, as data is often stored using unstructured formats, leading to the impossibility to effectively exploit it. This leads to the following research questions: What are the methods and technologies that can be exploited in order to improve the building management? How should they be implemented and applied to reach such result? To what extent is data exploitable for the building management enhancement? The manuscript aims to improve the management of buildings. The first research objective concerns implementing the BIM method, defining crucial FM system features and describing how to generate digital models to lay the foundation for an effective digital management of buildings. The second one focuses on proposing solutions for space and maintenance management exploiting innovative technologies and techniques, namely Digital Twins and text-mining algorithms, in order to improve the management of buildings. The outcome of this research is a series of guidelines, which both public and private organisations can use, for enhancing building management.

Section classification:

Section 1 introduces the management of buildings illustrating the issues and barriers related to it, the current situation in terms of technologies and methods, and the potential features and technologies for an effective digital management.

Section 2 delineates the research methodology defining the steps taken in order to carry out the work illustrated in the dissertation and reach the objectives.

Section 3 outlines the literature review describing the main applications developed and used for the digital management of buildings, along with processes to implement it.

Section 4 illustrates the applications carried out to improve the building management. First, a method to implement the BIM process and indicators to check it are presented. Second, a set of main aspects for effective FM systems and indicators to check them are proposed. Third, a process to develop digital models useful for the operational phase is described. In conclusion, two detailed studies on two specific disciplines of the building management, such as space management and maintenance management, are conducted.

Section 5 presents the conclusions of the research and suggests opportunities for further research.

Appendix A enriches the analysis regarding the maintenance management described in Section 4 by presenting a study of the most problematic buildings in terms of maintenance requests carried out for the local administration of the Municipality of Trieste.

Appendix B enriches the process of developing digital models described in Section 4 by presenting the documentations of the public tenders of the projects “Magazzino 26 - Museo del Mare” and “Palazzo Biserini” carried out for the local administration of the Municipality of Trieste.

# Abstract

La gestione degli edifici è attualmente un tema molto attrattivo e di grande rilevanza nel settore delle costruzioni. Enti pubblici e organizzazioni private che gestiscono patrimoni edilizi sono interessate e necessitano di usare qualsiasi tipo di mezzo e strumento al fine di gestire al meglio i loro business. Infatti, il ciclo di vita degli edifici è distribuito in modo asimmetrico, in cui la parte di gestione è la più lunga, generando così un enorme importanza per questa fase. Tradizionalmente, gli edifici venivano gestiti tramite approcci basati su documentazione cartacea, esperienza dei professionisti, e analisi manuali. Questo implicava la perdita di dati e creazione di silos di dati, intuizioni potenzialmente influenzati dalla conoscenza, e attività dispendiose in termini di tempo. Con l'avvento della quarta rivoluzione industriale, la tecnologia ha incrementato e supportato l'opportunità di utilizzare strumenti e applicazioni innovative per gestire efficacemente gli edifici in modo digitale, e il dato è stato posto al centro dell'attenzione. Nonostante la gestione degli edifici in modo digitale possa essere di estrema utilità per gestire l'utilizzo dei dati, le organizzazioni necessitano di appropriati metodi, strumenti e abilità al fine di padroneggiarla. Tuttavia, la maggior parte degli enti non sono pronti o capaci di intraprendere un percorso di innovazione e tuttora restano fedeli alle vecchie e tradizionali pratiche, anche se inclini ad errori e meno efficienti. Di conseguenza, la gestione digitale degli edifici non è adottata ad un livello soddisfacente. Inoltre, non solo la grande mole di dati può essere problematico, ma anche il suo formato, dato che i dati sono spesso salvati usando formati non strutturati, portando così all'impossibilità di utilizzarli in modo efficiente. Questo porta alla formulazione delle seguenti domande di ricerca: Quali sono i metodi e le tecnologie che possono essere utilizzati al fine di migliorare la gestione degli edifici? Come dovrebbero essere implementati e applicati per raggiungere tale risultato? Fino a che punto sono i dati utilizzabili per il miglioramento della gestione degli edifici? Lo scopo di questo documento è migliorare la gestione degli edifici. Il primo obiettivo di ricerca riguarda l'implementazione del metodo BIM, la definizione delle caratteristiche fondamentali dei sistemi di gestione degli edifici e la descrizione di come generare modelli digitali al fine di creare le basi per una gestione digitale efficace degli edifici. Il secondo obiettivo ha come focus la proposta di due soluzioni per la gestione degli spazi e la gestione delle manutenzioni che sfruttano tecnologie e tecniche innovative, cioè Digital Twins e algoritmi di estrazione di testo, al fine di migliorare la gestione degli edifici. Il prodotto di questa ricerca è una linea guida, che organizzazioni pubbliche e private possono usare, per migliorare la gestione degli edifici.

Struttura della tesi:

La Sezione 1 introduce la gestione degli edifici illustrando le problematiche e le barriere connesse ad essa, l'attuale situazione in termini di tecnologie e metodi, e le potenziali caratteristiche e tecnologie per ottenere un'efficiente gestione digitale.

La Sezione 2 delinea la metodologia di ricerca definendo gli step intrapresi al fine di svolgere il lavoro illustrato nel documento e raggiungere gli obiettivi prefissati.

La Sezione 3 traccia il contorno della letteratura descrivendo le principali applicazioni sviluppate ed usate per la gestione digitale degli edifici, insieme ai processi utilizzati per implementarla.

La Sezione 4 illustra le applicazioni ideate e svolte al fine di migliorare la gestione degli edifici. In primo luogo, un metodo per implementare il processo BIM e i suoi correlati indicatori per verificarlo sono stati illustrati. In secondo luogo, è stato presentato un set di aspetti fondamentali per ottenere un efficiente piattaforma di gestione degli edifici e i suoi corrispettivi indicatori per valutarlo. In terzo luogo, è stato descritto un processo per lo sviluppo di modelli digitali utili alla fase di gestione. Infine, sono stati condotti due approfondimenti su due temi di gestione degli edifici come la gestione degli spazi e la gestione delle manutenzioni.

La Sezione 5 presenta le conclusioni della ricerca e suggerisce alcune opportunità di sviluppo futuro.

L' Appendice A arricchisce l'analisi riguardante la gestione delle manutenzioni svolta nella Sezione 4 presentando uno studio sugli edifici più problematici in termini di richieste di manutenzione prodotto per il Comune di Trieste sul proprio patrimonio.

L' Appendice B arricchisce il processo per lo sviluppo di modelli digitali utili alla fase di gestione decritto nella Sezione 4 presentando la documentazione riguardante le gare di appalto dei progetti "Magazzino 26 – Museo del Mare" e "Palazzo Biserini" prodotta per il Comune di Trieste.

# Table of contents

## List of abbreviations

| Abbreviation | Explanation |
|---|---|
| AIM | Asset Information Model |
| AIR | Asset Information Requirements |
| ANAC | National Anti-Corruption Agency |
| AECO | Architecture, Engineering, Construction and Operation |
| AM | Asset management |
| AR | Augmented Reality |
| Auto-ID | Automatic objective Identification |
| BEP | BIM Execution Plan |
| BIM | Building Information Modelling |
| CAD | Computer-Aided Design |
| CAFM | Computer-Aided Facilities Management |
| CMMS | Computerised Maintenance Management System |
| COBie | Construction Operations Building Information Exchange |
| DESI | Digital Economy and Society Index |
| DT | Digital twin |
| EIR | Exchange information requirements |
| FM | Facilities Management |
| GIS | Geographic Information System |
| GUID | Global Unique Identifier |
| HVAC | Heating ventilation and air conditioning |
| IFC | Industry Foundation Classes |
| ICT | Information and Communication Technologies |
| IDM | Information Delivery Manual |
| IWMS | Integrated Workplace Management Systems |
| IFD | Integrated Workplace Management Systems |
| IoT | Internet of Things |
| KPI | Key Performance Indicators |

| | |
|---|---|
| MEP | Mechanical Electrical Plumping |
| MR | Mixed Reality |
| MVD | Model View Definition |
| O&M | Operation and Maintenance |
| OIR | Organisational Information Requirements |
| Pre-BEP | Pre-BIM Execution Plan |
| PIM | Project Information Model |
| PIR | Project Information Requirements |
| PA | Public administration |
| RFID | Radio Frequency Identification |
| UPC | Universal Product Code |
| VR | Virtual reality |
| WSNs | Wireless Sensor Networks |
| WO | Work order |

# 1 Introduction

The ISO 41011:2017 defines Facilities Management (FM) as "an organisational function which integrates people, place and process within the built environment with the purpose of improving the quality of life of people and the productivity of the core business" [1]. The FM phase, known also as the Operation and Maintenance (O&M) phase or building management phase, covers more than 50 years of the total life span of buildings. FM activities include acquiring, integrating, editing and updating data to generate information and operate facilities [2].

On the one hand, FM is regarded as a "non-core" part of the construction industry because of its lack of real business value [3]. Indeed, activities conducted during this phase are non-pivotal tasks of business, such as maintenance, cleaning and space configuration. Furthermore, in the past FM used to be overlooked compared to the design and construction phases, as these last ones have short period of work and substantial impact on the entire life cycle of buildings [4]. On the other hand, buildings' operational cost accounts for nearly five to seven times higher than costs of initial investments [5]. Since this phase represents the majority of expenses over their entire life cycle, potential benefits resulting from an effective management can be achieved. These advantages exceed financial savings. As well as reducing costs, not only a well-managed building fulfils its functional and business purposes, but also boost satisfaction and productivity of building's users [6].

Effective management stems from an efficient availability of data. Acquiring data is the first step to build a comprehensive knowledge of buildings. The next steps consists of exploiting this data in order to move from data to information, from information to knowledge and from knowledge to wisdom [7]. According to the USA General Service Administration, assets and asset information are equivalent in terms of value [8]. A lack of information implies making wrong decisions, resulting in unsuccessful business strategies, loss of productivity, and job-related stress [9]. However, not only the lack of data can present problems, but also its abundance. For instance, redundant data might hinder decision-making processes, leading to suboptimal decisions and incorrect assessment of risks. Other data-related issues stem from asymmetric data, namely different data related to the same aspects of a building, along with duplicated, inaccurate, incomplete, uncertain or misunderstood data. Thus, there is a need to integrate different and diverse data, which allows organisations to perform accurate analyses and consequently generate useful information and insights.

Nevertheless, data is often stored in sheets of paper and/or separated file notes. This implies some issues regarding current data storage. Firstly, since facility data is generated daily, a repetitive and ongoing manual process of collecting data is needed. Secondly, an accurate but time-consuming check of all its documents has to be performed due to potential incompleteness or obsolescence of data [10] [11] [12]. Thirdly, when FM personnel need to use this data, a wide effort to integrate it needs conducting. For instance, according to [13], FM personnel spend time valued at almost $610 million for transferring data into formats which are commonly used by their systems.

Computer-based systems, such as Computerised Maintenance Management System (CMMS), Computer-Aided Facilities Management (CAFM) and Integrated Workplace Management Systems (IWMS) are available to digitalise the management of buildings. However, only some of these systems are based on a unique and up-to-date database that can integrate data, and usually none of these few cases can successfully support activities in the O&M phase due to their current lack of spatial and topological information, and integration with other disruptive technologies.

FM does not rely only on technological platforms, but also needs methods to perform it effectively, and overall, a strategic approach to combining these two aspects. Useful information is generated only if raw data is integrated during the FM phase. However, not only operational data is necessary, but also building data derived from the construction process. Thus, a process which enables deciding, developing, and collecting useful data for FM has to be set up from the very beginning, before commencing the design and construction of a building [6]. On the whole, the digital management of facilities should not be seen as a simple technological improvement, but include a digital transformation based on a “begin with and end in mind” strategy.

## 1.1 Digitalising asset management

Digitalisation has been gaining increasing momentum in every industrial field over the last twenty years [14]. In spite of its wide use, this concept is often confused with digitisation or considered as the same word. However, these two themes are two different concepts. Digitisation is the process of converting data and documents from analogue to digital, while digitalisation is about applying digital technology into existing business [15] [16].

Asset management (AM) is a set of management processes and systems that encompass the management of an asset throughout its whole life cycle [17]. Depending on the context, the term ‘asset’ can represent a building, a component of infrastructure, a system or a piece of equipment. AM includes both the management of physical assets and the related data. The management of this data is conducted by using an asset register organisation, which can be characterised using either an analogical or a digital process to host asset data. The former regards storing data in sheets of paper, while the latter, namely the digital management or the digitalisation of asset management, can be performed by using file documents or appropriate digital platforms.

Compared to the other methods, using digital systems to manage FM processes can boost facility performance. Not only digital platforms allow FM personnel to conduct easily their FM tasks by enabling the visualisation and editing of all data, but also external users can benefit from the visualisation of this data. Thus, according to the level of permission, users can access to data by logging-in in the application, as shown in *Figure **1***. According to the purpose, these platforms are usually based on three levels of data access including basic, standard and advanced. Basic users are usually either external user or people who have nothing to do with FM. These users need data to conduct their tasks, therefore they have permission to visualise data, but have not possibility to alter it. Standard and advanced users are both in charge of managing facility data. Contrary to basic ones, they can modify, add and cancel data and the unique difference is the permission extent. For instance, if a system has several application modules, standard users can operate in only one module, whereas advanced ones can manage all modules.

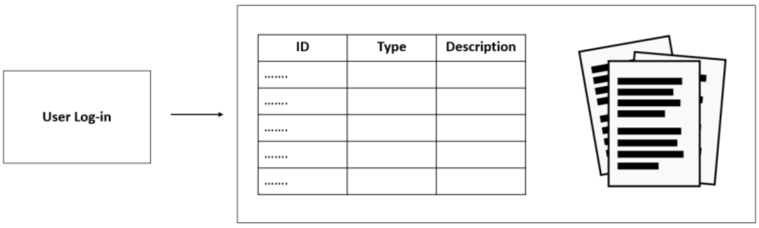


*Figure 1: Digital system*

There exist several systems which can provide useful data organisation, such as CMMS, CAFM and IWMS. CMMSs can store maintenance data, enable FM personnel to extract and use this data and consequently provide insights into operation systems performance. CAFM software enables FM managers to improve long-term planning by focusing on activities involved in space and workplace management. These two systems are useful tools to manage some aspects of FM. However, organisations need a comprehensive system able to manage all FM aspects, but only some software solutions exploit the same system to manage all FM tasks. IWMS can integrate application modules by using a unique database, which is in common among all modules, to conduct different FM tasks. According to a report produced by Mind Commerce [18], which is a strategic advisory and market diligence firm, the importance of using IWMS systems for FM will grow sharply. In particular, with reference to the global IWMS market, this will reach USD $11.2B by 2026, and referring to the usage of IoT systems embedded in IWMS, this market will reach USD $3.5B by 2026 [18].

IWMSs are based on different modules, as shown in *Figure **2***, which commonly regard the following aspects:

- Real estate and asset management: this module includes aspects related to property and economic management of facilies, check of water, light and gas supply, management and storage of facility documentations, such as certification and authorisations, and consultation of real estate registry;
- Maintenance and general services: this module concerns the daily management of replacement and maintenance activities, such as reactive maintenance, administration of supplying contracts, processes of opening and closing maintenance tickets, scheduling programmed maintenance, conducting extraordinary maintenance, and conducting technical and regulatory upgrade of assets;
- Space and emergency management: on the one hand, this module includes aspects related to optimisation and management of workstations and workspaces through key performance indicators (KPI) and Computer-Aided Design (CAD), respectively. The management of spaces also includes space booking and post-occupancy evaluation of workspaces. On the other hand, emergency management encompasses tasks including monitoring and localising hazards, getting access to facility data and consequetly providing emergency response, such as potential rescue and escape paths.
- Sustainability: this module concerns planning and managing consumes including electrical energy and water, cleaning and surveillance activities, and heating and cooling costs.

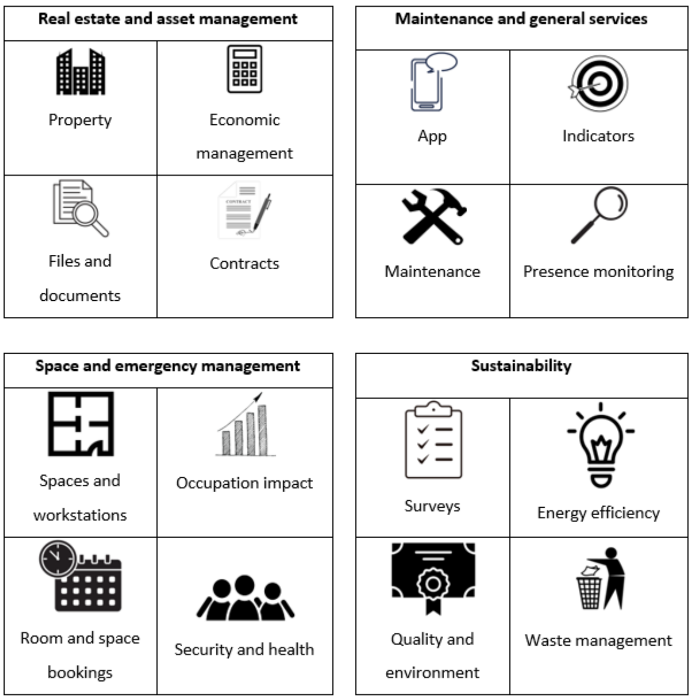


*Figure 2: Facilities management system*

This solution has gained great interest due to the fact that several benefits can be achieved if organisations can coordinate activities deriving from different departments by avoiding misleading or scattered data flow. However, operating it efficiently can be complicated when dealing with complex building portfolios. Current solutions support FM tasks, but do not fully enable retrieving all information needed to act effectively. For instance, data retrieved can include geometrical dimension of spaces, walls, furniture and equipment, but spatial and topological relationships are omitted [19]. Due to this lack, FM practitioners are forced to rely on personal experience. According to [20], "the solution for AECO/FM integration would be the development of a single 3D data model of each building". This also means collecting comprehensive data (e.g., historical O&M records, performances of facilities, accurate locations, etc.) which is obtained by integrating multiple technologies (e.g., sensors, cameras, etc.) in a unique repository. Avoiding interoperability issues and the lack of exchanging information can support business and profits [21] [22]. The rise of remote and mobile technologies which can enable the collection and audit of both static and dynamic facility data is a step towards an interconnected management [23]. This kind of management can lead to improvements in operational efficiency thanks to its capability to support facility managers in predicting and anticipating events instead of either relying on perceptions or responding to failures.

On the whole, it is necessary to integrate disruptive technologies to improve the management of facilities and consequently achieve its maximum value over their lifecycle.

## 1.2 Digital Transformation for digitalising FM activities

The construction industry has a wide impact on the economic, environmental and social development due to its feature of transversality. For instance, in the European Union in 2016, the construction industry contributed to almost 9% of Gross Domestic Product (GDP) [24]. However, compared to other sectors, the construction one presents a low level of digitalisation. In particular, despite its potential benefits, effective digitalisation has not fully implemented in FM. Indeed, integrating disruptive technologies for FM has been widely recognised as a potential game changer to improve the O&M phase in different application fields [25]. The role of buildings is beyond a mere support to operations. Facilities can be regarded as core productivity enabler, transitioning from an expense and fruitless asset to a high-value and dynamic one [23]. Since FM has started to move towards comprehensive digitalised information management, a shift from the traditional modus operandi to a new and integrated one is needed.

The digitalisation can be achieved through a digital transformation. The digital transformation is a "process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies" [26], as shown in *Figure **3***. This process aims to enable conducting tasks in a new and digital way. Digital transformation can be put in place thanks to the increasing growth of knowledge and the advancement of technology during industrial revolutions. The first industrial revolution happened at the end of the XVIII century and brought to light steam engines and consequently all its related applications. The second one took place between 1870 and 1914 and introduced the electricity. The third one is dated second half of the XX century and led to the advent of electronics, along with the birth of the computer world and automation of industrial processes. The current period of time is regarded as the fourth industrial revolution or also known as Industry 4.0. Thanks to improvement in technology, there has been an increasing diffusion of smart devices, along with a pervasive presence of internet, leading to Internet of Things (IoT).


*Figure 3: The digital transformation (https://www.sviluppoinnovazione.com/digital-transformation-mise )*

To succeed in implementing an effective digitalisation for FM, there is a need for a transformation. Compared to a change, which is a quick shift of traditional models from one version to a smarter one, a transformation involves a profound change in systems, people, culture and behaviours [27]. Technology is the main key factor for successfully digitalising FM activities, but it is also a part of a complex process and not the unique factor that is needed to support this adoption [26]. However, it is often believed that simply purchasing and installing software packages lead to a complete transformation and consistent results [28]. This is one of the common mistakes that many organisations make when trying to improve their performance. For instance, linking buildings to management systems enables performing analytics, resulting in a better control of assets and forecasting cost-benefits trend. However, these advantages can be obtained only if all data is integrated. Traditional FM practices do not succeed in effective sharing information throughout organisations. This issue is partly caused by the difficulties of the construction industry to embrace digital innovations. The other root problem is the presence of the information silos approach, resulting in an ineffective collaboration and information sharing among different office areas [29]. This means, for instance, that the real estate and property department relatively collaborates and consults the supplying department when conducting their activities. Furthermore, a sectorial organisation is preferred to a global one. This means that each department selects its own software tool, along with settling its own rules, organisation methodology, and operative procedures. This is due to the fact that there is a competitiveness among different departments which aim to demonstrate their efficiency. However, the more information is managed in a sectorial way, the less a good performance is achieved [30].

The digital transformation is not meant to be purely a technology-led change, but requires companies to undertake substantial organisational effort to achieve it effectively, otherwise many barriers can hamper the correct adoption. These obstacles include inertia, resistance and lacks of essential competences. The first one is about the inaptitude to improve a process due to addiction to standard processes, ingrained behaviours and existing resources. The second one regards the aversion to innovation. This issue arises when the method and the pace used to implement a change is not appropriate, but also there might be a cultural resistance which typically derives from instinctual reaction to the unknown. As a result of a half-heartedly transformation, operational difficulties can be encountered, resulting in what is usually called "innovation fatigue" [31] [32]. Finally, the gap of expertise have to be bridged, as there is no way to manage a change efficiently whether there is still a lack of knowledge [33].

To overcome the aforementioned issues during the digital transformation, a reasoned strategy has to be taken into consideration. This strategy needs to consider both human-related aspects and procedural steps of implementation. The human-related aspects include both interpersonal and intrapersonal aspects. The former consists of people involvement and adequate communication, while the latter is connected to the development of a digital mindset. Involving people in change processes is critical to achieve expected outcomes. This factor can determine the success of operations. When employees are aware of the benefits and difficulties of a change and they are interested in supporting it, the shift is smooth, well-accepted and effective. This means that a change in how people interact with the workplace is needed. Otherwise, resistance and discontent hinder its implementation. Another critical aspect concerns an adequate communication throughout organisations. This is paramount in any situation, especially in those where people need to share information each other. If there is no communication among employees, information useful to speed up and conduct activities is suppressed. As well as interpersonal aspects, intrapersonal factors are also key drivers to succeed in the transformation. In particular, there is a need to develop a digital mindset [34]. Since the world has become a dynamic environment, this condition is essential to understand the logic that are behind every process. As a result, a digital maturity which involves a progressive ability to properly cope with digital contexts needs achieving.

Strategies to accomplish transformations are necessary based on a series of procedural steps of implementation. These implementation processes refer to both the way a transformation is undertaken and the support received to undertake it. The first one concerns the method, pace and best practices exploited to reach the purpose. The method includes creating priorities, internal processes, coordination, and responsibility issues which can lead to an implementation of new digital solutions [32]. The second one concerns external and internal support. The former is about hiring expert people out, who can help in presenting a new way of conducting activities. This can be extremely fruitful, as they not only know the right method to introduce changes, but also practical and real examples to support it. Therefore, all aforementioned aspects are explored and handled through sessions of consultancy and training. The latter concerns the organisation endorsement. A part of this support comes from a workplace change management team, who is a crucial element when dealing with transformation. The role of this team consists of introducing a gradual shift for every process and technology and explain to employees how to behave and conduct activities in a new way. The other part of the organisation endorsement stems from involving the strategic level of the top management. Since top managers are in a position to influence the behaviour of employees and avoid resistance from different areas of companies, they have a great role in contributing to undertaking a transformation [33]. Furthermore, when decisions have to be taken, these always have to be accepted by managers. Thus, if an organisational change is needed, it is crucial that managers understand not only the benefits which might be achieved, but also the barriers that can hamper it.

On the whole, technology is paramount for an effective digital management, but also strategies to accomplish the transformation are necessary. Without the second one, the first one might not reach the level of performance planned.

## 1.3 FM Technologies

During the operational phase different and diverse technologies can be exploited. The main ones include BIM, GIS, IoT and visualisation techniques.

### *1.3.1 BIM*

Building Information Modelling (BIM) is defined as "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" [35]. BIM can be very powerful also if used during the O&M phase. According to [36], BIM manages all information through the whole life cycle of a built asset, namely initial design, construction, maintaining and de-commissioning, by exploiting digital models, also known as BIM models. Indeed, BIM is also known as a process based on BIM models. A BIM model is defined as "a digital representation of physical and functional characteristics of a facility. It serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward" [37] [38]. A BIM model can be regarded as a platform able to store FM data and visualise it though a 3D visualisation, as shown in *Figure **4***. Each component of a BIM model is a parametric object which contains geometric data and non-geometric attributes, such as functional, topologic or semantic information [39] [40] [41]. While the first one concerns data which is specific for each object, such as property of materials, the topologic ones provide information concerning object location, adjacency, coplanarity or perpendicularity and the semantic ones describe the properties of components, such as connectivity, aggregation, containment or intersection information [42] [40]. Furthermore, each object is characterised by a Global Unique Identifier (GUID), which is a unique value that enables object identification [43]. In particular, GUID is exploited to search terms, identify BIM entity relationships and avoid issues exchange delivery exchange [44].

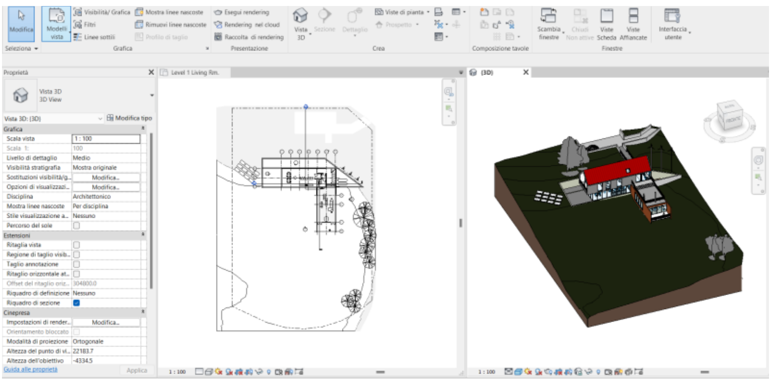

*Figure 4: BIM model*

BIM is based on an open data system, also known as openBIM, which consists of a set of standards, as shown in *Figure **5***, which regulates the processes of sharing and exchanging information throughout facility lifecycle. The main standard developed is a neutral data scheme called Industry Foundation Classes (IFC). IFC is defined as a “standardised, digital description of the built environment, including buildings and civil infrastructure” [45]. This description includes aspects regarding identity, semantics, attributes and relationships of elements and nowadays is recognised as an open and international standard. IFC is based on a vendor-neutral data structure that is independent from individual proprietary applications. Thanks to its properties, IFC is usually used to exchange models among different applications and project participants. This is considered as the backbone of BIM process and technology, enabling stakeholders, such as software vendors and end user organisations, to achieve interoperability [46]. As well as storing data in a central file, subsets of this can be obtained from the IFC schema for specific usages, avoiding overwhelming quantity of data which is useless for specific purposes. Starting from BIM models, different models can be derived by using different Model View Definition (MVD). A MVD is a subpart of the overall IFC schema, which can provide users with only the needed and selected data [47]. The other standards include the Information Delivery Manual (IDM) and the International Framework for Dictionaries (IFD). The former is an integrated reference for processes and data required during the entire life-cycle of a building. It provides detailed information and role-based workflow processes for supporting an integrated construction process, resulting in providing specifications for data communication [48]. The latter describes what is exchanged during this process by creating an international dictionary which enables linking existing database data to IFC data model [49]. Thus, this dictionary enables exchanging reliable data by means of a unified global terminology. This dictionary encompasses different BIM entities including both object descriptions and properties for comprehensive information exchange, resulting in a single unified bookcase formed by a union of libraries with the possibility of expanding [49]. Nowadays, this international dictionary is called buildingSmart Data Dictionary (bSDD), which is not a standard, but “an online service that hosts classifications and their properties, allowed values, units and translations” [44]. In particular, the GUID is the key element which is connected to bSDD to enable the association of BIM entity in different contexts and languages. Indeed, each BIM entity is mapped by using a language-dependent serial number inside bSDD.

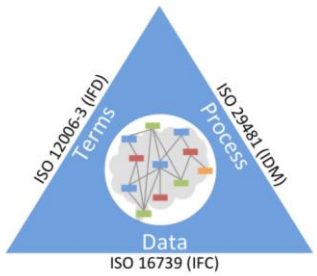


*Figure 5: buildingSmart standards (https://www.buildingsmart.org/ )*

The Construction Operations Building Information Exchange (COBie) is another important feature related to the BIM process. COBie is "a non-proprietary data format for the publication of a subset of building information models (BIM) focused on delivering asset data as distinct from geometric information" [50]. This format is used during the handover process, where there is an exchange of building data derived from the design and construction phases to be used during the operational one [51]. In particular, COBie enables the creation of a standard process of data exchange, avoiding time-consuming manual tasks and loss of essential building information [51]. COBie has two main types of representations including spreadsheet and IFC model. The first one is a spreadsheet composed of a number of sheets which is equal to the number of element types in the model. In each sheet, the rows describe instances, whereas the columns headers provide description of what kind of attribute is stored. The second one regards an MVD, namely the basic FM handover view, which enables exporting a BIM model from BIM authoring systems for FM purposes.

Thanks to its properties, BIM can bring several benefits. Firstly, the process of data collection, transfer and storage is improved. Traditionally, delivering data acquired during the design and construction processes can last several weeks. This process is conducted manually after the handover of buildings and need a massive effort due to the huge work of re-documenting "as-built" conditions and field surveys [3]. BIM can speed this process up. For instance, according to [52], a case study of Coast Guard Facility Planning demonstrated that BIM models can bring up to 98% time savings for collecting, storing and using information. Secondly, 3D models enable virtual walk through facilities, leading to a smart way of investigating building spaces, components, and equipment [53]. For example, BIM schedules set up according to their typology allow complex queries and specific data acquisition, such as area and volume. Furthermore, visualising 3D BIM models can help non-experts, such as occupants, have a clear understanding of facilities and how to move inside them. At the same time, workers can benefit from this aspect by eliminating additional and unnecessary trips due to the opportunity to visualise the shortest path to reach every asset. This leads to time savings which stem from dodging time to check field conditions. Thirdly, compared to CAD or other traditional data representation formats, BIM provides a central integrated storage that avoids data redundancy and enables automatic changes in all related components. As a result, this process can improve the quality of data stored by providing updated and accurate existing condition data and avoiding loss of information. Another upside regards the opportunity to perform different type of simulations. Exploiting BIM models as base models, different software tools can be used to conduct specific analyses, avoiding the laborious work of reinserting all features and characteristics of facilities. Furthermore, BIM technology offers the opportunity to visualise and use models on the web. The ifcOWL ontology "provides a Web Ontology Language (OWL) representation of the IFC schema", which enables linking facility data using internet, leading to an improvement in data management [54].

In spite of potential benefits of BIM, its implementation is still scarce in the operational phase rather than in the design and construction phases [11] [40]. Several difficulties and limitations hinder the effective use of BIM for FM. Firstly, BIM models provide accurate FM data, such as specification details and quantities, only if models are constantly updated [55]. According to [56], "maintaining a BIM file with regard to facility management information is similar to maintaining the actual facility. As components are replaced, repaired, or removed, those changes will need to be reflected in the BIM file". When this condition is not satisfied, BIM models cannot provide a source of truth and its usage fall down dramatically. This situation is the effect of exploiting BIM only until the handover phase due to its wide use by designers and constructors, but then there is a lack of proper knowledge and expertise in managing BIM tools [57]. Specialist training is critical to operate BIM applications, but these skills are not still developed in the O&M context [6]. Secondly, issues regarding using BIM for FM usually spring up when models are not specifically set for day-to-day FM tasks. Indeed, there is often a misconception about how to deliver asset information and a lack of clear understanding of the information needed for FM and the appropriate level of detail of it, leading to an overwhelming volume of data generated during the design and construction phases which is not relevant to the O&M phase. At the same time, the opposite result can happen, therefore resulting in incomplete, fragmented or obsolete data which is uncertain to handle [10] [41] [40]. Furthermore, FM role is often underestimated and facility managers are not involved during the early stages of the project delivery process due to a lack of understanding of benefits of BIM for FM. As a result, roughly 86% of BIM models created during design and construction are not used anymore during the operational phase [58].

BIM can be applied to many potential FM applications and consequently improve decision-making during the asset life-cycle [3] [59]. These applications regard the management of facilities including management of maintenance and warranty issues, inspection planning, space management, retrofit planning and deconstruction, emergency management, controlling and monitoring energy [53] [60]

[11] [61] [62]. Nevertheless, although there is a high degree of awareness of potential applications for BIM in FM phase, the added value of BIM for FM is considered marginal and its usage is still in infancy [63] [64] [65]. This is due to the fact that, facilities are part of dynamic environments where changes occur every day and not all information related to them can be stored in BIM models. Indeed, BIM cannot provide a central data repository platform for all operational AM/FM data, but need integrating other FM software tools to collect real-time and accurate data and manage facilities effectively. Thus, BIM is a part of the infrastructure needed to deliver efficient asset management and acts as a starting point for an integrated management [6] [66].

### *1.3.2 GIS*

Geographic Information System (GIS) is "an information system that is designed to work with data referenced by spatial or geographic coordinates" [67]. It is commonly used as a decision-support system for spatial analyses, as it is able to aggregate and store spatial geo-referenced data in relational databases [68] [69]. Indeed, GIS can store data including land use maps and plans, socioeconomic data, and environmental data. This data can be extracted and visualised easily from databases by using spatial query and powerful visualisation tools in GIS, respectively.

BIM and GIS have differences but also similarities if compared. GIS has a focus on the geographical perspective of aspects and the spatial scale is wide, as shown in *Figure* ***6***. This means that GIS takes into consideration geographical information and shape of buildings and building components, omitting a detailed digital repository of building information [69]. In contrast, BIM focuses on a narrow scale which refers to detailed geometric and semantic information of buildings and building elements, neglecting surrounding information [70]. Similar to BIM, GIS is based on an object-oriented approach and exploits a standard open data model to extract and share data [71]. This standard is known as City Geography Markup Language (CityGML) and is defined as "a common semantic information model for the representation of 3D urban objects that can be shared over different applications" [72]. Its main property is the ability to collect and sort classes and relations of objects according to geometrical, topological, semantic and appearance properties [72].

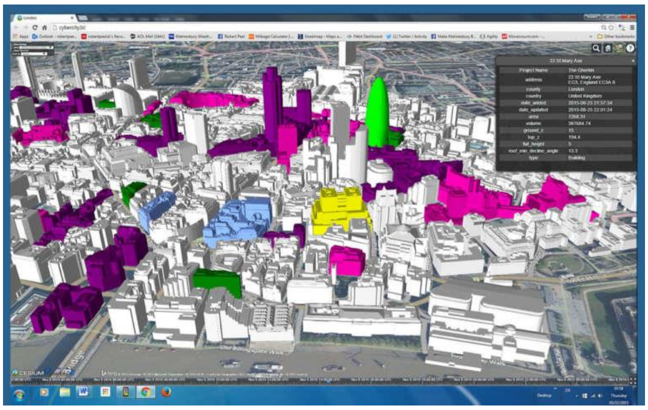

*Figure 6: GIS model (https://www.01building.it/smart-city/smart-city-bim-progettazione-digitale-citta-futuro/)*

GIS can bring several benefits whether used in the operational phase. Firstly, GIS enables improving the access to and visualisation of maps by using effective thematic mapping. This feature enables better communication with the public which can properly picture and understand the context even if they have no expertise. Secondly, professionals can take advantage from GIS due to its great efficiency in retrieval and use of data. Indeed, GIS has the ability to explore a wider range of 'what if' scenarios analyses, leading to improving quality of services. Finally, since the management of documents and maps is digital, there is an improvement in storage both in terms of cost and space. Furthermore, GIS can be integrated with other disruptive technologies to achieve better FM management performance. For instance, BIM and GIS integration has been gaining momentum both in research fields and industrial practice over the last decade [73].

### *1.3.3 IoT*

Facilities are dynamic environments where data is generated on an ongoing basis. Monitoring and consequently exploiting this data enables boosting not only facility performance but also human life related conditions. The Internet of Things (IoT) is defined as "interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications" [74]. This technology provides an understanding of what is happening to and around a certain facility by providing huge amount of data in real-time. As a result, the gap of knowledge between the real facility and its digital representation in terms of data stored is dramatically reduced.

A common IoT system consists of a set components including data acquisition objects and actuators, networks, cloud systems, and analytics [75]. These components are part of a generally represented four-layer architecture, where each layer is connected to another one in order to exchange data among them, as shown in *Figure 7*. The fist layer regards the perception layer. This tier can be divided in two parts. The first one regards the perception nodes, which is based on electronic devices that can produce electronic signals from physical conditions [75]. The most exploited technologies for sensing and collecting data, also known as pervasive sensing technologies, include wireless sensor networks (WSNs), video cameras, Radio Frequency Identification (RFID), QR codes and barcodes. The second one refers to the actions which are taken after having processed data collected. This part is based on actuators which transform electronic signals gathered into actions. The second tier refers to the transmission layer. This tier is based on a communication infrastructure able to cope with processing and sharing raw data acquired in the perception layer. This communication is usually performed by using wireless technologies such as WI-FI, Bluetooth, and Zigbee. The third layer concerns the data storage layer. Data collected in the perception layer is usually stored in cloud computing technology. Indeed, cloud systems have gained momentum in the construction industry thanks to its properties of illimited storing space and remote deliver of data [76]. The last layer provides data analysis, which enables enhancing decision-making processes by using different and diverse algorithms including machine learning, computer vision, speech recognition, and natural language processing.

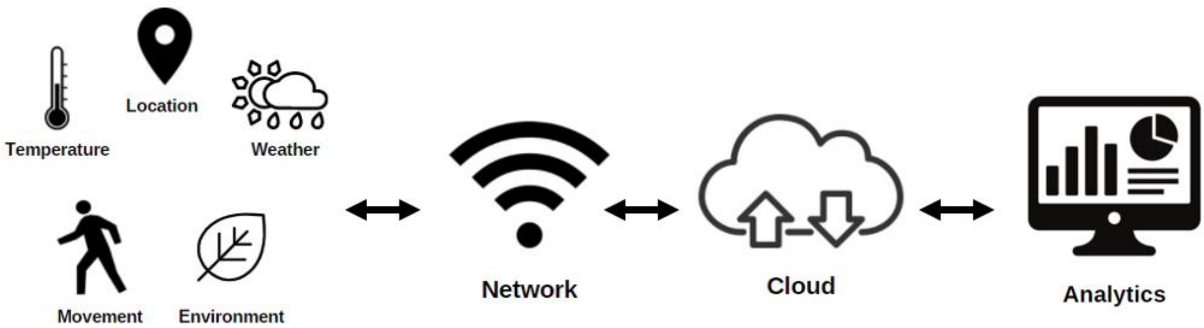


*Figure 7: IoT system*

IoT supplies several benefits. First, there is no need to go on site to collect data, but this data can be visualised directly on a digital device. This means reducing the gap between the office and the site, leading to savings both in terms of money and time [27]. Second, changes from normal conditions are identified and localised immediately [77]. Compared to the traditional method, digital devices are capable of recognising issues related to assets and providing instant reports and notifications. With reference to the operational phase, this feature can help to act in response to the failure, reducing downtime and improving asset resilience. Third, IoT provides a solution to the problem of data islands, namely storing data in different silos without any kind of integration among them [29]. IoT has the potential to horizontally link and integrate functional silos by collecting and consequently storing data in a unique central repository. Finally, this technology is able to process, analyse and diagnose huge quantity of data in order to provide predictions in terms of asset behaviours in a long-run, leading to improved services, high customer satisfaction, and savings in terms of energy and operation/maintenance costs.

The applications of IoT technologies in the operational phase are multiple and encompass all main O&M sections including the management of information, space, energy, emergency and maintenance. For instance, with reference to information management, real-time and automatic actions of inventory information storage, such as storing asset location coordinates, can replace manual interventions [78]. Energy management activities can benefit from IoT due to the opportunity to turn on/off air conditioning and heaters in offices according to pre-configured settings based on specific requirements [75]. With reference to indoor wellbeing, IoT technologies can help monitor indoor environmental conditions by collecting data regarding CO2 levels, temperature, humidity, and light intensity. Similarly, indoor safety can be boosted by using unobtrusive sensors and flame/smoke detectors, which can identify break-in attempts and hazardous situations, respectively. Space management can also take advantage from this technology by monitoring and analysing real-time and historical occupations and activities in buildings, and consequently improving hotdesking and setting of space layouts. Referring to maintenance management, not only IoT can be applied to detect faulty equipment, but also update asset's information during inspection [79].

#### *1.3.3.1 Pervasive Sensing Technologies*

IoT is based on a series of technologies that enable acquiring data. These technologies can be split in four groups including automatic objective identification (Auto-ID) technology, sensors, laser scanning and photogrammetry/videogrammetry. With reference to the operational phase, the first two technologies are more widely exploited compared to the others due to their ongoing use.

Auto-ID technology is based on three parts including tags, readers and backend systems [80]. Tags have the capability to store unique identification numbers. Readers read tags and get access to data collected by them. Backend systems refer to databases where files are stored and data can be retrieved [81]. These technologies include RFID and barcode. RFID technology can be grouped in two factions, namely active and passive RFID. The active RFID works only in connection with the reader, as the last one provides power for communicating wireless. In contrast, the passive RFID has power sources installed inside and does not need any other support to enable wireless communication [78]. RFID tag is a transponder which is able to store unique data by exploiting an electronically programmed microchip. RFID readers are interrogators capable of reading and writing by using an integrated antenna. Antennas carry out the communication process between tags and interrogators [82], as shown in *Figure **8***. Data collected using RFID can be stored in three main storing places including remote databases, storing on the tag, and storing using an integrated method.

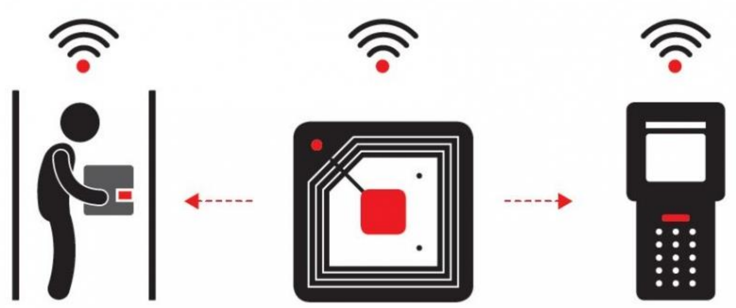

*Figure 8: RFID technology (https://www.replica.it/it/prodotto/rfid )*

Barcode technology consists of 1D barcode and 2D barcode, as shown in *Figure **9***. 1D barcodes consist of two parts including a linear barcode and the 12-digit universal product code (UPC) number. The barcode is represented by vertical lines of varying widths with specific gaps in order to generate a particular pattern. The UPC number consists of three parts including the first six numbers of the barcode, the next five digits and the last number, which represents manufacturer's identification number, item's number and a check digit for ensuring correct scanning, respectively. 2D barcodes are symbolised by a geometric diagram in a matrix square shape area, which consists of an alternate distribution of black and white elements [83]. Common examples of this technologies include QR Code and Maxi Code. Compared to 1D barcodes, 2D barcodes can be scanned in many orientations, resulting in higher tolerance and retention of efficiency. Both technologies are able to supply text information, but 2D barcodes can also deliver more complex data, such as audio, video and location [83]. Furthermore, generating and scanning barcodes can be conducted by using free scanning tools.

978123456789

***a*** ***b***

*Figure 9: a) 1D barcode (https://www.cognex.com/it-it/resources/interactive-tools/free-barcode-generator ), b) 2D barcode*

Sensors are defined as "physical devices able to capture external signals and convert them into an analogue or digital voltage" [84]. Sensors can be divided in two main categories including wireless and wired. Compared to the wired one, wireless sensors are widely used in many applications due to their flexibility and convenience. Overall, sensor applications include both measuring environmental and equipment conditions. The former mainly regards data concerning indoor temperature, light, sound, relative air humidity, pressure, motion and pollutant substances. The latter refers to specific asset features including component vibration, surface temperature and the speed of rotating parts. These kinds of sensors usually are connected one to each other generating a self-configured and infrastructure-less wireless networks, also known as WSNs, as shown in *Figure* ***10***. This network refers to a collection of distributed and dedicated smart devices including sensor nodes which aim to monitor conditions of environments and equipment and gateway[1] nodes which aim to link local sensors and remote applications for visualising data. Once sensors have collected data, this data is transferred to a storing place by exploiting the gateway nodes. Compared to Auto ID technology, sensors are small and powerful for complex system and do not suffer from vulnerability, avoiding reducing reliability or endangering privacy issues. However, the price of sensors and their customisation is far higher than RFID and barcodes.

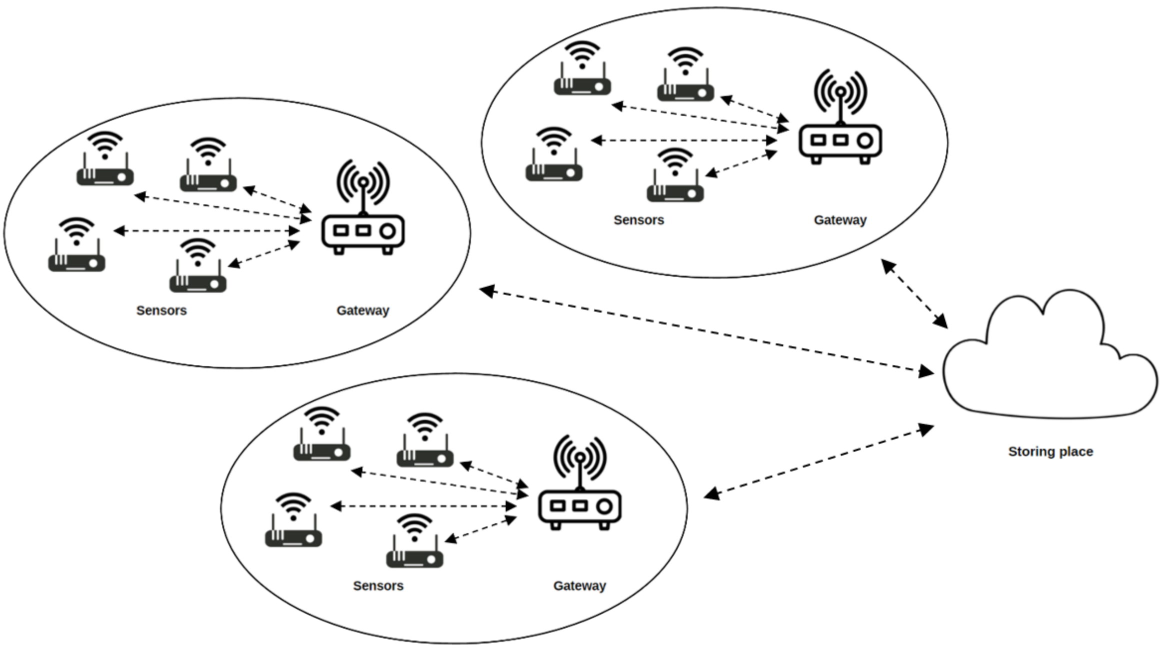


*Figure 10: Wireless sensing network*

Photogrammetry and videogrammetry are technologies which share the same working mechanism, namely taking several frames to transforms a bi-dimensional data into 3D objects, as shown in *Figure* ***11***. While the former exploits images to acquire parameters and characteristics of target objects, the latter uses video clips. Frames can be recorded by using a unique or multiple cameras and techniques.

[1] Gateway: a network node used in telecommunications that connects two networks with different transmission protocols together [85]

Furthermore, these two techniques offer a non-invasive and cost-effective means of generating 3D facilities useful for FM activities.

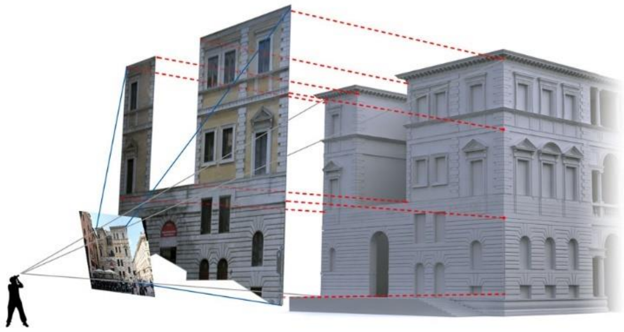

*Figure 11: Photogrammetry technique (https://www.goform.it/c/corso-fotogrammetria-principi-e-metodi/ )*

Laser scanning systems consist of four parts including a laser ranging unit, an opto-mechanical scanner, a GPS receiver, and an inertial measurement unit, which are embedded in a unique device, as shown in *Figure **12***. Laser scanning working mechanism is based on the reflection of laser pulses on the surface of objects. While the scanner is in charge of emitting a laser pulse, the GPS receiver captures the reflection of this laser and then measures the coordinate of points.

*Figure 12: Laser scanner*

Both photogrammetry and laser scanning techniques can generate computable point cloud[2] data. This set of data is widely applicable in reconstructing 3D objects.

### *1.3.4 Visualisation Technologies*

Advanced visualisation technologies have gained an increasing interest in the construction industry over the last decade due to their characteristics and potential applications [36]. The state-of-the-art of

[2] Point cloud: a series of points of the building which are mapped in space and generate a 3D object

these technologies includes Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR). These technologies are located in different and consecutive locations in the visualisation spectrum, starting from the real and physical world and arriving at the complete virtual world, as shown in *Figure 13*. These technologies are supposed to replace traditional method based on manual and phone assistance due to their potential to give a boost in conducting operation and maintenance tasks [86][61].


*Figure 13: Visualisation technologies*

Augmented Reality (AR) is defined as a technology which "allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore AR supplements reality, rather than completely replace it" [87]. In other words, AR generates a variation of the real environments by providing users with virtual images of objects and computer-generated information.

Mixed Reality (MR) is defined as a technology which enables "real and virtual elements to interact with one another and the user to interact with virtual elements like they would in the real world" [88]. This means that a strong connection between the real and virtual world is achieved. For instance, one category of MR is the Augmented Virtuality (AV). AV can be considered as the opposite technology of AR. This technology "refers to the inclusion of real world elements into a virtual environment" [89]. This means that instead of having an entire virtual environment as VR technology, it enables augmenting virtual environments with the integration of real-object visualisations, resulting in a better understating of facility features, locations and shapes.

Virtual reality (VR) is defined as "the use of computer graphics systems in combination with various display and interface devices to provide the effect of immersion in the interactive 3D computer-generated environment" [89]. This means that what users see is completely generated by a computer. Compared to AR, VR technology generates a 3D visualisation which completely immerses users in a virtual environment and cannot allow seeing the real world around them.

To visualise digital elements, all these technology can exploit different types of devices including head mounted display, hand held display, and Desktop PC able to supply dynamic and static 2D and 3D visualisation, text and audio [90].

## 1.4 Digital Twin

The effective digital management of facilities is based on an ongoing acquisition, collection, storage and update of data in a central repository and its consequent exploitation. This is why it needs something more than a simple digital model. Digital twin (DT) is “a digital model, which is a dynamic representation of an asset and mimics its real-world behaviours” [66]. Since this topic has been analysed from different perspectives in many fields of study, other definitions of Digital Twin can be useful to understand its centrality in diverse applications, as shown in *Table **1***. Digital Twins can be regarded as the digital counterparts of physical objects, but differs from the concepts of simple digital models and digital shadows in terms of level of data integration between the physical and digital object [91]. Simple digital models do not use any kind of automatic data integration, but relies on manual exchange of data, leading to a lack in directly updating digital objects when physical objects change, as shown in *Figure **14***.


*Figure 14: Data flow in simple digital model*

Digital shadow refers to a semi-automatic exchange of data, as shown in *Figure **15***. This exchange is automatic when changes are conducted on the state of an exisiting physical object, while is manual when the existing physical object needs updating.


*Figure 15: Data flow in Digital shadow*

Digital twin concerns the double automatic exchange of data, as shown in *Figure 16*. In this case, every change made both on the physical and digital objects are exchange automatically to the other one, as they are fully integrated in both directions.


*Figure 16: Data flow in Digital Twin*

| Reference | Definition | Industry |
|---|---|---|
| [92] | An integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin. | Aerospace vehicles |
| [93] | A software representation of a physical asset, system or process designed to detect, prevent, predict and optimise through real time analytics to deliver business value. | Asset, Network and Process |
| [94] | A set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin | Complex systems |
| [95] | A model of the physical object or system, which provides connectivity between digital and physical assets by transmitting data in at least one direction and monitors the physical system in real-time. | Manufacturing equipment |

*Table 1: Definition of Digital Twin*

DT is mainly composed of three elements including a BIM model, a set of sensors and actuators and a cloud computing system, as shown in *Figure* ***17***. In other words, a DT platform consists of a system able to receive, store, manage, and use facility data during the facility lifecycle and a series of smart devices which can capture data and act in response to inputs. The platform refers to a central 3D facility model which can enable the visualisation of specific facilities and a central system based on integrating data derived from different facility sections. BIM models are considered as critical parts and important sources of data for the DT. BIM was designed to be used in the maintenance stage and work with static data which is updated phase by phase. Indeed, BIM models are able to accumulate and collect data related to the design, construction and management of facilities, leading to a comprehensive data digital construct. Therefore, BIM can fulfil the need of having a single 3D model, but lacks in providing an integration during facility life cycle in daily O&M management. This means that simple BIM models cannot provide integration with real-time data fed by the sensor systems, resulting in a lack of ongoing data update useful for the operational phase. In other terms, BIM cannot act as a standalone repository capable of managing FM activities, but is regarded as the starting point for enabling DT [96]. The platform exploited for storing data is similar in its working mechanism to FM tools, such as CMMS, CAFM, or IWMS. This means that all data is stored in a digital tool by using a specific decided hierarchy which enables filtering information effectively. However, traditional FM platforms lack to incorporate the emerging BIM technology, limiting the potential benefits that can be gained within the O&M phase. In other cases, these platforms integrate a module to only visualise BIM models in their interface. Compared to them, DT platforms are able to record, integrate and analyse BIM and data to improve the building's interaction with the environment and with users. Data stored inside the platform can be both static and dynamic, received in real-time, and used to conduct instant, short-term and long-term performance analysis. This data not only concerns information about the past and current operations of the physical systems, but takes also into account environmental data [97]. IoT is the technology enabling communication between the physical real facility and the digital one and storage of data. This data is usually stored into cloud computing technology in order to avoid data silos throughout different department of organisations and enable instant data exchange and communication though internet. Thanks to its feature of central database, real-time highly accurate simulation and data analytics can be conducted. Furthermore, linking components in the model files with other systems can consequently create living digital simulation models able to learn and update from multiple sources [98]. Overall, the main operating mechanism of DT platforms is based on four phases including capturing data by using sensors, transmitting this data to the central platform, managing and analysing data to understand and predict facility behaviour, and eventually activating actuators to control and conduct actions on the facility.

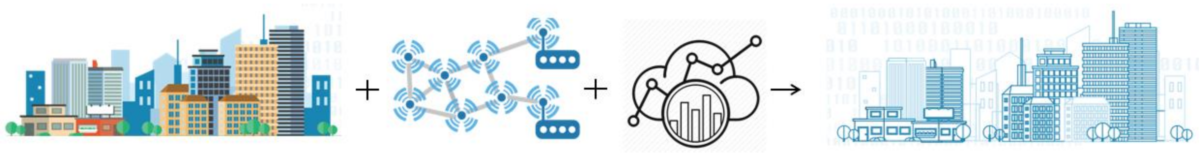

*Figure 17: Digital Twin*

### *1.4.1 DT characteristics*

Digital Twins enable a comprehensive management of assets. In order to achieve this result, DT are based on a series of fundamental principles, which has to be always and entirely present to enable a correct functioning.

The first principle regards the single source of truth. This critical feature consists of a unified, hierarchical, and extensible architecture storage where assets of different scales can be classified and described. Having a single location for data is necessary to establish and generate a reliable data storage location, namely maintaining data integrity. This means that each change generated on data is always kept track, resulting in avoiding data duplication, extra work for updating data in multiple locations, and consequently reducing the risk of incorrect or out-of-date use of information. Referring to the hierarchy and extensibility, each piece of data is encompassed in a well-organised and structured system where all relationships among them are mapped and new ones can be implemented in order to improve and increase its functioning. In other words, data storage is based on a highly structured data schema, which organises the relationships among different aspects associated to a specific piece of data, leading to an effective digital information management.

The second principle refers to the comprehensive connection of data. This feature is strictly related to the first principle and is about connecting the pieces of data stored as single source of truth in order to obtain valuable information from its integration. For instance, data concerning a building component can be linked to data regarding the space where this component is located and vice versa. Linking data has a multiple effect. It is possible to easily retrieve relevant and updated data connected to the specific analysed component in order to conduct analyses, without the need to search from scratch this data in separated files. Furthermore, since data and new data is modified and stored continuously over facility asset life cycle, respectively, the benefit of having a strong connection among data is critical to enhance data availability and minimise the problem of outdated data. This means that when the data of an item changes, data of all the other items which are connected to it also changes accordingly. Moreover, this feature helps to avoid the issue of information silos within organisations. In other words, all needed data for a particular work should be accessible, reliable, and comprehensive through data linkages, resulting in a huge improvement in efficiency.

The third principle concerns the object-based approach. Each element inside the DT, such as a building component, is represented by a digital object which has a specific identity number and each object contains data as a unifying point of reference, as shown in *Figure **18***. This means that keeping the ID number of objects as basis, all related data to objects are linked to these ID numbers. Compared to a file-based approach where data is stored in multiple different locations, the object-based approach enables maintaining data integrity. Furthermore, objects are encompassed in a geometric location referencing method which is based on coordinate geometry within local model coordinates, such as 3D models. This enables an improved management of facilities due to the fact that assets and data deriving from these assets can be visualised, and consequently easily understood and analysed. As well as enhanced visualisation, powerful filters can be applied to enables more sophisticated queries to be addressed to a body of data.

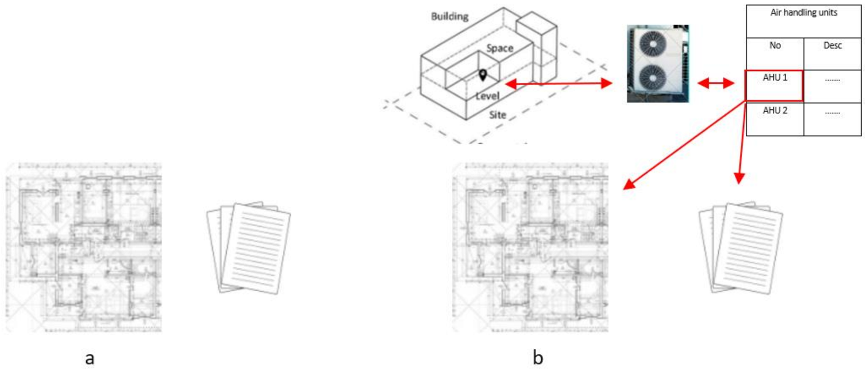


*Figure 18: File-based approach (a), Object-based approach (b)*

The fourth principle regards the continuous update of data. Not only objects contain static data, such as dimensions, date of creation, cost, etc, but they can also produce data every day based on their normal functioning and according to the living environments in which they are located. These external causes, which include environmental and human actions, can generate changes in asset operation trend. Thus, the body of asset data is not composed only by static data, which is altered occasionally, but also by dynamic data, which is useful to monitor as-is condition and activities in real time and conduct short-term and long-term investigations. Overall, integrating these two sources of data allow FM professionals to obtain the most from asset data and consequently achieve detailed and critical information to prevent potential issues.

### *1.4.2 DT benefits*

According to a Gartener prediction [99], the spread of using DT will have a broad impact in the next few years and beyond, leading to a substantial enhancement in effectiveness. Potential benefits encompasses both facility managers and users.

From a facility manager perspective, as well as being a comprehensive repository of asset data, DTs provide a complete management of facilities by dealing with the ever-changing data associated with asset management. As a result of it, several benefits are achieved. First, an improvement in identifying facility components which cause inadequate energy wastage and constantly stand in need of maintenance can be reached. To achieve it, DTs not only enable searching, filtering and sorting data about assets, but also allow integrating and linking three-dimensional digital models to improve its visualisation. Second, since each asset is linked to its relevant information sources, time used to generate equipment inventories from plans and specifications is shortened, and facility equipment and facility square footage can be pinpointed and extrapolated effectively. Indeed, these living links between physical and digital objects enable tracking equipment data and consequently performing equipment condition assessments. This aspect helps in reducing O&M contracting costs from 3% to 6% [6]. Furthermore, aggregating heterogeneous data sources, DTs can provide support to generate insights into patterns and trends useful for strategic decision-making, and predictions of potential failures and costs by exploiting analytics. These aspects result in an optimisation of building performance and a return on investment of 3% in cost savings [6].

From a facility user perspective, DT enables the increase of satisfaction and well-being. These benefits derive from several improvements in solving issues including quicker resolutions to unscheduled work orders and response times to emergency work orders. Furthermore, not only a better communication between tenants and building maintenance workers is achieved, but also an enhanced interaction which enables bridging the gap between human relationships and facilities.

### *1.4.3 DT challenges*

Digital Twins are powerful tools to exploit during the O&M phase, but need that several challenges are overcome to work properly. First, a heterogeneity of source systems is paramount to have a clear and comprehensive view of what is happening to a specific asset. Second, an efficient data integration is necessary to combine data from autonomous, disparate and heterogeneous sources including real-time sensors, building management systems, cloud services, and asset management systems, etc. [100]. Linking components together is a critical task that have to be manually created and effectively maintained. This means that not only a large variety of systems which capture different data should be involved, but also a well-structured schema and an efficient execution of queries to enable combining and extracting this data is imperative. Furthermore, to perform an effective integration, there is a need to solve any issues regarding how to reconcile the differences in data semantics, syntax, and nomenclature. For instance, different applications might use different units of measurement or include different aspects which others do not cover when defining assets [101]. Third, FM needs real-time data to boost its operation, therefore a continuous and robust stream of data synchronisation is critical [100]. Synchronising data is a fundamental task for updating data in DT and consequently maintaining its use efficient. However, synchronisation can lead to disruptions to system activities due to its massive effort to transfer data. As a result, a key problem in running DT is to define the timing and the frequency of synchronising data. This means that a trade-off between data synchronisation costs, such as information technology (IT) staff and computing resources, and data quality needs to be established. For instance, a good practice is to avoid synchronising during business hours and performing it overnight. Lastly, data is necessary to conduct analysis, but it is not sufficient if it is not adequate for its use, therefore data quality is a challenge that has to be taken into account. This challenge is based on two concepts including the way in which data is exploited and its achievement of use requirements. To exploit data effectively, only that part which is useful to support the interested application has to be considered. Nevertheless, data might be deficient and not fit for the use due to several reasons. The first cause is the quality of the data extraction. During this process data is extracted from data sources and might suffer from reduced and incorrect data output if the query used to extract data and the transformation method are not properly set, respectively. The second cause regards the quality of data sources. Even if data is collected and extracted in a proper way, incorrect results are reached if data sources are not reliable. The third cause refers to the potential quality loss when performing the integration of data. There are differences in the quality requirements according to the diverse applications. In other words, each application needs specific data quality requirements which need tailoring to match different intended uses of data.

### 1.5 DT platform architecture

DT platforms are complex systems which aim to acquire, transmit, integrate, manage and exploit a comprehensive and ongoing flow of data. These systems are usually based on five layers including data acquisition, transmission, data/model storage, application, and visualisation layer, as shown in *Figure **19***. Each data used in a specific layer is strictly related to the layers which are immediately above and below it. In other words, each specific layer performs an action by using data created in the previous layer as input and generating output which will be exploited by the successive layer. There is not a unique and unidirectional flow of data, but data transmission follows initially a bottom-up approach and then becomes a bi-directional flow where data is created from scratch and data is modified generating new information. Based on the specific considered layer, many technologies can be exploited to conduct tasks. Nevertheless, it is paramount that there is integration among these technologies in order to avoid any kind of disruption and achieve a complete and effective functioning. Overall, the integration of all these layers enables achieving a dynamic DT system.

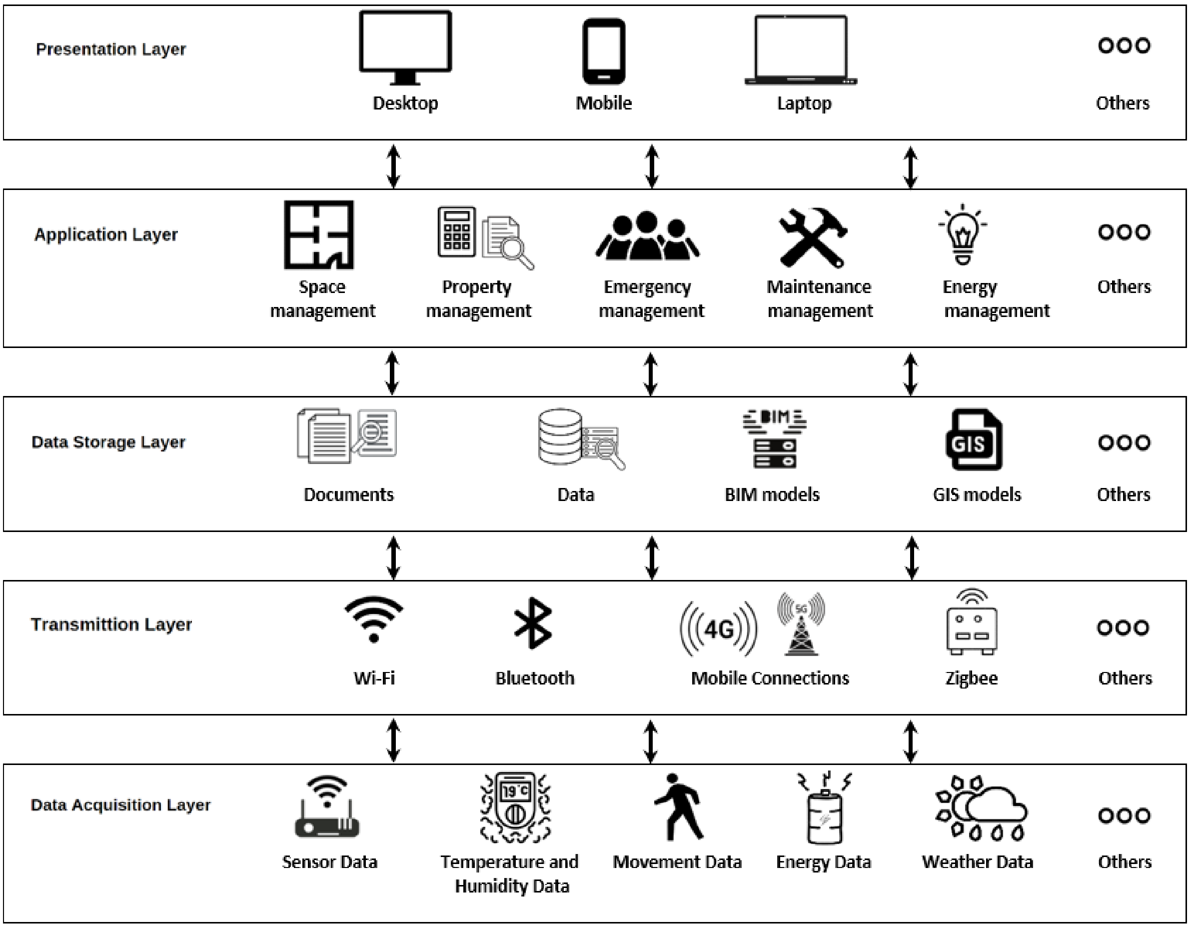


*Figure 19: DT platform architecture*

The first layer regards the data acquisition layer. This layer can be regarded as the foundation for creating a solid basis for acquiring data. Data pertaining to facilities can be acquired from multiple sources due to its high heterogeneity and large volume. Thus, an established approach able to overcome issues, such as lack of collecting specific types of data, the interruption of data acquisition, and the acquisition of incorrect data format, is needed. This approach has to enable a mechanism to fully monitor the environment and physical assets in order to acquire the necessary set of data to conduct FM activities according to the different function requirements of daily building management. Technologies advances allow different kinds of data acquisition techniques including contactless data acquisition, such as RFID and image-based techniques, distributed sensor systems, wireless communication, and mobile access [101]. To achieve a comprehensive mapping, sensor and RFID technology are the most exploited technology. In particular, sensors have to be deployed and installed at distributed locations. This system needs to be scalable in order to be extendible in the case of new assets are installed or new parameters need monitoring. As well as sensors and RFIDs, assets are commonly tagged with QR codes. These tags are attached to the surfaces of assets and enable FM managers to track them individually.

The second layer refers to the transmission layer. This particular layer aims to transmit data acquired in the previous tier to the next one, namely the data storage layer. To perform this task, there is a need to establish an effective strategy according to the type of data acquisition device is used. Referring to sensors, these are usually equipment with both transmitter and receiver and eventually, data acquired from these technologies is uploaded and transmitted from local locations to a central one. However, since assets are deployed all around facilities, it is not feasible to use a unique point of transmission to communicate with the next layer. Therefore, grouping the nodes of WSN into clusters is a common strategy to enable an efficient transmission of data. This means that once data acquisition devices have collected asset and facility data, this data are sent to specific devices, namely gateways, which collect data and, in turn, send this data to a central repository. The method used to group data acquisition devices regards minimising the distance between the location of gateways and the location of data acquisition devices. Thus, each data acquisition device is associated with the closest gateway in order to enable a robust connection. According to [85], a gateway is "a network node used in telecommunications that connects two networks with different transmission protocols together. Gateways serve as an entry and exit point for a network as all data must pass through or communicate with the gateway prior to being routed". These network nodes usually exploit ethernet ports to communicate, resulting in transferring data to remote applications over the internet using the hypertext transfer protocol (HTTP). With reference to the RFID technology, data collected by scanning codes is transferred to remote applications via a representational state transfer ful (RESTful) web application programming interface. This process of transferring data towards remote applications is performed by using multiple communication technologies including short-range and long-range coverage access network technologies. The former includes WiFi, which is the most exploited technology for this application, Zigbee, near-field communication (NFC), and mobile-to-mobile (M2M), whereas the latter encompasses long-term evolution (LTE), 5G, and low-power wide-area networks (LP-WAN) [100].

Overall, the first two layers of the DT architecture enable a data collection which includes both real-time and static data by generally exploiting IoT-enabled WSNs and QR code–based asset management networks, respectively.

The third layer concerns the data and model storage layer. This layer enables the storage of data and models related to facilities. The data refers to not only that data acquired in the acquisition tier and transferred by the transmission layer, but also manual additions and changes of data performed through the DT platform during the operational phase. Generally, this data provides critical information regarding the details, historical records and operating conditions of assets. The models consist of a series of digital models which refer to physical entities. Each model contained in the storage place is related to a specific real entity with the aim of representing it for a specific and appropriate purpose. This means that starting from a wide context, such as countries, region, cities, but also big infrastructures, and going towards a limited one, such as buildings and their components, it is possible to exploit a specific digital model rather than another to enable an efficient management. Models share many similar concepts, but compared to limited-context models which are based on BIM technology, wide-context models are generally based on GIS systems in order to extend the use of data to an urban level. These models are critical for providing additional info such as the geometry, semantics and location of assets and facilities. This layer is usually represented by a cloud computing technology. This technology enables storing complex and massive amounts of data by using a hierarchical model/data storing and consequently generating a reliable and powerful source of information easy to access. Thanks to the capacity of cloud systems, models and data can be accessed remotely, resulting in avoiding barriers of data silos. Overall, this technology is the enabler for achieving dynamic and effective facility data management due to its features of providing data for historical and real-time data analysis and processing functions.

The fourth layer is about the application layer. The aim of this layer is to allow users to exploit data stored in the previous layer to manage ordinary tasks including querying and integrating data and models, and consequently produce potential analyses and predictions. In other words, this layer contains all the operating mechanisms required for conducting data and model manipulation and processing. These kinds of mechanisms can be regarded as critical engines which play key roles in interpreting data and generating better-informed decisions which ultimately enable facility mangers to provide services for building users [100]. Indeed, data integration capability, which exploits all the available data resources, is a value added for transforming raw data in useful information. In particular, advanced modules able to perform simulations by using algorithms for machine learning and data science[3] can lead to advanced decision support. These modules enable monitoring and evaluating facility performances by assimilating data continuously, resulting in generating a dynamic management. Nevertheless, different engines are needed for different applications, therefore the establishment of algorithms to conduct analysis is highly dependent on the domain of application. These domains encompass FM areas including maintenance management, space management, emergency

[3] Data science: the field of study that combines domain expertise, programming skills, and knowledge of mathematics and statistics to extract meaningful insights from data [102]

management, information management, and energy and sustainability management. In addition, since the application layer might be used by both FM professionals and end-users, the latter can provide external data, such as feedback, which can help to improve the overall performance and consequently human satisfaction [101].

The fifth layer, namely the visualisation layer, represents the front-end interface. This is the place where users can visualise and exploit data stored in the system by using services embedded in the application layer.

# 2 Research methodology

The devised research methodology is a process composed of a series of steps which regards general actions taken in order to carry out the work illustrated in the dissertation and reach the desired outcomes. For each of these general actions, a specific activity was identified, as shown in *Figure* ***20***. In particular, the entire process consists of five steps, which has been grouped in three macro phases in order to better classify and determine how tasks are organised and what tasks are included in that particular macro phase. This process begins with the phases of analysis and definition, which is the starting point for understanding problems. After this first part, the second macro phase concerns the ideation and prototyping of methods, processes, and solutions to overcome the identified issues. Finally, the test and validation of ideated solutions is carried out by using case studies and simulations when possible.

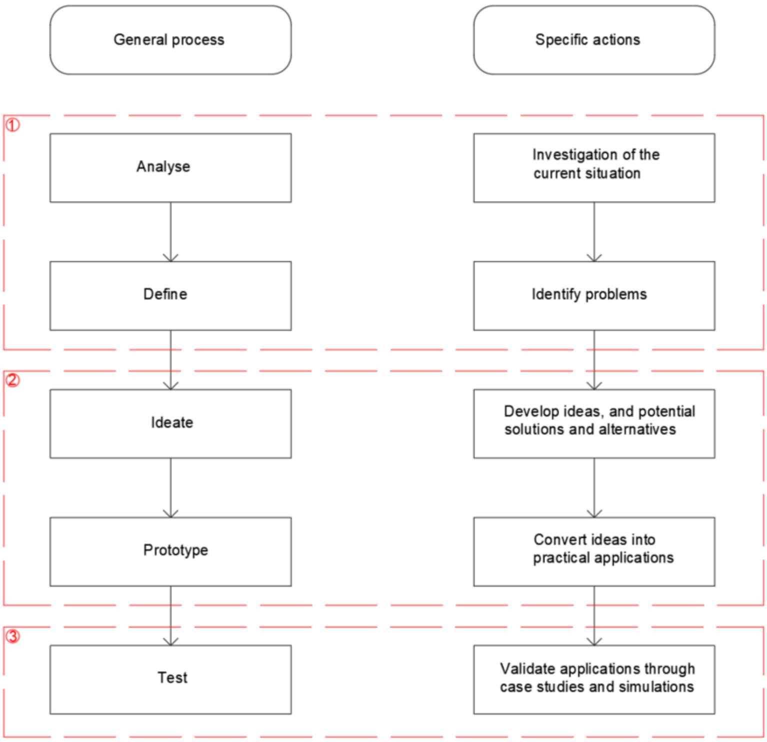


*Figure 20: Research methodology*

With reference to the first macro phase of the research methodology process, the action involved is organised as a structured approach, as shown in *Figure* ***21***. This approach takes into consideration four parts including objectives, methods used, sources and topics analysed, and results. The main action takes into account the analysis of the already existing initiatives and proposals regarding the digital management of buildings, and the definition of potential problems which can hamper its adoption and management. These topics were analysed through an in-depth literature review in order to study and understand what had already been examined, developed and presented, and ultimately collect useful background information. In particular, different and diverse sources that include those which stems from the academic field, namely review and research articles, and conference proceedings, and those from the working environment, namely surveys, government reports, and industry studies and recommendations, were considered and examined by using Scopus and Google scholar databases and internet websites, respectively. Overall, the literature review helped in identifying the main directions of the research by understanding and critically analysing the current research and situation, along with the potential obstacles and challenges which hamper and derive from the digital management of buildings. As a result, criticalities, issues and gaps regarding the digital management of buildings were defined and consequently, the research questions and the delimitation of the research project were identified.

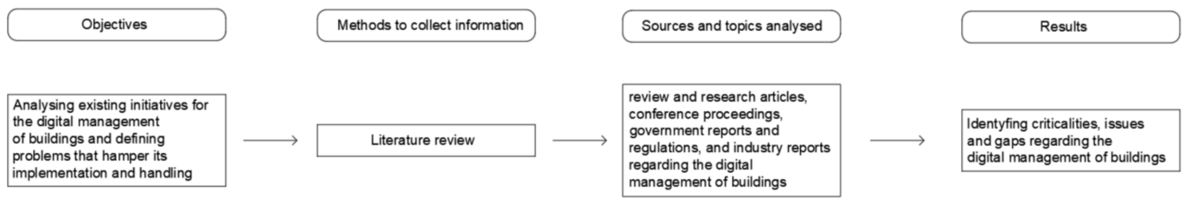


*Figure 21: Research methodology of the first phase*

Referring to the second macro phase of the research methodology process, the two actions which are involved aim to develop and implement approaches which enable overcoming the identified issues and addressing the defined research gaps. These two actions are strictly connected in a unique process, as the second one is the direct and natural consequence of the first one. This process is based on an iterative multi-step approach that aims to find the best solution to defined issues, as shown in ***Figure 22***.

The first action refers to the general concept of ideating, which can be specifically detailed as the process of developing ideas, solutions and alternatives. Beginning with the identified problems in mind, first and foremost, necessary objectives and requirements are defined. This step aims to fix what are the outcomes that are interested to achieve. Next, a massive brainstorming is carried out. During this phase, several ideas are conceived, generically expressed, and finally collected. When a good amount of potential useful ideas is collected, these are analysed one after another. This means that, in turn, each idea is picked and a Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis is conducted on it. As a result of this analysis, all ideas are sorted in order of their possibility to solve the defined issues. Then, the second action of the macro phase begins.

The second action refers to the general concept of prototyping, which can be specifically detailed as the process of producing a valuable application from a chosen idea. The best idea is chosen as main solution and consequently is further developed. After it, this idea is converted into a relevant application, which can be exploited in real life. This application can be innovative procedures/processes, practical methods, or disruptive technologies, tools and algorithms. Once this application is developed, a general checking of its suitability is carried out. This means that objective and requirements initially defined are taken into account and compared with the developed application to observe if all of them are efficiently fulfilled. If this is not achieved, either the idea is further developed again to address the remaining gaps, or if this is not feasible, another idea from the sorted list of ideas is chosen and developed. Otherwise, if the application fits needs, this can be finalised and become a potential solution to the defined issues.

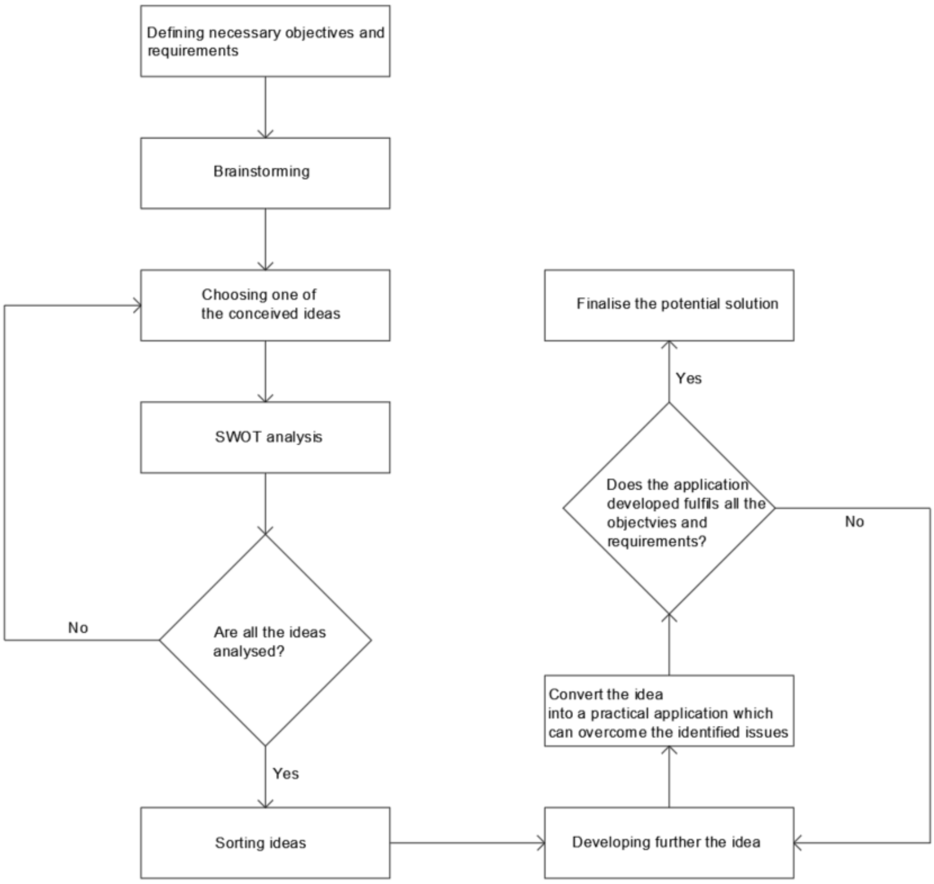


*Figure 22: Research methodology of the second part*

With reference to the third macro phase of the research methodology process, the unique action involved aims to test and validate the developed application by using case studies and simulations. This action consists of an iterative multi-step approach that aims to examine the potential solution in real situations, as shown in *Figure* ***23***. The first step of the process regards searching and finding potential case studies which can be exploited to test the application. Next, one of the identified case studies is chosen. Its selection takes into consideration as main feature the capacity of the scenario to be as much representative as possible. This characteristic enables applying the application to only a few situations to cover a high percentage of potential real situations. Then, the application is adapted and consequently applied to the selected case study. This means that any necessary adjustments to effectively tailor the proposed application from a general context to a specific one is put in place. After it, the application is validated. An assessment of the proposed solution is conducted to observe its feasibility and efficiency.

If the application cannot achieve efficient results, then an evaluation of its applicability is carried out. Thus, if the application cannot be properly applicable and needs further adjustments to work properly, then there is a need to come back to the prototyping phase, where ideas are further developed. Otherwise, if the application can be properly applicable to the case study, there is a need to come back to the application phase, where the application is fitted from a general situation to a specific one, for further adaptation.

Instead, If the application can achieve efficient results, then an evaluation of the need of other validations is carried out. In the case of the need of further validation, the process starts again from the selection of a representative sample, otherwise the application is finalised and ready to be used.

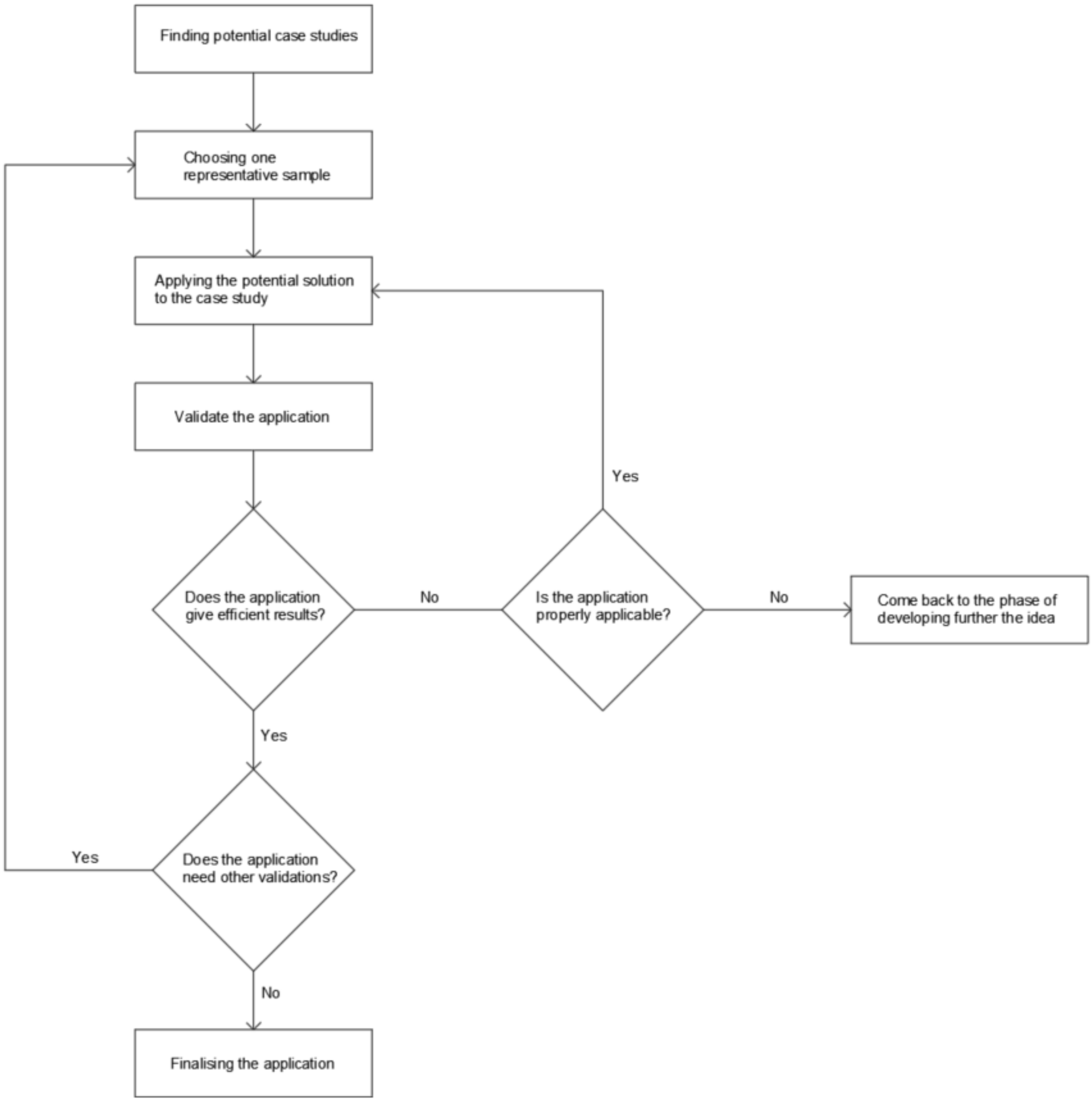


*Figure 23: Research methodology of the third part*

# 3 Literature review

In this section the main applications for the digital management of buildings in terms of methods and technologies which can be found in literature are analysed. As a result, the research questions and the delimitation of the research project were identified.

## 3.1 Digital building management

The Facilities Management can be described as “the tools and services that support the functionality, safety, and sustainability of buildings, grounds, infrastructure, and real estate” [103]. FM can be divided in two main areas including hard FM and soft FM. The former refers to the management of physical assets, such as Mechanical Electrical Plumping (MEP) systems, whereas the latter regards tasks and activities conducted by people, such as security. In addition to enabling efficient operations, FM is strictly connected to people. Indeed, since the time which human beings spend in buildings is roughly 87% of the life time, there is a need to maintain a certain level of quality [103]. This allows users of facilities to feel safe and comfortable, resulting in an increased productivity.

The effective digital management of facilities is a critical point for achieving a high level of operation performance. This kind of management is connected to the concept of smart buildings, which can be defined as “any structure that uses automated processes to automatically control the building’s operations including heating, ventilation, air conditioning, lighting, security and other systems” [104]. Smart buildings are characterised by an interconnected set of smart devices, such as sensors, actuators and microchips, and technologies which enable integration of data and consequently its usage according to business’ tasks and requirements. Integrating different and diverse technologies and systems for FM can achieve 30–50% savings in existing buildings [105]. Overall, the effective digital management of buildings contributes to minimise risks, improve performance and increase the short-term and long-term value of facilities [23].

The digital management covers all FM application fields which are mainly based on five areas of application including information management, space management, maintenance management, energy management and emergency management. To improve the digital management, several studies regarding the integration of disruptive technologies for FM have been carried out over the last decade.

### *3.1.1 Information management*

Information management refers to all the activities which concern the collection, storage, update, and use of data during the operational phase. This management ensures that fundamental conditions, such as having accurate as-built data, are always available and do not hamper a functional operation. Among the various tasks referring to information management, those which were investigated most over the last ten years include localising building components, retrieving and tracking facility information, storing asset information, and visualising and interacting with facilities information.

Localising building elements can be conducted on-site or remotely. The on-site approach is the traditional way of carrying out this task and is based on hardcopy, professional know-how and background, and in person investigation. Although this way of performing this activity has been used for ages, it can be improved by exploiting appropriate technologies. The use of innovative tools can improve the way assets are pinpointed on-site, avoiding relying only on personal experience and knowledge. For example, Baek et al. [106] proposed an AR system which exploits an indoor image-based localisation method to localise assets. This system compares physical objects scanned by an AR device with 2D BIM images of objects corresponding to the user location by using a deep learning-based computation, such as the pre-trained convolutional neural network. Another way to improve the localisation of assets concerns moving from an on-site approach towards a remote one. In this last case, the exploited technologies, which use proprietary and non-proprietary formats, are usually BIM-based due to the fact that BIM tools own the property of identifying elements using GUIDs. For instance, Kim et al. [107] proposed a semantic web-based system for information management which integrates BIM and FM information. Compared to other systems which are based on proprietary tools, this system enables converting IFC format into web-readable format, such as the web ontology language (OWL), resulting in improving interoperability and accessibility. Overall, this kind of remote systems can avoid inspections when they are not necessary and at the same time increase efficiency in searching building components.

Retrieving and tracking facility information are usually carried out during on-site programmed and scheduled inspections. This tasks can benefits from the use of innovative technologies that if integrated together, enable accelerating processes which are usually repetitive and time-consuming [53]. The most exploited approach refers to the combination of BIM tools and pervasive sensing technologies, such as barcodes, QR codes and RFID. For instance, Lin et al. [108] proposed a mobile automated BIM-based facility management system based on 2D barcode technology. This system is capable of collecting updated data and consequently transferring it in real-time to BIM models. Comparing 2D barcode technology with the others, it can be noticed that 2D barcode labels are easily damageable and can be scanned only from short distances. On the contrary, RFID has gained increasing attention for FM applications [109] [110]. For example, Motamedi et al. [111] proposed a cluster-based movable tag localisation method which integrates BIM and RFID technologies to track moveable assets. In particular, each tagged object in BIM models is linked to a unique RFID ID tag. Compared to other similar systems that use RFID, this exploits radio signals transmitted by omni-directional identical long-range fixed tags attached to fixed assets instead of using wired real-time location systems. RFID readers identified elements by receiving signals from available reference tags according to pattern matching and clustering algorithms.

Storing asset information, along with searching specific data are fundamental FM tasks which can be time-consuming if not conducted smartly and connected to each other. Compared to traditional ways of performing these activities which are manual and error-prone, the smart process involves using digital technologies which are able to properly save data in a structured manner and consequently seeking information based on these organised schemes. Several applications for transferring and storing data from the construction to the operational phase have been studied over the last decade [112]. For instance, Kang & Choi [113] presented an extendible BIM database based on BIM perspective definition metadata. This application aims to integrate FM and BIM data by exploiting an extract, transform and load process to generate a data warehouse for FM purposes. As well as using BIM tools as the unique technology to store data, combining BIM with IoT systems is another potential application which has been exploited to store FM operational data [114] [115] [116]. For example, Motamedi et al. [79] proposed a BIM extension system which extends the IFC schema by adding the definitions for RFID components in it. This enables mapping data which is stored in RFID tags in a BIM database.

Visualising and interacting with facilities information are critical aspects when dealing with managing building in their operational phase. The improved visualisation of facilities can help in acquiring a comprehensive vision of the interested asset and understanding all its possible relationships with other entities. BIM models have been used to achieve this objectives in different application contexts [117] [118]. For example, González et al. [119] proposed an indoor navigation support system based on ifcOWL ontology which aims to enable visualising facilities by combining BIM models and Web-based technologies. As well as BIM models, advanced visualisation technologies, such as Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), have been investigated to provide interaction with facility information [120] [121]. For instance, Du et al. [122] presented the BIM-VR Real time Synchronisation system. This system provides a cloud-based BIM metadata interpretation method which enables users to alter facility data when they are conducting inspections on site by using VR headsets. Compared to traditional approaches which are manual-based, these innovative technologies reduce errors and wastage of time usually lost for updating data, improve the interaction between users and facility data, and consequently increase efficiency and accuracy of FM activities [86] [61].

### *3.1.2 Space management*

Space management concerns all the tasks which focuses on improving working and living environment conditions. In particular, these tasks aim to facilitate and support core business activities by combining space, users, activities, and technologies [123]. Among the various tasks referring to space management, those which were investigated most over the last decade include useable space optimisation and space allocation management, and enhancing space information management.

The optimisation and allocation of spaces are necessary tasks that enable fulfilling users' space requirements and consequently reduce costs regarding energy and cleaning. In order to achieve these objectives some studies investigated methods and tools in order to increase the presence of useable workspaces by optimising spaces for different purposes. For instance, Colin et al. [124] investigated the usage of a BIM-based VR to improve space utilisation in healthcare facilities. The study exploited an activity-based workplace design approach which aims to organise spaces by exploiting a co-design solution which reduces stressful workspace planning initiatives. After having generated a 3D BIM model by using a point cloud support, the VR technology was used in order to enable full immersion and consequently analyse and redesign the space layout. On the whole, exploiting this technology allows users to provide constructive feedback to improve space management. Ma et al. [125] proposed a Building Information Modelling Space Management system for indoor space allocation management and indoor path navigation for an educational office building. This space management tool is based on the combination of the Space Usage Analysis theory, an algorithm for measuring the shortest indoor path and BIM models. The tool enables conducting updated queries and building usage checks and defining space requirements according to user needs. Furthermore, the BIM technology helped in conducting the space allocation and visual management of indoor direction with a consequent improvement of users' satisfaction.

Space information is traditionally maintained and handled by exploiting a manual data management, which is not effective to support space management. For this reason, some studies focused on the management of facilities by using innovative building information search methods able to switch from a 2D CAD, text-based document and scattered computer files situation to a better integrated approach [11] [126]. For instance, Ji et al. [127] proposed a system which combines BIM and AR technologies to manage spaces and facilities of university campuses with the specific aim of avoiding unproductive budget investment and integrating building information. In particular, the exploited technology applies an algorithm of the computer vision technique, namely Automatic Number Plate Recognition, to the room numbers of the schools. This enables the integration of room data including occupancy, energy and asset management, and construction information.

### *3.1.3 Maintenance management*

Maintenance management regards a set of activities related to maintaining facilities in an adequate level of operation. This management ensures that facilities can be properly used and tries to avoid or find solutions to their potential failures and interruptions. Referring to this management, four main topics including work order management, decision-making processes for maintenance, detecting assets faults and inspecting building assets, and predictive maintenance, have been investigated in the last ten years.

Work order (WO) management concerns tasks related to generating, carrying out, using and analysing work orders for FM activities. A work order is an order for a specific work which, in the particular FM context, encompasses a series of information for the operational and maintenance phase. WOs are used to provide useful observations and comments regarding failures and potential solutions. Nevertheless, the traditional ways of exploiting WOs are usually paper-based or, in the best case, conducted by using digital documents which do not provide spatial and topological information to properly understand the context of the issue. To this end, Lin & Su [128] presented the BIM-based facility maintenance management system to get access to, alter and use facility data. The system is based on web technologies and enables reviewing maintenance records inside 3D BIM models, which, in addition to it, provides a comprehensive view of the asset and its relationship with entities by which is surrounded. As well as spatial and topological information, traditional WO management does not provide spatio-temporal clues, resulting in wastage of time when conducted. To solve this issue, research on developing systems able to automatically create optimised schedules of maintenance WOs according to the distance from, problem type, emergency level and location of the interested issue has been analysed [129].

Decision-making processes for maintenance are fundamental sets of mechanisms and procedures which have to be constantly and continuously enhanced during the FM stage. Owning information to run a facility is not enough sometimes to understand how assets deteriorate and achieve an effective management. Indeed, since there are regular updates of facility information during the operational stage, often the amount data and aspects to take into consideration are overwhelming and cannot be handled by only using human skills. On this purpose, several studies on boosting these processes have been proposed over the last decade [130] [131] [132] [133] [134]. Two kinds of assistance have been proposed including visual and data-driven support. The former focuses on reducing the cognitive load to process information. For instance, Motamedi et al. [135] proposed the FM Visual Analysis System which aims to boost the recognition of failure root-cause by using BIM-based colour visual representations. The latter has the objective to analyse historical data trends in order to provide informative and organised sets of data, and consequently meaningful insights regarding failures and abnormalities [117]. For example, Ma et al. [136] proposed a data-driven approach for decision-making on equipment maintenance. The system exploits the Reliability Centred Maintenance, which, in turn, uses quantitative decision-making models and the Monte-Carlo Simulation, in order to support processing different data aspects together including the diversity of equipment systems, and the data repetition of equipment replacements. On the whole, both methods help in acquiring a better awareness of the interested problems, learn from previous experiences, and boost decision-making processes.

Detecting asset faults and inspecting building assets are FM activities which try to identify and checking conditions of failures, respectively. Referring to detecting asset failings, this activity is traditionally performed by conducting on-site inspections. However, checking asset by asset is a time-consuming procedure. For this reason, systems able to provide automatic detection of defects have been developed over the last years [77] [137]. For example, Lu et al. [138] presented a Digital Twin-based system which aims to detect anomalies of centrifugal pump vibrations in Heating ventilation and air conditioning (HVAC) system during the operational stage. The system exploits a Bayesian change point detection method to analyse monitoring data extracted from the building DT. The analysis refers to identifying when parameters of vibration drift deviates from normal values by using a cross-referencing approach with external operation information. With reference to inspecting building assets, this activity is conducted on site and traditionally based on professional experience and knowledge. On the one hand, acquiring specific and relevant asset information is a critical aspect of this task and its performance can be improved by exploiting innovative technologies. For instance, Chen et al. [139] presented a system based on BIM and AR, which focusses on providing efficient access to information for fire safety equipment inspections. When conducting inspections, users can retrieve FM data stored in a cloud database and easily visualise it by exploiting mobile devices endowed with BIM and AR technology integration, resulting in overcoming limitations due to paper-based approaches. On the other hand, having a clear idea of where failing assets are and, in particular, how to reach them is another fundamental aspect. To this end, Diao & Shih [140] presented a BIM-based Augmented Reality

Maintenance System which aims to provide a suggested maintenance route through AR visualisation. The system shows safe indications and route to reach the interested asset by avoiding potential obstacles and hazards.

Predictive maintenance is an advanced method to conduct maintenance and is based on analysing patterns related to asset failings to identify when they can occur. Compared to reactive and programmed maintenance, the predictive one exploits advanced data-driven approaches to monitor and assess asset conditions, resulting in avoiding faults during the operational phase [141] [77]. Several studies have been carried out on this topic in the last decade [142] [143] [144]. For example, Peng et al. [145] presented a BIM-based data mining approach which aims to identify and extract patterns and schemes from information management systems. The system is capable of detecting and discarding improper records, along with processing complex data records through data mining algorithms. Nevertheless, data collected is not always immediately feasible to analyse, but there is a need of proper methods to interpret it and generate meaningful results. In particular, with reference to free-form work order texts, specific algorithms need developing to efficiently retrieve and extract information from data stored. Very few studies have been carried out on this topic [146]. For instance, McArthur et al. [147] proposed a FM-BIM integration approach which aims to classify and predict unstructured written WO categories and subcategories. This approach exploits a series of supervised machine learning models in combination with term frequency and term frequency-inverse document frequency algorithms.

#### *3.1.4 Energy management*

Energy management is the critical process which concerns a series of tasks performed in order to reduce energy consumption and consequently achieve energy savings and efficiency. Energy management has been investigated for years due to two main reasons including consumption and emission issues. The first one is due to the fact that buildings represent more than one third of the total energy consumption, while the second one is connected to the well-known problem of carbon emission, which needs reducing in order to achieve sustainability goals and regulatory requirements [148] [149]. Among the various tasks referring to energy management, those which were studied most over the last decade include real-time energy monitoring, and assessing and optimising energy building performance.

Real-time energy monitoring is the process of tracking energy consumption by using smart devices which are able to capture environmental conditions, check control parameters and automatically notify or take actions if the parameter values overpass specific thresholds. Compared to the traditional energy monitoring, the real-time one enables monitoring the energy usage of buildings both over a selected period of time and during the actual moment, resulting in opportunities to act immediately if any issue arises [53]. For this reason, several investigations have been carried out on this topic [150] [151] [152]. For instance, Kang et al. [153] presented an application of BIM and IoT integration for energy management of an office building which aims to provide a clear view of the building status and boost information usage efficiency. BIM models were used as 3D building data storage, while a set of sensors deployed around the building collected environmental data and stored it in a cloud database. Along these lines, other contributions took into consideration wider scopes, such as city districts. For this purpose, the GIS technology was exploited to manage and simulate energy analyses around ample areas [154]. Other studies focused on improving the visualisation of energy consumption during its monitoring [155]. For instance, Chang et al. [156] presented a platform which aims to boost energy management efficiency by providing coloured visualisation of building indoor comfort. In this application, after collecting energy data through sensors, data was transferred to BIM models, which were exploited to display the indoor comfort by using a grid visualisation of the planar space of target rooms.

Assessing and optimising energy building performance are two connected activities intended for reducing energy waste and enhancing building occupant well-being. Several studies have been investigated over the past decade on this topic [157] [158]. With reference to exploiting building simulation models, a considerable number of studies focused on supporting energy management based on BIM optimisation has been carried out [159] [159] [160] [161]. For example, Abdelalim et al. [162] proposed a framework which exploits calibrated and adjusted BIM models to generate building performance simulation models in order to estimate and consequently display energy flows and the associated costs. Other investigations aimed to integrate several energy data sources to conduct an effective energy performance management. For instance, Gökçe & Gökçe [163] presented an Holistic Multi-Dimensional Information Management System which takes into consideration different and diverse energy data sets with the aim of optimising energy consumption. After collecting data through wired and wireless sensing devices, this system exploits an extraction transformation and loading tool to extract ifcXML and comma separated values (CSV) data types from BIM tools and sensors, respectively, and finally displays this data. To further boost energy management, applications regarding predicting energy consumes have been developed. For example, McGlinn et al. [164] proposed the web-interface BuildVis which aims to enhance the accessibility of facility energy data by collecting and storing data in a cloud database and conduct energy consumption prediction through data mining techniques.

### *3.1.5 Emergency management*

Emergency management refers to all the activities which concern preventing and solving hazardous situations, and accelerating and improving rescue and escape processes. This management deals with having real-time and updated data which can bring immediate response to requests of intervention. Indeed, emergency is an unpredictable condition as it can be caused not only by human mistakes, but also by natural disasters [53]. Referring to this management, two critical topics including emergency response and path optimisation, and hazard monitoring have been mainly investigated in the last ten years.

Emergency response and path optimisation are two fundamental tasks which have to be taken into consideration together, as one is directly connected to the other. The former regards the process of responding to emergency situations. Since actions to be taken to solve hazardous situations are always different and depend on diverse aspects, such gravity, time and context, they have to be considered in real-time and cannot be programmed. To this end, numerous studies have been carried out over the last decade to boost this process. For instance, Ma & Wu [165] proposed a BIM-based fire emergency management system which aims to detect fire, alert occupants and provide a countermeasure to emergency. Integrating multiple data sensing networks with video surveillance, the system is able to inspect the emergency, assesses its danger and its possibility to be controllable, and consequently advises the best action to be taken according to the behaviour decisions of building users, such as escape, wait for rescue, and fire extinguishing. Other studies have focused on the escape process, where building users need to be provided as soon as possible with an optimised path in terms of distance and safety to reach a safe zone [166] [167]. For instance, Zhang et al. [168] developed a BIM-based fire evacuation management framework which aims to collect data about emergency situation and consequently provide adequate escape paths. After collecting data through a Bluetooth low energy-based indoor real-time location system, the framework supplies occupants with a customised evacuation route according to the weighted summation of risk level index value calculated for the entire route. As well as improving the escape process, several investigations have been carried out to help first responders and rescuers to access to updated and useful building information and consequently act accordingly. For example, Cheng et al. [169] proposed a BIM-based Intelligent Fire Prevention and Disaster Relief System to dynamically generate optimised rescue and evacuation routes. Exploiting a 3D data visualisation for navigating inside buildings, the web system retrieves data through Bluetooth technology sensors and provides a 3D real-time and dynamic route of the shortest and safest path.

Hazard monitoring aims to detect the occurrence of emergency situations. Traditionally, this activity is carried out by human inspections and system alarms if buildings are equipped with them. For this reason, several studies have been conducted to improve this task [170] [171]. For instance, Vandecasteele et al. [172] presented a BIM-based methodology which aims to detect and localise hazards by using video analysis techniques. Comparing images of object taken from visual and thermal cameras in real-time with historical ones, the approach can identify emergency situations. Other studies focused on anticipating and predicting potential emergencies. For instance, Parn et al. [173] developed the BIM-based Confined Spaces Safety Monitoring System which aims to pinpoint hazards by integrating data collected though smart devices and archival records, and consequently produce useful insights.

#### *3.1.6 Research gaps*

Numerous studies have been carried out to improve the management of buildings over the last decade. During these research investigations, the main common denominator of the current studies is the generation of data and the use of valuable information. On the whole, it can be noticed that most of the studies for the effective digital management in different application fields lead towards the implementation of DT systems. However, a current gap in the literature includes the dearth of studies regarding the field of space management. In particular, there is a lack of investigations of the potential opportunities that the availability of an appropriate amount of up-to-date and real-time data generated by digital twins can provide for improving the space management of buildings. Along the lines of using information, another challenge concerns its comprehensive use for boosting decision-making processes. Since the quantity of data has been broaden in terms of volume, velocity and variety, but also complexity, analysing data has become more laborious and challenging [174]. In particular, when data is not collected in a numerical or structured way, but in the form of text, appropriate methods able to analyse this data are sought-after and required. Nevertheless, there is still a lack of specific and analytical methods for the transformation of text-based data into valuable information.

### 3.2 Digital management implementation

Adopting technologies and methods for integrating and analysing data is a critical aspect that has to be fulfilled when dealing with FM. Nevertheless, this aspect is not the only one that has to be considered to achieve an effective management of buildings. Indeed, disruptive technologies are not simple to implement, but need appropriate and structured methods [175] [176] [177]. Without a proper process of digital management implementation, several challenges including lack of in-house skilled professionals, costly software, lack of knowledge of the processes and workflows required, resistance to change from traditional working practices, and undefined return of investment can hamper their proper usage [178] [179]. To this end, few studies concerning new technology adoption processes in different management-related contexts have been carried out to accomplish an effective implementation. For instance, Petrova-Antonova & Ilieva [180] proposed a methodological framework which aims to guide and support the digital transition towards smart cities. This framework is based on six steps including analysing potential benefits derived from generating a digital city, identifying areas of intervention, using a pilot project, growing-up the process and extending it to another area of intervention, scaling the digital model, and monitoring and assessing by using performance indicators. Along these lines of digitalising the management of assets, other studies focused on the industrial context. For instance, Trauer et al. [181] presented a DT-based implementation method for an industrial case study, which uses a standardised use case template and a procedural model to formulate the value proposition, analyse the process and ideate a target process. This method is based on five steps including project initiation and goal definition, situation analysis, target conception, supplier analysis, and ultimately implementation. The first step identifies the relevant stakeholders, analyses the value proposition and implementation effort of existing case study, and formulates overall DT strategy. As a result, a priority-based implementation roadmap is generated by using a set of user stories which state the objectives and needs of stakeholders. Next, the situation is analysed by assessing potential areas of implementation. This means finding an area where DT has the opportunity to create a valuable improvement. After that, the target area where the most enhancement can be implemented is defined by using the documented starting situation. Finally, suppliers or internal stakeholders for implementation are identified. Similarly, Wei et al. [182] proposed an implementation strategy for DT manufacturing systems. This strategy is composed of two parts including the application-oriented requirement analysis of physical entities for DT manufacturing systems and the optimal requirement deployment scheme by using the axiomatic design. With reference to the implementation strategy, this is mainly based on the requirement analysis of DT-based applications. This analysis takes into account the characteristics of specific applications for different physical entities in manufacturing systems and the requirements of physical entities for DT manufacturing systems designed for specific applications. In particular, the requirement analysis includes DT model construction ability, data acquisition ability, data processing ability, and application service support ability. The first ability refers to the capacity to generate a DT, which has features according to different physical entities and specific application requirements, and determines if the model can be generated based on the information demand. The second one concerns the usage of technology able to collect data and operating states of physical objects. The third one regards the real-time mapping strategy between DT entities and physical entities. This means generating a mapping model support which is able to convert data and deals with interoperability issues. The last part is about providing decision-making tools, such as prediction of potential failures and behaviours. Aivaliotis et al. [183] proposed a general framework to generate DT for predictive maintenance of industrial robots. The approach consists of three phases including machine modelling selection, virtual sensors modelling identification, and modelling parameter definition. The first phase concerns selecting crucial machine components that has to be modelled and defining the principal physical phenomena which considerably affect the machine's behaviour. The second phase regards identifying data that needs to be gathered by the simulation and modelling virtual sensors according to the prefixed need. Finally, modelling parameters useful for updating and adjusting the model to the real machine's behaviour are defined.

Other studies focused on developing a framework for implementing DTs that meets the requirements of synchronous operation of production and logistics [184]. For instance, Jeschke & Grassmann [185] proposed a generic implementation strategy for implementing DT in logistics systems for rail transport with a focus on socio-technical and user-oriented development perspectives. The strategy is based on four steps including design, development, operation and decommissioning. The first phase aims to design the DT prototype of existing assets. This step begins with the analysis of the entrepreneurial environment, regulations and guidelines in order to identify the objectives and problems and consequently find the solutions by using a comparison methodology. After that, identifying stakeholders needs, which are related to the DT, is conducted in order to achieve a user-centric solution. Next, these needs are transformed in requirements and potential constrains are identified. These requirements are then transformed in technical specifications and checked for their meaningfulness by specific evaluation criteria. In the last process step of the design phase, an analysis of the designed DT is carried out, which is the basis for the technical understanding of the DT and the subsequent development of the DT. The development phase encompasses the connection between the real and virtual space by analysing the limitations that may occur and assembling the elements into a DT that verifiably fulfils the previously defined DT requirements, architecture and design. The operational phase of the DT regards an operational procedure on how operations will be carried out. This encompasses the planning of resources needed and the definition of relevant performance operational criteria, along with defining constraints on operations and appropriate systems and services, and identifying essential training and operators for operations. Furthermore, during the operation phase, the performance of the DT is recorded and monitored in order to provide the feedback of maintenance claims. Finally, in the fourth phase the DT is decommissioned. Zheng et al. [186] proposed a DT application framework for product lifecycle management. This framework has three core elements including physical space, virtual space and information-processing layer. The physical space refers to a dynamic production environment including people, machines, material, and rules, whereas the virtual space concerns the virtual environment platform and the DT application subsystem. Referring to the information processing layer, this layer has the main function of data storage, data processing and data mapping. To implement such framework, the implementation process took into consideration four main phases including the analysis of systems, the development of information models, the development of the simulation model, and finally, the integration of models. Ma et al. [187] presented a generic DT-based approach for quality control and optimisation of complex product assembly. This approach takes into consideration five main aspects for an effective implementation including building digital entities of assembly lines through historical data and process knowledge, real-time online sensing in multi-source heterogeneous environment, simulating equipment and assembly process in real-time, generating an intelligent production scheduling under uncertainty conditions, and dynamical adjusting assembly processes.

### *3.2.1 BIM implementation*

Among all the aspects for implementing an efficient system for managing buildings, one of the most problematic ones regards the BIM implementation. This challenge is due to the fact that BIM is a completely new process compared to traditional systems of collecting and managing building information. Thus, this has brought to difficulties in its implementation starting from the design phase to the operational phase. To overcome this issue, several studies regarding obstacles, limitations, key-enable aspects and benefits have been carried out in the construction industry over the last two decades [40] [188]. In addition, numerous proposals of framework with a focus on both macro and micro levels of initiatives which can support BIM implementation in organisations have been presented.

From the macro level point of view, governments take a leading role when new topics, which are critical for country economic growth, have to be implemented. In the particular context of BIM adoption, authority support can boost this process by providing regulation, education, funding, analysis and investigations, and case studies [189]. An increasing number of governments have been promoting BIM policies, along with implementation programmes in order to achieve growing participation and awareness. Among these initiatives, few cases have focused on advocating the usage of BIM in the operational phase. For instance, the UK government construction strategy after having mandated the exploitation of Level 2 BIM on all public sector projects in 2011, demanded the development of fully collaborative 3D BIM models, which have to include project and asset documentations starting from

2016 in order to achieve an effective asset management [190]. Similarly, the Building Construction Authority of the Singapore's building and construction industry after having announced their pioneer roadmap regarding the BIM technology adoption in 2011 [191], continued to pursue this path by presenting a second BIM roadmap which supported and boosted BIM for facilities management and asset management, especially promoting research and development, the development of BIM capabilities, and triggering process transitions [192] [64]. As well as governmental plans for adopting BIM, some schemes to implement BIM and evaluate its maturity within countries have been developed and presented. For example, Succar & Kassem [193] proposed a model which aims to illustrate which are the aspects and initiatives referring to BIM implementation at the national-level that influence a market-scale BIM diffusion policy by exploiting a market maturity-based matrix for large-scale implementation evaluation.

From the micro level point of view, several investigations which aim to analyse promising approaches and propose valid indicators for BIM implementation assessment have been carried out. With reference to a generic application context, Hochscheid & Halin [194] focused on detecting the main factors that can guide a BIM implementation process and proposing a five-stage process which can be divided in two sides including the decision side, which takes into consideration the choice of adoption and the implementation part, which concerns effective implementation and confirmation of adoption. Abdirad [195] proposed a thematic framework which aims to evaluate and promote BIM implementation in organisations by using two groups of classified metrics including general tool-related metrics, such as direct cost/time/performance, and scanning and image-processing metrics, such as scanner and registration tools and image recognition algorithms. Other studies focused on BIM adoption in private organisations and project teams [196] [197]. For instance, Juan et al. [198] conceived a predictive model which aims to assess BIM implementation practicality and viability in architectural firms. After having analysed organisational readiness and technology acceptance, the predictive model, which exploits an artificial neural network (ANN) method, was developed to provide a decision support for supporting BIM applications. Mirarchi et al. [199] presented an analysis of information requirements for BIM implementation in construction companies. In particular, this study focused on a process which aims to integrate quantity estimation models in construction company databases. Similarly, Nast & Koch [200] developed a concept framework which aims to support 5D BIM implementation in small and medium-sized enterprises, construction companies and project developers by showing priorities and hierarchies of this process. Troiani et al. [201] examined the potentiality of established macro BIM maturity factors in order to support BIM implementation in design firms. Among the aspects that has to be considered for adopting this new process, the key drivers included the readiness of using standard deliverables and components, namely BIM objects and libraries, and the requirement for including BIM in education. Olawumi & Chan [202] developed a BIM benchmarking model and a qualitative assessment template which aim to support BIM implementation for project organisations and project team in countries which are still in the early development phase of BIM adoption. The developed model is structured in three high-level concepts, namely innovative strategies at the BIM process level, innovative strategies at the BIM product level and measures of good practices. This model, along with the assessment template, which provides a quantitative metric system for the proposed model, aim to provide stakeholders of the construction industry with insights and counter-intuitive perspectives for BIM adoption. Along the lines of implementing BIM at an organisational level, Jallow et al. [203] analysed the process of adopting BIM collaborative practice by using a four-step approach. After having assessed historical projects and current processes, limitations and barriers are identified. Starting from these premises, a collaborative workflow which exploits a common data environment system is developed. The last step consists of an assessment of project achievements, which is carried out by the information exchange team. Other studies investigated methods for assessing the BIM level applied to construction projects. For example, Vilutiene et al. [204] presented a system of indicators based on both quantitative and qualitative features for evaluating the performance of BIM projects. The main aspects that were considered as crucial for BIM adoption assessment include project cost and schedule variance, the organisational scale of BIM deployment, BIM competency granularity level, BIM capability level, and BIM maturity level. Referring to public organisations, Giuseppe Miceli Junior et al. [205] proposed a basic BIM framework which aims to support BIM implementation in Brazilian federal PAs for an optimised development of a construction projects. This framework is based on a three-axial conceptual structure where the factors that governs each axis include model management, product management, and governance management. Ullah et al. [206] analysed the BIM adoption in a public authority and presented a generic model BIM adoption process with a focus on issuing building permits. The process consists of four steps including initiation, planning, execution and evaluation. As well as this process, a generic factor classification was developed to provide an analytical framework which aims to analyse the adoption process.

This sub-section is taken from an article written by the author of this dissertation which is under peer-review in the journal Architectural Engineering and Design Management, Taylor & Francis Group.

### *3.2.2 Research gaps*

On the whole, it can be noticed that although different digital management applications have been developed in the past years, there have been several investigations in general implementation strategies, but only a few studies considering the practical side. Thus, there is a lack of research regarding operational aspects which aim to support organisations in the implementation of an effective digital building management and its consequent assessment. In particular, with reference to the BIM implementation, it can be noticed that despite the investigations on this topic, some limitations and barriers, such as a change-resistance attitude to new methods and a lack of technical skills to manage cutting-edge technology, still hamper this process, especially in public organisations. Indeed, there is still a dearth of studies which investigate the process of putting in practice and checking BIM adoption by proposing practical frameworks that can support organisations to achieve this result.

# 4 Applications

In this section a series of applications to achieve an effective management of buildings is shown. The display order of these applications was decided following a strategy. The digital management of buildings can be obtained through a digital transformation. Thus, the devised strategy to achieve an effective management is based on a step-by-step improvement, which starts from implementing innovative methods and systems for the general purpose of building management and ends with developing and adopting technical solutions regarding specific fields. In other words, organisations need to gradually introduce new technology by starting with the main system that can collect, store, and use data and, when the main system is in place, focussing on specific issues. To this end, this section is structured in the following parts. The first sub-section begins with the implementation of BIM, which is the main common denominator for the digital management of buildings in both the design, construction, and operational phases. After that, the subsequent application expands the previous one with a focus on the facility management phase. Then, an operational process which exploits the knowledge gathered from the previous applications and consequently helps organisations to develop digital models for the operational phase is presented. Lastly, applications in the space management and maintenance management of buildings, which exploit the digital models developed following the previous applications and use data that is commonly generated and collected during the operational phase, respectively, are proposed to improve the management of buildings.

Some of these applications have been already presented at international conferences or published in international scientific papers. These parts are added entirely in this dissertation and citations have been added at the beginning of their sections.

## 4.1 BIM implementation method

The digital management of facilities is a complex process which needs appropriate elements, namely strategies, tools and skills, to be effectively conducted. New and innovative methods and pieces of software have been developed to obtain consistent results. However, before these powerful elements reach efficient outcomes, a successful digital transformation is needed. This means setting strategies and methods which enable the implementation of these components, especially if these proposed elements are cutting-edge.

After having identified the criticalities, issues and gaps regarding the digital management of buildings in the literature review section, the first issue which was taken into consideration is the adoption of the

BIM process. For this reason, a method which supports the implementation of the BIM process inside organisations is proposed. In order to properly manage buildings in a digital way, these have to be designed following specific procedures, and employees need to have a comprehensive education regarding managing new and existing buildings. Indeed, during the operational phase organisations can be in the middle of two situations. The first one concerns the new construction of a building that then the organisation will have to manage. The second one regards the maintenance, decommissioning or extension of an existing construction. Both situations follow the same procedure to be carried out in the BIM process. Thus, there is a need for organisations to know how to manage their buildings for all these situations.

Part of the following sub-sections is taken from an article written by the author of this dissertation which is under peer-review in the journal Architectural Engineering and Design Management, Taylor & Francis Group.

#### *4.1.1 Methodology*

The methodology employs a framework which aims to facilitate organisation to implement digital systems and innovative methods and check its effective adoption. To achieve BIM implementation, there is a need of organising and putting in practice a set of activities which are instrumental in managing, supporting and enhancing BIM deliverables and their related workflows. Based on the difficulties and strong attachment to old standards of operation, especially in the PA scenario, the proposed scheme supports a gradual and progressive transition. The framework is based on three main milestones including acquisition, modelling and validation, as shown in *Figure* ***24***.

The implementation steps follow the y-axis, namely time, where the three milestones have been identified, whereas the x-axis shows the autonomy level reached and the activity process that can be put in practice at each milestone. These defined milestones are three consecutive steps where each successive step begins only when the previous one is completed due to the fact that knowledge and competencies are developed in sequence. This means that there should be a transition to the next step only after a growth of the autonomy level.

The first step, namely acquisition, includes all the necessary actions to start adopting BIM tools, workflows and protocols. The second step extends the previous one in terms of tasks that need taking, but also in terms of abilities acquired for using modelling tools. The third step concerns the last part of knowledge required for achieving a complete BIM implementation. As well as having the ability to perform the previous steps effectively, in this last step the BIM skills and processes are broadened by covering the checking phase, where all the defined requirements and actions previously taken are verified based on the project objectives.

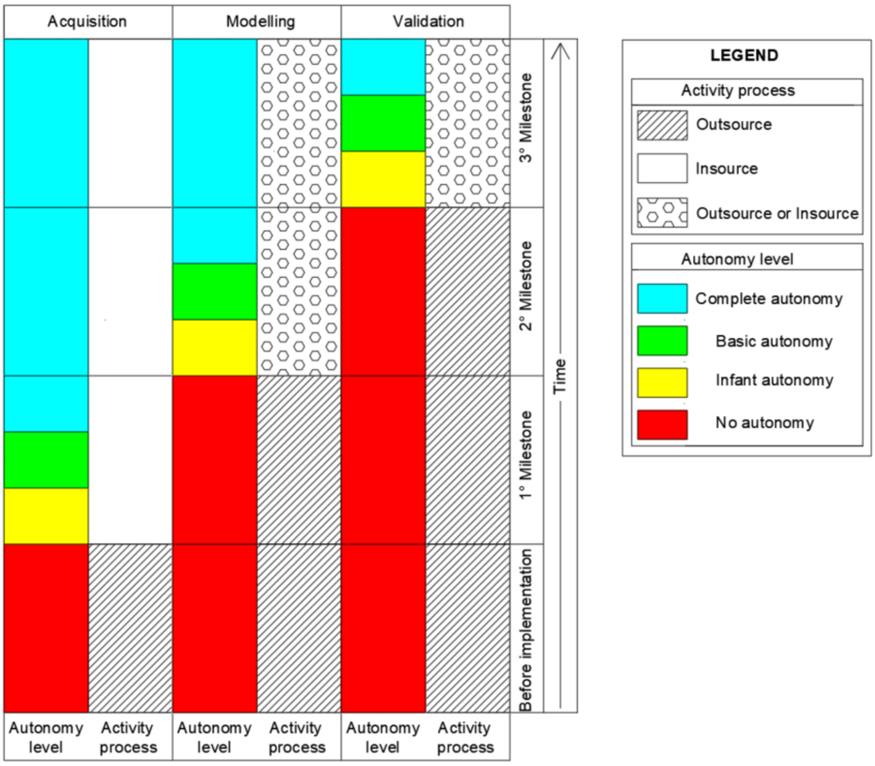


*Figure 24: Roadmap of implementation*

With reference to the way of managing the activity process, organisations should be supported and rely on third party professionals to perform BIM related activities until a basic level of autonomy is achieved. After reaching this autonomy, a choice between insourcing and outsourcing activities can be made in accordance with specific project types. Indeed, some process strategies, such as deciding whether to insource specific tasks or not, can be adopted on the basis of the availability of personnel and other priorities.

The achievement of the milestones is based on an iterative process, as shown in *Figure **25***, which aims to reach a continual improvement in quality, repeatability and confidence in performing BIM tasks. Each milestone begins with assessing the activities and procedures currently adopted and the BIM maturity level by using a survey. The second step consists of stating objectives defined for the specific milestone. For instance, being capable of preparing a BIM execution plan (BEP)[4] or developing a BIM model are common examples of objectives for the first two milestones. After defining goals, considerable investment in human resources, such as a series of educational and training activities, and

[4] BIM Execution Plan: a document which aims to define a foundational framework to ensure successful deployment of advanced design technologies on your BIM enabled project [207]

physical resources are necessary in order to boost BIM adoption. Next, a new process which includes different and diverse aspects is developed and implemented for the specific milestone. Depending on the scenario circumstances and choices of the organisations, this process of innovation can be conducted either by using own competences achieved until then or also being supported by expert third parties. Then, a pilot case study is carried out to test the acquired knowledge and the new innovative process. Finally, the results of the case study are presented and assessed. During this phase, the fulfilment of the defined objectives is checked and a series of Key Performance Indicators (KPIs) based on five-point-based levels is used in order to evaluate the current situation of implementation. In particular, level zero corresponds to no BIM autonomy, level one to infant autonomy, level two and three to the basic autonomy, while level four indicates a complete BIM autonomy. Finally, a set of lessons learnt to be used in the next iterative cycle can be produced. The lack of complete fulfilment of goals can stem from an inadequate education and/or a deficient process of implementation.

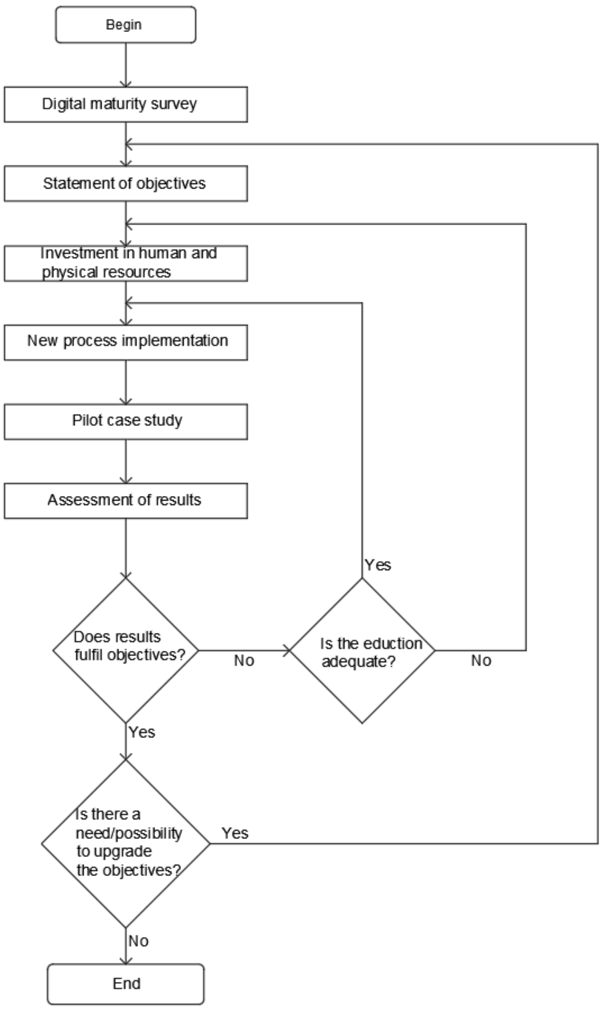


*Figure 25: Iterative process*

With reference to the aspects to be considered when implementing new BIM processes, the proposed methodology divided these aspects in two main categories including technical and organisational aspects, as shown in *Figure **26***. The former consists of two subcategories, namely technology and specific skills. The technology subcategory refers to all aspects connected with technological tools, while the specific skills one regards all the competences and knowledge to perform specific tasks effectively. Similar to the technical part, the organisational aspects consist of two main subcategories including internal coordination and internal collaboration.

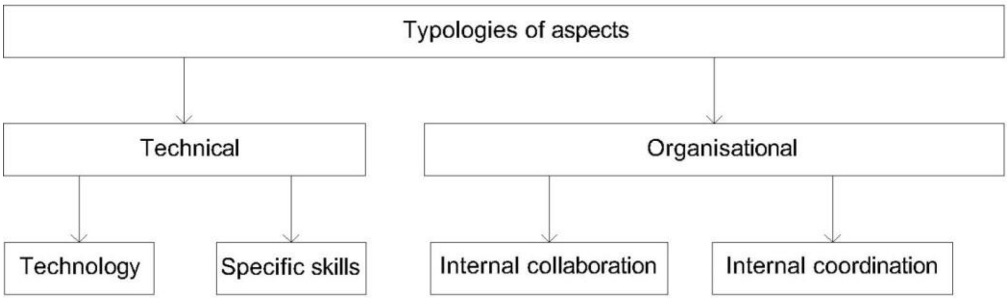


*Figure 26: Typology of aspects*

For each of the defined milestones, the set of aspects which are proposed to be taken into account when implementing the BIM process is summarised in *Table **2***.

<table>
<tr><th></th><th colspan="2">Organisational</th><th colspan="2">Technical</th></tr>
<tr><th></th><th>Internal collaboration</th><th>Internal coordination</th><th>Technology</th><th>Specific skills</th></tr>
<tr><td>Acquisition</td><td rowspan="3">Collaboration process<br><br>Colleague collaboration</td><td rowspan="3">Coordination system</td><td>Acquisition software<br><br>Means of exchanging information</td><td>General strategic priorities<br><br>Project deliveries<br><br>Level of Information need<br><br>BIM model objectives and uses</td></tr>
<tr><td>Modelling</td><td>Modelling software</td><td>Modelling standards<br><br>Modelling skills</td></tr>
<tr><td>Validation</td><td>Validation software</td><td>Skills in clash detection<br><br>Skills in model and code checking</td></tr>
</table>

*Table 2: Aspects for BIM implementation*

### *4.1.2 Checking indicators*

#### *4.1.2.1 Organisational aspects*

Innovative processes need suitable internal reconfiguration of organisations. This means avoiding the scarcity of sharing information, failure of processes, and the lack of cooperation among professionals involved. Thus, organisational aspects are key drivers for successful BIM implementation. The proposed methodology identified two principal aspects including internal collaboration and internal coordination. The former aspect refers to establishing effective ways and means of communicating among colleagues of the same and different offices inside the organisation. The latter regards establishing systems and protocols of coordination and defining new roles. To assess the readiness and maturity of organisations regarding the above skills, a set of Key Performance Indicators (KPIs) is developed, as shown in *Table 3*. Each of the indicators is based on a five-point-based evaluation which enables conducting the implementation assessment.

Since organisational aspects consist of cross-competences and soft skills, the proposed organisational aspects are relevant and have to be taken into consideration for all tasks conducted during the operational phase. This means that with the necessary changes, each of these aspects can be adapted to be suitable for all situations.

| **Performance category** | **Indicator** |
|---|---|
| Internal collaboration | Collaboration process<br>Colleague collaboration |
| Internal coordination | Coordination system |

*Table 3: Categories of indicators*

With reference to the internal collaboration part, the collaboration process and the colleague collaboration are vital features for effective workflows. The former regards the existence of a defined collaboration process and its efficacy. This indicator takes into consideration the extent of process mapping completeness and improvement as principal features for avoiding time-consuming and useless workflows, as shown in *Table **4***. The latter concerns the relationships among workers of the same organisation with a focus on conducting tasks as an effective teamwork. In this case, the degree and intensity of collaboration among workers are the main considered features, as shown in *Table **5***.
Since both indicators refer to collaboration, these two indicators are related one to each other. However, each of them describes a specific aspect of collaboration in an organisation which cannot be

completely overlapped by the other one. For instance, the existence of a collaboration process indicates the preparation of an organisational defined scheme, while collaboration among workers highlights the willingness and capacity of workers to exchange information to each other in order to put effectively into practice the collaboration process.

Once the internal collaboration is effectively handled, its aspects can be extended to the external collaboration by shaping its application. This means that after having acquired a good preparation and experience of how to manage internal aspects, this can be applicable to external contexts.

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No collaboration process | Limited collaboration process with time wastage | Integrated collaboration process with a surplus number of times of exchange of information | Standardised collaboration process | Standardised and continuous improving collaboration process |

*Table 4: Collaboration process*

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No collaboration | Mess collaboration among workers | Effective linear collaboration with same area colleagues | Effective linear collaboration with same area colleagues and limited and poor collaboration with different area colleagues | Effective linear collaboration with same area colleagues and close collaboration with different area colleagues |

*Table 5: Colleague collaboration*

Referring to the other part of the organisational aspects, namely internal coordination, the indicator monitors the management of operations by taking into account the presence and degree of a coordination system and the quality of process organisation. The former indicator considers the centrality of decision making as the principal feature, as shown in *Table **6***. The more tasks are coordinated by means of a centralised system, the more these activities can be accurate and detailed and employees are assigned to specific roles. Furthermore, this leads to a clear setting of responsibilities. The latter takes into account the importance of having a well-structured organisation to put in place and conduct processes related to all activities, as show in *Table **7***. This means that having a procedure protocol to follow in which processes are well analysed and articulated enables boosting the coordination inside organisations.

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No central system | Optional and secondary systems | Optional and poor central system | Standardised central system | Central system continuously improved |

*Table 6: Coordination system*

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No process organisation | Process organisation based on personal knowledge and experience | Optional and scarce procedure protocol for process organisation | Standardised general procedure protocol for process organisation | Detailed and continuously improved procedure protocol for process organisation |

*Table 7: Process organisation*

#### *4.1.2.2 Technical aspects*

Contrary to the organisational aspects, the technical ones are assessed by considering different indicators for each of the three identified milestones. These aspects belong to two categories including technology and specific skills.

##### *4.1.2.2.1* Acquisition

Since the level of skills takes time to be elevated, the predominant and forthcoming need, especially for public organisations, includes possessing the necessary equipment to manage BIM models and having a professional knowledge about the use of methods and electronic tools to request works regarding the BIM process. To this end, the first step of the proposed process aims to provide organisations with a body of knowledge suitable for verifying that they are in possession of all the equipment and skills to outsource BIM projects and consequently receive and use the deliverables. Thus, during this acquisition phase, organisations specify their needs in terms of standards and requirements and are supposed to receive an appropriate response in terms of documents and consequently in terms of digital models. In particular, in this context the specific skills part mainly refers to identifying project requirements and preparing the related document, namely the BIM Execution Plan (BEP). To assess the readiness and maturity of organisations regarding the above skills, a set of Key Performance Indicators (KPIs) is developed, as shown in *Table* ***8***.

| **Performance category** | **Indicator** |
|---|---|
| Technology | Acquisition software<br>Means of exchanging information |
| Specific skills | General strategic priorities<br>Project deliveries<br>Level of Information Need<br>BIM model objectives and uses |

*Table 8: Categories of indicators*

With reference to the technology part, indicators monitor features including the acquisition software and the means of exchanging information. The former represents the package of tools which organisations are in possession of and use for complying with the acquisition of BIM models. This indicator takes into consideration as a principal feature the capability of the set of organisation tools for importing both non-proprietary and proprietary formats, as shown in *Table* ***9***. This choice is due to the fact that the exchange process needs as much interoperability as possible to manage models in the building life cycle phases. Since there should not be a preference of a software house rather than others, organisations may conduct a survey to identify the most used proprietary format of their possible future project stakeholders to reduce interoperability issues. For instance, if an organisation's action range is limited to a local area, only local professionals and firms need to be investigated.

The second indicator concerns the means of exchanging information. This refers to the method of how information, models and issues are communicated among project stakeholders. In this case, the capability of viewing, uploading and downloading models and files in a secure, organised, shared and traced way along with highlighting and solving issues are the main considered features, as shown in *Table* ***10***.

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No acquisition tool | The acquisition tool can support only non-proprietary formats | The acquisition tool can support non-proprietary formats and one proprietary format specific for one construction discipline | The acquisition tools can support non-proprietary formats and some proprietary formats which are specific for more than one construction discipline | The acquisition software can support non-proprietary formats and some proprietary formats which encompass all construction disciplines |

*Table 9: Acquisition software*

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No exchange of information | Exchanging information in person by using CDs or USB drives | Exchanging information through internet by emails | Exchanging information by using a smart web platform, such as Dropbox, which allow stakeholders to upload and download models and files in a secure, organised, shared and traced way | Exchanging information by using a smart web platform which allow stakeholders to view models and directly highlight issues, upload and download models and files in a secure, organised, shared and traced way |

*Table 10: Means of exchanging information*

On the other hand, the specific skills part concerns the competence to write the BEP, which is the vital reference in which the needs of organisations are stated. Four main parts including the definition of general strategic priorities, project objectives, level of information need for models, and BIM model objectives and uses were identified as crucial and essential points to convey the message to companies tendering for the role of lead appointed party. Referring to the first two indicators, their KPIs are similar as one is derived from the other, as shown in *Table **11*** and *Table **12***. Indeed, general strategic objectives stem from the need to satisfy high-level goals of organisations, while project objectives aim to translate the strategic ones into information requirements based on the specific project.

With reference to the other two indicators, these are specific and technical features, which describe the quality of BIM models, and their objectives and uses, respectively, as shown in *Table **13*** and *Table **14***. BIM models should not contain an overwhelming quantity of data but need to be inputted with precise information for conducting specific tasks. At the same time, their use should be appropriately defined in order to be exploited properly when needed and relevant. All these indicators take into consideration the ability to define them in a clear and functional way in order to suit the needs of organisations and avoid misleading and inaccurate requirements.

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No definition of strategic priorities | Optional and poor strategic priorities | Basic, standard and common strategic priorities | Simple and general strategic priorities | highly relevant, well fitted and detailed strategic priorities |

*Table 11: General strategic priorities*

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No definition of project objectives | Optional and poor project objectives | Basic, standard and common project objectives | Simple and general project objectives | highly relevant, well fitted and detailed project objectives |

*Table 12: Project objectives*

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| Lack of definition of Level of information need | Sporadic and erroneous definition of Level of information need | Limited and poor definition of Level of information need | General and relevant definition of Level of information need | Detailed and relevant definition of Level of information need |

*Table 13: Level of Information Need*

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No definition of BIM model objectives and uses | Optional and poor definition of BIM model objectives and uses | Basic, standard and common definition of BIM model objectives and uses | Simple and general definition of BIM model objectives and uses | highly relevant, well fitted and detailed definition of BIM model objectives and uses |

*Table 14: BIM models objectives and uses*

##### 4.1.2.2.2 Modelling

Once the basis of the BIM process for receiving BIM models is understood and properly put in practice through the first phase, the next step regards the need of improving specific technical skills related to BIM tools in order to develop models in-house. Similar to the previous step, organisations specify their needs in terms of standards and requirements, but in this case the outcomes in terms of digital documents and models are provided by the same organisation. Thus, this second step of the proposed process aims to provide organisations with the proper body of knowledge and skills for setting up the modelling requirements and developing appropriate informative models. Specifically, this step concerns the detailed preparation of model settings, which are preliminary to start developing complex BIM models, and the consequential modelling. In particular, in this context the specific skills part mainly refers to the modelling standards and modelling skills. To assess the readiness and maturity of organisations regarding the above skills, a set of Key Performance Indicators (KPIs) is developed, as shown in *Table **15***.

| Performance category | Indicator |
|---|---|
| Technology | Modelling software |
| Specific skills | Modelling standards<br>Modelling skills |

*Table 15: Categories of indicators*

Referring to the technology part, the indicator monitors the presence of modelling applications within the structure. The modelling tools represent the package of software used by the organisation for developing BIM models. This indicator takes into consideration the capability of tools to develop BIM models related to different construction disciplines, such as architectural, structural, and mechanical, electrical and plumbing (MEP) as a principal feature, as shown in *Table **16***. For instance, a tool can be appropriate to develop architectural models, but cannot produce structural ones. This means that organisations have to own different and diverse tools to effectively manage specific types of data during modelling activities. However, it is important to underline that owning several BIM tools encompassing all the different construction disciplines is not fundamental, as organisations may not need all of them due to their specific target or the choice of outsourcing tasks. Thus, organisations should equip themselves only with tools which involve the core competence of the organisation. This means that since organisations have specific areas of expertise, the top level to be considered in *Table **16*** has to be up to level 1, level 2, level 3 or level 4 according to the organisation's core competencies. For instance, an organisation that needs to manage only the architectural part fulfils its top level when reaches level 1.

| **Level 0** | **Level 1** | **Level 2** | **Level 3** | **Level 4** |
|---|---|---|---|---|
| No modelling tool | The modelling tools consists of one BIM tool which is specific for one construction discipline | The modelling tools consist of BIM tools which are specific for two main construction disciplines | The modelling tools consist of BIM tools which are specific for the three main construction disciplines | The modelling tools consist of BIM tools which are specific for the three main construction disciplines and other subsidiary construction disciplines |

*Table 16: Modelling software*

With reference to the specific skills part, this consists of two main indicators: modelling standards and modelling skills. The former indicator concerns the definition of specific settings before starting to generate BIM models, as shown in *Table **17***. The more specific settings an organisation configures, the more useful and easy-to-use BIM models are. Two aspects including defining specific templates and generating specialised object libraries are considered. The first one varies from a general customisation of definition of project data and layouts to highly specific customisations. The general personalisation takes into consideration one configuration which can be used for all construction activities. The specific customisations are used to fit the request of detailed data properties which are needed to be generated in specific construction scopes. The second aspect concerns the creation of an object library which focuses on the organisation needs. While a generic object library corresponds to a set of object families which are customised with generic parameters useful for all modelling tasks, the specific object library encompasses object families with an addition of detailed parameters for specific construction information to the general ones.

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No modelling standards | Definition of a customised generic template | Definition of a detailed customised template for each construction discipline | Definition of a detailed customised template for each construction discipline and definition of a generic object library | Definition of a detailed customised template for each construction discipline and definition of a specific object library |

*Table 17: Modelling standards*

The latter indicator focuses on the ability to develop BIM models, as shown in *Table **18***. Organisation target in terms of construction discipline managed can be different according to the types of organisations, therefore there is a need to learn how to manage all of them. The proposed indicator takes into account the learning process which usually takes place. This learning process is composed of four steps. Firstly, skills for modelling one construction discipline, which is usually the architectural one, are developed. Secondly, organisation personnel develop specific skills in all construction disciplines. Third, modelling skills for one of the construction disciplines are highly developed. Finally, modelling skills for all construction disciplines are developed with high expertise.

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No modelling skills | Basic and general modelling skills for one construction discipline | Basic and general modelling skills for all construction disciplines | High modelling skills for one construction discipline, and basic and general modelling skills for the rest of construction disciplines | High modelling skills for all construction disciplines |

*Table 18: Modelling skills*

#### 4.1.2.2.3 Validation

Once the previous two milestones are achieved, there is a need to cover one last part which needs a comprehensive understanding and view of the preceding phases to be performed properly. This third step of the proposed process aims to provide organisations with suitable skills for managing the validation phase. It concerns the accurate verification that every requirement requested and information generated in the previous phases are in compliance with the objectives stated at the beginning of the project. Although this is a crucial part for achieving accurate results, it needs time and skills to be handled completely. In particular, in this context the specific skills part mainly refers to checking skills, namely ensuring that models are error-free, avoiding geometric interference and verifying that defined informative requirements are fulfilled. To assess the readiness and maturity of organisations regarding the above skills, a set of Key Performance Indicators (KPIs) is developed, as shown in *Table **19***.

| **Performance category** | **Indicator** |
|---|---|
| Technology | Validation software |
| Specific skills | Skills in clash detection<br>Skills in model and code checking |

*Table 19: Categories of indicators*

With reference to the technology part, the indicator monitors the validation software. The checking software represents the software which the organisations are in possession of and use for complying with checking BIM model requirements and detecting potential errors. This indicator takes into consideration the capability of a tool of supporting both clash detection[5] and model and code checking[6] activities for different construction disciplines as a principal feature, as shown in *Table **20***. The more the tool has an inclination for customising checking rules, the more it is useful for adapting to any situation and avoiding misleading results. For instance, managing the process of thousands of potential clashes in which some of them are false positives can be daunting and time consuming, therefore the possibility to set up clash rules is extremely valuable.

[5] Clash detection: the activity which manages and pinpoints geometric interferences that can occur when models are generated

[6] Code checking: the activity which substantiates essential and quality requirements

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No validation software | The tool used as validation software can support only visualisation of BIM models | The tool used as validation software can support basic clash detection and model and code checking activities for only one construction discipline | The tool used as validation software can support basic clash detection and model and code checking activities for all construction disciplines | The tool used as validation software can support rule-based clash detection and model and code checking activities for all construction disciplines |

*Table 20: Validation software*

Referring to the specific skills part, this concerns the ability to identify duplication and overlapping objects, data inaccuracies and mistakes in models by conducting clash detection and model and code checking activities. The former indicator focuses on clash detection skills, whose aim is to manage and pinpoint geometric interferences that can occur when models are generated. Being capable of setting up an appropriate set of clash rules allows detecting both hard and soft clashes and ignoring those that are not currently of interest or are not real clashes. For instance, a window object might be composed of a frame and a pane and they can be modelled so that their parts touch or are overlapped. Smart and appropriate rules can ignore these clashes, resulting in reducing false positives. Thus, the indicator assesses the approaches used to conduct clash detection activities, as shown in *Table **21***.

The other activities refer to checking model global coordination and informative requirements. The former consists of verifying the correct alignment among models in terms of global shared and geo-referenced coordinates, shared grid tracing and elevation levels. The latter concerns tasks to substantiate essential and quality requirements including category assignment, object nomenclature, and level of information need compliance among principal and secondary elements of all disciplines. Similar to the previous indicator, this one assesses the approaches used to conduct checking activities, as shown in *Table **22***. The more an approach is appropriate and adaptive to projects, the more it is valuable.

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No clash detection | Manual clash detection | General pre-defined rules for clash detection | Static customised clash detection rules | Highly relevant, dynamic and continuous improving customised clash detection rules |

*Table 21: Skills in clash detection*

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No model and code checking | Manual model and code checking | General pre-defined rules of model and code checking | Static customised rules | Highly relevant, dynamic and continuous improving customised rules |

*Table 22: Skills in model and code checking*

#### *4.1.3 Discussion and considerations*

Digital systems and innovative methods, such as BIM, have been gaining momentum in the construction industry over the last few decades. However, organisations, especially public ones, have not implemented BIM in a successful manner yet [208]. For instance, in the particular context of Italy, public organisations have shown a medium–low level of BIM maturity and a small level of knowledge about the BIM process is still persistent even if the Italian law on the use of BIM (DM 560/2017) has been already mandated [209]. To this end, according to [210] [211] [212], practical frameworks can be extremely valuable especially for organisations which lack expertise on BIM implementation, and have cultural and organisational barriers.

On these premises, the proposed application provides exploratory research contributing to the body of knowledge regarding the BIM process by developing an operational framework for its implementation and consequent assessment. The proposed framework supports organisations in adopting BIM thanks to its operational settings which enable understanding what are the main aspects to take into considerations and how to implement and assess them. The valuable strength of this framework stems from the inclusion of not only technical aspects, such as developing BEPs, BIM library, and personnel skills, but also organisational aspects, such as optimised collaborative work, which are fundamental for an effective adoption [213] [208].

Aligned with previous studies found in literature, this research addresses the need for a more practical and applied view of BIM, as operational mechanisms to support the BIM implementation are still lacking or are still not at an adequate level [214] [215]. Along these lines, organisations often lack the knowledge to guide BIM implementation, generating a demand for processes and frameworks for BIM implementation [216] [217]. On this purpose, the framework addressed this issue by providing a step-by-step BIM implementation framework. Furthermore, according to [218] [219], the need for organisations to assess their performance is paramount to compel progress and innovation. Aligned with these works, the provided framework fulfils the need of organisations to monitor their BIM process by highlighting important aspects to check the adoption. In particular, [220] pointed out that very limited practical measures for assessing BIM implementation have been developed. To overcome this issue, the proposed work presents a series of KPIs which helps to monitor, measure, and improve BIM practice, with a focus on people, process and technologies as identified by [221]. The implementation for innovative technologies in the construction industry is a lengthy process and needs a continuous improvement [210]. To this end, this work is also aligned with [215] [222] [210], as it underlines the importance of exploiting an iterative approach which modifies its objectives in accordance with the grade of maturity. In addition to a cyclical framework, this work also supports the parallel reconfiguration of practice identified by [218] [219], where performance assessment and BIM implementation need to be developed conjointly to serve one another and enhanced in an ongoing manner.

No published works contradict the findings. However, some of them defined what are the main and subsidiary aspects to be considered in BIM implementation, while the proposed framework gives an equal importance to all of them. For instance, [209] stated that the definition of design and deliverable standards are not so important, whereas the proposed framework highlights them as an important ones. The same conclusion can be seen for other aspects including defining clear objectives for BIM implementation, and requesting help from external consultants [223]. Nevertheless, these studies supported the proposed framework highlighting a great need for technological and skills aspects, and need for an organisational improvement.

## 4.2 FM system aspects

Once requirements and processes which lead to the generation and consequent management of digital models are effectively applied and managed, organisations need to set up a system able to acquire, transmit, integrate, manage and exploit a comprehensive and ongoing flow of data. BIM brings a great change in modus operandi for all construction disciplines, and when BIM models are integrated with operational data in FM systems, this enables managing the Digital Twins of facilities. Digital models are not the only critical part of management systems. Indeed, what is strongly highlighted and regarded as a fundamental feature of the O&M stage is the centrality of data. Both static and dynamic data need to be available to support FM activities. The efficient digital management of buildings is not simple, as the amount of data produced in this phase is exponentially increasing. Its amount is a double-edged sword. On the one hand, data is a valuable and great resource. This allows FM personnel not to start from scratch to handle FM tasks. On the other hand, its abundance might compromise an effective management, leading to time-consuming analysis and incorrect outcomes. Thus, it is fundamental to have access to the right data, in the right format, at the right time in order to perform efficient FM decision-making processes. To this end, a set of essential features which can lead the implementation of an efficient FM system for managing buildings is proposed, as shown in *Table **23***.

| | **Technical** | |
|---|---|---|
| | **Technology** | **Specific skills** |
| **Management system** | Data acquisition<br>Data transfer<br>Data storage<br>Data integration<br>Data analysis | |

*Table 23: Main aspects for FM systems*

### *4.2.1 Checking indicators*

In the previous section of BIM implementation, indicators for checking aspects covering both organisational and technical parts have been already mentioned to achieve the result of an effective management. For instance, editing data of a BIM model might not be easy for technicians who have not received an appropriate education of modelling. Nevertheless, indicators for specific technical aspects regarding the system which puts in practice the management of buildings need to be accurately considered.

#### 4.2.1.1 Technical aspects

The technical aspects are assessed by considering different indicators which consider both technology aspects and specific skills. Overall, these aspects imply having a system which possesses the capacity to collect, transfer, store, integrate, visualise, edit and manage data in order to provide high information quality for managing buildings.

First of all, the management system needs an adequate method for collecting data during the operational phase. During this stage data is continuously produced and is critical to conduct FM activities, but not always this data is captured effectively. The indicator takes into consideration as main feature the capacity of the management system to record data by using automatic systems, as show in *Table* **24**. Traditionally, data is collected by conducting on-site inspections in order to capture information in that occasion. Nevertheless, there exists the opportunity to exploit fixed devices which can perform ongoing and accurate measurements, avoiding time-consuming tasks for data acquisition. This enables an efficient collection of data both in terms of quantity and quality.

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No data acquisition | Manual on-site data acquisition | Semi-automatic data acquisition | Automatic data acquisition after a fixed period | Automatic data acquisition in real time |

*Table 24: Data acquisition*

Secondly, once data is collected, it needs to be transmitted to a storage place to be successively used. Data transfer is the second fundamental feature that has to be considered for management systems. Indeed, there is a need to efficiently communicate data collected from the physical world to a working one, such as the digital world. Similar to the data acquisition, the indicator considers as principal feature the capacity of the management system to transfer data through automatic systems, as show in *Table* **25**. Data can be transmitted by using different means. For instance, data can be transmitted by using portable devices, such as USB. This means obliging FM professionals to manually transmit the data acquired, leading to a slowing down of the management process. Furthermore, the next step would be managing data in terms of interoperability in order to make it usable for successive applications with a consequent waste of time. On the contrary, what is highly valorised is the capacity of transmitting data by using intangible means, such as internet. This enables not only an easy and fast exchange of data between the collecting device and the storage place, but also a compatibility in the data transmission process due to strong processes and links of data format conversion.

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No data transfer | Manual data transfer | Semi-automatic data transfer | Automatic data transfer after a fixed period | Automatic data transfer in real time |

*Table 25: Data transfer*

Thirdly, data needs an appropriate place to be stored. Data storage is the third vital element that has to be taken into consideration for management systems. Even if data is collected, it is accessibility has not to be underrated. Wasting time in retrieving data needed can result in delays and cost for organisations. This means that having a specific place where to obtain what is needed can boost the overall management. The indicator takes into consideration as principal feature the data storage typology of the management system, as show in *Table* ***26***. Traditionally, data was stored by using paper-based documents. This method entails not only a need of a huge space to accumulate folders, but also people to manage the depository and time to find the correct document. Thus, the trend has moved towards a computer-based storage. In particular, the more a data storage system enables accessing data from different worksites and information is readily available, the more this approach is valuable.

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No data storage | Paper-based data storage | File-based data storage on hard drive repositories | File-based data storage on intranet repositories | File-based data storage on a central cloud repository |

*Table 26: Data storage*

Management systems which store data is not enough for an efficient management. As well as storing data, data needs to be integrated. Data integration is the fourth top priority that has to be considered when managing buildings. Even if data is stored, there might exists duplication of data due to acquiring data by using different and diverse devices. Furthermore, when data is modified, added and deleted, there is a need to have a comprehensive change in each part of the management system. This means that integrating data in a structured way enables sharing useful information to create knowledge and potential gains, avoiding the phenomenon of data scattering and data silos. The indicator regards as principal feature the data integration quality of the management system, as show in *Table* ***27***. Since a set of data is beneficial if this derives from heterogeneous sources, what is necessary to achieve is reducing manual work to combine data. In addition, exploiting automatic change of data values which encompass all organisation application fields enables an improved data synchronisation, which in turn leads to substantial benefits.

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No data integration | Manual data integration of singular organisation departments | Manual data integration of all organisation departments | Semi-automatic data integration of all organisation departments | Automatic data integration of all organisation departments |

*Table 27: Data integration*

Data stored and integrated can produce useful information to conduct tasks, especially when this is investigated by exploiting data analysis techniques. Data analysis is another fundamental characteristic that has to be considered when managing buildings. Data analysis can be carried out both outside and inside the management platform, leading to different upsides and downsides. On the one hand, if data is analysed by using alternative methods rather than the management system, the opportunity to conduct this task do not have extension limitations, but implies the need to perform import/export procedures and the increase of time to have a consistent and immediate result to consult. On the other hand, using a management system which is provided with a data analysis section enables speeding the process of having supporting outcomes and automatically produce accurate and detailed reports, but does not allow further analysis than those already implemented in the system. Nevertheless, in this latter case, there is always the opportunity to export data to conduct further investigations if needed. The indicator takes into consideration as principal feature the potentiality of management systems to include a section of advanced data analysis, as show in *Table **28***. To produce valuable insight, there is a need to search, filter, and sort data. In addition to it, the more a management system is provided with powerful analytics, the more straightforward and efficient understanding issues and trends, and consequently developing strategies to obtain high results is.

| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| No data analysis | Data analysis based on paper-based documents and personal knowledge and experience | Data analysis based on descriptive analytics | Data analysis based on descriptive and diagnostic analytics | Data analysis based on descriptive, diagnostic and predictive analytics |

*Table 28: Data analysis*

### *4.2.2 Discussion and considerations*

The operational phase needs ongoing updated data to conduct FM activities effectively. This means that FM systems needs to possess the main features to proceed in all steps from acquiring data from the physical world to ultimately make it available in a digital way for analyses and elaborations. In this regard, a set of aspects which are fundamental for setting a reliable FM system is proposed. Overall, the valuable strength of this proposal stems from the statement of the main features for FM systems and useful indicators to practically assess their quality.

Aligned with past research present in literature, this proposal highlights the main points for FM systems to manage operational data. First of all, data needs to be acquired from the physical world and consequently transferred to a repository. Exploiting an automatic manner can avoid time-expensive on-site investigation, speed up data acquisition and transmission, and diminish the possibility of having lack and shortcoming of data [224] [225] [226]. According to [227] [228], the management of smart buildings needs automatic processes in order to enhance accuracy, productivity, and efficiency of building data acquisition and transmission. Aligned with these studies, the proposed indicators regarding data acquisition and data transferring present a scale which rewards the availability of real-time data acquisition and transmission and their level of automation. When collected, data needs to be stored in a repository. The third indicator considers critical moving from separate data storage repositories to a unique central one and exploiting cloud computing systems to store data. The fourth one is strictly connected to the previous one and emphases the importance of having an automatic data integration. Diverse sources support these two indicators and several applications have been already developed using the web to store and integrate data [229] [230] [231] [232]. For instance, [233] pointed out the value of having a central repository due to its capability to share the same data throughout the organisation, reducing time-consuming updates and redundancies. Once data is stored and integrated, it can be analysed to provide useful insights. The main kinds of analysis exploited in different applications includes those which present what happened in the past and why it happened, namely the descriptive analytics and diagnostic analytics, respectively, up to reach a more advance one able to predict what might happen, namely the predictive analytics [234] [235]. In particular, this last one is regarded as the one able to avoid unwanted consequences and consequently yield significant savings [236] [237]. According to [238], the value contribution, but also the complexity of these kinds of analytics is in ascending order. Aligned with these works, the provided indicator regarding data analysis presents gradual steps of improvement in conducting analysis following the previous approach, with predictive analysis as final step.

## 4.3 The process of developing digital models for FM

The development of BIM models lays the foundations for the operational phase. This means that the management of buildings needs to be supported by different digital models in order to conduct its tasks and achieve an efficient performance. Developing digital models includes different and diverse tasks according to the purpose and situation. In particular, there exist two different paths, which organisations can exploit in order to reach the same objective, including outsourcing and insourcing the development of digital models.

With reference to the outsourcing procedure, this option leads to three main upsides. Firstly, organisations have the opportunity to hire expert professionals to carry out the task. Secondly, organisations can focus more on the core business, namely the operational management of buildings. Thirdly, costs for buying and/or hiring specific equipment and tools are reduced or even avoided. However, this option has also downsides. For instance, there might be necessary to conduct an extra-control of what external workers do compared to the internal ones. Along these lines, organisations allow other parties to come into possession of and manage private and sensitive data belonging to the organisations. Furthermore, in the case of an outsourcing procedure for any development of digital models, this might lead to a decrease of specific know-how of organisations. This means that when this competence is requested in future, it is possible that nobody has it or knows how to put it into practice.

Referring to insourcing the tasks of developing digital models, this option is the opposite of the previous one and leads to different and contrary pros and cons. On the one side, there is a need to have expertise, along with appropriate software and machineries to carry it out. On the other side, the leakage of information is avoided and a simple average supervision of the task is necessary to achieve a high standard result. Moreover, organisations possess the specialised competence and control the entire workflow of operations. As a result, organisations can coordinate and regulate processes in order to boost them and avoid any bottleneck.

In their procedures these two paths encompass parts which are in common and parts which are specifically conducted in one particular path in order to reach same objective, as shown in *Figure **27***. In this figure the main steps that has to be taken into consideration to develop a digital model for FM purposes are illustrated. In particular, compared to the outsourcing procedure which does not have particular differences in its flow, the insourcing one has to deal with two different situations, which are the following:

a. New construction;
b. Existing construction.

The main difference between the two situations is the presence of data available. In the first case the facility is not built yet and therefore there is no data available, but this data is going to be generated throughout the design and construction processes. In the second situation data belonging to the existing facility is already created and available to be used after being checked and integrated. These two options are considered as one in the outsourcing procedure, as all works are entrusted to third parties.

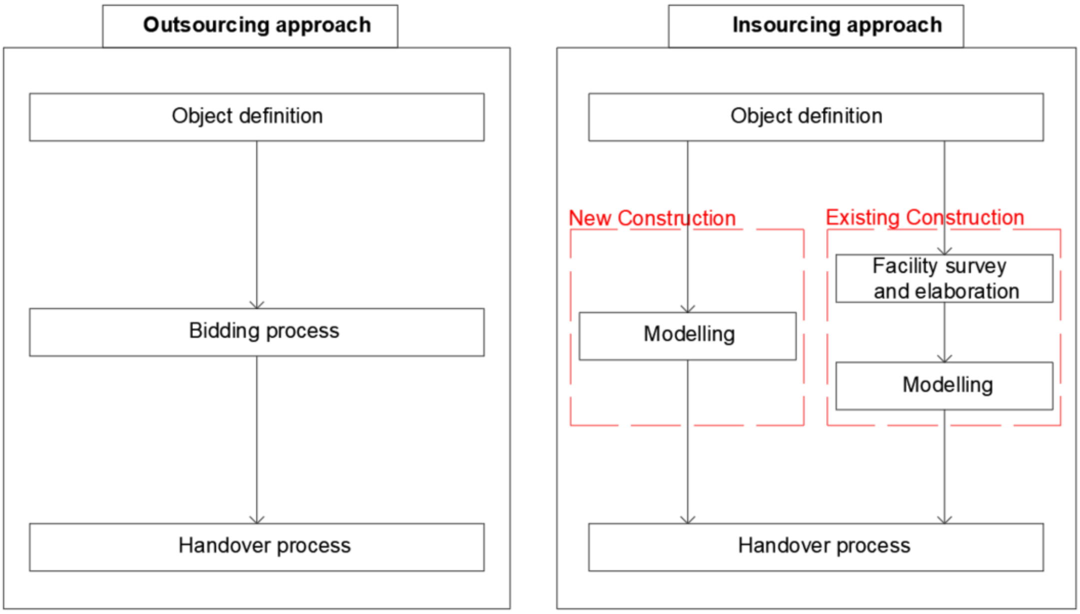


*Figure 27: Developing digital model workflow*

### *4.3.1 Object definition*

Beginning with an end in mind. In order to develop digital models that can be useful during the operational phase, a set of clear objectives has to be defined. These objectives aim to establish a system which contains all relevant and important data to support FM activities. According to the specific situations, these objectives are converted in different kinds of requirements. This means that in order to put the identified objectives into practice, there is a need to define a series of general and peculiar specifications, as shown in *Figure **28***.

The first need regards setting the Organisational Information Requirements (OIR). OIR establish what are the requirements that a specific organisation is needy in order to conduct decision-making processes with reference to high-level strategic objectives. In particular, these are set according to the principal strategies of organisations.

Starting from these requirements, other requirements, such as the Project Information Requirements (PIR) and the Asset Information Requirements (AIR), are established. Both series of requirements are necessary to achieve the same result, namely a digital model for the FM phase. However, the former regards strategic requirements related to a project level, while the latter concerns information requirements related to an asset level. PIR consist of strategic information requirements which are requested and necessary during the projects. These information requirements describe what is the information that is fundamental in order to carry out decision-making processes regarding projects. These requirements are generally generic and consequently customised and applied to every project. Similarly, starting from the strategic OIR, AIRs are established. AIR consist of information requirements which regards the operational phase. AIR specify what are the technical aspects which have to be taken into consideration in order to assist FM tasks. These aspects consist of structured and unstructured information. The former refers to general asset data including ID number, location, warranty start and expiry date, and specific asset data such as voltage, air flow, etc. The latter regards a series of documentation including management handbook, instruction manual, contracts, and reports, which are useful for their management. Since facility management data is principally those which is not geometric, the main aim of AIR concerns defining and conveying FM requirements to project suppliers. The main questions that organisations need to answer in order to outline these requirements are the following:

- What kind of assets and systems need to be regarded as priority and managed in operational phase?
- What are the custom properties to store for each of the items?
- What level of detail does asset information need to be in order to be considered useful for managing buildings?
- What is the classification system and data structure to use?

In order to perform it effectively, it is paramount to involve FM personnel in the process of AIR definition. Their experience can boost the process of asset property selection, identifying and prioritising assets. This is critical both for new constructions and existing constructions. Furthermore, conducting post-occupancy evaluation and using feedback, mistakes happened in past situations can be stored and provide the knowledge to enhance FM tasks by avoiding error repetitions and helping in predicting FM requirements. In this context, data importance is the central theme. For this reason, defining AIR needs to take into account the following set of best practices:

- Choose quality rather than quantity: this means emphasising aspects including validity, reliability, structure and organisation of data rather than its amount.

- Recognise data interconnection: this means that data is not an independent element, but most of the cases a piece of data is connected to another, leading to creating micro and macro systems.
- Avoid useless data abundance: this means that collecting and storing more data than necessary produces an overload of information which is not productive, but implies a consistent exploitation of resources to manage and filter data.
- Specify data granularity: this means identifying the level of detail that data has to reach in order to satisfy specific FM tasks.

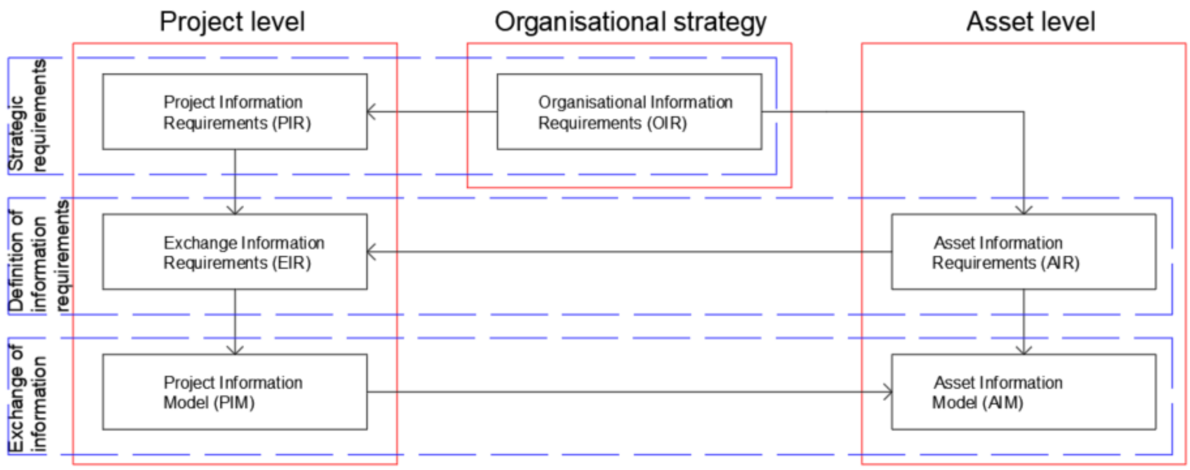


*Figure 28: Requirements*

Along the lines of information related to project level, Exchange information requirements (EIR) are specifications derived from both PIR and AIR. Compared to the previous two requirements, EIR focuses on answering to three specific questions including who delivers outcomes, how outcomes are delivered, and when outcomes are delivered.

As a result of these requirements, a Project Information Model (PIM) is developed. This model is the outcome which is produced by following all the EIR. The PIM is not only a 3D digital model which is visualised during the project phases, but also a storage of information, such as scheduling, costing, and details of systems, which are useful during projects.

In the end, the combination of both AIR and PIM enables producing the Asset Information Model (AIM). Compared to the PIM, this model does not contain all project information, but only that which is relevant to conduct the management of facilities. In particular, AIM is the outcome derived from the requirements defined in the AIR. It aims to provide FM personnel with the set of data which is necessary to effectively handle the O&M phase.

#### 4.3.2 Bidding process

The bidding process is one possible second step of the procedure for developing a digital model for the management of building. This process is taken into consideration only for the outsourcing scenario. During this phase organisations follow a specific process to directly obtain a complete digital model, as shown in *Figure **29***.

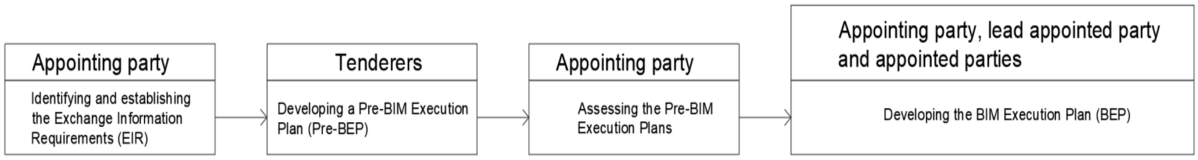


*Figure 29: Bidding process*

The organisation who asks for the development of the digital model is considered the client. The client can directly deal with potential tenderers by acting as the appointing party or hire a third party to perform this task. The appointing party produces the EIR document, which stablishes a set of characteristics including description of project stakeholder positions and responsibilities, the standard and format of data, the processes for producing data and the schedules for exchanging information. This means that the EIR document encompasses the information requirements applied to technical, commercial and managerial features in order to produce the BIM Execution Plan (BEP) at the end of the process.

After having analysed the EIR of the interested project, external professionals formulate a Pre-BIM Execution Plan (Pre-BEP). This document aims to answer specifically to all needs and requests which are stated by the client. Next, the appointing party assesses the set of proposed Pre-BEP and, taking into consideration all aspects of the bidding, decides to which tenderer entrust the interested project. After that, the winning tenderer becomes the lead appointed party, while the potential support teams of the winning tenderer are the appointed parties. In the end, the lead appointed party and the appointing party modify and adjust the Pre-BEP in order to produce together the BEP which is the fundamental document to follow for achieving the final PIM.

#### 4.3.3 Facility survey and elaboration

The facility survey is another possible second step of the procedure for developing a DT for the management of building. This process is taken into consideration in the insourcing scenario and when the facility is already built. This phase involves acquiring and collecting all building information which is useful to develop or update the digital model of the facility. Furthermore, it plays a key role for FM activities due to the fact that it provides both geometric and non-geometric data to have a better understanding of building features. This data is obtained by following specific procedures of documentation.

Traditional methods are based on manual and topographic tools, and consistent on-site inspections. Manual tools, which exploit simple equipment, such as measurement tapes, and laser distance meters are cheap and flexible tools for surveying, but have a low accuracy and are time-consuming measurements, especially for big facilities. Topographic tools, such as total stations, can improve the limitation of previous mentioned techniques, but still lack of data completeness. Compared to the traditional surveying method, advanced technologies can be exploited to conduct such activity. These technologies support data acquisition by enhancing the quality, speed, and accuracy of documentation process. In the end, the main aim of the techniques which use these advanced technologies is to record the 3D geometry of a facility. The surveying process is generally carried out by using the following techniques:

- Photogrammetry;
- Laser scanning.

The first technique consists of a set of photography of the interested building taken through a camera. The second technique consists of a set of scans of the interested building taken through a laser scanner. Both techniques can be exploited using a common specific process. The procedure begins with identifying the aim of the survey. Depending on what is the facility to be surveyed or what part of it has to be surveyed, surveys of a facility can encompass both external and internal inspections. External inspection aims to acquire a set of information from all around the facility in order to acquire its external boundaries. Internal inspection is more specific and usually exploited if other facility information is not available or reliable. For instance, detailed CAD drawings can be a valid support to avoid carrying out accurate, but time-consuming internal inspections. Once the aim of the survey is defined, there is a need to analyse the interested facility and subsequently define potential criticalities for its survey. This means that while open and simple facades are easy to inspect and survey, elements that are difficult to see and complex structures need more attention and consideration. Next, the survey is carried out starting from a decided point and continuing sequentially in a circle around the interested object.

When conducting the survey of the interested facility it is fundamental to take into consideration the following aspects:

- The settings of the device: it is critical to use the same settings of the device during the entire survey in order to achieve a coherent result in terms of resolution and size. For instance, having images with the same size facilitates the further elaboration.
- The distances of surveying: it is important to consider both the distance from the device to the facility and the distance among viewpoints. The former remains the same for the entire survey, especially for the photogrammetry technique, namely for each photograph the distance remains the same in order to facilitate processes in the elaboration step. The latter means the distance from one point of surveying to the successive one and needs not to overstep a threshold distance. This distance has to consider the necessity to overlap data in the elaboration phase. This means that data coming from two consecutive point of survey needs to be partially overlapped to create an ongoing shape of the facility interested. The overlap has to reach a percentage between 60 and 80 per cent in order to achieve an efficient result. Furthermore, the more surveys are conducted closely, the more details can be acquired and then used in the elaboration step. This is particularly important for part of facility where there is a complex shape or when the part that has to be surveyed is highly detailed.
- Weather conditions: the characteristics of data retrieved during the survey rely on the aspects of weather conditions. For instance, in order to obtain clear images, there is a need to take photographs with specific weather conditions. This means that images have to be taken during daylight period of time day, avoiding period of time when the sun is already set. For the same reason, foggy and rainy days are not advisable. On the other side, excessive sunny days might also be not appropriate if the environment and the surface of the facility reflect it too much. Indeed, this may result in blurred photographs. The optimal condition regards cloudy, but not dark days.
- The material of the object to be surveyed: this feature is valid especially for laser scanner. It is important to take into consideration the difficulty of laser scanner to capture data from reflective surfaces. In this case a paper-based support might help in identifying some critical points of the surveyed object in order to capture its shape.

With reference to the photogrammetry technique, once the survey is completed, the set of photographs is stored in a computer and elaborated with advanced tools to produce a usable result. The aim of the photogrammetry techniques is to retrieve and extract data from a set of 2D pictures and consequently export and integrate it in a 3D environment. Thus, the conditions previously mentioned are fundamental to this phase. Indeed, during the elaboration process the pictures are used together to build a basis for the further development of the digital model. The course of the elaboration phase concerns merging consecutive couples of pictures and applying on them the principle of triangulation. This principle exploits the intersection of lines of sight to determine the location of points. This means that combining together the 2D location of a common point captured from two different camera locations enables mapping this point on a 3D space. The result of this elaboration phase is a point cloud of the facility, namely a series of points of the building which are mapped in space and generate a 3D object, as shown in *Figure **30***. This result is a preliminary outcome which needs two further steps to be used. Firstly, there is a need to insert a geo-referenced point in the point cloud. This means that after having surveyed the facility, a real point is identified as a fixed reference for geographical purposes and has to be linked to a digital point in the point cloud. This enables the recognition of orientation and position of the facility. Secondly, the mere point cloud is further developed to generate a dense 3D object which resembles more the real facility. This means increasing the density of the point cloud by using pattern recognition techniques which are encompassed inside technical tools, as shown in *Figure **31***.

With reference to the laser scanning technique, the elaboration process is similar to the photogrammetry one. In order to create a 3D object, the laser scanning technique uses a remote sensing process. This process exploits ultraviolet, visible, or near-infrared light to acquire the time of flight, namely the time that is taken by signals to reach the interested object and return to the scanning device. This enables defining the spatial relationships and shapes. Similar to the photogrammetry approach, using specific technical tools, it is possible to process and organise data extracted from scans in order to generate a point cloud. Contrary to the former technique, laser scanners are equipped with GPS which enables an automatic process of geo-referencing of the point cloud.

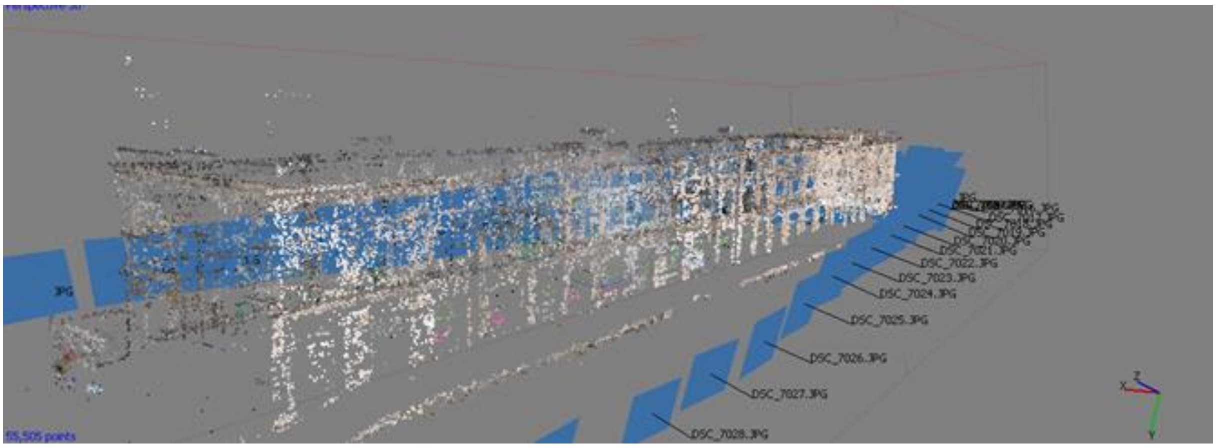


*Figure 30: Mere 3D point cloud*

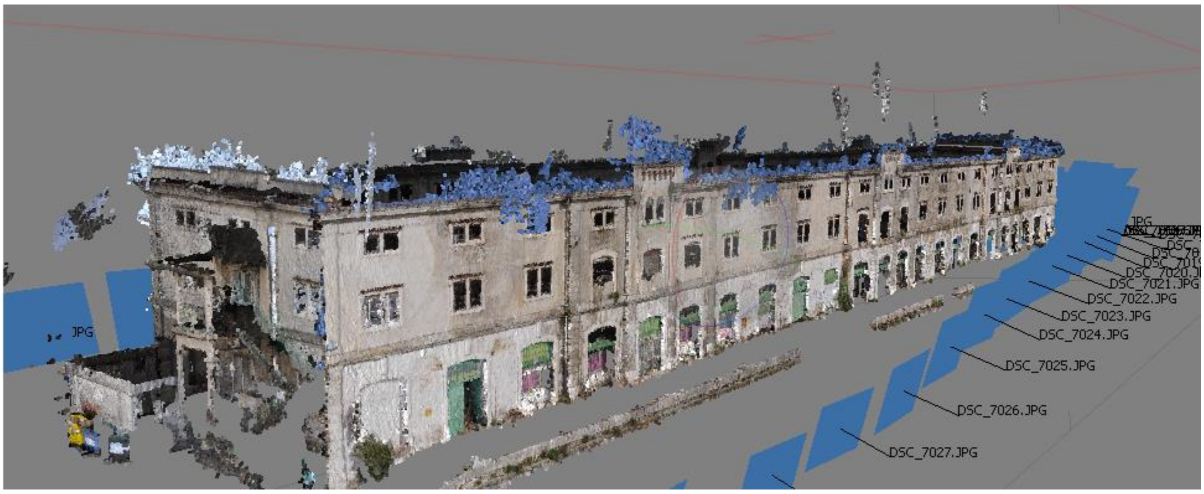


*Figure 31: Dense 3D point cloud*

In order to define what kind of technology to put in place to obtain expected results, a series of considerations has to be analysed. Both techniques are non-invasive 3D documentation methods, but there are critical differences between them, such as accuracy level, surveying speed, chromatic aspects, and cost. On the one hand, laser scanning technique provides highly detailed 3D geometry, which photogrammetry cannot. Thus, if the survey needs a high level of detail due to complex buildings, laser scanning technique is the most appropriate. On the other side, talking about the computational time expense, namely the average time taken for a tool to produce useful information, shows that laser scanning is a time-consuming surveying technique compared to photogrammetry, especially for external environments. Photogrammetry enables high positional accessibility and its outcome produces colourised point cloud compared to laser scanning technique. Furthermore, photogrammetry is cheaper in terms of tool cost, but referring to the labour input, it requires a high computational effort for outcome elaboration.

### *4.3.4 Modelling*

Modelling is the process of using information established and retrieved to generate a 3D BIM model. In order to conduct it properly, the previous stages are fundamental to create its starting point. Indeed, the point cloud generated in the facility survey stage can be imported in modelling tools as a basis for modelling. This means that internal and external length, such as room dimensions, can be seen using the point cloud and used as a visual reference when modelling, as shown in *Figure **32***. As well as data acquired from surveys, if available, accurate CAD files can strongly support the modelling phase.

*Figure 32: Modelling from point cloud reference*

The modelling phase needs to start from the premises of the object definition. This means that starting from the set of identified AIR, there is a need to develop an appropriate BIM model. When performing this phase, it is fundamental to take into consideration that when modelling is concluded, information related to FM activities, especially those which is non-geometric, should be available and ready to be used. To achieve this result properly, the identified requirements can be converted in a set of shared parameters in BIM tools. A parameter is an object property or attribute. BIM authoring tools enables creating shared parameters, which can be exploited across multiple projects, and then assigned them to families or categories in the model. Shared parameters can be saved into template models, which are blank model rich of established settings. This enables avoiding conducting the same tasks of setting properties each time a new project is started, along with reducing duplication of work. Attributes and properties have to be standardised and therefore are gathered together into main categories. These categories regard the following principal fields of information which are needed to conduct FM activities:

- General project information;
- Architectural and structural attributes;
- Electric equipment;
- Mechanical equipment;
- Information related to spaces;
- Maintenance data;
- Equipment for fire prevention.

During the modelling phase there is a great need to also attached information to objects. These attachments are the following:

- Documents;
- Technical data sheets;
- Use and maintenance handbooks.

On the whole, the result of the modelling phase is a series of digital models which are useful to manage buildings during the operational phase. According to the file size of digital models, models regarding the main construction disciplines, such as architecture, structure, and MEP, can or cannot be federated in a unique model. On the one side, it is common practice to merge models together when the related facilities are not too huge, resulting in avoiding several linked models to be maintained. On the other side, in the case of large projects, models are usually kept separated to enable reducing computational costs and consequently providing a practical and fast management of digital models.

#### *4.3.5 Handover process*

Once all necessary objects are modelled, there is a need to store their information inside FM tools. This process is traditionally manual, where FM technicians insert step by step all attributes necessary for managing buildings. This process can be sped up if automatic processes are involved. This means that models are exported in specific file formats that can be successively used to automatically import data in FM tools. Implementing a data transfer mechanism is crucial to avoid time-consuming tasks and manual errors. Different approaches which are able to conduct asset data transfer and upload from the modelling to FM tools can be used. These approaches are different in terms of the mode of data transfer and the direction of integration, as shown in *Figure **33***. The first approach uses a one-directional link method. This approach exports data properties and attributes from BIM models to an Excel file by exploiting export functions provided by BIM tools. The export process is mainly based on COBie spreadsheet. Data generated during the design and construction phases which is useful for FM activities is exported by using COBie data parameters. This data parameters can be defined at the beginning of projects by using a template file. Then, data is inputted inside FM tools by using data integration tools or developed algorithms. The second approach also exploits a one-directional link method, but compared to the first one, avoids the intermediate step by transferring data directly from BIM models to FM systems. In this case, specific data integration tools need to be exploited to export information and transmit it in the database of the FM platform. The third approach is a one directional method and has the peculiarity of using a middleware tool to conduct the task. This means that technical tools are used to import BIM model and consequently manage and edit data. Next, data can be directly imported into FM tools by exploiting the automatic connection provided by the middleware software. The fourth existing method uses a bi-directional link method. This means that data which is modified in one part is also changed in the other one and vice versa. This approach exploits Application Programming Interface (API) to link one side to the other. This means that in order to connect a BIM authoring tool to a FM platform, a specifically developed application is created. On the whole, comparing the mentioned approaches, it can be noticed that the last one seems to be the most efficient process due to the two-way synchronisation of data. Indeed, this capacity is also strongly recommended to manage building information during the operational phase. On the other side, this needs specific development and is limited to the specific FM system.

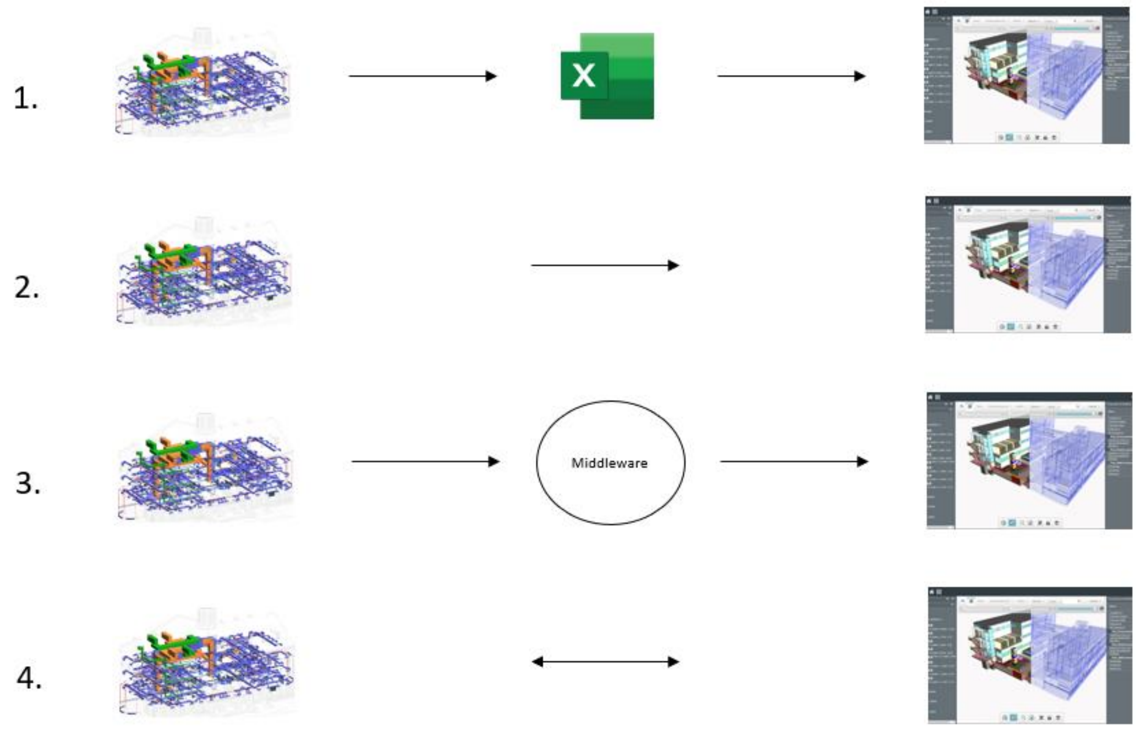


*Figure 33: Handover approaches*

#### *4.3.6 Considerations*

Once BIM models are transferred to FM tools, there is a need to have an integrated and organised visualisation of data. This means that models need to be connected to FM information contained inside FM systems. Thus, when specific data is searched in the FM software, its visualisation is supported not only by numerical information, but also by the part of the digital model which contains that data. For instance, when the dimension of a particular room of a facility is taken into consideration, the FM system supports its understanding providing on one side of the application interface all data and on the other side of the application interface the visualisation of the digital model with a focus on the specific interested room. In order to achieve it, an effective structure of data and models inside FM tools is fundamental for boosting activities during the operational phase. This organisation has to be arranged following a Work Breakdown Structure (WBS) which organisations define according to their criteria. For instance, a facility is part of a site and inside the facility there are one or more floors, which in turn encompass one or more rooms, which can include one or more elements and/or systems.

Along the lines of information organisation, both searching tools and digital models can be used to search and identify assets inside FM systems. In the particular case of using digital models, a strategic setting of data visualisation is paramount to boost its performance. The process starts from a general perspective and continues going into details of each facility. The scale of the starting point depends on the extension of area managed by organisations. This means that if an organisation manages facilities all around a country, there is a need to circumscribe the interested area to the national boundaries. Instead, if the extension of interested area is more limited, the starting point is more focused on a specific zone. In any case, the starting point needs to exploit a GIS system to provide a general overview of the real-world context. Starting from the GIS model, interested facilities are easily pinpointed by searching them on the map. Once the facility is identified, there is a need to get access to all information related to it. To read this data and further investigate on the interested facility, its BIM model has to be associated. This means that clicking on the GIS map, the scale of perspective moves from a general area to a specific facility, as shown in *Figure **34***.

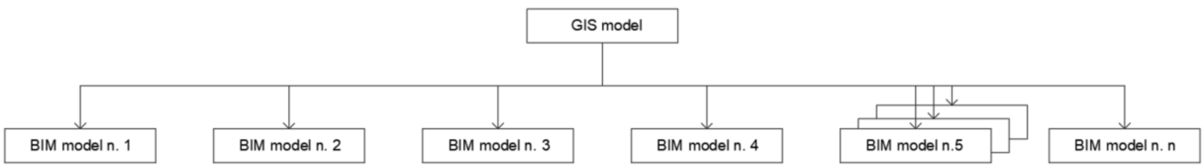


*Figure 34: Visualisation scale process*

## 4.4 Space management

Space management is one of the fundamental disciplines that has to be considered for improving the management of buildings. This area of study mainly encompasses activities including space information management, space planning and allocation, and space utilisation analysis. The first one refers to the procedure which aims to retrieve and collect information of facility spaces and consequently classify and manage it. The second one regards tasks including the recognition of the amount and type of spaces and consequent planning of their layout according to space characteristics and user needs, and then assigning these spaces by taking into consideration both short- and long-term scenarios. The last task is about assessing all the aspects related to the use of spaces.

This section analyses the opportunity to improve the space management of buildings and part of the following sub-sections is taken from a version of a manuscript published by the author of this dissertation. In particular, this version of the contribution has been accepted for publication, after peer review (when applicable) but is not the Version of Record and does not reflect post-acceptance improvements, or any corrections. The Version of Record is available online at: http://dx.doi.org/10.1007/978-3-031-11232-4. Use of this Accepted Version is subject to the publisher's Accepted Manuscript terms of use https://www.springernature.com/gp/open-research/policies/accepted-manuscript-terms".

### *4.4.1 The problem*

Reducing the energy wastage of working practices, along with meeting the aspirations of staff for an improved work-life balance are critical goals for organisations. As a result of it, smart working has become more important and far-reaching, also due to pandemic problems, such as COVID-19. Smart Working can be considered as the practice which exploits advanced technology to enable a better management of working environments and working life. This means that workers can have more control on where to work and when to work, leading to enhancing productivity.

Among different facility management tasks, space management is the one mostly related to smart working, as both try to provide adequate business service level and occupant satisfaction inside organisations. With reference to offices, it is critical to manage how spaces, such as informal breakout spaces, meeting rooms, spaces for confidential one-to-ones, spaces for Skype calls and project rooms, are used and shared for various kinds of activities. These spaces need to be assigned according to the activities which are conducted inside and with the aim of improving teamwork and information sharing. In addition, space utilisation needs to be regularly assessed in order to verify the match between requests and allocations. Managing spaces according to their real usage and utility is critical to reduce direct and indirect costs. However, switching to a new way of working is a delicate matter that involves different stakeholders and necessitates the integration of performing technologies.

The usage of Digital Twin (DT) platforms has gained increasing interest in the construction industry for dealing with issues related to FM activities. In the specific context of space management, its components can be extremely valuable for conducting FM tasks effectively. BIM can be used for visualising and storing building information, while the Internet of Things (IoT) technologies can provide real-time and dynamic data. Thus, digital twin platforms can be the technology which provides an effective space management of buildings, along with enabling smart working processes. However, there is a need to device the structure of the operative part of FM systems in order to conduct space management activities effectively. For this reason, the design of the application tier of a Digital Twin-based system which enables an effective digital space management is presented. In particular, since space management of building is fundamental when dealing with working environments, the focus of the space management application is office spaces.

### *4.4.2 Methodology*

The devised application is a part of a web-based decision support system based on five layers including acquisition, transmission, data/model storage, application and visualisation layer, as shown in *Figure **35***. Among these, the application layer is the one which exploits data to produce outcomes. In the particular case of the space management module, data which is integrated and used for conducting activities related to space management includes as-is BIM models, real-time and historical information (e.g. historical booking records, comments and request of repair/adjustments) related to workspaces, and monitoring data from sensors (e.g. presence or absence of occupants in office rooms and workstations).

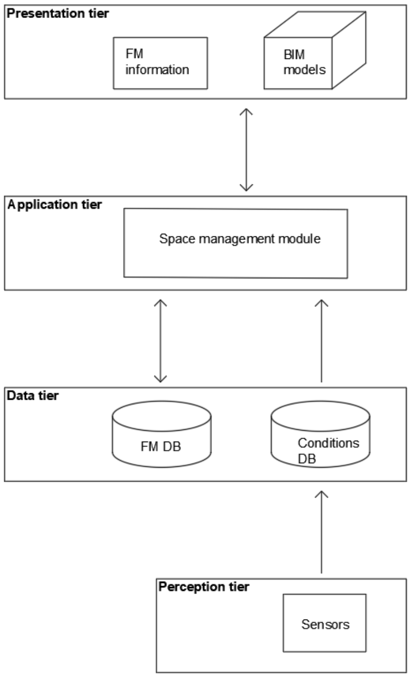


*Figure 35: Architecture of the web-based system*

The architecture of the specific space management module of the application tier is structured in order to provide different services to different users, as shown in Figure 36. To get access to the system, users have to log in with specific credentials to ensure that information is not visible to everybody. Each type of user can see and use different services according to the privileges of their account. While employees have the possibility to book a workspace and provide feedback, managers dealing with space management have access to the modules of data analysis and space planning. In particular, the system aims to book workspaces in organisations by avoiding repeated bookings or unused spaces and offer potential insights to new arrangements of spaces by using BIM technology and a post-evaluation analysis based on data provided by occupants and sensors.

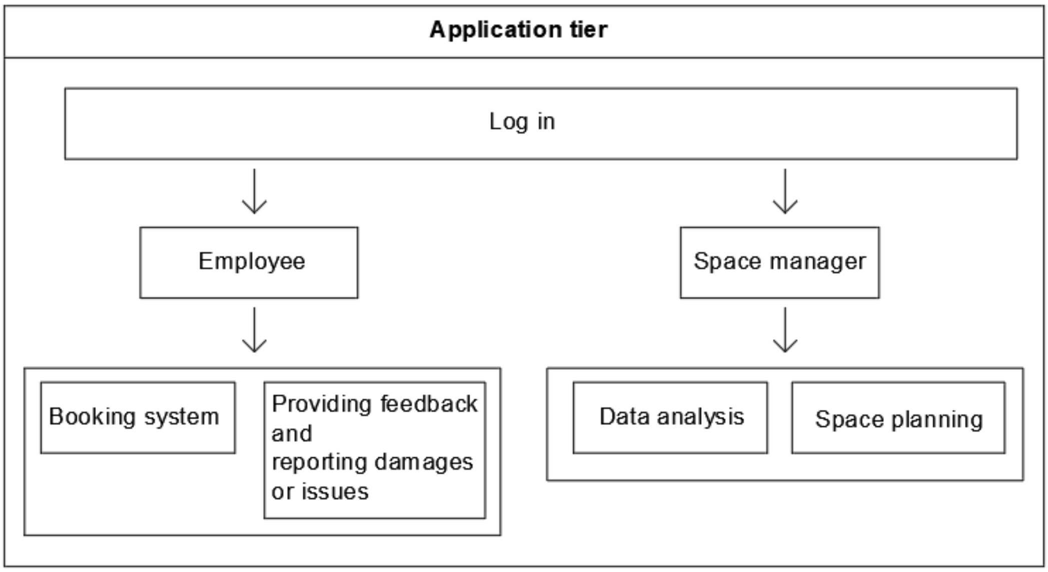


*Figure 36. Space management application tier*

#### *4.4.2.1 Booking and feedback modules*

The part of the system accessible to common users consists of two application modules including a booking system and a feedback/reporting damages system.

The first one encompasses a searching and a result section. The searching section enables finding specific spaces to book. Traditional offices enable space booking only for meeting rooms. However, the advent of smart working has taken space management to new ways of organising spaces. Thus, office spaces including informal breakout spaces, single office workstation, meeting rooms, spaces for confidential one-to-ones, spaces for Skype calls and project rooms can be booked. This means that workspaces are different one from another, resulting in a need for a system able to manage all available options. Each result obtained by using the searching section is linked to a page corresponding to the exact workspace searched. The page of the workspace contains all information regarding the workspace, which is structured following a certain code classification system including site, building, floor, room and workstation (if necessary). Additional information, such as technical equipment and furniture is also added. A set of images are attached to the page in order to provide users with a better recognition of the space and understanding whether it can be suitable for their activities. Another attached source of information is the BIM model of the entire building with the workspace location highlighted. This allows users to navigate the building and immediately understand where the workspace is located and how to reach it. Finally, a digital calendar provides users with the exact period of time in which the selected workspace is or is not available and a system to book that space.

The application provides occupants with a clear vision of the spaces available in each building by allowing selecting and booking a specific space. The booking procedure, as shown in Figure 37, is structured as follows: 1) pinpointing the interested space, 2) checking time availability and 3) booking.

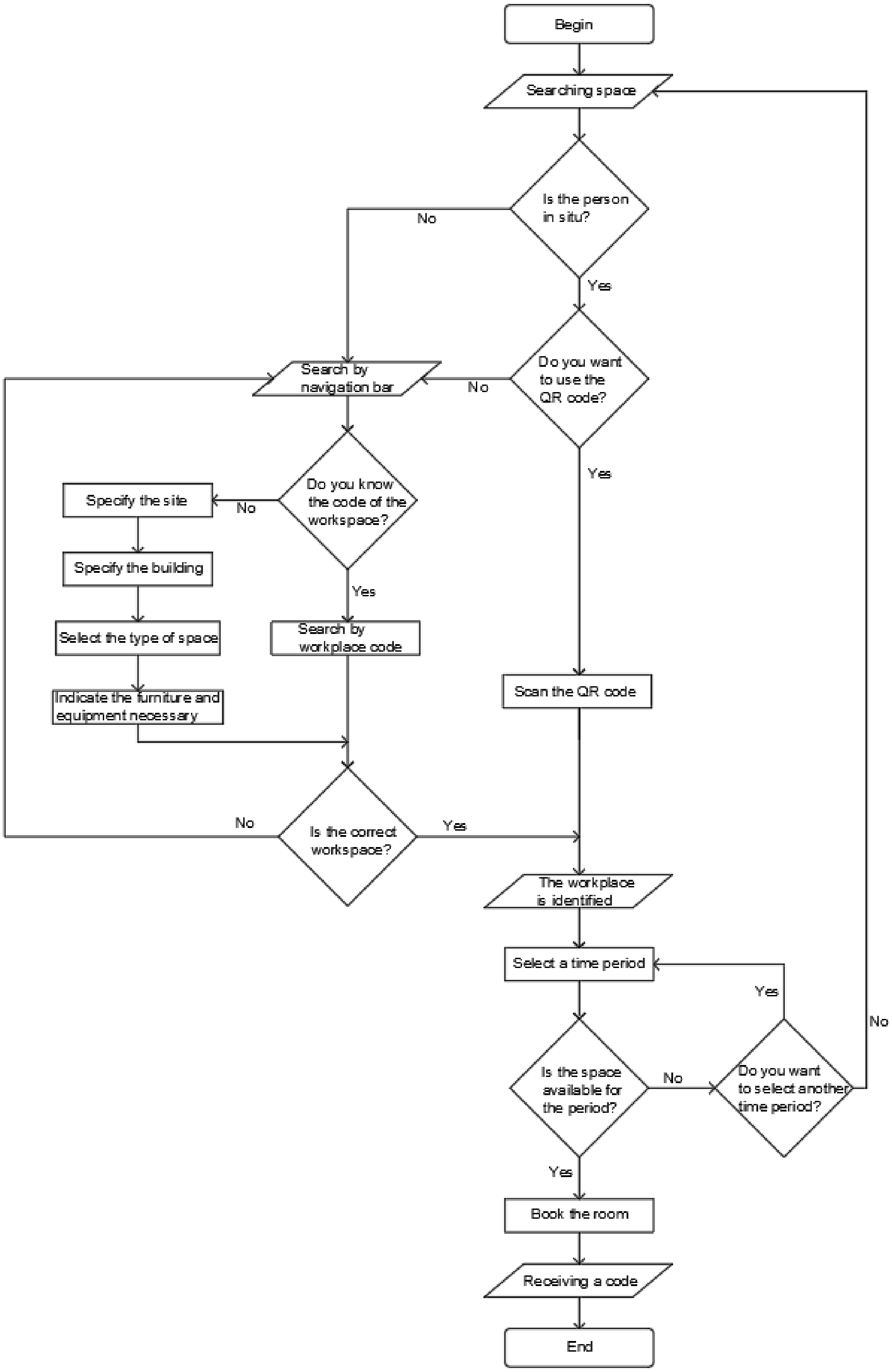


*Figure 37. Booking procedure*

To locate the interested workspace and easily get access to the information of the specific working space, QR code can be a potential solution due to its properties of security and high fault tolerance. Scanning tools are free and QR Code can be scanned in many orientations without having trouble with problems of recognition. A QR code is applied to each office workstation and working space in order to exactly pinpoint the interested area. Scanning the QR code of workspaces or office workstations, users are linked to the correct page of the room/space searched. Otherwise, in case of a lack of complete knowledge of buildings, to solve the problem of searching a workspace suitable for specific activities, a smart query provides users with some filters to direct their search. The process of querying consists of three steps. First of all, users are asked to specify the site and the building where they want to book a space. Next, they are asked to select the type of space they are looking for, such as a meeting room. Then, furniture and equipment necessary to perform the activity are indicated if necessary. As a result, only workspaces which fit with the requirements previously selected are shown. After pinpointing the interested space, the selection of time period interested is performed. If the workspace is not available, another time span can be selected or the space searching is conducted again. Otherwise, if the workspace is available, this can be booked and consequently a code of registration is received.

Booking a workspace for more time than actually necessary is one of the main issues related to space booking systems. Ensuring instant availability when spaces are not used can be supported by sensors deployed around organisations that check the presence of occupants. To this end, if a workspace is reserved, but sensors do not detect any occupants in that space for more than a certain threshold of time, which try to avoid misleading situations, such as coffee break, the booking is automatically deleted.

As well as the booking module, users can provide advice and report issues related to workspaces. In particular, feedback for the usage of space can be provided at the end of the booking. Inserting the code created by the booking system, the workspace reservation can be identified in terms of space and time. To better process a huge amount of information, a questionnaire based on a five-point score from one to five is asked to every user. The list of question is the following:

- Was the space suitable for the activity?
- Was the space clean?
- Was the space supplied with the equipment necessary?
- Was the level of noise acceptable?
- Was the level of light acceptable?

- Was the temperature acceptable?
- Was the space ergonomic?
- Was the space enough to work?
- Was the space comfortable overall?

For each question, additional free-form comment of the given score can be submitted to give the possibility to users to motivate the selected score and report possible damages or issues. On the whole, this module can support FM personnel to conduct space planning and allocation activities, as it provides an aid to evaluating space utilisation.

#### *4.4.2.2 Data analysis module*

After collecting information of space usage, bookings and feedback, data is organised and stored into a database. This data is ready to be exploited by the data analysis module in order to discover interesting patterns and/or insights. The data analysis module is divided in two parts, which are the following:

- evaluating the trend of occupant satisfaction by considering the feedback of the usage of space at the end of bookings;
- analysing the trend of space utilisation by using several indicators according to the analysed workspace.

The shift to new office buildings and smart working models needs to be verified ex-post. An evaluation of space utilisation based on feedback provided by occupants is the critical step to implement and enhance space management effectively. This process helps to manage space planning according to a user-centred method and focuses on a user-experience approach. Since the answers to the set of questions are based on a five-point score, trends can be studied by using advanced techniques of analysis. As well as these structured answers, the additional free-form comments can strongly support the analysis. Although these results are less structured than the five-point score answers, they allow users to completely express their real evaluation.

As well as occupants' feedback, space utilisation data is necessary to manage facility efficiently. This data needs to be as much reliable, accurate, updated and accessible as possible, and therefore sensing performing technologies are exploited to enable automatic data acquisition. In particular, using sensors, such as wireless sensor networks (WSN), it is possible to monitor physical and environmental conditions of buildings including temperature, humidity, etc. Space utilisation indicators can provide potential insights to help decision-making processes of space planning. The historical and real-time monitoring of working space usage is a crucial task for avoiding organisation wastage. The utilisation of workspaces is analysed by using a few indicators for each type of space. Since there are diverse workspace types, such as a single workstation in a co-working room and meeting room, there is a need to consider indicators for both the single workstation and the whole room. To gain additional insights from data, rooms can be grouped according to their type and analysed by using information including the specific departments to which they belong and their position in the building. For instance, a conference room might be used far less than others. This may depend on its location or if it is really necessary to the particular organisation department by which it is managed. The indicators which are taken into account to evaluate the usage of workspace are described in *Table 29*, *Table 30* and *Table 31*. The working time considers only workday, namely from Monday to Friday, and during each day the boundaries of working time are from 8:00 to 18:00 o'clock.

| **Indicators for a workstation** | **Formulae** |
|---|---|
| Workstation used [%] | $\frac{\Sigma \text{ Time a workstation is used}}{\Sigma \text{ working Time}}$ x 100 |
| Workstation used, but not booked [%] | $\frac{\Sigma \text{ Time a workstation is used, but is not booked}}{\Sigma \text{ Time a workstation is used}}$ x 100 |
| Number of times a workstation is booked, but not used | n° of times a workstation is booked, but is not used |

*Table 29: Indicators for a workstation*

| **Indicators for a room regarded as a single workspace** | **Formulae** |
|---|---|
| Workspace used [%] | $\frac{\Sigma \text{ Time a workspace is used}}{\Sigma \text{ working Time}}$ x 100 |
| Workspace used, but not booked [%] | $\frac{\Sigma \text{ Time a workspace is used, but is not booked}}{\Sigma \text{ Time a workspace is used}}$ x 100 |
| Number of times a workspace is booked, but not used | n° of times a workspace is booked, but is not used |
| Square meters for worker [$m^2$/workstation] | $\frac{\Sigma \text{ net lettable room area}}{\Sigma \text{ number of workers}}$ |

*Table 30: Indicators for a room regarded as a single workspace*

Since a room can include more than one workstation, the room capacity is regarded as the total number of workstations in a room.

| Indicators for a room regarded as sum of workstations | Formulae |
|---|---|
| Room used [%] | $\frac{\Sigma \text{ (workstation x Time workstation in a room is used)}}{\text{Room capacity x working Time}}$ x 100 |
| Room used, but not booked [%] | $\frac{\Sigma \text{ (workstation x Time workstation in a room is used,but not booked)}}{\Sigma \text{ (workstation x Time workstation in a room is used)}}$ x 100 |
| Square meters for workstation [m²/workstation] | $\frac{\Sigma \text{ net lettable room area}}{\Sigma \text{ number of workstations}}$ |

*Table 31: Indicators for a room regarded as sum of workstations*

The result of the space utilisation and occupant satisfaction analyses is a set of illustrative charts which show the real usage of workspaces and their level of satisfaction, respectively, resulting in potential understanding of what, where, when and how work is carried out. On the whole, periodical post-occupancy evaluations can provide useful information for allocating spaces according to users and organisation needs and priorities both in terms of current and future requirements.

#### *4.4.2.3 Space planning module*

To ensure the effective utilisation of workspaces, space should not be allocated on the basis of seniority, habit or personal preference, but considering the activities that have to be carried out and understanding what their space requirements are. For instance, activities that have to be conducted in informal meeting spaces should not take place at workstation desks. Furthermore, not always workers are in their office to perform their work, but depending on jobs, work can be carried out remotely. For these reasons, assigning a specific workspace to the service of a worker can lead to a waste of resources. On the whole, defining the goals of space users is the first step and it includes all necessary analyses including establishing spatial requirements and deciding the dimensions and layouts of spaces.

Having understood the amount and types of spaces needed in the office, space managers have to establish strategies and targets for managing workspaces. Spaces which can be used in organisations are not unlimited, therefore a precise planning and scheduling of activities can improve the overall organisation. The results of space usage can highlight the need for more workspaces of a certain type rather than others. Based on results provided by the data analysis module, re-allocation can be planned in the case of unsuitable space allocation. BIM can provide space managers with the clear view of rooms and up-to-date data, such as geometry and equipment of workspaces, therefore avoiding misleading information and potential controversy. Indeed, BIM supplies a structured method which is able to organise, classify and store spaces and their attributes, such as ID, area and volume, etc. In particular, this enables a reliable way to encode, add information to, and update facility elements by exploiting the GUID of elements.

Establishing a method to continuously manage and improve processes is critical to efficiently run an organisation. With reference to space management, the method might consist in a preliminary space planning based on studies carried out inside the organisation and two review processes, which consider different periods of time, to validate the space management. Applying this method, issues regarding space utilisation priorities, space requests and occupant complaints can be regularly solved throughout the operational phase. Each of the two review processes consists of a build-measure-learn cycle, as shown in *Figure **38***, that drives the optimisation approach after the first planning task. With reference to the cycle, the first step refers to the action of space planning and carrying out a specific space configuration, the second step regards the analysis of the upsides and downsides of the space configuration by using the above-mentioned indicators, and the third step concerns the recognition of potential mistakes and solutions to reallocate the space.

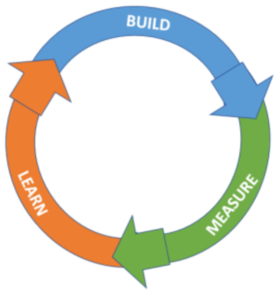


*Figure 38: Build-Measure-Learn cycle*

The first process is conducted after short periods, while the second one examines the management in the long term. In the short period, only data regarding feedback provided by occupants is analysed. This process consists of three steps, as shown in Figure 39. The first one is the analysis of occupants' feedback. Using the answers to the employee's satisfaction questionnaire, it is possible to create a report which shows if there is any trouble with workspaces and which workspace is involved. If a workspace is reported, an inspection is carried out by going in situ and/or exploiting BIM technology. The last step concerns the adjustments of workspaces and little movements of workspaces if possible and necessary. On the whole, this process enables improving workspaces and ensuring more comfort for employees without requiring complex and expensive actions.

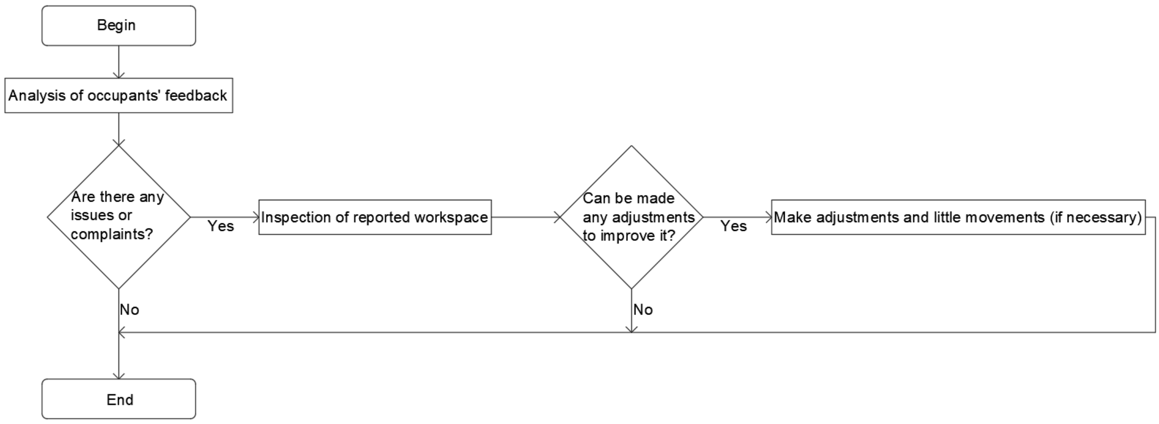


*Figure 39. Short period review*

In the long period, data regarding indicators of space utilisation are considered, along with an analysis of the occupants' feedback collected during the short periods. This case concerns major operations, such as reallocating activities, to better manage space. This process consists of three steps, as shown in Figure 40. The first one regards an accurate analysis of space utilisation preferences by measuring how space is occupied and considering the feedback of the short period reviews throughout the fixed long period of time. If the indicators of space utilisation are under a certain threshold, workspaces related to those indicators need to be considered for improvements. Next, a list of unused or underused spaces is compiled by integrating data regarding space usage of different departments. Then, relationships and interactions between departments and work teams are mapped to have a better understanding of worker requirements. Lastly, space managers reallocate spaces into their organisations by exploiting BIM technology. On the whole, the long-term review enables conducting high-level "what-if" scenario due the huge amount of data stored in that period. As a result, this allows organisations to align space usage with space requirements.

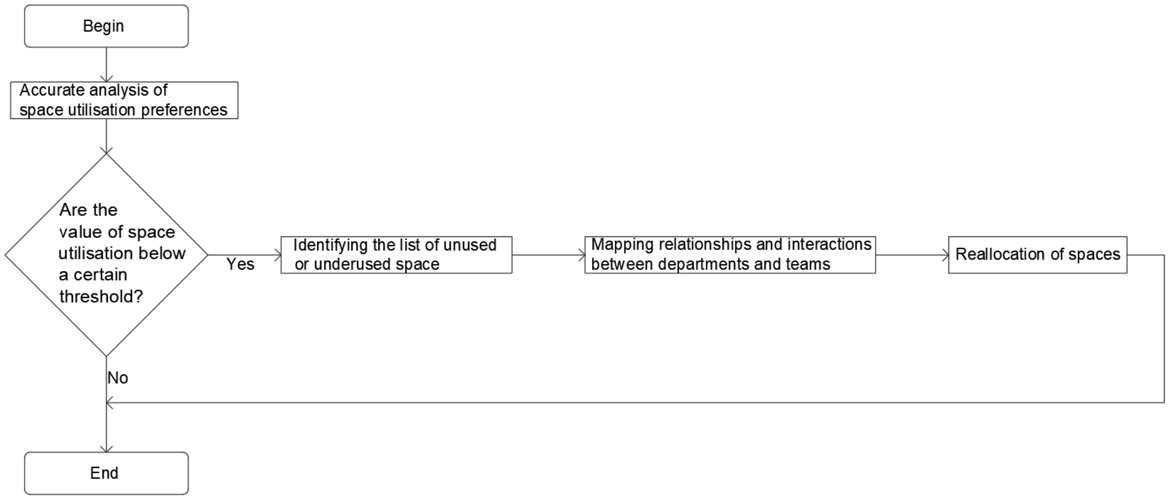


*Figure 40. Long period review*

### *4.4.3 Discussion and considerations*

**Theoretical implications**

Getting reliable information of how building spaces are managed can enable space managers to support decision-making processes regarding space allocation and reallocation, along with boosting the overall utilisation and related savings. To improve space management efficiency, this study presents a Digital Twin-based system for the effective digital management of office spaces.

The next step for FM platforms including those involving space management is to extend their functionalities by adopting digital twins [100]. Indeed, according to [239] [240], DT-based system can be used to provide advanced decision-making using space utilisation data and monitoring ambient conditions. Aligned with these considerations, the valuable strength of the presented system stems from the proposal of a practical application of a DT system, which encompasses the use of both dynamic data acquired from sensors and BIM technology, to manage workspaces. The operational phase needs data including the occupancy and actual use of spaces in order to enhance the efficiency of workspace organisations [241]. This study proposes a system which exploits sensors and QR codes in order to detect and communicate the presence of workers in specific workspaces and consequently reducing issues including the absence of knowledge of available spaces and the improper management of bookings. Along these lines, this study overcomes issues identified by [242], which pointed out issues in booking space system of organisation, as these are often based on mail systems. The presented system is supported by [242], which advises the usage of QR codes in order to check whether users are really using the booked space at the chosen time. Furthermore, the proposed system also aligns with [243], as strategic planning can be conducted in order to optimise spaces and reduce energy wastage through the implementation of systems which operate based on occupancy indicators. According to [244], as well as being acquainted with space usage data, insights can be gained by exploiting observations, comments and critics of space users. On this premise, the proposed work regards and uses user feedback as a high effective means to meet employee needs. Furthermore, the system exploits the visual aid advantages provided by the BIM technology. This is aligned with [11], as BIM can provide an efficient 3D visualisation of the exact location of workspaces compared to the traditional two dimensional drawings. In the end, the study exploits an iterative process to conduct space planning and allocation. This method of conducting work is aligned with [245] [246], which state that in order to continuously provide user with what they need for perform their tasks, one potential solution concerns the use of an iterative planning process.

**Practical implications**

The proposed system can provide space managers with an up-to-date schedule of what workspaces are used, when and how much time these spaces are occupied and who the occupants are, leading to potential benefits to decision-making processes. Among the several types of information, users' feedback and space utilisation trends are fundamental to improve productivity and maximise the amount of time office buildings are used. If workspaces are used efficiently, costs related to wastage which derive from other FM disciplines, such as lighting, ventilation, heating and cooling systems, can be saved throughout the working time. Indeed, it is possible to configure facility equipment according to specific requirements in order to accrue savings. For instance, with reference to energy management, actuators, which are connected to sensors, can avoid wastage of energy by performing specific tasks, such as switching on/off lights, heating and air-conditioning, whether sensors do not detect the presence of occupants or according to the type of workspace and the preferences of occupants. As well as direct expenses for using a space, each space generates associated costs, such as cleaning costs. Taking into account the usage frequency of a space and what kind of operation is performed inside, potential optimisation algorithms can maximise the savings by reducing useless and unneeded cleaning operations and defining where and when to perform cleaning. To this end, tangible and intangible benefits and associated savings should be analysed in the next years to validate the proposed system. The system should be also expanded by developing more modules in the application tier, such as an energy management module and a maintenance management module, connected to the space management module in order to generate an IWMS for an integrated management of all activities regarding the facilities management.

Nevertheless, developing a tool is not sufficient to have an effective management of spaces inside organisations. The efficiency of processes depends on the overall management of organisations. Integrating the Digital Twin-based system with smart working processes can help to break down organisational silos, encourage cross-team working and improve the overall management of spaces. However, a resistance to change from enclosed offices to open spaces and desk-sharing configurations can be encountered among employees. As well as this hindrance, organisations still focus on management by presence rather than emphasising management by results. Thus, more effort on internal processes and responsibility issues are needed to change the way people work and organise their work by exploiting smart working. This will improve the relationship between work and the rest of life and support workers' autonomy. To this end, managers of organisations should focus on the cultural space transition by urging workers to think beyond the classical workplace and supporting management by outcomes rather than by presence.

## 4.5 Maintenance management

Maintenance management is another critical discipline that is conducted during the operational phase for the management of buildings. This area of management mainly refers to tasks related to repairing and preventing potential damages to and failure of buildings and their systems, respectively.

This section analyses the opportunity to improve the maintenance management of buildings and is taken from a manuscript published by the author of this dissertation. In particular, this version is an 'Accepted/Original Manuscript' of an article published by Taylor & Francis Group in Building Research and Information on 01/08/2021, available online:

https://wwww.tandfonline.com/10.1080/09613218.2021.1953368.

### *4.5.1 The problem*

During the operational phase data is at the centre of attention due to its potentiality to avoid useless costs and enable an ongoing efficient management. With reference to maintenance activities, data is collected by performing in situ inspections and exploiting FM systems. In situ inspections allow FM personnel to diagnose and assess the condition of building elements at an exact point in time, but cannot be valuable for developing an exhaustive view of what the principal issues of buildings are and what buildings are mainly affected by failings over long time periods. In contrast, FM systems can integrate data and support analyses in order to present a comprehensive picture of building conditions. Indeed, exploiting a detailed inventory, FM system can link each asset with its historical maintenance data, such as when and why a specific maintenance tasks were conducted.

Maintenance requests are the work order (WO) requested through the FM system if a building has a problem. These problems not only include the failures of building systems, but also issues related to structural, architectural, and other deficiencies. During the operation and maintenance (O&M) phase, this data is usually stored in FM systems and can generate a general knowledge of building fault trends. Maintenance requests usually contain the textual descriptions of issues, which can include irrelevant details, but also important ones. Although the data extracted from CMMS data sets can be used to provide insights into building performance, when dealing with unstructured data, such as texts, difficulties in conducting analyses are encountered.

There is a dearth of studies regarding the exploitation of unstructured data contained in CMMSs and, among those, there is a lack of investigations focusing on the practical and operational extraction of information to acquire a comprehensive knowledge of building faults and gain insights for preventive maintenance. Nevertheless, with the increasing interest in boosting the management of buildings, there is a great need of analysing data stored in FM databases to generate potential benefits for organisations. To this end, two methods to support FM by generating useful insights from maintenance requests stored in a CMMS database are presented. The proposed methods focus on investigating textual maintenance requests to conduct operational actions for preventive maintenance by extrapolating the room ID numbers where faults mainly occur and the most problematic building elements/systems. These methods are based on the development of text mining[7] algorithms that enable the extraction of this useful information from data sets. Eventually, these methods were applied to the case study of the local administration of the Municipality of Trieste, where 12655 maintenance requests derived from 33 buildings were analysed.

#### *4.5.2 Methodology*

The research methodology employs two methods to acquire a comprehensive knowledge of maintenance work orders (WOs). Firstly, a method to detect the identifier number of rooms where faults mainly occur was proposed. Secondly, a method to identify the most problematic building elements and systems was suggested. For each of the proposed methods, a text-mining approach was implemented to obtain information that can be useful to generate insights for building management from unstructured textual data contained in the CMMS. The process of identifying and extracting parts of texts is subjected to conditions that are dictated by the language rules of the analysed texts. This means that parts of texts are not always organised in the same way in different languages. On the other hand, ways of writing specific pieces of sentences are not influenced by the syntactic structure of single languages, but are shared by most of them. For instance, “there is a fault in room 44” in English, “c’è un guasto nella stanza 44” in Italian, “il y a un défaut dans la chambre 44” in French and “hay una avería en la habitación 44” in Spanish collocate the word “room” next to the number of the room. Databases are not always highly organised, but owing to previous decisions that organisations make when they develop or buy their maintenance management platform, they are structured in a way that data cannot generate useful information when integrated. To this end, organisations that are in possession of such unorganised data have to find other ways to efficiently analyse their databases. For instance, as shown in *Figure **41***, room and element ID numbers might be omitted, leading to difficulties in extracting this data from the description of maintenance requests.

[7] Text-mining: the process of analysing large unstructured machine-readable documents to extract useful information [146]

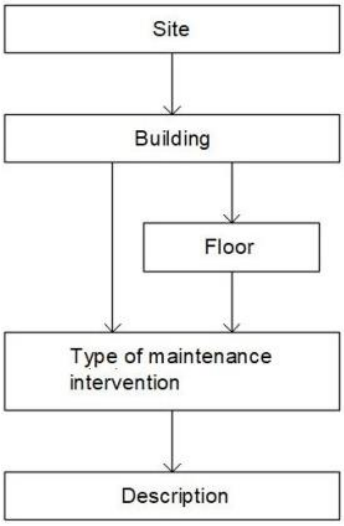


*Figure 41: Example of a database structure*

To this end, text-mining algorithms can be a solution. This technique can analyse textual data which is contained in CMMS databases to obtain information about specific warnings of maintenance requests. The process of analysing these warnings begins with exporting the maintenance requests from the database and generating a data set with an extension, such as .xlsx or .csv, which can be read by advanced tools of programming, such as Jupyter Notebook. These tools exploit programming language scripts to modify and exclude unnecessary parts of text, as shown in *Figure **42***. Firstly, a list of work order descriptions is identified and selected from the database. Secondly, for each description, the text is broken into single words and unnecessary punctuation marks and spaces are removed. Then, all the words are converted into lower case and added to a list of words. This process is repeated until the last description of the list is analysed. The list of words can contain both words and numerals and preserves the original order and sequence of words as they were in the sentences. At the end of the process, an extensive list of words is created and ready for subsequent elaborations.

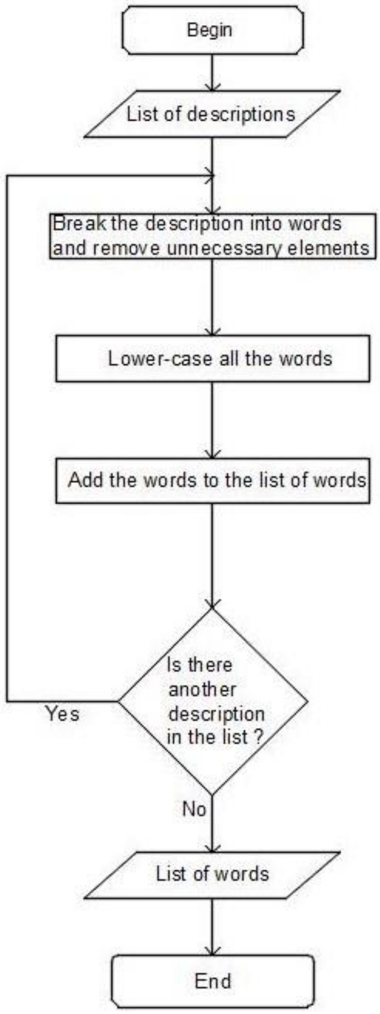


*Figure 42: The process of generating the list of words*

#### *4.5.2.1 Identifying room ID numbers*

The proposed method, which is shown in *Figure* ***43***, aims to identify room ID numbers from textual data in order to allow FM personnel to enhance maintenance management by shrinking and limiting the area where faults usually occur. Before starting the process, an empty list which will store room ID numbers is created and a set of secondary variables which are crucial to generate pieces of sentence by keeping string values are defined. This method is composed of four phases including adjusting numeric words, defining variables, extracting room ID numbers and setting new rules for variables. This method is repeated in a loop cycle as many times as the quantity of words that composes the list of words previously generated.

The first phase standardises the formulation of words, as people in charge of reporting issues in buildings use different expressions. In particular, this step takes into account each word and checks whether it starts with a zero. If the Boolean validation produces a positive result, the initial letter of the word is removed, or else the word is not modified. This allows standardising the ways representatives[8] write the room ID numbers.

The second phase concerns the statement of a series of principal variables that are used for building chunks of sentences. The number of variables depends on the number of different logic structures and vocabulary compositions identified for describing the room ID numbers. In the former case, the position of specific words is different from one sentence to another, while in the latter case, words that carry a particular meaning can be written in different forms. Five representative cases that can describe the logical sequences were identified. For each of these cases, a principal string variable composed of two or more secondary string variables was defined. As a result, complex and composite pieces of phrases can be created. As well as these main variables, a subsidiary one that represents whether the analysed word is or is composed of a number was defined, too.

The third phase exploits the previous steps to add one of the primary variables above described to the list of room ID numbers after processes of validation. Thus, five processes of validation, which take into account different syntax structures and several synonyms to write “room”, were applied by following an exact order. These processes were developed in such a way that one differs from another unequivocally, consequently enabling unique choices in precise situations. This means that two validation processes cannot be involved at the same time, therefore avoiding multiple extractions of the same information.

The fourth phase is a crucial part of the algorithm, which allows retaining specific words as values of the secondary variables for successive extractions. Five conditional processes of verification were employed to alter the values of the secondary variables, which are used in the consecutive loop cycle that restarts from the beginning of the four phases of the method. Each of these five conditional processes checks whether a precise variable possesses or not an exact value. Since the word “room” can be written in various manners in a text, not only were synonyms considered, but also possible abbreviations. As a result, the considered secondary variable acquires a new value or maintains its value according to a specific verification code. Similar to the second phase of the method, also this set of conditional verification processes is univocal, which leads to assigning a certain value to an exact variable at a specific point of the entire loop cycle.

[8] Representatives: people in charge of reporting issues in buildings

In order to strengthen the code, potential human mistakes in writing texts were considered. For instance, while it is less probable that orthographic mistakes are overlooked, when typing, it is possible that workers neglect typing errors, such as double spaces among words. In addition, due to a lack of attention and unusual ways of writing maintenance requests, a threshold of word frequency occurrence was defined as a limit for acceptance of results. The whole process keeps on extracting pieces of phrases until the last word is analysed. In the end, a list of room ID numbers is extracted from raw data.

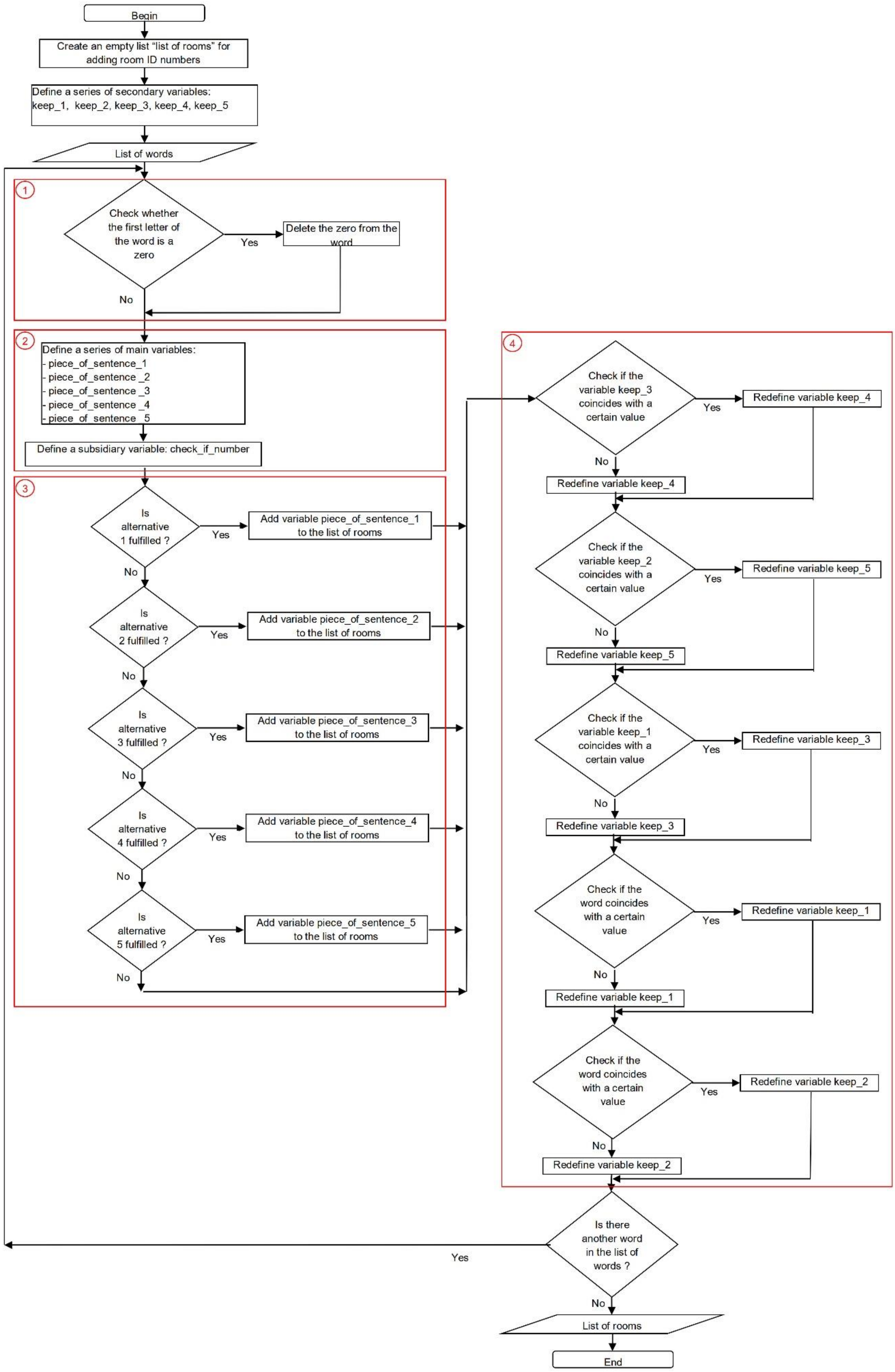


*Figure 43: The process of identifying room ID numbers*

#### *4.5.2.2 Identifying the most problematic building elements*

Although identifying room ID numbers is a useful step to better analyse maintenance problems of buildings, there is also a great need to discover what building components and systems are the most problematic. However, since the database is not organised in order to store element ID numbers of failing elements, workers in charge of warning malfunctions and faults are not used to referring to a specific ID number, but they use simple sentences to describe these deteriorated elements. To this end, the proposed method, as shown in *Figure* ***44***, aims to identify the most frequent words from textual data in order to pinpoint the primary elements that present problems.

This method is composed of a few steps including creating a Bag of words[9], comparing the Bag of words with a list of stop words[10] and then updating the Bag of words. The method begins with adding each word of the list of words previously generated at the end of the process shown in *Figure* ***42*** to a Bag of words. In this process the Bag of words represents a data frame composed of words which is organised in descending order where each word has an absolute value that derives from counting how many times it appears in the initial list of words generated at the end of the process shown in *Figure* ***42****Figure* ***46***. In the second step, the Bag of words is compared with the list of stop words. Before starting this step, there is a need to create the list of stop words, namely a list of words that do not refer to building elements and systems. Next, any word of the Bag of words that is contained in the list of stop words is removed from the Bag of words because it is not useful to identify issues in buildings, while the others are preserved. Afterwards, the components of the Bag of words are updated and then sorted again in descending order. Eventually, the results allow classifying words to give major attention to those which have the highest frequency.

Since creating on the first try a list of stop words with all the unnecessary words, which must be removed from the Bag of words, is quite challenging, this is an iterative process. Thus, when the Bag of words is sorted, the most repeated words are assessed and those which are not considered interesting for the analysis are selected and added to the list of stop words. This means updating the list of stop words to allow restarting a new cycle of the method with a major number of common words regarded as noisy data removed.

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[9] Bag of words: a representation of text that describes the occurrence of words within a document. It involves two things either a vocabulary of known words or a measure of the presence of known words [247]

[10] Stop word: a word which is excluded from a text because it is useless for the scope of analyses.

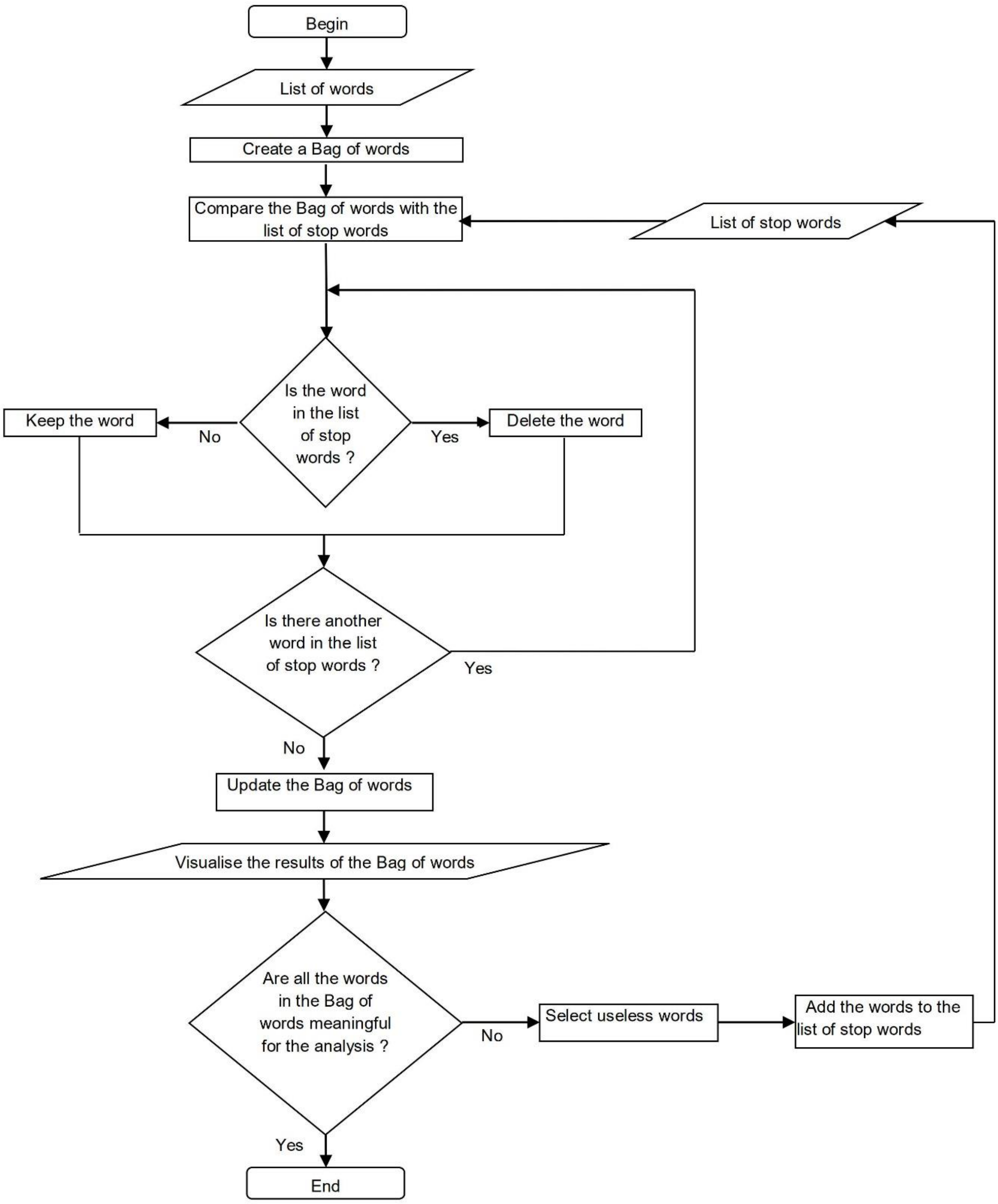


*Figure 44: The process of identifying the most repeated words*

As well as identifying single words that can specify issues, pairs of words can often describe better what the problem is. This is why a pattern to extract pairs of words that can have a more meaningful value for stakeholders was developed. Similar to the process for room ID number identification, a process to gather meaningful single words to create pairs of words is shown in *Figure **45***.

This method exploits an iterative process that begins with selecting one word from the list of the most repeated words, namely the Bag of words. This selected word is regarded as the reference for creating a valuable pair of meaningful words, which means that at the end of the cycle another word is added to the referenced one. Similar to the method of identifying room ID numbers, an empty list for adding the pairs of meaningful words is created and secondary variables are defined.

Next, for each of the selected words of the Bag of words, a sub-loop cycle is created, where the other word which will generate the pair of meaningful words is extracted from the initial list of words generated at the end of the process shown in *Figure **42***. Inside the sub-loop cycle, the process consists of three phases, including defining principal variables, extracting pairs of meaningful words and setting new rules for variables. The first phase states the main variables, which are composed of two or more secondary string variables, used for generating the pairs of words. The number of variables depends on the number of different logic structures and vocabulary compositions identified for describing the pairs of meaningful words specifically. A representative case that can describe the logical sequence was identified. The second phase exploits the previous step to add the primary variable to the list of pairs of meaningful words after a process of validation. The process of validation, which takes into account a specific syntax structure, was developed in such a way that pairs of words can be retrieved only in a particular situation, avoiding erroneous extractions. The third step alters the value of the secondary variable by retaining specific words as value for successive extractions.

This process is repeated in the sub-loop cycle as many times as the number of words that composes the initial list of words generated at the end of the process shown in *Figure **42***. As a result, a list of pairs of words is extracted from raw data. Eventually, the whole loop cycle is reiterated as many times as the number of words in the Bag of words.

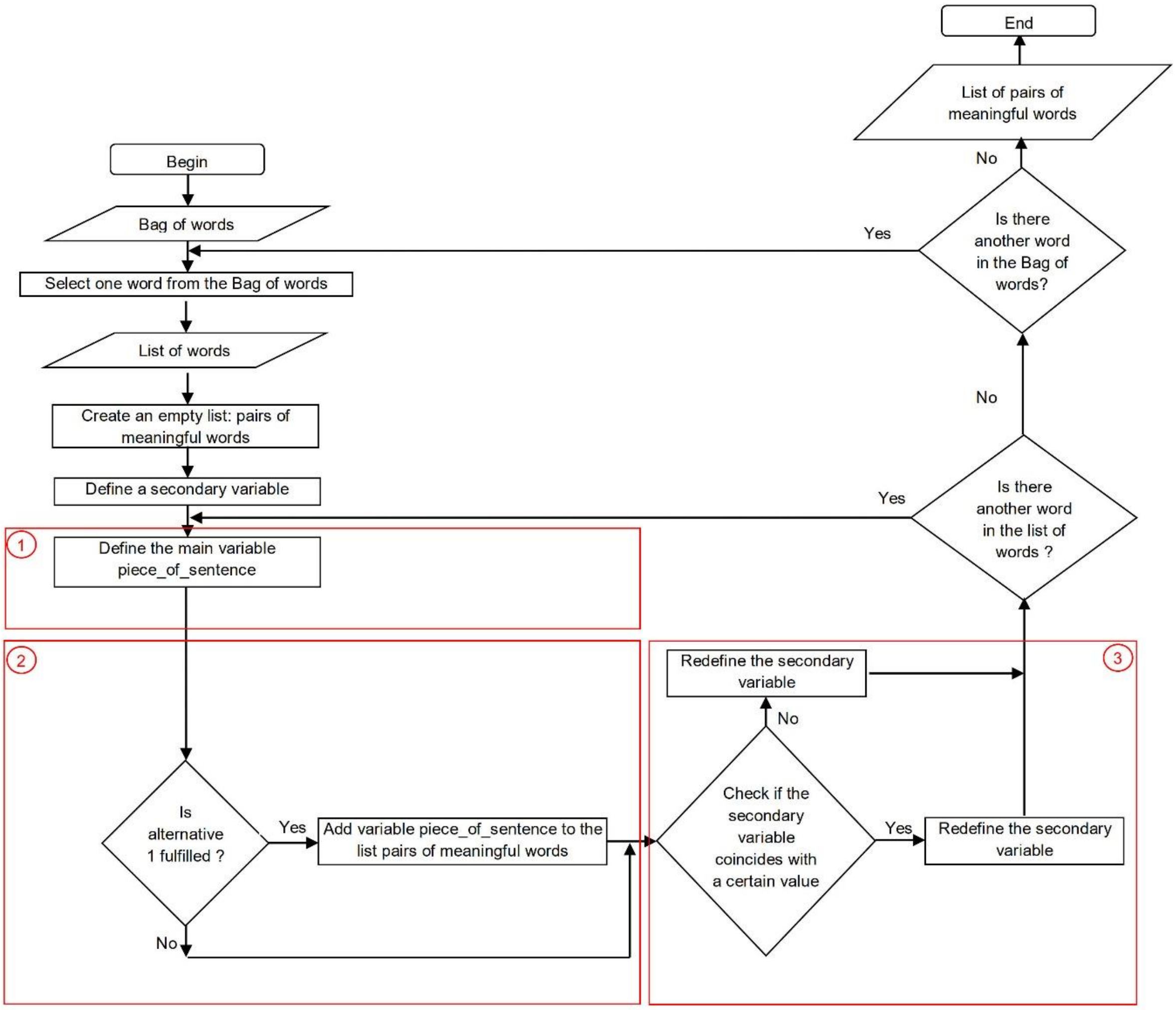


*Figure 45: The process of identifying pairs of meaningful words*

### *4.5.3 Case study*

The case study examines the maintenance management of the facilities that are managed by the local administration of the Municipality of Trieste (Italy), as shown in *Figure **46*** and *Figure **47***. The buildings that are under this local administration control are deployed around the city and surrounding areas and include schools, churches, residential houses, public toilets, nursing homes, libraries, museums and offices. Similar to other public administrations, the strategy of the local administration of the Municipality of Trieste is based on a mix of outsourcing and in-house processes. With reference to the maintenance service, this service is outsourced, namely the management is entrusted to a third party, which provides the platform to manage the maintenance of buildings and the document management of WOs and conducts repair works on site. Data regarding maintenance requests is stored in different databases according to different types of service contracts. In this particular situation, the number of cases, namely the maintenance requests, derives from 33 buildings including buildings for assistance, museums and offices, as they are part of a unique contract. This set of buildings was chosen as test subject because the Municipality of Trieste regarded data contained in this database as high priority data. As shown in *Table* ***32***, both museums and offices account for nearly 40% of the analysed buildings, while the remaining 20% are assistance buildings.

The data set consists of 12655 maintenance requests gathered from the local administration's CMMS for which building maintenance works were conducted. The period of analysis includes requests submitted between 2013 and 2020 by end users and the FM team through the maintenance platform linked to the CMMS database. The information gathered is restricted to the fields of input that the maintenance platform provides. These fields include request code, date, requester (name, phone number and e-mail), the location of the problem by specifying site, building and floor, the category of problem type by using predefined labels, the description of the problem, the priority of intervention, supplier for the service and a field for additional notes.

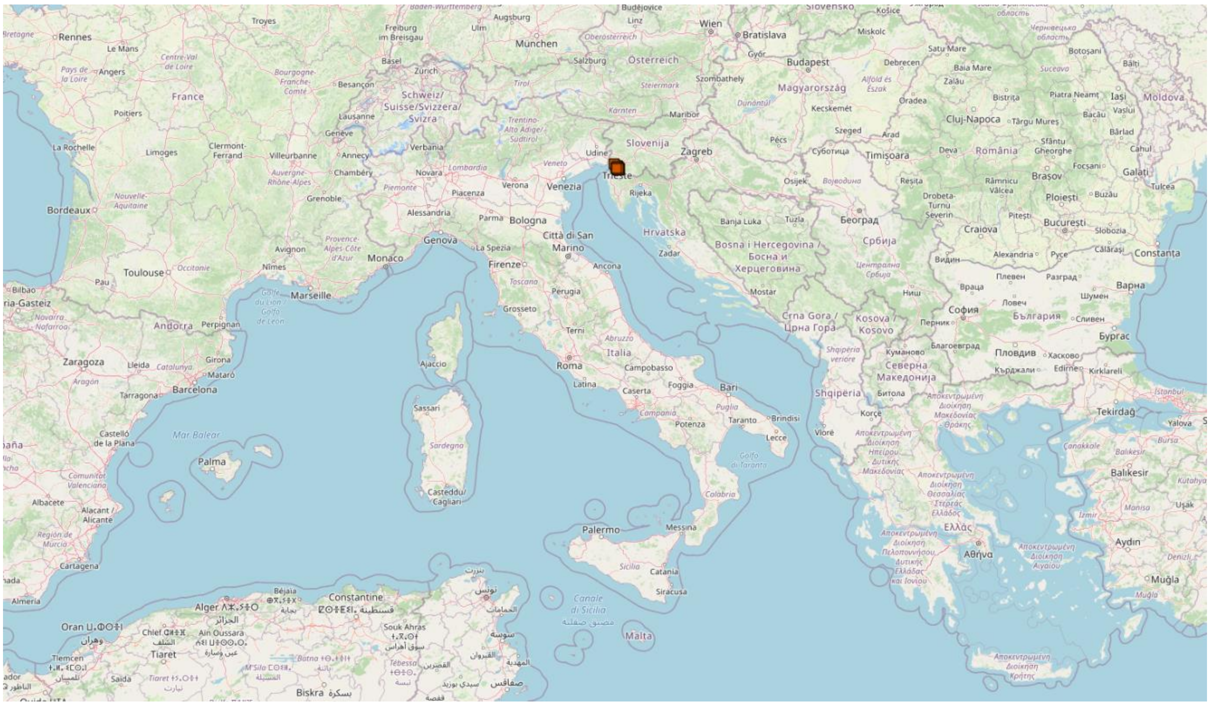


*Figure 46: Pinpointing Trieste in the map of Italy*

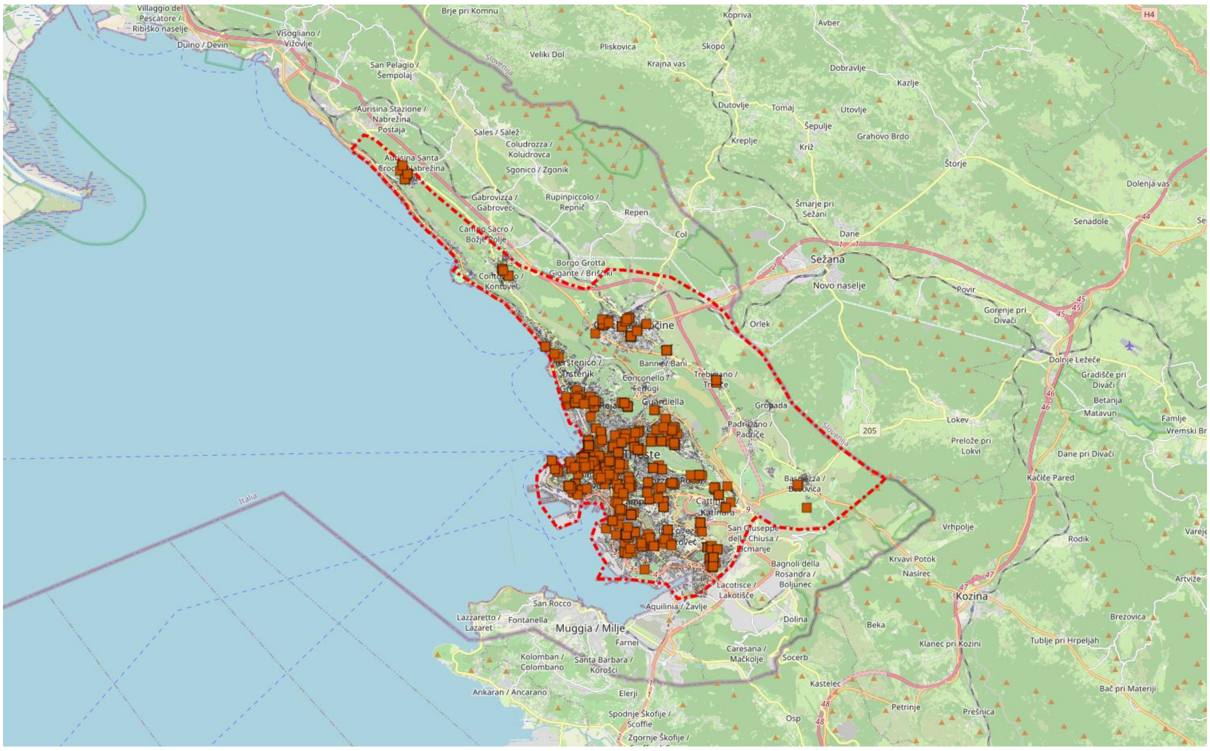


*Figure 47: The buildings managed by the local administration of the Municipality of Trieste*

| Building | Typology of building | Volume (m³) | Number of cases |
|---|---|---|---|
| 0165 | assistance | 27275 | 1737 |
| 0260 | offices | 40733 | 1171 |
| 0733 | assistance | 11892 | 683 |
| 0261 | offices | 23885 | 603 |
| 1077 | museums | 19194 | 577 |
| 0277_1 | offices | 20878 | 508 |
| 0387 | assistance | 19295 | 492 |
| 0710 | museums | 19716 | 452 |
| 1119 | offices | 29050 | 447 |
| 0281 | museums | 40306 | 429 |
| 0723 | offices | 66254 | 409 |
| 0048 | offices | 16771 | 352 |
| 0262 | offices | 9450 | 332 |
| 0622 | museums | 8030 | 319 |
| 0282 | museums | 39540 | 298 |
| 0545_1 | museums | 5483 | 278 |

| Building | Typology of building | Volume (m³) | Number of cases |
|---|---|---|---|
| 0289_0484 | museums | 7970 | 278 |
| 0545_2 | museums | 38910 | 267 |
| 0439_1 | assistance | 8562 | 255 |
| 0732 | offices | 8520 | 253 |
| 0729_1 | museums | 2740 | 244 |
| 1105 | offices | 1662 | 221 |
| 0726 | offices | 6136 | 218 |
| 0591 | museums | 15870 | 212 |
| 0439_2 | assistance | 12329 | 203 |
| 0574 | museums | 28398 | 193 |
| 0236 | offices | 35900 | 187 |
| 1055_1 | museums | 3037 | 184 |
| 0717 | assistance | 2130 | 182 |
| 0751 | assistance | 6352 | 174 |
| 0249 | offices | 1500 | 171 |
| 0718 | assistance | 2130 | 163 |
| 1116 | museums | 17488 | 163 |

*Table 32: The main characteristics of the analysed buildings*

In order to compare buildings according to their typology, the distribution of building maintenance requests was normalised with respect to their volume, as shown in *Figure **48***. The chart shows a significant quantity of maintenance requests for buildings for assistance, while a less remarkable importance for offices and museums. It appears that since buildings for assistance aim to help and accommodate several people, this may cause repeated WOs in buildings.

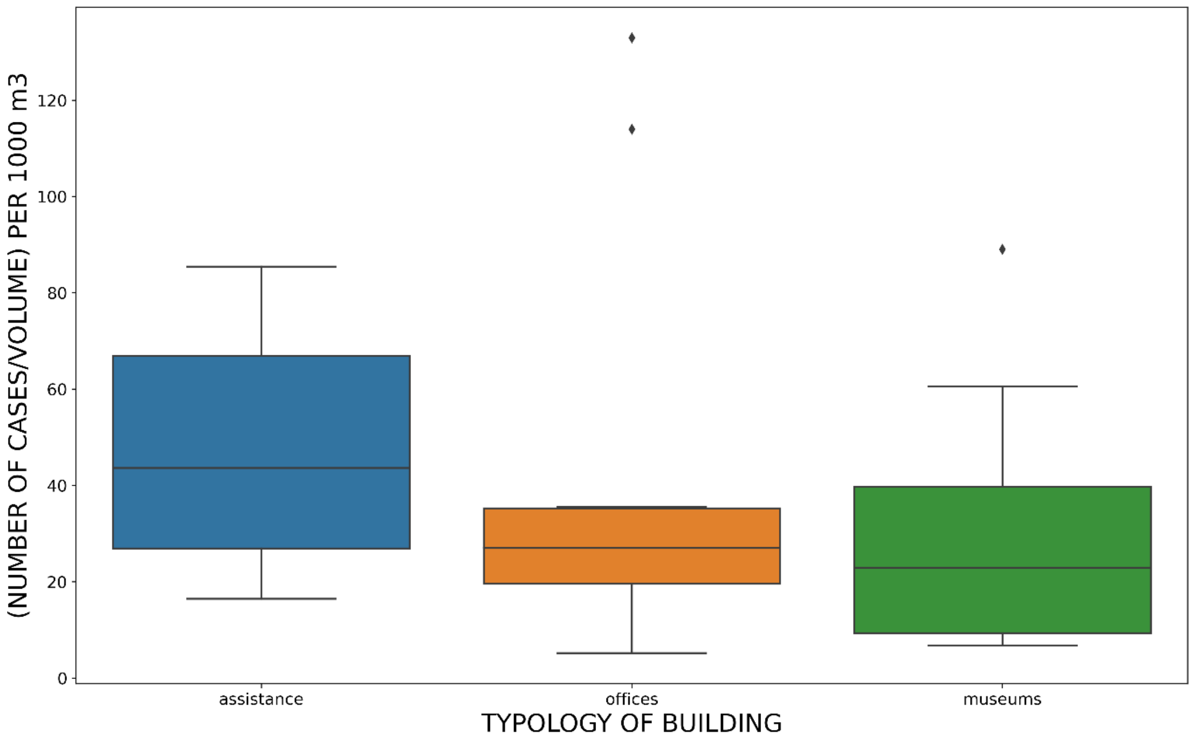


*Figure 48: The distribution of maintenance requests per 1000 m³ with respect to building typologies*

Based on an internal organisation of problem types adopted by the local administration of the Municipality of Trieste, the categories of problem types that were analysed include: electrical maintenance, metalwork/carpentry maintenance, water/sanitary maintenance, special installations maintenance, construction maintenance, external areas maintenance, elevators maintenance, sewer maintenance and fire extinguisher/hydrant maintenance. The three most prevalent typologies of intervention, namely electrical, metalwork/carpentry and water/sanitary, account for nearly 80% of the total of maintenance interventions, as shown in *Table **33***.

| Type of intervention | Number of interventions | % of the total | % routine | % urgency | % max urgency |
|---|---|---|---|---|---|
| Electrical | 4473 | 35,3 | 70,6 | 22,2 | 7,2 |
| Metalwork/Carpentry | 2931 | 23,2 | 57,6 | 30,1 | 12,3 |
| Water/Sanitary | 2487 | 19,7 | 60,8 | 31,2 | 8,0 |
| Special Installations | 1241 | 9,8 | 39,1 | 36,8 | 24,1 |
| Construction | 837 | 6,6 | 56,0 | 32,7 | 11,3 |
| External Areas | 268 | 2,1 | 46,3 | 37,3 | 16,4 |
| Elevators | 154 | 1,2 | 47,4 | 35,7 | 16,9 |
| Sewer | 140 | 1,1 | 25,0 | 42,9 | 32,1 |
| Fire Extinguisher/Hydrant | 124 | 1,0 | 44,4 | 45,1 | 10,5 |
| | | | | | |
| Total | 12655 | 100 | | | |

*Table 33: Problem type categories*

Eventually, analysing the priorities of intervention, it is noticeable that routine maintenance requests account for 60% of the total maintenance requests, urgent maintenance requests account for 29% and extreme urgent maintenance requests account for 11%. The distribution of maintenance request priorities of the analysed buildings is shown in *Figure 49*. For each building shown along the x-axis, the total number of maintenance requests, which are divided in routine, urgent and extreme urgent, is shown using a stacked bar chart. It is worth noticing that buildings 0260 and 0165 have received nearly double and triple maintenance requests compared to the third most problematic building, respectively.

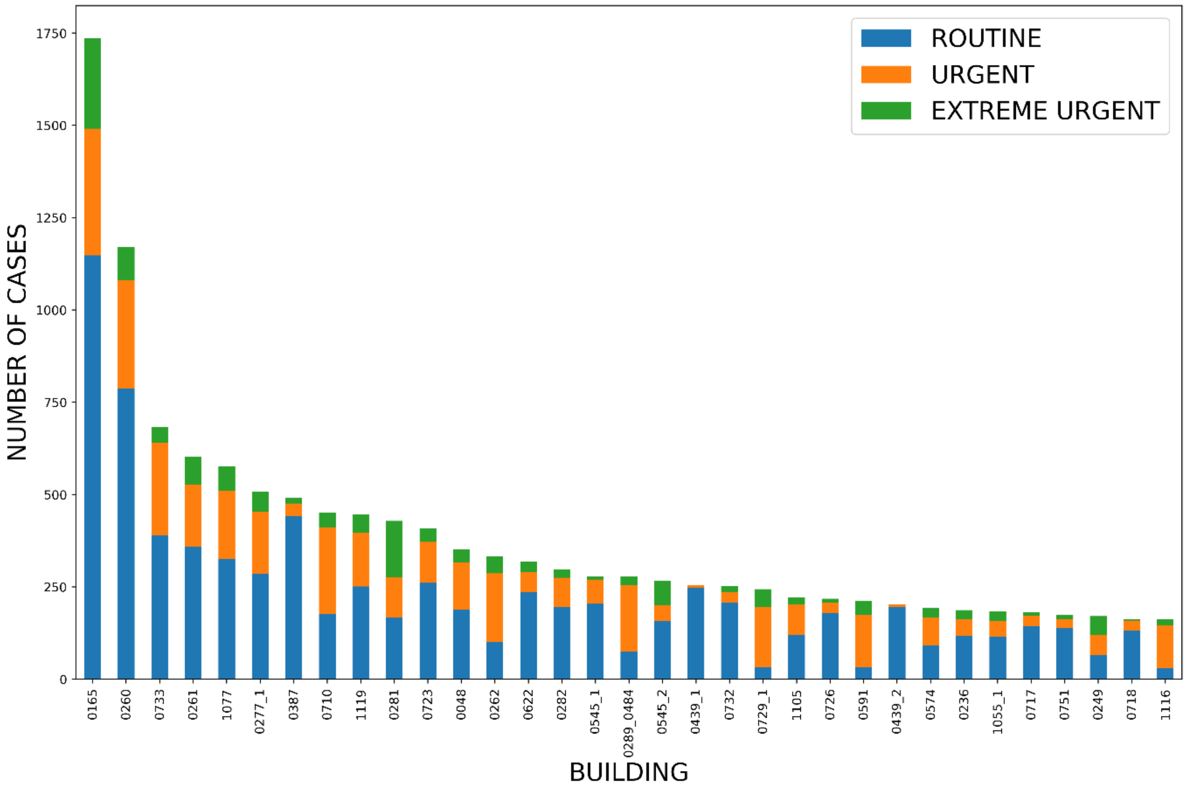


*Figure 49: The analysis of intervention priorities*

#### *4.5.3.1 Results for room ID number identification*

The first part of the research focused on developing a method that can extract the ID number of rooms where faults mainly occur. Before beginning the analysis, all the maintenance requests pertaining to the types of intervention "External Areas" and "Elevators" were excluded, as they cannot contain room ID numbers in their maintenance request descriptions. Thus, the analysed data frame for this specific investigation contained 12233 maintenance requests. Three kinds of analysis were conducted: a general analysis, an analysis of the single types of intervention and a detailed analysis taking into account a specific building.

The first analysis was conducted to have a comprehensive view of the total amount of identified rooms. As a result, 3939 room ID numbers were identified. Comparing this number with the overall number of maintenance requests, the method identified room ID numbers for 32,2% of the total number of descriptions.

The second investigation analysed maintenance requests of all buildings taking into account the specific types of intervention. Results showed that the percentages of room ID numbers found for the type of intervention compared to the total number of maintenance requests for the specific type of intervention were: 43,8% for the water/sanitary maintenance, 31,2% for the electrical maintenance, 35,3% for the metalwork/carpentry maintenance, 33% for the construction maintenance, 9,1% for the special installations maintenance, 13,6% for the sewer maintenance and 10,5% for the fire extinguisher/hydrant maintenance, as shown in *Figure* ***50***.

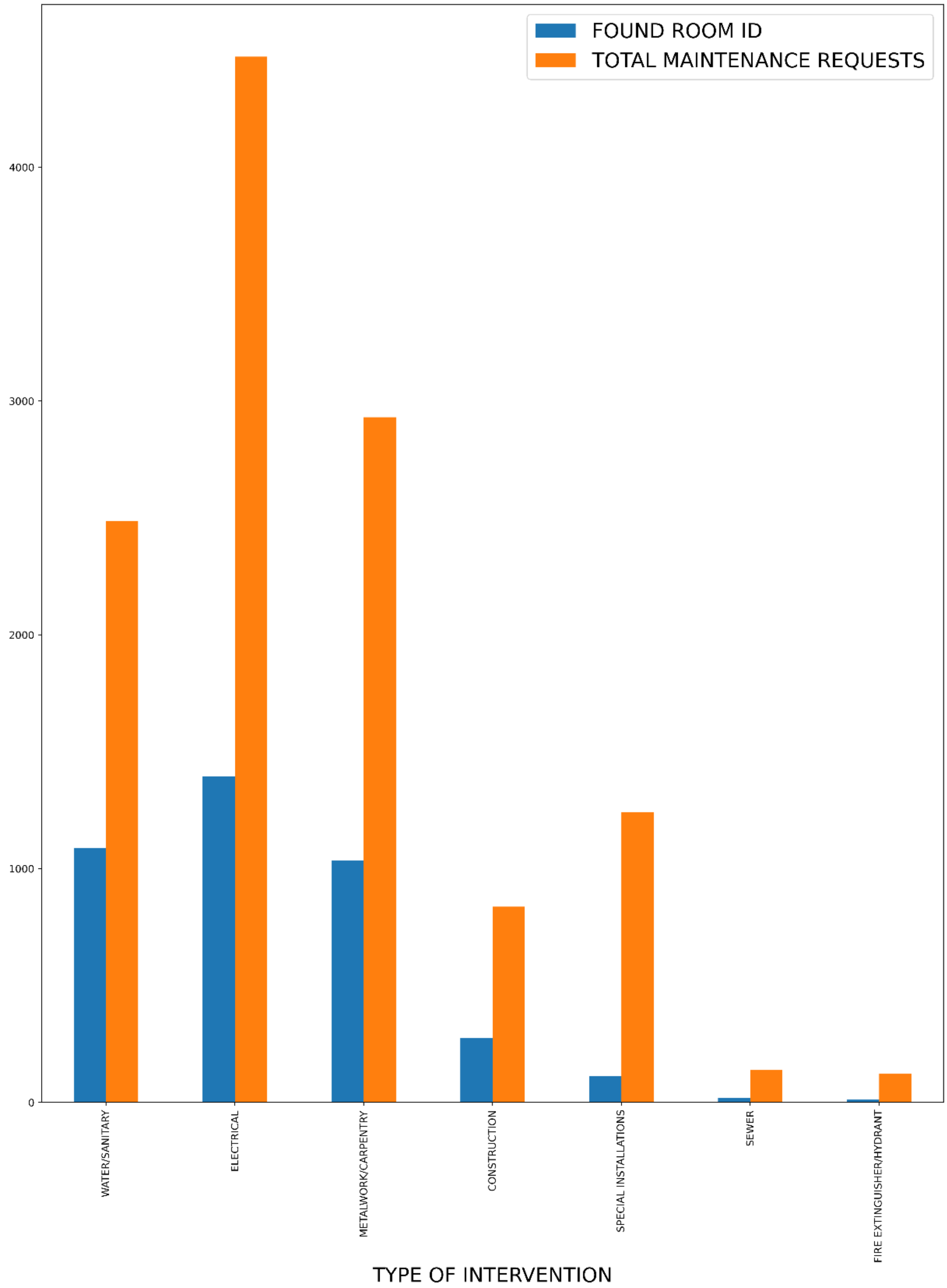


*Figure 50: Room ID number percentages according to the type of intervention*

The third analysis took into consideration the maintenance requests of a specific building so as to assess the method precisely and whether incoherent results occur. The building chosen was the 0165, a five-storey building, where rooms are numerated by hundreds, namely room ID numbers of the ground floor are within a range between 1 and 99, room ID numbers of the first floor are within a range between 100 and 199 and the other storeys have the same numeration pattern. Thus, checking whether some results are inconsistent can be conducted in two ways.

The first way checked the room ID numbers of the overall building. In this case, room ID numbers can be within a range of value between 1 and 499. Results showed that none of the room ID numbers extracted had an incoherent value compared to what expected, as shown in *Figure* ***51***.

The second way checked the room ID numbers for a specific floor. The fourth floor was chosen as a reference, as any kind of numbers in descriptions that do not concern with the room ID numbers, for instance the quantity of windows broken, are quite difficult to reach a value between 400 and 499, therefore allowing a valuable test. Results demonstrated that all room ID numbers extracted had a value included in the predefined range, as shown in *Figure* ***52***.

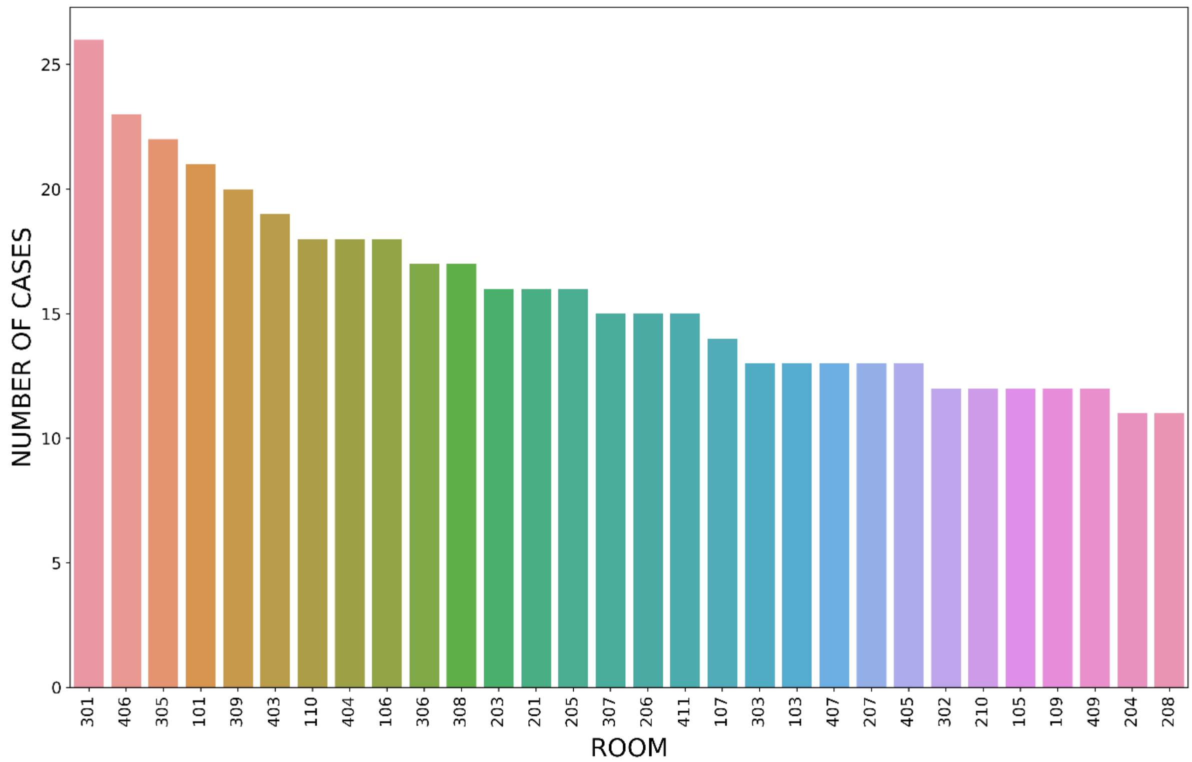


*Figure 51: Room ID numbers of the building 0165*

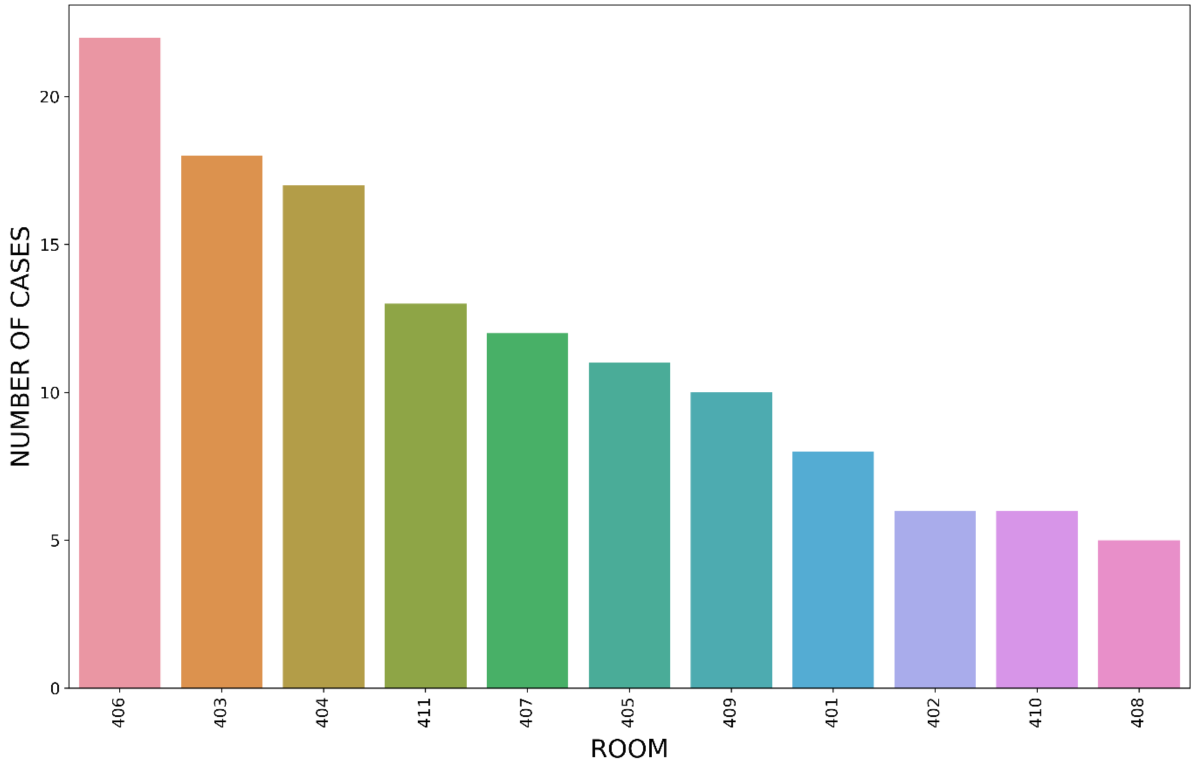


*Figure 52: Room ID numbers of the floor P4 of the building 0165*

#### *4.5.3.2 Results for the most problematic element identification*

The second part of the research focused on generating a method that can acquire the most repeated words in the maintenance requests for discovering what building components and systems are the most problematic. Since the analysis included all the potential faults, the analysed data frame for this specific research contained the whole data set, namely 12655 maintenance requests. To better analyse the results, *Figure* ***53*** displays the occurrence value for each of the most repeated words shown along the x-axis. The results showed that the two most repeated words were terms related to electrical issues, such as neon light, which was cited 3312 times, and light bulb, which was cited 1948 times. The third most quoted word referred to water/sanitary problems, such as wc, which was cited 1659 times, namely less than half of the word neon light. The other words that were considered relevant were part of a range of frequency from slightly below 1000 times to 250 times.

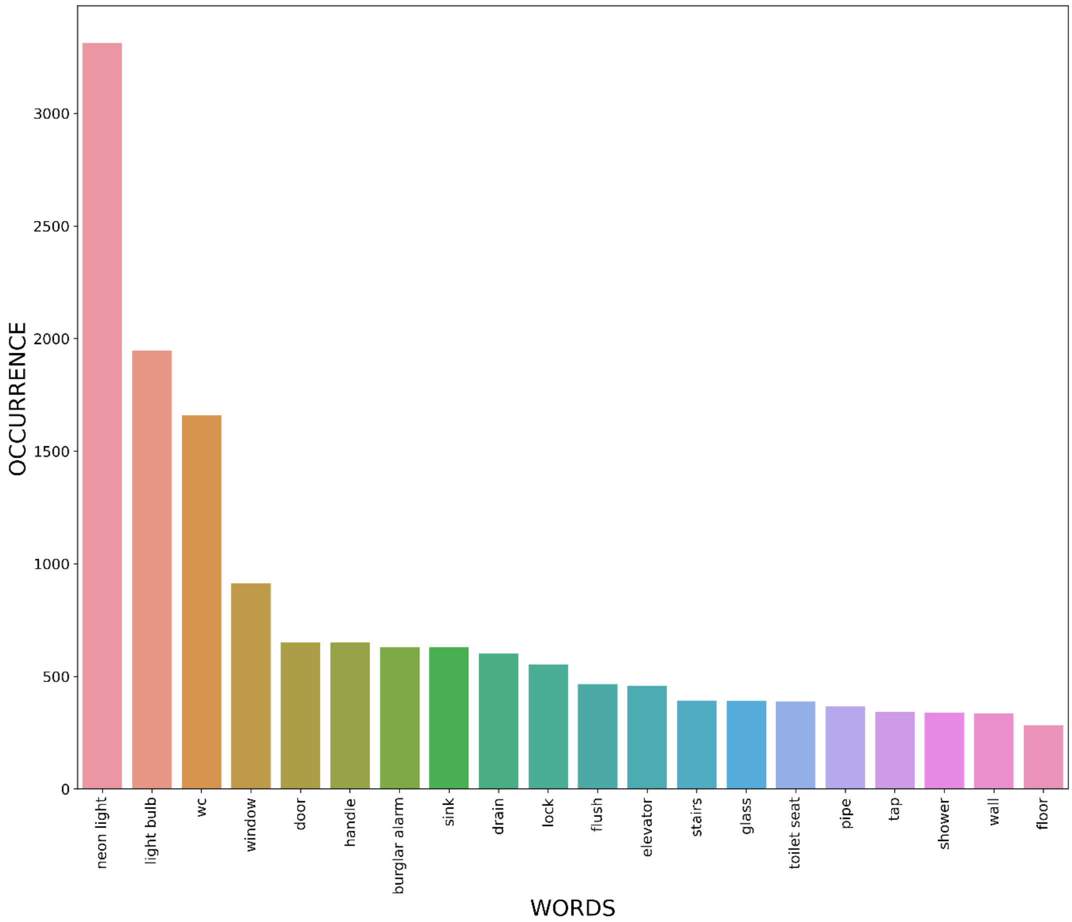


*Figure 53: The most repeated words*

After identifying single words that can specify the issues, the analysis focused on the pairs of meaningful words that can describe better what the problems are by exploiting the words found in the previous analysis. The considered words included wc, window and door, namely the three most repeated words with general meaning so that they could be combined with other words to generate terms with specific significance. The results of the meaningful pairs of words are shown in *Figure **54***, *Figure **55*** and *Figure **56***, where only the results above a threshold of fixed frequency, namely 10% of the total amount of extracted pairs of words for each analysis, were considered in order to avoid meaningless outcomes derived from misleading ways of writing. The results revealed that the most problematic fault related to water/sanitary problems and linked to the word wc was toilet seats, which occurred 307 times, namely more than twice of the second most frequent issue. The other failings included basins, flushes, drains, neon lights, light bulbs and sinks. With reference to the words linked to window, glass and handles problems were the most significant ones, while the other words encompassed issues connected with blinds and frames. Eventually, problems related to door consisted of locks, closers, handles, bells and glass.

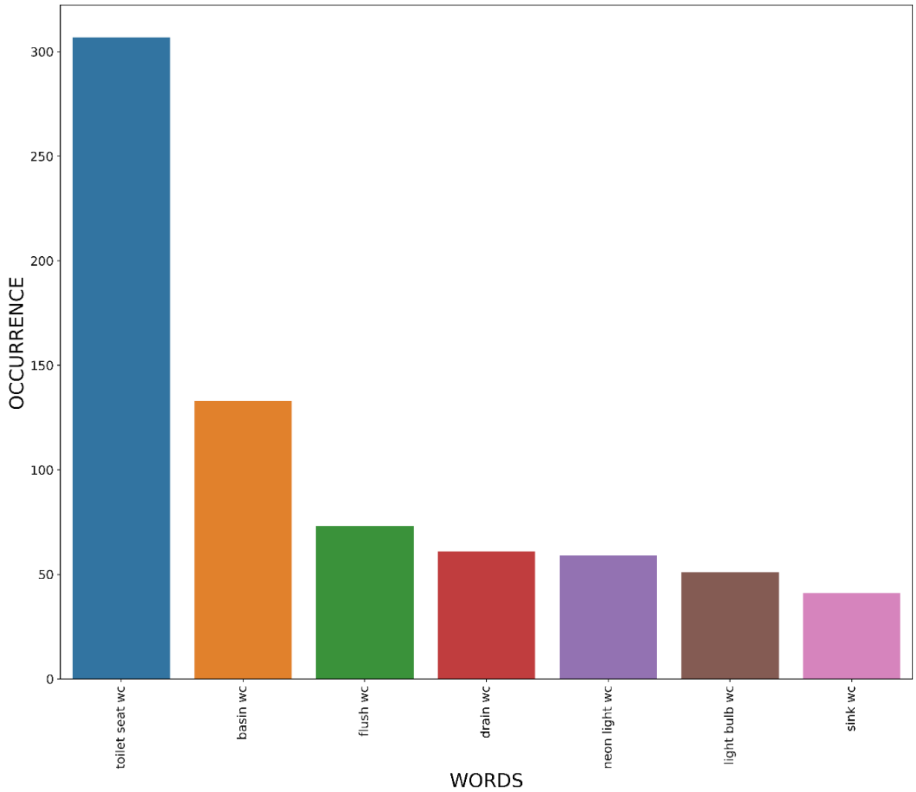


*Figure 54: The pairs of meaningful words connected with the word "wc"*

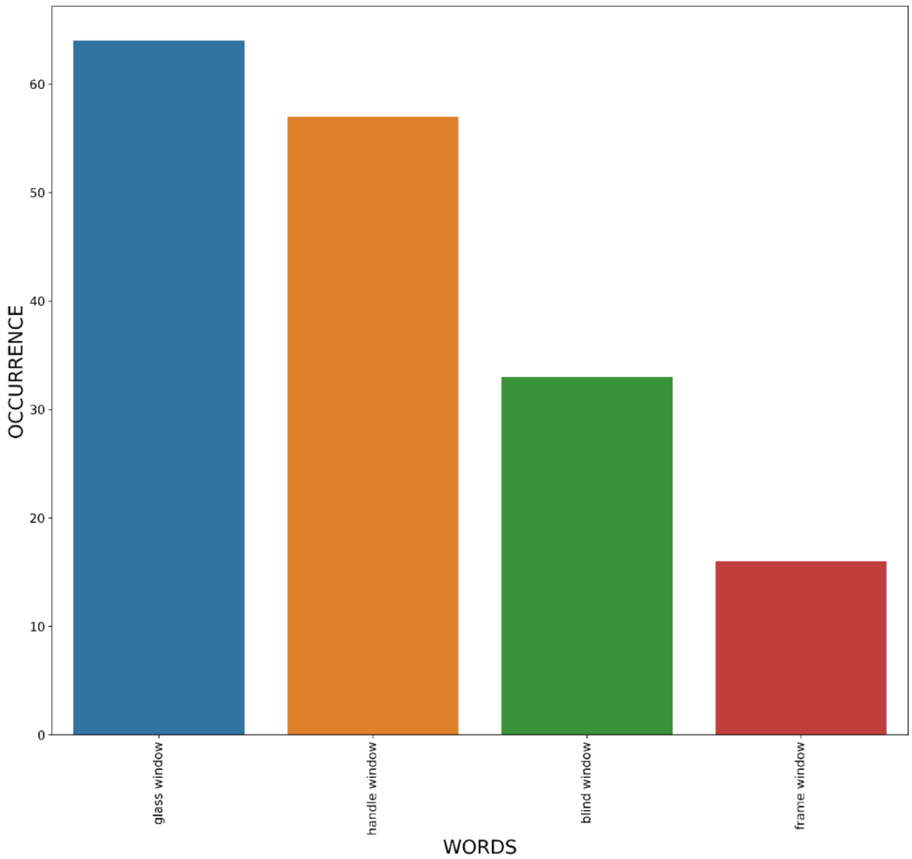


*Figure 55: The pairs of meaningful words connected with the word "window"*

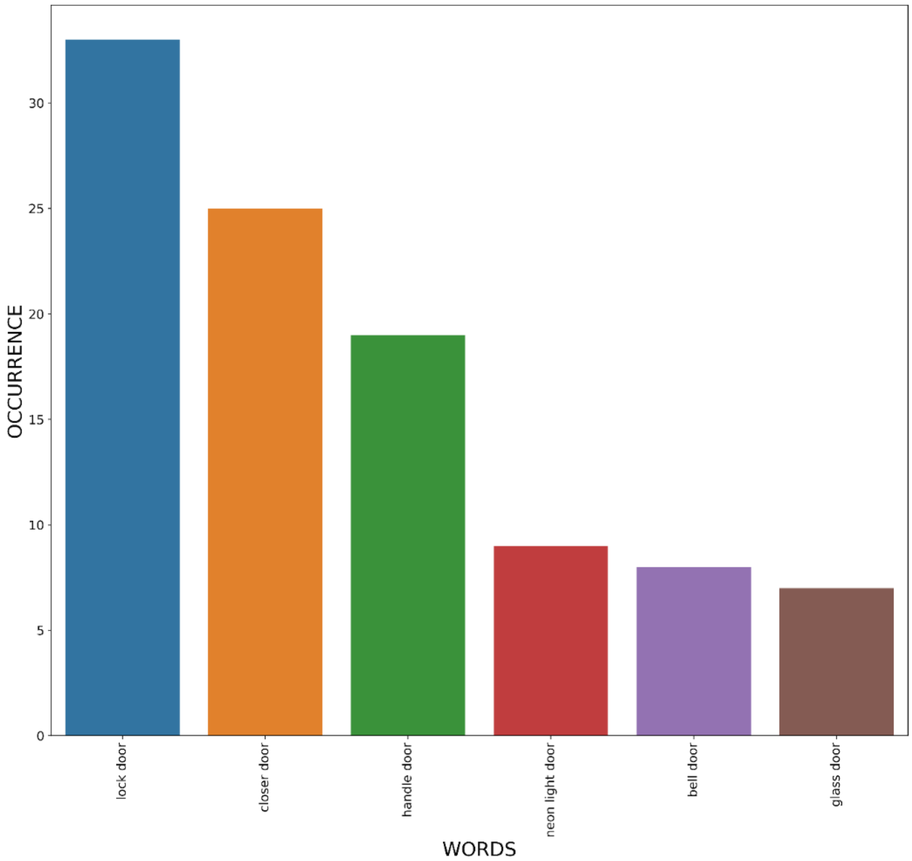


*Figure 56: The pairs of meaningful words connected with the word "door"*

### *4.5.4 Discussion and considerations*

**Theoretical implications**

Similar to other research on this topic [248] [146], this study presents results from a real case study and contributes to the body of knowledge regarding the extraction of valuable information from CMMSs by using text-mining algorithms.

Aligned with previous studies found in literature, this research overcomes issues identified by [249], which pointed out a lack of practical use regarding most of the data collected from computerised systems. To this end, this study proposes two methods to allow exploiting unused data, such as text records, in order to provide an exhaustive view of what the principal issues of buildings are and what buildings are mainly affected by failings. The proposed methods also support the problem of insufficient level of data usability identified by [250]. According to Tretten and Karim (2014), information stored in the FM system needs to be easily analysed to plan and conduct maintenance tasks. Along these lines, the two proposed methods support effective building maintenance management by generating useful information from raw textual data. Furthermore, this study also addressed issues such as improperly standardised and organised maintenance requests pointed out by several research [53] [251] [252], as this study focuses on developing methods to precisely identify operational faults in buildings by using unstructured data contained in CMMSs. Considering data as fundamental for supporting the decision-making processes for maintenance management [253], this work also aligns with Lateef (2009) because it enhances the performance of building maintenance management by using a data-driven approach instead of relying on hypothetical and experience-based systems.

With reference to the adoption of text-mining for extracting useful information from CMMSs, the work of [146] showed how to cluster specific work orders limited to HVAC issues, avoiding superfluous and misleading data, such as routine maintenance requests, whereas the research carried out by [248] identified the correlations between building characteristics and faults by considering data including gross floor area, year of construction, type of building use and building property. Compared to the works of Bortolini and Forcada (2020), and Gunay et al. (2019), this research proposed two methods which focus on pinpointing building areas where failures more often occur and identifying precisely all flawed building elements and systems. This means that not only principal failures are recognised, but also a specific component of the flawed element is identified, leading to a major accuracy of what sub-component is damaged.

**Practical implications**

The first part of the research focused on developing a method that can extract the ID number of rooms where faults mainly occur. Three types of analysis were conducted in order to assess whether the methodology works or needs adjustments. The general analysis concluded that the method identified the room ID numbers for 32,2% of the total number of maintenance requests. With reference to the analysis of the specific types of intervention, the results demonstrated to be consistent with the previous outcome, as for most of the types of intervention, the percentages of found room ID numbers were close to a third of the overall number of maintenance requests per the same type of intervention, as shown in *Figure* ***50***. On the other hand, some limitations of the proposed method were identified. Firstly, some of the types of intervention showed a lower percentage of found room ID numbers due to their limited pertinence with identifying room ID numbers. For instance, the category "Fire extinguisher/hydrant" is rarely applicable to a single room, as fire extinguishers are usually located in building corridors. Secondly, the results are influenced by the maintenance representatives' accuracy and completeness ways of writing. Indeed, most of the WOs do not contain a room ID number, but rooms are described and pinpointed by using another name, such as "bathroom" instead of "room 12", or describing how to reach them. Furthermore, some manners of writing room ID numbers can be extremely unusual, such as "room ID number 112-3", which means "room ID number 112 and 113".

Another issue concerns the limits to explain precisely the whole problem, which can affect other spaces and elements close to damaged areas. For instance, a leaking problem may involve two floors, but rigid forms for stating maintenance requests do not allow inputting two data in the same field, leading to difficulties in identifying and localising an issue properly. Finally, this method can be extended to other maintenance scenarios, such as industrial and commercial scenarios, to reach similar results due to the fact that each of these scenarios usually have a digital maintenance management system. In these cases, instead of searching for room ID numbers, the validation processes would need to be adapted to identify the ID numbers of areas, such as laboratories or stores, on the basis of the type of portfolio analysed, On the other hand, the identified limitations might occur, as well. Indeed, problems related to limited pertinence with identifying area ID numbers are troublesome if these areas cannot be defined properly, while issues related to the maintenance representatives' accuracy and completeness ways of writing mainly depends on the instructions and education received.

The second part of the research focused on generating a method that can acquire the most repeated words in the maintenance requests for discovering what building components and systems are the most problematic. Since the data set is derived from an Italian database, the translation of some words into English words needs more than one word, such as light bulb and neon light. The analysis demonstrated to be coherent with the information shown in *Table **33***, as most of the maintenance requests concerned electrical, metalwork/carpentry and water/sanitary problems. One part of the results can be considered as stand-alone words, which can provide useful insights into what needs more attention. For instance, the most significant result was the word neon light, which was cited more than twice than the third most quoted word. On the other hand, the other part of the results cannot supply meaningful outcomes, but needs another word to describe better what the problems are. For instance, results revealed that many water/sanitary problems related to the word wc were toilet seats, basins, flushes, drains, neon lights, light bulbs and sinks. Generalising these results with other maintenance scenarios, it can be noticed that this method might be also valuable for identifying more specific and technical issues related to other scenarios, such as hospital and factory scenarios. In particular, the proposed method might be helpful to identify the groups of or individual most problematic specialised machines and systems. To adapt the algorithm, there would be a need of grouping similar ways of naming equipment at the beginning of the extraction process to identify unequivocal and peculiar machinery ID numbers.

Another limitation of the proposed methods concerns the fact that WOs are usually subjected to misleading information due to space name abbreviations, no space names or incorrect space names, which leads to time-consuming operations of identifying the correct place or component. Although commercial systems, such as CMMS, can support keeping trace of building maintenance requests, they are often badly organised and cannot always constrain storing all the necessary information. One solution to this problem which avoids complex activities, such as modifying the structure of the CMMS database, concerns improving the internal processes of stating maintenance requests. Representatives of maintenance work orders should be instructed on how to write a request in a standard way. A default form which expresses maintenance requests in order to get the right data at the right point should be developed. Descriptions should contain the position of where the problem occurs, a summary of the problem which states what element or system has a malfunction and then a brief explanation, as shown in *Table **34***. This form might be able to allow FM personnel to easily extract and exploit data due its well-organised pattern.

| | |
|---|---|
| Position of the problem: | e.g. “Room 19” |
| Summary of the problem: | e.g. “Toilet seat broken” |
| Brief explanation: | e.g. “...text...” |

*Table 34: The proposed default form for maintenance requests*

Although this solution can be useful to generate insights to manage buildings, it cannot provide the exact identification of elements. For instance, a building corridor can have several neon lights, therefore without specifying which one is the problem, it is not possible to carry out an in-depth analysis. This leads to a need to improve the structure of databases, where each element is linked to a specific ID number in the database so as to identify it whenever necessary. Well-structured databases can be organised according to a classification system of building components as proposed in *Figure 57*. The classification system has a tree structure, which starts from the site of where buildings are located up to specific element ID numbers. Information, such as work order ID number, facility ID number, location, the description of previous works, but also documents required to perform maintenance, has to be attached to building elements during FM processes.

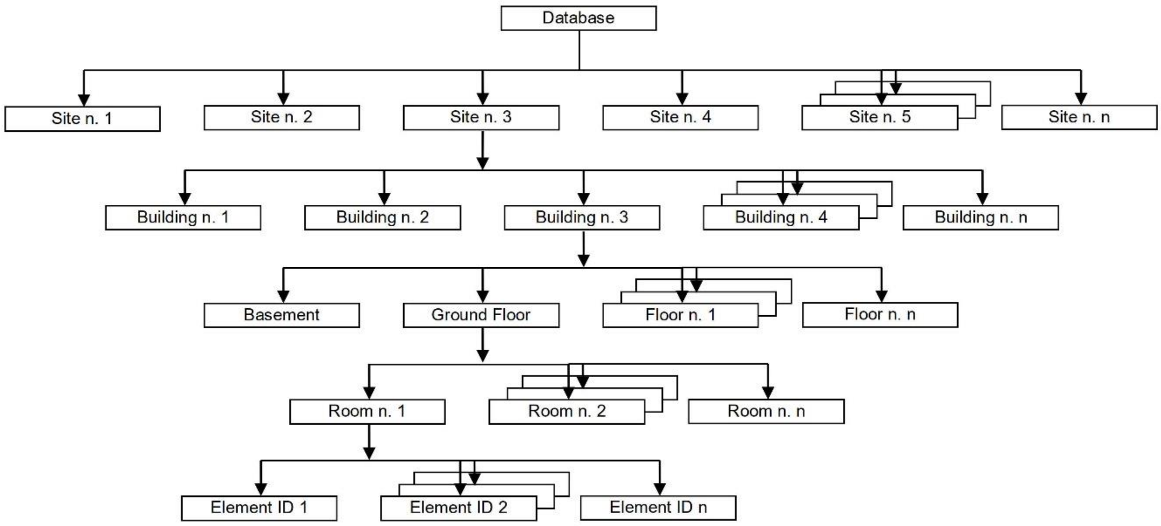


*Figure 57: An example of a structured database*

However, this solution cannot provide comprehensive spatial and topological information that is needed to identify and fix issues. Thus, these platforms should be expanded by adding additional modules that can achieve this accuracy. Digital twin platforms can be the technology which enables an effective management of buildings in the operational phase. As well as dynamic data retrieved by smart devices, such as sensors, deployed around buildings, the other root component of these platforms is the use of BIM models to represent buildings. One of the basic properties of a BIM object is its Globally Unique Identifier (GUID), which is unique for each element in the model. Due to this characteristic, these systems allow detecting elements, simplify access to data and automate the process of linking elements with WOs.

# Conclusion

The research activity concerns the digital management of buildings. While traditionally the design and construction phases used to be regarded as the most important stages in the construction industry, this focus has shifted towards the operational one over the last decade. It is well-recognised that after a short amount of time due to the design and construction stages, buildings can be operative for more than fifty years. This leads to growing interest in improving building efficiency in order to reduce costs and wastage, and boost occupant well-being. Nevertheless, the digital management of buildings is still relatively a new topic. On the one side, it is true that new technologies have been developed to collect data and enhance activities. On the other side, it is also true that disruptive technologies acting alone cannot achieve the interested results due to difficulties in their adoption. Furthermore, data managed in the FM phase are not always easy to deal with, but includes different, complex and unstructured formats. For these reasons, a set of methods, tools and techniques are proposed in order to achieve an effective digital management of buildings.

The first part of the research regards a method to implement the BIM process in organisations. BIM can be regarded as the starting point for managing building information, as when BIM models are integrated with operational data in FM systems, this enables an efficient digital management of buildings by generating the Digital Twins of facilities. Since organisations, especially public ones, often suffer from a change-resistance attitude to new methods, a lack of technical skills and strong attachment to old standards of operation, a guided step by step adoption which provides hints on the main aspects organisations need handling is proposed. This concerns a gradual implementation which considers a practical framework based on an iterative approach in order to achieve the interested results. The framework consists of three main milestones including acquisition, modelling and validation. The proposed work also presents a series of KPIs which helps to monitor, measure, and improve BIM practice during the milestones, with a focus on people, processes, technologies and tools. The considered aspects consist of organisational and technical ones. The former is divided in internal collaboration and internal coordination, which take into account collaboration process and colleague collaboration, and coordination system, respectively. The latter is dived in technology and specific skills, which consider the software used, and knowledge and competences, respectively. Future research could focus on applying this framework on organisations of different type and size, and assessing the results obtained in order to validate it. On the whole, as BIM is a completely new and innovative process, this framework allows organisations to have a guide regarding how and what aspects and education have to be possessed in order to properly manage buildings in a digital way.

The second part of the research concerns a set of essential features to set up a FM system able to manage buildings smartly. As well as having digital models to manage buildings, organisations also need to set up a system able to acquire, transmit, integrate, manage and exploit a comprehensive and ongoing flow of data during the operational phase. Since the centrality of data is a critical aspect of the O&M stage, a set of indicators which can lead the implementation of an efficient FM system for managing buildings is proposed. To speed up processes, avoid potential human errors and provide useful insights, the main common denominators which are regarded as worthy features include automation, real-time data availability, central online data storage and advanced data analytics. Automatic processes, along with real-time data enable enhancing accuracy and efficiency when collecting and integrating data. Using a unique repository accessible from anywhere allows employees to work and share the same data throughout the organisation. Advanced methods for analysing data can boost decision-making processes and consequently yield significant savings. Future directions should focus on applying the proposed indicators on different organisations in order to validate their quality and significance. On the whole, the proposed aspects and indicators guide organisations towards developing a system able to access to the right data, in the right format, at the right time in order to manage buildings.

The third part of the proposed series of guidelines is about the process to develop digital models for the operational phase. This process has different paths in accordance to the specific situation. The principal distinction regards the type of approach chosen, namely outsourcing or insourcing approach, while the secondary difference depends on the types of construction situation, namely new construction or existing construction. All of them share a common path which begins with the object definition and ends with the handover process. Between these two phases, a bidding process is conducted in the outsourcing approach, while in the insourcing approach facility survey and modelling, or just modelling is conducted for existing construction and new construction, respectively. For each of the cases, a set of instructions and advice is presented, and eventually a consideration regarding the strategic setting of data visualisation which aims to boost building management performance is proposed. Future research could focus on defining when it is more convenient to insource or outsource a project by analysing different cases in terms of size and complexity. On the whole, the presented process is a helpful protocol which organisations can use in order to develop BIM models for the management of buildings.

The fourth part of the proposed series of guidelines involves the design of an application for the space management of buildings, with a particular focus on office workspaces. Space management, along with smart working are critical tools that organisations equipped with the suitable technology can exploit to reduce the energy wastage of working practices and meet the aspirations of staff for an improved work-life balance. On these premises, the design of the application tier of a Digital Twin-based system which enables an effective digital space management is presented. The proposed system has a double perspective use. On the one side, it allows employees to book workspaces and provide feedback about them. This leads to avoiding repeated bookings or unused spaces, along with collecting useful information including advice and issues related to specific workspaces. On the other side, it allows space managers to have access to reliable and comprehensive data provided by sensors and exploit this data with BIM technology in order to conduct space planning. Space management is only one of the multiple topics of FM, therefore a potential future direction is the extension of this system by adding other modules in the application tier. Linking the space management data with others FM data, such as energy and maintenance data, enables creating an IWMS for an integrated management of all activities regarding the facilities management. On the whole, the proposed DT system can boost the space utilisation and occupant satisfaction inside organisations, along with reducing direct and indirect costs related to space use.

The last part of the research regards two operational text mining-based methods able to extract relevant information from maintenance requests in order to improve building management. Maintenance requests stored in CMMSs are directly linked to operational faults and building deteriorations. However, due to unstructured CMMSs, this data is not valuable to plan effective maintenance strategies until integrated and transformed into a piece of valuable information. The proposed methods focus on investigating textual maintenance requests to conduct preventive maintenance. The first method aims to extrapolate the room ID numbers where faults mainly occur, while the second one focuses on the most problematic building elements/systems. These methods were applied to the case study of the local administration of the Municipality of Trieste, where 12655 maintenance requests derived from 33 buildings were analysed. The results of the first method show a significant efficacy to detect room ID numbers where this approach is applicable, while the results of the second method reveal the typology and overall significance of specific building element/system faults. Based on these results, the proposed methods can be extended to other maintenance situations, such as industrial and commercial scenarios. Therefore, future studies could focus on applying these methods to other scenarios in order to identify major faults pertaining to different typologies of assets. In addition to it, since WOs are influenced by the maintenance representatives' accuracy and completeness ways of writing, it is critical to identify and put in place well-organised patterns and internal processes of requesting maintenance works to improve the extraction of information from CMMS databases. On the whole, not only numerical data can be useful to support building maintenance management, but also textual data can be worth considering. To this end, the proposed methods provide organisations with a solution to exploit this type of data in order to gain a comprehensive knowledge of building faults and insights for preventive maintenance.

**Final considerations**

The research has highlighted a strategy which is based on a transformation to achieve an effective management of buildings. It is clear that a digital transformation needs an effort regarding both technical and organisational aspects. Indeed, when both aspects are not taken into account, this leads to barriers, issues and difficulties in embracing innovation. The proposed strategy advises to follow a comprehensive and gradual process to implement new solutions in order to gain potential benefits both in the short term and especially long term. This starts from implementing the BIM process and efficient FM systems, which are the starting points for an efficient management of buildings and ends with focussing on two specific applications in two FM disciplines including space management and maintenance management. This strategy leads towards the implementation of DT systems, which can provide great benefits for the management of buildings in the operational phase. On the whole, organisations which manage buildings should not avoid the pervasive digital revolution, instead they ought to embrace it and exploit its great potentiality by putting in place an effective digital transformation in the management of buildings. Finally, it is hoped that this dissertation will contribute to help organisations, both private and public ones, to introduce and support innovation to the operational phase, and eventually lead to an efficient management of buildings.

## List of figures

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# Appendix A

This part of the dissertation includes the report produced for the local administration of the Municipality of Trieste regarding the maintenance management of the buildings managed by the local administration of the Municipality of Trieste. In particular, this part enriches the analysis regarding the maintenance management described in Section 4 by providing a report on the most problematic buildings in terms of maintenance requests.

The document was produced in Italian for the practical utility of the local administration.

# Sommario

## Premessa

Il Comune ha interesse a conoscere le problematiche riscontrate durante la gestione dei propri edifici pubblici. Tramite il database del software gestionale Floora è possibile solo analizzare puntualmente le segnalazioni di intervento per il servizio di manutenzione degli edifici ad uso uffici, sedi museali, assistenziali e bagni pubblici gestito tramite Global Service. Tuttavia, non è possibile integrare i dati delle segnalazioni per creare informazioni utili alla gestione del patrimonio immobiliare. Conoscere le tipologie di problemi che si verificano nelle proprie strutture e quali siano le strutture che maggiormente richiedono interventi può aiutare il Comune di Trieste ad individuare i casi più critici e a operare di conseguenza.

Il presente Report riassume graficamente i principali risultati relativi alle segnalazioni "chiuse" raccolte negli ultimi 7 anni, cioè da maggio 2013 fino a settembre 2020. La finalità del report è di evidenziare le criticità riscontrate e il generale andamento delle richieste di intervento di manutenzione del patrimonio immobiliare, ad uso uffici, sedi museali, assistenziali e bagni pubblici, del Comune di Trieste.

Il primo capitolo "**Anagrafica**" riporta l'anagrafica di tutti gli edifici e impianti associati a segnalazioni di intervento chiuse registrate nel database di Floora nei sette anni considerati.

Il secondo capitolo **"Analisi degli edifici e impianti"** riassume la distribuzione complessiva delle segnalazioni di intervento nei sette anni di riferimento, considerando tutti gli edifici ed impianti elencati nel precedente capitolo.

Il terzo capitolo **"Analisi casi significativi"** evidenzia tra tutti gli edifici e impianti gestiti quali siano i casi significativi[11].

Il quarto capitolo **"Analisi complessiva delle priorità di intervento dei casi significativi"** analizza l'andamento delle richieste di intervento in base alle priorità di intervento, considerando solo i casi significativi individuati nel capitolo precedente nei sette anni considerati.

Il quinto capitolo **"Analisi complessiva delle tipologie di intervento dei casi significativi"** analizza in modo complessivo gli andamenti delle richieste di intervento dei casi significativi in base alla tipologia di intervento considerata nei sette anni di riferimento.

Il sesto capitolo **"Analisi puntuale delle segnalazioni dei casi significativi nell'arco del tempo"** analizza in modo puntuale, cioè edificio per edificio, gli andamenti nel tempo delle richieste di intervento dei casi significativi nei sette anni considerati.

Il settimo capitolo **"Analisi puntuale delle segnalazioni dei casi significativi per tipo di intervento"** analizza in modo puntuale, cioè edificio per edificio, gli andamenti delle richieste di intervento dei casi significativi in base alla tipologia di intervento considerata nei sette anni considerati.

Il report si conclude con il paragrafo **"Conclusioni "** in cui si riepilogano le criticità riscontrate e il generale andamento delle richieste di intervento di manutenzione del patrimonio immobiliare gestito dal Comune di Trieste tramite il gestionale Floora.

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[11] casi significativi: edifici e/o impianti a cui corrisponde nel database un numero di segnalazioni chiuse superiore alle 150 volte nell'arco dei sette anni di osservazione. Il valore 150 rappresenta il doppio della media delle segnalazioni chiuse rispetto al numero di totale di impianti ed edifici.

# 1 Anagrafica

Nella seguente tabella vengono elencati tutti gli immobili e impianti associati a segnalazioni di intervento chiuse registrate nel database di Floora nei sette anni considerati. I dati dell'anagrafica derivano dall'integrazione della tabella del documento "ELENCO IMMOBILI 11-10-18" e da dati presenti nelle schede di manutenzione inserite nel database di Floora. L'integrazione di tali dati ha mostrato diverse incongruenze tra le due parti. Per tale motivo si è deciso di segnalare in rosso il numero identificativo degli elementi per cui si sono utilizzati dati presenti nelle schede di manutenzione inserite nel database. Tali dati presentano alcuni errori tali da far presumere la mancanza di aggiornamento e correzione dei dati e quindi non sono completamente affidabili. La restante parte dei dati, cioè quelli provenienti dal documento "ELENCO IMMOBILI 11-10-18", sono stati considerati affidabili e non sono stati segnalati in rosso. Tali dati sono considerati corretti dall'ufficio comunale responsabile e utilizzati nelle gare di appalto.

Le incoerenze comprendono due marco tipologie: la nomenclatura degli edifici nel database di Floora rispetto alla nomenclatura utilizzata nel documento "ELENCO IMMOBILI 11-10-18" e la presenza di edifici con destinazioni d'uso diverse da quello che il database dovrebbe contenere. Vengono di seguito spiegate in modo generale le incoerenze:

- Nel gestionale Floora viene utilizzato il trattino basso "_" per indicare "sub", ad esempio: edificio 0512 sub 1 nel documento "ELENCO IMMOBILI 11-10-18" viene indicato come edificio 0512_1 nel database di Floora;
- Alcuni edifici sono stati associati ad altri, ad esempio: gli edifici 1022, 1104,1105,1117 e 1135 sono stati raggruppati e vengono rappresentati ad oggi dal codice identificativo dell' edificio 1022;
- Alcuni edifici vengono denominati come interi nel documento "ELENCO IMMOBILI 11-10-18", ma nel gestionale Floora tale edificio viene rappresentato da un insieme di parti dello stesso edificio, ad esempio: l'edificio 0296 viene chiamato 0296 nel documento "ELENCO IMMOBILI 11-10-18" e vi viene assegnato un volume totale, ma nel database di Floora si scompone in sottoparti 0296_1 e 0296_2 con relativi volumi che però non danno come risultato della loro somma il valore del volume totale dell'edificio 0296;
- Alcuni edifici contenuti nel database hanno destinazioni d'uso diverse rispetto alle destinazioni ad uso uffici, sedi museali, assistenziali e bagni pubblici. Ad esempio: l'edificio 1033 con destinazione d'uso alloggi. Probabilmente i dati di tali immobili sono rimasti nel database dopo la variazione negli anni della scelta delle tipologie di destinazioni d'uso da comprendere nell'appalto;

Per quanto riguarda le prime due incoerenze, il problema è minimo siccome è sufficiente essere a conoscenza del fatto che vi è una diversa tipologia di nomenclatura tra i vari documenti di riferimento.

Invece, per quanto riguarda le ultime due incoerenze, queste possono influenzare le analisi. Nel primo caso ci potrebbero essere delle dimensioni di volumi non corrispondente a quelli reali, portando l'analisi degli edifici problematici rispetto alla cubatura del seguente capitolo ad avere dei risultati alterati. Nel secondo caso porta alla considerazione nelle analisi di edifici con destinazioni d'uso diverse rispetto a uso uffici, sedi museali, assistenziali e bagni pubblici.

| EDIFICIO | TIPOLOGIA | EDIFICIO | INDIRIZZO | CUBATURA | CUBATURA A SERVIZIO RIDOTTO |
|---|---|---|---|---|---|
| 0006 | assistenza | Portierato sociale | Via Grego, 48 | 290 | |
| 0007 | assistenza | CEST | via Valmaura, 39/1 | 2.803 | |
| 0016 | assistenza | CEST | via Caravaggio, 6 | 2.346 | |
| 0047_1 | uffici | Centro Civico e UOT | Via Giotto,2 | | 1.600 |
| 0048 | uffici | Uffici Assistenza | via Mazzini, 25 | 16.771 | |
| 0105 | uffici | Uffici Protezione civile / Polizia Locale | Santa Croce, 441 | 1.853 | |
| 0133_3 | uffici | orto botanico | via De Marchesetti 2 | 418 | |
| 0133_4 | uffici | orto botanico | via De Marchesetti 2 | 63 | |
| 0133_5 | uffici | orto botanico | via De Marchesetti 2 | 16 | |
| 0134_1 | uffici | Ortobotanico - Serra - Magazzini -Uffici | via Marchesetti, 2 | 550 | |
| 0134_2 | uffici | orto botanico | via De Marchesetti 2 | 221 | |
| 0140 | uffici | Villa Engelmann (casa del custode e wc) | via di Chiadino, 5 | 420 | |
| 0154 | assistenza | Stabile | Via dell'Istria, 89 | 1.153 | |
| 0165 | assistenza | Struttura residenziale per anziani E. GREGORETTI | via Paolo de Ralli, 1 | 27.275 | |
| 0175_4 | assistenza | Alloggio per disabili "Il Cenacolo" (1° piano) | Strada per Longera, 1 | 722 | |
| 0186 | uffici | Scuderie di Villa Revoltella (deposito, spogliatoio e wc) | Via dei Pellegrini 55 | 430 | |
| 0189 | museale | Villa revoltella: chalet | via Marchesetti, 33 | | 1.094 |
| 0194 | museale | Villa Revoltella: casa custode e 2 Wc | via Marchesetti, 33 | 620 | |
| 0208 | bagni | stadio Grezar | via dei macelli | 18.744 | |
| 0212 | uffici | 2° Distretto VV.UU. | Str. Vecchia dell'Istria, 43 | 670 | |
| 0216_1 | uffici | Villa Sartorio - verde pubblico | via dei Modiano 4 e 5 | 4.643,10 | |
| 0216_2 | uffici | Villa Sartorio - verde pubblico | via dei Modiano 4 e 5 | 719,18 | |
| 0216_3 | serra | Villa Sartorio - verde pubblico | via dei Modiano 4 e 5 | 1.088 | |
| 0218_1 | serra | Villa Sartorio - verde pubblico | via dei Modiano 4 e 5 | | |
| 0218_2 | serra | Villa Sartorio - verde pubblico | via dei Modiano 4 e 5 | 270,47 | |
| 0218_3 | serra | Villa Sartorio - verde pubblico | via dei Modiano 4 e 5 | 523 | |
| 0234 | uffici | Villa Prinz - III° Circoscrizione (Villa Primc) | salita di Gretta, 38 | 3.412 | |
| 0236 | uffici | Autoparco e magazzini comunali | viale Miramare, 65 | 35.900 | |
| 0240 | uffici | Sede Prevenzione e Protezione | via Fabio Severo, 46/1 | 2.486 | |
| 0241 | bagni | Servizio igienico pubblico | piazza Ponterosso | 233 | |
| 0249 | uffici | 3° Distretto Polizia Locale | via Giulia, 2 | 1.500 | |
| 0250 | uffici | Depositi e spogliatoio verde | via Giulia, 2 | 1.145 | |

| EDIFICIO | TIPOLOGIA | EDIFICIO | INDIRIZZO | CUBATURA | CUBATURA A SERVIZIO RIDOTTO |
|---|---|---|---|---|---|
| | | pubblico | | | |
| 0251 | uffici | Padiglione ARAC | via Giulia, 2 | 2.325 | |
| 0260 | uffici | Palazzo Anagrafe | passo Costanzi, 2 | 40.733 | |
| 0261 | uffici | Palazzo Comunale | largo Granatieri, 2 | 23.885 | |
| 0262 | uffici | Palazzo Costanzi | passo Costanzi, 1 | 9.450 | |
| 0276 | assistenza | GOAP (gruppo operatrici antiviolenza e progetti) | L.go Barriera Vecchia, 5 - int, 24 (piano 3) | 409 | |
| 0277_1 | uffici | Palazzo municipale | piazza Unità d'Italia, 4 | 20.878 | |
| 0277_2 | uffici | Palazzo Municipale | Piazza Unità d'Italia, 4 | | |
| 0277_3 | uffici | Palazzo Municipale | Piazza Unità d'Italia, 4 | | |
| 0277_4 | uffici | Palazzo Municipale | Piazza Unità d'Italia, 4 | | |
| 0281 | museale | Museo Revoltella | via Diaz, 27 | 40.306 | |
| 0282 | museale | EX Museo Storia Naturale, biblioteca civica, emeroteca | Piazza Attilio Hortis, 4 | 39.540 | |
| 0288 | bagni | Servizio igienico pubblico | via della Cattedrale | 218 | |
| 0289_0484 | museale | Museo di Storia ed Arte, orto Lapidario e alloggio custode | via Cattedrale, 15 | 7.970 | |
| 0295 | uffici | V circoscrizione | via Caprin, 18/1 | 776 | |
| 0296 | uffici | Deposito Servizio Strade | via Diacono, 3 | 526 | |
| 0296_2 | uffici | Deposito | via Diacono 3 | 429,3 | |
| 0321 | uffici | Ufficio Protezione Civile | Strada per Vienna, 80 | 527 | |
| 0328 | bagni | Bagno Lanterna | molo Fratelli Bandiera, 2 | 2.500 | |
| 0387 | assistenza | Casa Bartoli | via Marchesetti, 8/2 | 19.295 | |
| 0415_6 | uffici | 7 Circoscrizione | via Paisiello, 5/4 | 735 | |
| 0439_1 | assistenza | Residenza Pineta e res.Giardino (ex casa Serena) | via Marchesetti, 8/3 | 8.562 | |
| 0439_2 | assistenza | Residenza Pineta e res.Giardino (ex casa Serena) | via Marchesetti, 8/3 | 12.329 | |
| 0439_4 | assistenza | Casa di riposo Serena | via Marchesetti n° 8 | 4044 | |
| 0452_6 | uffici | Vigili Urbani - uffici | Ple XXV Aprile, 4 | 325 | |
| 0454 | museale | Biblioteca Stelio Mattioni c/o polo "Tre Casette" | via Petracco, 10 | 2.800 | |
| 0463 | bagni | Bagni pubblici comunali | via Veronese, 8 | 6.600 | |
| 0479 | assistenza | casa Capon | via Sant'Isidoro, 13 | 2.830 | |
| 0512_1 | uffici | centro civico | via Locchi, 23 | 3.097 | |
| 0512 _2 | assistenza | UOT 2 | via Locchi, 27 | | |
| 0512 _3 | uffici | 1° Distretto Polizia Locale | via Locchi, 29 | | |
| 0514 | uffici | Deposito Verde Pubblico | P.le 11 Settembre | | 87 |
| 0519 | uffici | uffici comunali, UOT 4 | via Roncheto, 77 | 985 | |
| 0545_1 | museale | Aquario Marino | riva N. Sauro, 1 | 5.483 | |
| 0545_2 | museale | Salone degli Incanti (ex Pescheria) | riva N. Sauro, 1 | 38.910 | |

| EDIFICIO | TIPOLOGIA | EDIFICIO | INDIRIZZO | CUBATURA | CUBATURA A SERVIZIO RIDOTTO |
|---|---|---|---|---|---|
| 0546 | museale | Museo Risorgimento-sacrario Oberdan-Casa del Combattente | via XXIV maggio, 4 | 14.830 | |
| 0555 | uffici | Ex Area Beleno ed. 2 - Polizia Locale sede Ed. Stradale. | via Revoltella, 29 | 1.208 | |
| 0560 | uffici | Ex Area Beleno ed. 7 – dep. Economato, depositi biblioteche | via Revoltella, 33 | | 18.842 |
| 0561 | uffici | Ex Area Beleno ed. 8 - magazzino | via Revoltella, 29-35 | | 3.510 |
| 0564 | uffici | Ex Area Beleno ed. 11 - sede degli Alpini | via Revoltella, 35 | | 2.600 |
| 0574 | museale | Risiera San Sabba | via Palatucci, 5 | 28.398 | |
| 0588 | uffici | Ex Area Beleno ed. 1 – Ex Depositeria | via Revoltella, 29 | | 442 |
| 0591 | museale | Museo Sartorio | l.go Papa Giovanni XXIII, 1 | 15.870 | |
| 0617 | museale | Serra espositiva di Villa Revoltella | via Marchesetti, 37 | 1.945 | |
| 0622 | museale | Biblioteca Civica Attilio Hortis | via Madonna del Mare, 13 | 8.030 | |
| 0705 | uffici | Centro civico, UOT 1, II Circoscrizione | via Doberdò, 20/3 | 2.420 | |
| 0710 | museale | Palazzo Gopcevich | via Rossini, 4 | 19.716 | |
| 0711 | museale | Ex Tempio Anglicano | via San Michele – via Cereria, 1 | 2.307 | |
| 0712 | museale | Museo Arte Orientale (Palazzo Leo) | via S. Sebastiano, 1 | 3.757 | |
| 0713 | assistenza | Centro ass. domiciliare (CAD) | via Sant'Isidoro, 1 | 2.130 | |
| 0714 | assistenza | Centro ass. domiciliare (CAD) | via Sant'Isidoro, 3 | 2.130 | |
| 0715 | assistenza | Centro ass. domiciliare (CAD) | via Sant'Isidoro, 5 | 2.130 | |
| 0716 | assistenza | Centro ass. domiciliare (CAD) | via San Biagio, 1 | 2.130 | |
| 0717 | assistenza | Centro ass. domiciliare (CAD) | via San Biagio, 3 | 2.130 | |
| 0718 | assistenza | Centro ass. domiciliare (CAD) | via San Biagio, 5 | 2.130 | |
| 0722 | uffici | Villa Cosulich (solo casa custode e wc) | strada del Friuli, 36 | | 495 |
| 0723 | uffici | Palazzo Carciotti | via Genova, 2-6 | 66.254 | |
| 0724 | uffici | UOT 1 | via dei Moreri, 5/b | 983 | |
| 0725 | uffici | Centro civico e uffici assistenza sociale | loc. Prosecco, 159 | 1.120 | |
| 0726 | uffici | Palazzo Eisner Civrani | via Procureria, 2 | 6.136 | |
| 0727 | uffici | Officine Servizio Manutenzione | via Papiniano, 4 | 1.900 | |
| 0729_1 | museale | Castello S. Giusto: Lapidario Tergestino (bastione Lalio) | piazza della Cattedrale 3 | 2.740 | |
| 0729_2 | museale | Castello S. Giusto: | piazza della | 2.500 | |

| EDIFICIO | TIPOLOGIA | EDIFICIO | INDIRIZZO | CUBATURA | CUBATURA A SERVIZIO RIDOTTO |
|---|---|---|---|---|---|
| | | Armeria e casa del Capitano | Cattedrale, 3 | | |
| 0729_3 | museale | Castello S. Giusto: Portineria e bagni (ingresso, piazzale e bastione Veneto) | piazza della Cattedrale, 3 | 500 | |
| 0730 | uffici | Uffici, garage e deposito Servizo Strade | via Giarizzole, 36 | 2.054 | |
| 0731 | assistenza | Centro Assistenziale Marenzi | via dell'Istria, 102 | 948 | |
| 0732 | uffici | Palazzo Zois | androna del Pozzo, 1 | 8.520 | |
| 0733 | assistenza | Residenza Campanelle (crh) | strada di Fiume, 201 | 11.892 | |
| 0734 | assistenza | Comunità alloggio | via San Lazzaro, 1 | 1.642 | |
| 0735 | uffici | UOT 3 | via Pascoli, 35/1 | 1.350 | |
| 0737 | uffici | 6° consiglio circoscrizionale | rot. del Boschetto, 2-4 | 638 | |
| 0738 | assistenza | I.C.S. Trieste | via Gatteri 24 | 2720 | |
| 0745 | assistenza | GOAP (gruppo operatrici antiviolenza e progetti) | Via S. Silvestro, 3 - 5 | 1.535 | |
| 0750_2 | uffici | Sala riunioni | via Capitelli 8 | 350 | |
| 0751 | assistenza | Stabile | Via dei Soncini, 102 | 6.352 | |
| 1002 | uffici | Servizio manutenzione (galleria) | via Tibullo | 810 | |
| 1005 | uffici | centro civico | largo Roiano 3/3 | 570 | |
| 1009_1 | uffici | Uffici VV.UU. | Strada per Vienna, 53 | | |
| 1009_3 | uffici | Uffici VV.UU. | Strada per Vienna, 53 | | |
| 1011 | assistenza | Villa Haggiconsta (ex CEM) | viale Romolo Gessi, 8/10 | | 7.837 |
| 1012 | museale | Museo di storia patria, coll. Stavropulos e museo morpurgo | via Imbriani, 5 | 8.511 | |
| 1015_1_2 | bagni | Bagni Topolini e riviera di Barcola | viale Miramare | 3.230 | |
| 1015_3 | bagni | Bagni Topolini | Viale Miramare | 3230 | |
| 1015_4_5 | bagni | Bagni Topolini | Viale Miramare | 3230 | |
| 1015_6_7 | bagni | Bagni Topolini | Viale Miramare | 3230 | |
| 1015_9_10 | bagni | Bagni Topolini | Viale Miramare | 2130 | |
| 1016 | museale | Museo del Mare | campo Marzio, 3 | 6.320 | |
| 1016b | museale | Magazzino museo del Mare | campo Marzio, 1 | 3.279 | |
| 1019 | assistenza | CST (Centro Socio Territoriale) | via Weiss 3 | 6.020 | |
| 1022_1 | uffici | Edificio ex Carli | Via del Teatro Romano, 7/a | 22.328 | |
| 1022_2 | uffici | Uffici area educazione | Via del rosario 2 | 2175,26 | |
| 1023 | uffici | Giardino di Via S. Michele (chiosco bar, wc, magazzino) | Via S. Michele | 328 | |
| 1025 | bagni | Servizio igienico pubblico | piazzale 11 Settembre | 12 | |

| EDIFICIO | TIPOLOGIA | EDIFICIO | INDIRIZZO | CUBATURA | CUBATURA A SERVIZIO RIDOTTO |
|---|---|---|---|---|---|
| 1026 | assistenza | Edificio uffici assistenza | Via M. a Vento, 83, 83/a e 83/b pt. | 768 | |
| 1028 | assistenza | Alloggio assistenza | Via Battera, 14 - int. 10 | 178 | |
| 1029 | museale | Foiba di Basovizza | località Basovizza | 500 | |
| 1031 | alloggi | interno 11 | via dei Carmelitani, 5 | 160,62 | |
| 1032 | assistenza | Alloggio assistenza | Viale d'Annunzio, 66 - int. 2 | 270 | |
| 1033 | alloggi | Alloggio interno 7 | via Flavia 4 | 184,01 | |
| 1036 | assistenza | Alloggio assistenza | Via Grego, 44 - int.44 (piano 11) | 239 | |
| 1042 | assistenza | Alloggio assistenza | Viale d'Annunzio, 64 - int. 1 pt | 152 | |
| 1044 | assistenza | Alloggio assistenza | Via Giuseppe Giusti, 6 - int. 14 p.3 | 186 | |
| 1045 | alloggi | alloggio interno 9 | Largo Barriera 5 | 360,27 | |
| 1046 | alloggi | alloggio interno 13 | via foschiatti 3 | 626,74 | |
| 1049 | assistenza | Portierato sociale "cupola" | Via Valmaura, 67 - (piano 10) | 338 | |
| 1050 | assistenza | Sede programma Habitat Microaree | Via dell'Istria, 44 - (piano terra) | 162 | |
| 1052 | assistenza | Portierato sociale | Via Pasteur, 7/B - (piano terra) | 140 | |
| 1054 | assistenza | Portierato sociale | Via Toffani, 2 | 98 | |
| 1055_1 | museale | Biblioteca Quarantotti Gambini | Via delle Lodole 6 e 7/a | 3.037 | |
| 1055_2 | museale | Biblioteca Quarantotti Gambini | Via delle Lodole 6 e 7/a | 1.241 | |
| 1056 | assistenza | Alloggio assistenza | Via Zorutti, 9 - int. 8 (piano 3) | 141 | |
| 1061 | assistenza | Alloggio assistenza | Via S. Pelagio, 3 - int. 3 (piano terra) | 95 | |
| 1063 | assistenza | Alloggio assistenza | Via Grego, 36 - int. 36 (piano 8) | 105 | |
| 1064 | alloggi | alloggio interno 14 | via pasteur 1 | 353,52 | |
| 1065 | | Alloggio interno 11 | Via dell'Istria, 40 | | |
| 1070 | assistenza | Alloggio assistenza | Via Grego, 34 - int. 10 (piano 2) | 224 | |
| 1074 | assistenza | Centro diurno | Via Udine, 19 - (piano terra) | 2.130 | |
| 1075 | alloggi | alloggio interno 1 | piazzetta tor cucherna 13 | 144,12 | |
| 1077 | museale | Museo di storia naturale | Via Tominz | 19.194 | |
| 1079 | assistenza | Alloggio assistenza | Via dell'Istria, 34 - int. 14 (piano 4) | 165 | |
| 1081 | assistenza | Alloggio assistenza | Via Capitolina, 3/3 - int. 13 (piano 5) | 246 | |
| 1082 | assistenza | Alloggio assistenza | Via Capitolina, 3/3 - int. 14 (piano 5) | 247 | |
| 1083 | assistenza | Alloggio assistenza | Vie del Seminario, 2 - int. 21 p.4 | 322 | |
| 1084 | assistenza | Alloggio assistenza | Via Pondares, 23 - int. 10 (piano 3) | 258 | |
| 1085 | assistenza | Alloggio assistenza | Via Grego, 44 - int. 49 (piano 13) | 235 | |
| 1086 | museale | Magazzino e ufficio | Via Tominz | 15.021 | |

| EDIFICIO | TIPOLOGIA | EDIFICIO | INDIRIZZO | CUBATURA | CUBATURA A SERVIZIO RIDOTTO |
|---|---|---|---|---|---|
| | | Area Cultura (Ex Palazzina Comando) | | | |
| 1088 | assistenza | Alloggio assistenza | Via Grego, 42 - int. 45 (piano 12) | 290 | |
| 1089 | alloggi | alloggio interno 24 | via tor san piero 4 | 311,05 | |
| 1091 | assistenza | Alloggio assistenza | Via Zorutti, 14 - int. 6 (piano 1) | 156 | |
| 1092 | assistenza | Alloggio assistenza | Via Schiapparelli, 10 - int. 14 p.5 | 141 | |
| 1093 | assistenza | Alloggio assistenza | Via Timignano, 1 - int. 5 | 211 | |
| 1094 | assistenza | Alloggio assistenza | Via Timignano, 1 - int. 7 | 109 | |
| 1095 | assistenza | Alloggio assistenza | Via Timignano, 1 - int. 10 | 177 | |
| 1096 | assistenza | Alloggio assistenza | Via Timignano, 1 - int. 12 | 109 | |
| 1097 | assistenza | Alloggio assistenza | Via Timignano, 1 - int. 31 | 107 | |
| 1098 | assistenza | Alloggio assistenza | Via Timignano, 1 - int. 32 | 105 | |
| 1099 | assistenza | Alloggio assistenza | Piazzale Alcide de Gasperi, 3/1 | 175 | |
| 1100 | assistenza | Alloggio assistenza | Piazzale Alcide de Gasperi, 3/5 | 202 | |
| 1101 | assistenza | Alloggio assistenza | Via Capitolina, 3/2 - int. 5 (piano 2) | 219 | |
| 1102 | assistenza | Alloggio assistenza | Via Capitolina, 3/3 - int. 5 (piano 2) | 216 | |
| 1103 | assistenza | Alloggio assistenza | Via Trissino, 25 - int. 14 (piano 5) | 106 | |
| 1104 | alloggi | servizio avvocatura | via del teatro romano 7 | 2585,11 | |
| 1105 | uffici | Nuovi locali area educazione | via del teatro romano 7 | 1.662 | |
| 1108 | uffici | Ufficio Consulta Immigrati | Piazzetta Tor Cucherna, 15/A | 136 | |
| 1109 | assistenza | Alloggio assistenza | Via Machlig, 14 - int. 9 (piano 4) | 195 | |
| 1110 | assistenza | Alloggio assistenza | Via Grego, 44 - int. 48 (piano 12) | 113 | |
| 1111 | assistenza | Alloggio assistenza | Viale D'Annunzio, 62 - int. 3 pt. | 142 | |
| 1112 | assistenza | Alloggio assistenza | Piazzetta Tor Cucherna, 13 - int.7 p.2 | 78 | |
| 1113 | bagni | Servizio igienico pubblico n°1 | Pineta di Barcola | 15 | |
| 1114 | bagni | Servizio igienico pubblico n°2 | Pineta di Barcola | 15 | |
| 1115 | bagni | Servizio igienico pubblico | Piazzale XXV Aprile (Bgo San Sergio) | 53 | |
| 1116 | museale | Museo di guerra per la pace "Diego de Henriquez" | Via Cumano, 22-24 | 17.488 | |
| 1117 | uffici | Centro civico | via del teatro romano 7B | 1065,45 | |

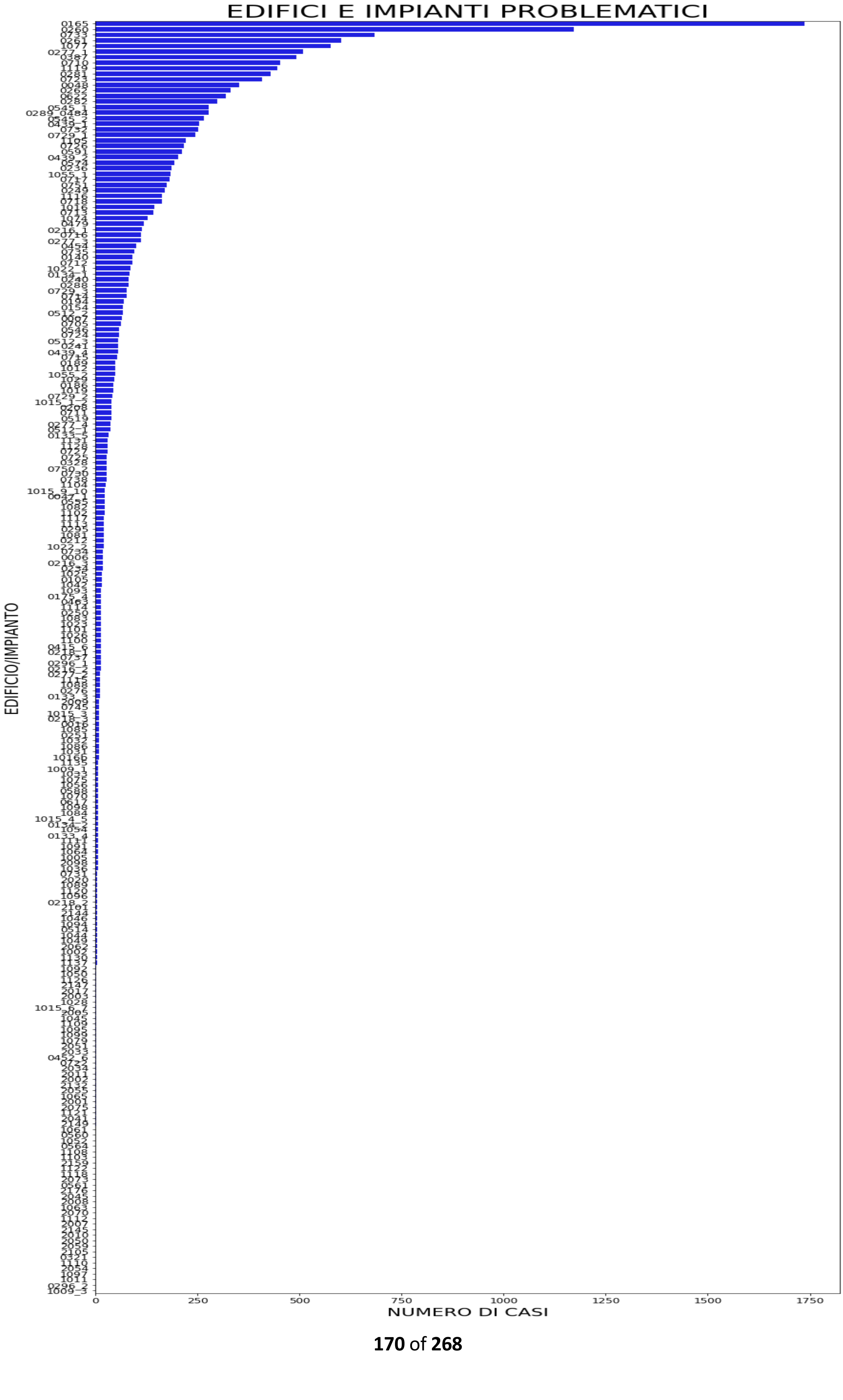
| EDIFICIO | TIPOLOGIA | EDIFICIO | INDIRIZZO | CUBATURA | CUBATURA A SERVIZIO RIDOTTO |
|---|---|---|---|---|---|
| 1118 | assistenza | Alloggio assistenza | Via Orlandini, 47 - int. 12 p.4 | 152 | |
| 1119 | uffici | Caserma S.Sebastiano | Via Pasquale Revoltella, 35 | 29.050 | |
| 1120 | assistenza | Padiglione Ralli | via Paolo de Ralli, 1 | 5.190 | |
| 1121 | alloggi | Umi 60 (alloggi erdisu) | Via dei Capitelli, 11 | 2337,7 | |
| 1122 | alloggi | Appartamenti Umi 61 | Zona Urban | 1582,02 | |
| 1126 | assistenza | Alloggio assistenza | Strada per Longera, 16 int.7 p.2 | 120 | |
| 1128 | museale | Porto vecchio - Magazzino 26 (parte agibile) | zona Porto Vecchio | 29.308 | |
| 1130 | museale | Porto vecchio – Sottostazione elettrica | zona Porto Vecchio | 6.700 | |
| 1131 | museale | Porto Vecchio - Centrale idrodinamica | zona Porto Vecchio | 22.460 | |
| 1135 | assistenza | Alloggio assistenza | via Carpineto 5/7 int.4 p1 | 202 | |
| 1137 | uffici | UOT 2 | Strada vecchia dell'Istria 27 | 1.974 | |

| SITO IMPIANTO - ID IMPIANTO | EDIFICIO | INDIRIZZO |
|---|---|---|
| SUB B1 - 2001 | Farmacia “Al Cedro” | Piazza Oberdan 2 |
| SUB B1 - 2002 | Mercato Coperto | Via Carducci 36 |
| SUB B1 - 2003 | Ufficio del giudice di sorveglianza | Via Zanetti 2 |
| SUB B1 - 2005 | Mercatino “Silos” | Via F. Gioia |
| SUB B1 - 2007 | Palazzo di Giustizia (3° Piano) | Foro Ulpiano 1 |
| SUB B1 - 2008 | Palazzetto “PALATRIESTE” | Via Flavia 3 |
| SUB B1 - 2009 | Stadio Comunale Nereo Rocco | Via Macelli 5 |
| SUB B1 - 2010 | Archivio procura della Repubblica | Via Stazione di Prosecco 15 |
| SUB B1 - 2011 | Posteggi Comunali | Via Punta del Forno |
| SUB B1 - 2017 | Sottopassaggio | Piazza della Libertà |
| SUB B1 - 2020 | Stadio Comunale Nereo Rocco | Via Macelli 5 |
| SUB B1 - 2033 | Mercato Coperto | Via Carducci 36 |
| SUB B1 - 2034 | Mercato Ortofrutticolo all’Ingrosso | Riva Augusto 12 |
| SUB B2 - 2041 | Mercato Ortofrutticolo all’Ingrosso | Riva Augusto 12 |
| SUB B2 - 2045 | Palestra Cobolli | Via della Valle 3 |
| SUB B2 - 2050 | Stadio Comunale Grezar | Via Macelli 2 |
| SUB B2 - 2051 | Stadio Comunale Nereo Rocco | Via Macelli 5 |
| SUB B2 - 2054 | Mercato Coperto | Via Carducci 36 |
| SUB B2 - 2055 | Mercato Ortofrutticolo all’Ingrosso | Riva Augusto 12 |
| SUB B2 - 2059 | Palestra Cobolli | Via della Valle 3 |
| SUB B2 - 2062 | Ufficio del giudice di sorveglianza | Via Zanetti 2 |
| SUB B3 - 2070 | Palazzo di Giustizia | Foro Ulpiano 1 |
| SUB B3 - 2073 | Stadio Comunale Nereo Rocco | Via Valmaura 2 |
| SUB B3 - 2075 | Giudice di Pace | Via Coroneo 13 |
| SUB B4 - 2098 | Civica Orchestra di fiati “G. Verdi” | Via Besenghi 2 |
| SUB B4 - 2101 | Alloggi | Via Cuniculi 11 |
| SUB B4 - 2105 | - | - |
| SUB B4 - 2132 | Alloggi | Via Tor San Piero 4 |
| SUB B4 - 2144 | Mercato Ortofrutticolo all’Ingrosso | Riva Augusto 12 |
| SUB B4 - 2145 | Mercato Coperto | Via Carducci 36 |

| SITO IMPIANTO - ID IMPIANTO | EDIFICIO | INDIRIZZO |
|---|---|---|
| SUB B4 - 2147 | Stadio Comunale Nereo Rocco | Via Macelli 5 |
| SUB B4 - 2149 | Palazzetto “PALATRIESTE” | Via Flavia 3 |
| SUB B4 - 2159 | Parrocchia di San Pasquale di Bayoln | Via de Marchesetti, 29 |
| SUB B5 - 2176 | Archivio Procura della Repubblica | Via Stazione di Prosecco 15 |

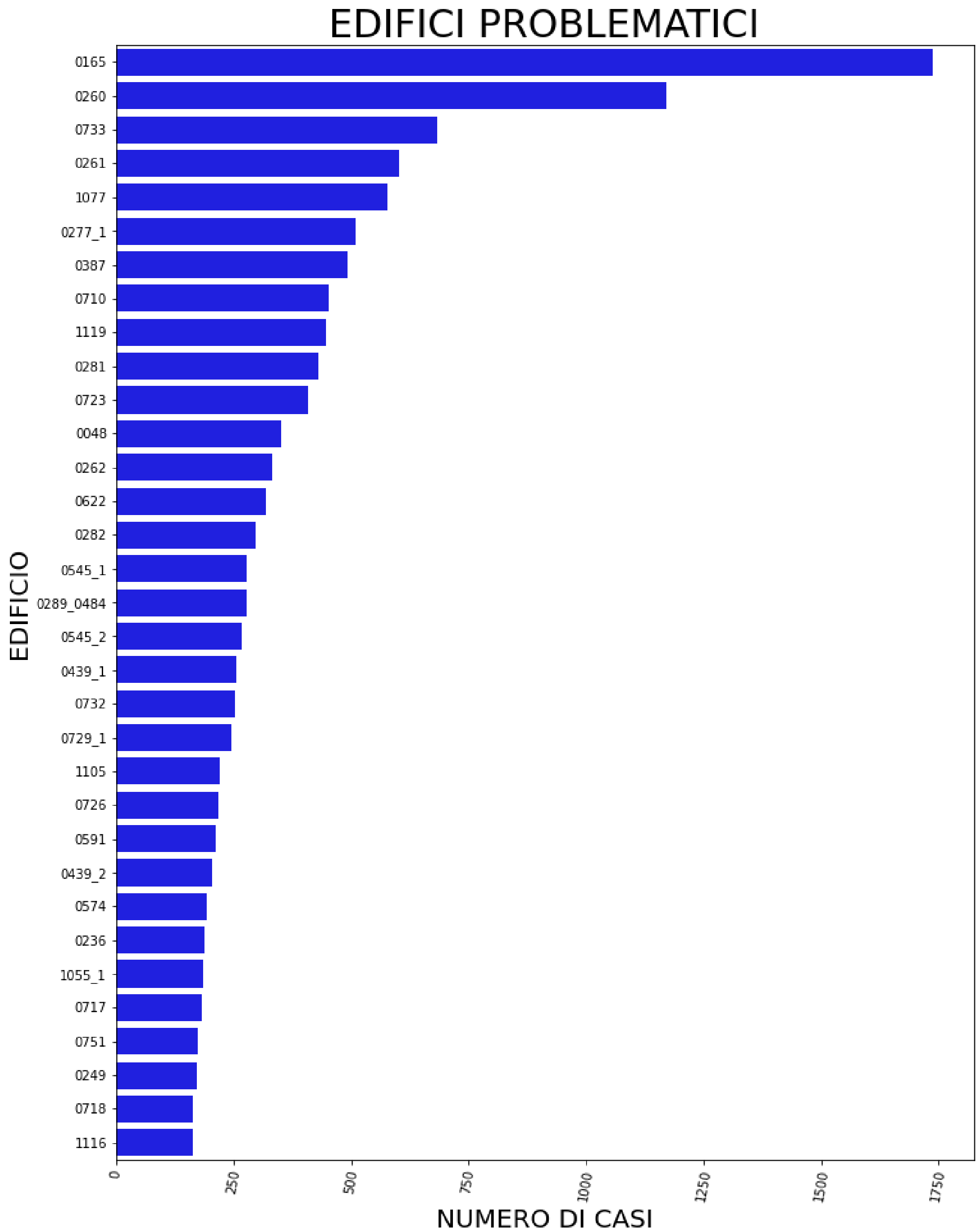
# 2 Analisi degli edifici e impianti

Il primo aspetto considerato riguarda il numero totale di segnalazioni chiuse relativo a tutti gli edifici e impianti presenti e gestiti nel software gestionale Floora che abbiano richiesto interventi di manutenzione nei sette anni di osservazione. Il numero totale è 229 elementi ed è composto da 195 edifici (che comprendono servizi ad intera cubatura e a cubatura ridotta) e 34 impianti. Nel seguente grafico si ordinano gli elementi per numero totale di interventi e verrà mantenuto tale ordine nelle analisi successive.

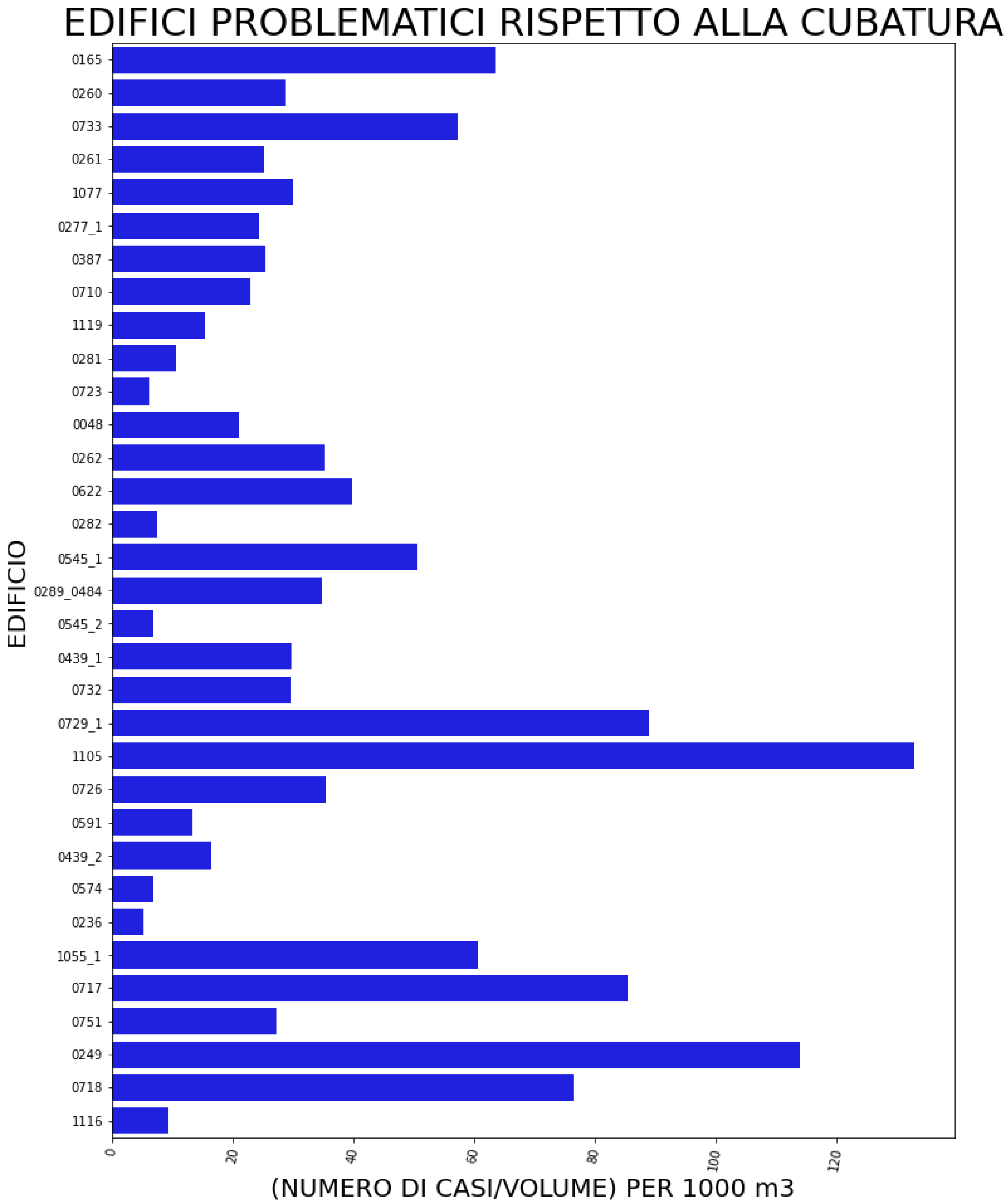

EDIFICI E IMPIANTI PROBLEMATICI
EDIFICIO/IMPIANTO
NUMERO DI CASI
0
250
500
750
1000
1250
1500
1750

# 3 Analisi casi significativi

Sono stati considerati casi significativi tutti gli edifici e impianti a cui corrisponde nel database un numero di segnalazioni chiuse superiore alle 150 volte nell'arco dei sette anni di osservazione. Si tratta di 33 edifici su un totale di 229 elementi. I casi significativi rappresentato il 14,4% del totale degli elementi che per contro hanno richiesto 12655 interventi, cioè il 74,7% del totale degli interventi (16947). Il numero di casi significativi gestiti dal software Floora dall'anno 2013 è di 29 su 33 totali. Si può notare nel seguente grafico come gli edifici con identificativo 0260 e 0165 abbiano ricevuto rispettivamente circa il doppio e il triplo delle richieste di intervento rispetto al terzo edificio (0733) nell'arco dei sette anni considerati.



Tuttavia, le richieste di manutenzione non sono direttamente proporzionali alla cubatura dell'edifici. Infatti, si può notare nel seguente grafico come gli edifici 1105, 0249, 0729_1, 0717, 0718, 1055_1 e 0545_1 abbiano mostrato un valore di numero di casi su volume per 1000 metri cubi pari o superiore rispetto all'edificio 0165, cioè quello con più richieste di manutenzione.

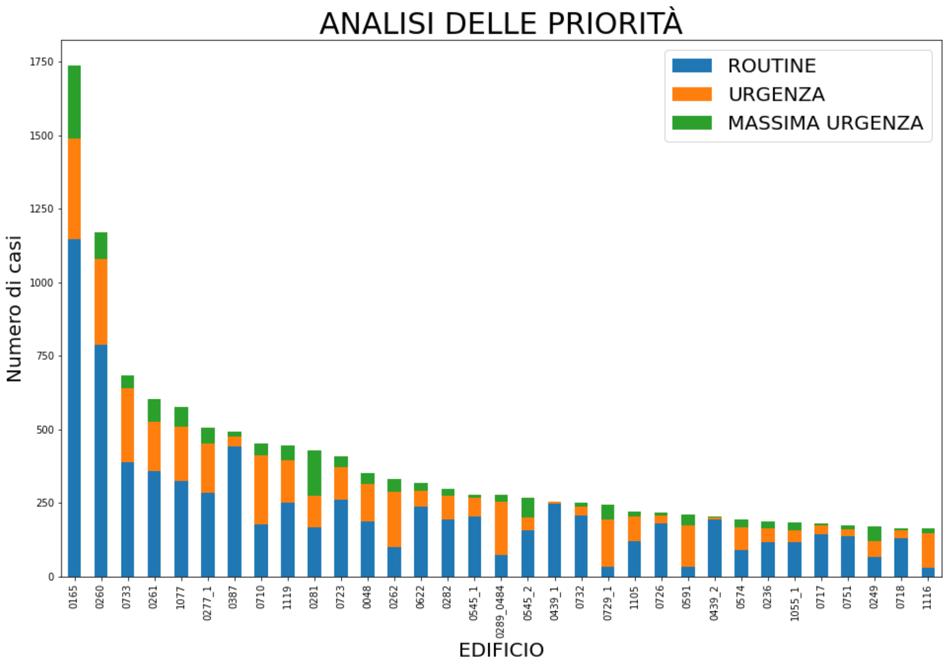


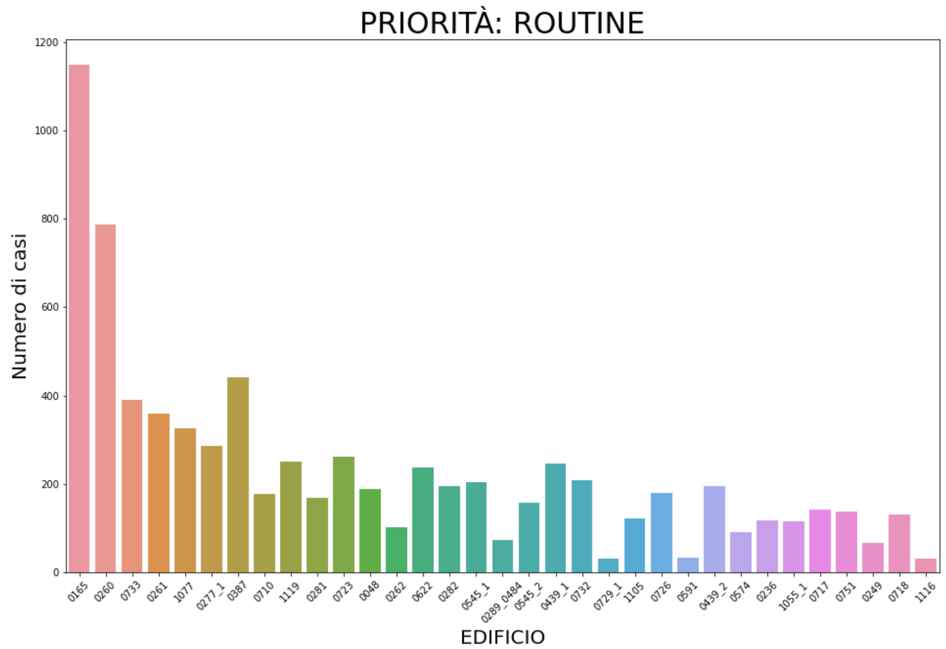
In particolare, nella seguente tabella si aggregano e vengono mostrati in modo dettagliato i dati degli edifici significativi e si mettono in evidenza in rosso l'edificio 0165 e in giallo i sette edifici sopra citati con valori elevati e significativi di numero di casi su volume per 1000 metri cubi .

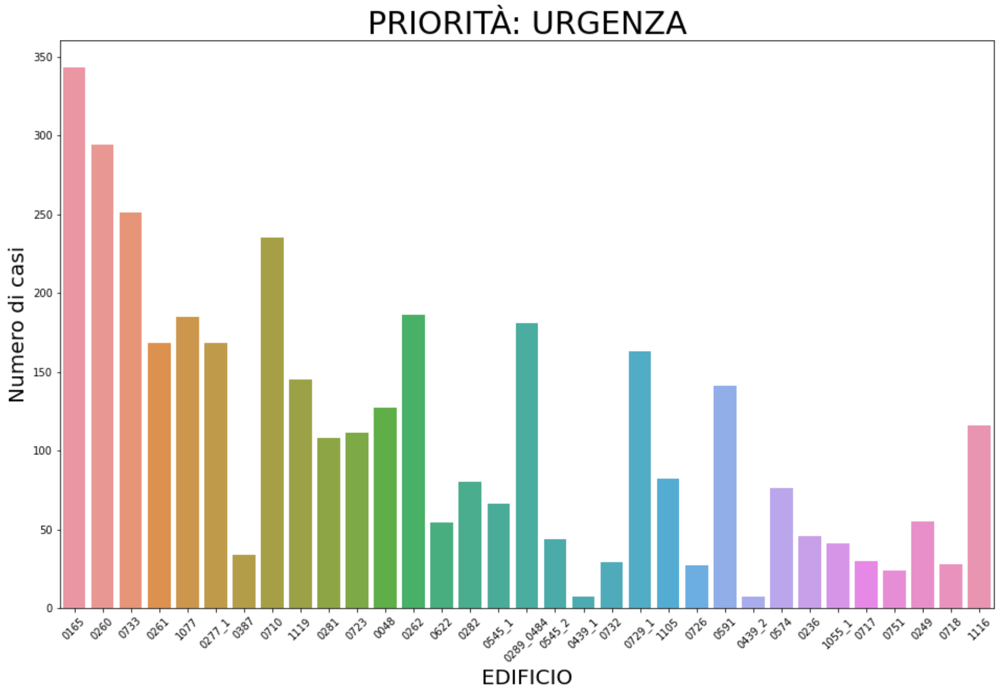
| EDIFICIO | TIPOLOGIA | VOLUME [m3] | NUMERO DI CASI | (NUMERO DI CASI/VOLUME) PER 1000 m3 |
|---|---|---|---|---|
| 0165 | assistenza | 27275 | 1737 | 63,684 |
| 0260 | uffici | 40733 | 1171 | 28,748 |
| 0733 | assistenza | 11892 | 683 | 57,433 |
| 0261 | uffici | 23885 | 603 | 25,245 |
| 1077 | museale | 19194 | 577 | 30,061 |
| 0277_1 | uffici | 20878 | 508 | 24,331 |
| 0387 | assistenza | 19295 | 492 | 25,498 |
| 0710 | museale | 19716 | 452 | 22,925 |
| 1119 | uffici | 29050 | 447 | 15,387 |
| 0281 | museale | 40306 | 429 | 10,643 |
| 0723 | uffici | 66254 | 409 | 6,173 |
| 0048 | uffici | 16771 | 352 | 20,988 |
| 0262 | uffici | 9450 | 332 | 35,132 |
| 0622 | museale | 8030 | 319 | 39,726 |
| 0282 | museale | 39540 | 298 | 7,536 |
| 0545_1 | museale | 5483 | 278 | 50,702 |
| 0289_0484 | museale | 7970 | 278 | 34,880 |
| 0545_2 | museale | 38910 | 267 | 6,861 |
| 0439_1 | assistenza | 8562 | 255 | 29,782 |
| 0732 | uffici | 8520 | 253 | 29,694 |
| 0729_1 | museale | 2740 | 244 | 89,051 |
| 1105 | uffici | 1662 | 221 | 132,948 |
| 0726 | uffici | 6136 | 218 | 35,528 |
| 0591 | museale | 15870 | 212 | 13,358 |
| 0439_2 | assistenza | 12329 | 203 | 16,465 |
| 0574 | museale | 28398 | 193 | 6,796 |
| 0236 | uffici | 35900 | 187 | 5,208 |
| 1055_1 | museale | 3037 | 184 | 60,577 |
| 0717 | assistenza | 2130 | 182 | 85,446 |
| 0751 | assistenza | 6352 | 174 | 27,392 |
| 0249 | uffici | 1500 | 171 | 114,000 |
| 0718 | assistenza | 2130 | 163 | 76,525 |
| 1116 | museale | 17488 | 163 | 9,320 |

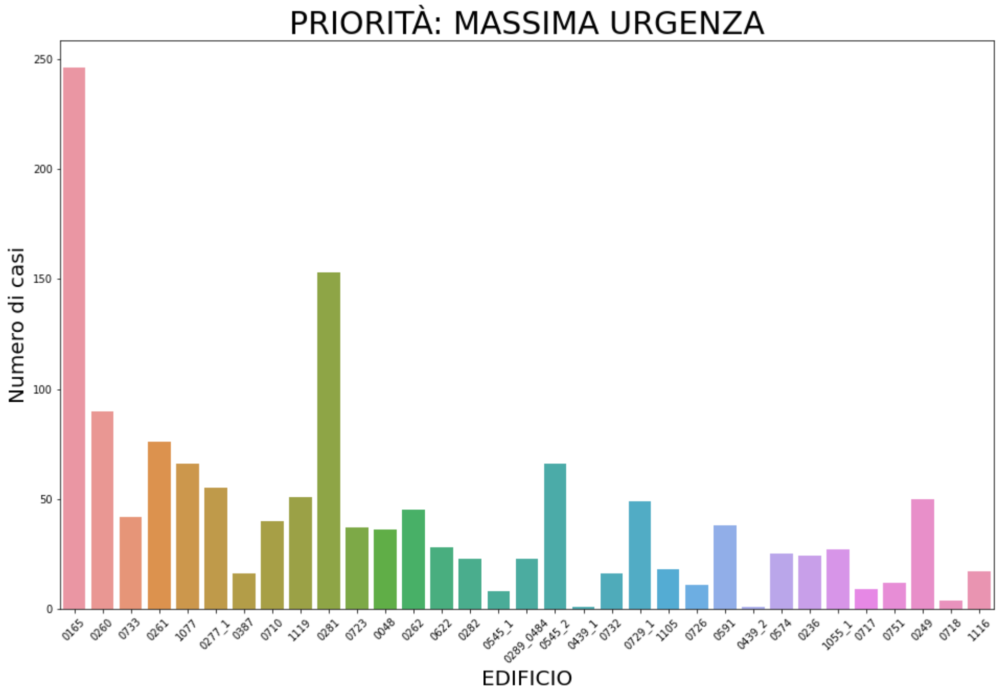
# 4 Analisi complessiva delle priorità di intervento dei casi significativi

Nel primo grafico sono stati analizzati i casi significativi rispetto alla priorità di intervento, mostrando in un unico grafico le distinzioni tra le priorità relative alle richieste nei sette anni considerati. Nei successivi tre grafici si è analizzato l'andamento delle richieste dei casi significativi priorità per priorità nei sette anni considerati. Si evidenzia nell'analisi delle priorità di intervento che, rispetto al totale di segnalazioni dei casi significativi (12655), le richieste con priorità routine sono il 60%, con priorità urgente sono il 29% e con priorità massima urgenza sono l'11%.




PRIORITÀ: URGENZA
Numero di casi
EDIFICIO
0165
0260
0733
0261
1077
0277_1
0387
0710
1119
0281
0723
0048
0262
0622
0282
0545_1
0289_0484
0545_2
0439_1
0732
0729_1
1105
0726
0591
0439_2
0574
0236
1055_1
0717
0751
0249
0718
1116

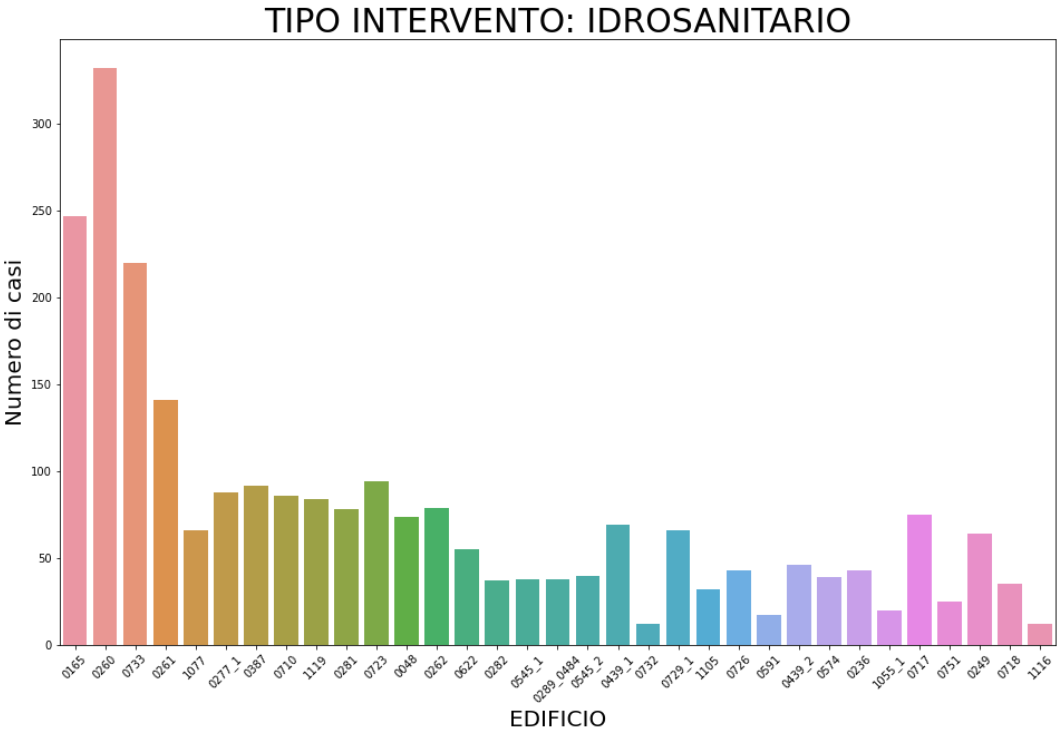

PRIORITÀ: MASSIMA URGENZA
Numero di casi
EDIFICIO
0165
0260
0733
0261
1077
0277_1
0387
0710
1119
0281
0723
0048
0262
0622
0282
0545_1
0289_0484
0545_2
0439_1
0732
0729_1
1105
0726
0591
0439_2
0574
0236
1055_1
0717
0751
0249
0718
1116

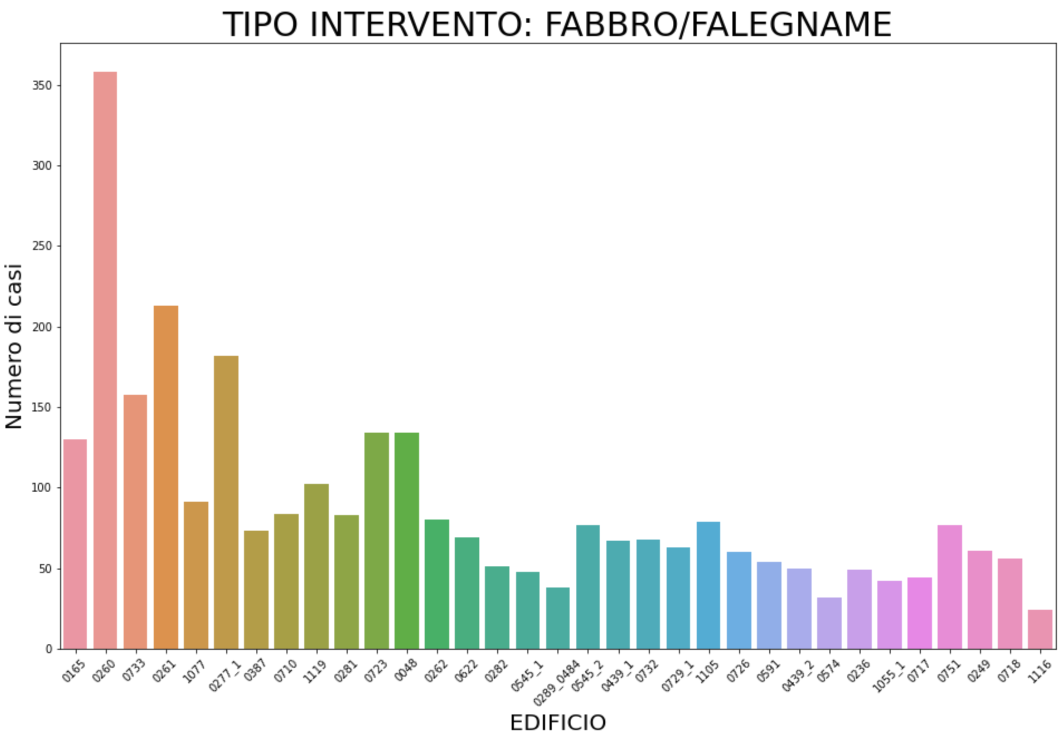
# 5 Analisi complessiva delle tipologie di intervento dei casi significativi

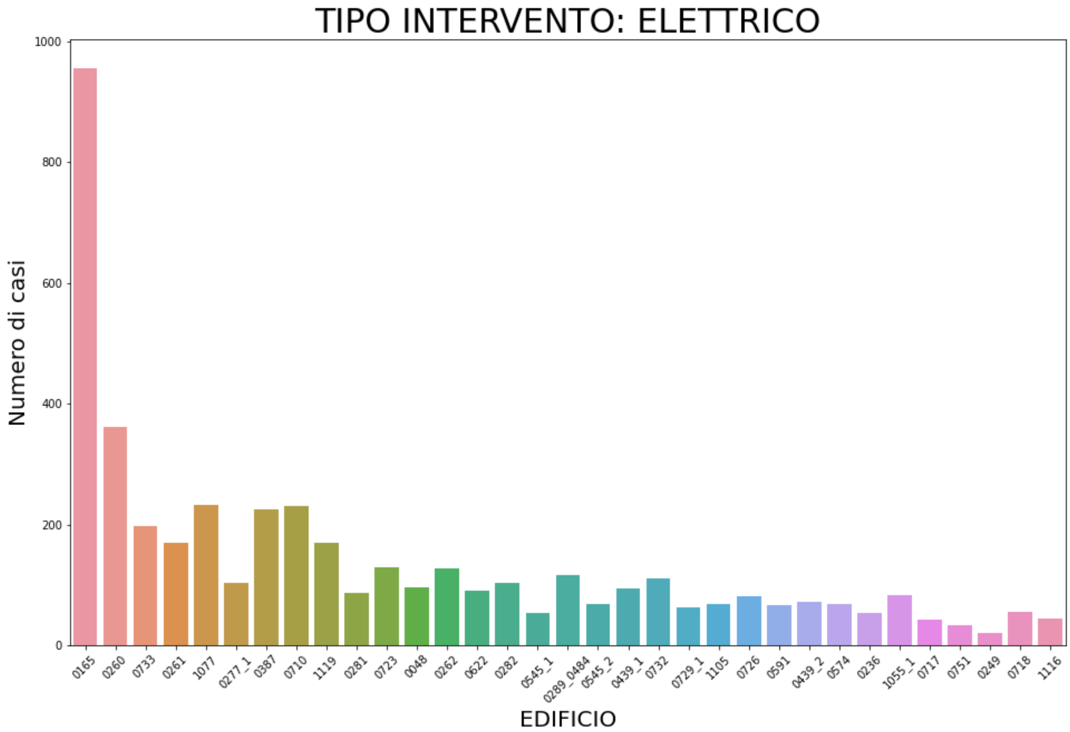
Nel seguente capitolo vengono mostrati gli andamenti complessivi delle richieste di intervento dei casi significativi per le nove tipologie di intervento nei sette anni considerati. Le tipologie di intervento codificate nel gestionale Floora sono le seguenti: idrosanitario, fabbro/falegname, elettrico, edile, aree esterne, speciali, elevatori, fognario ed estintori/idranti.

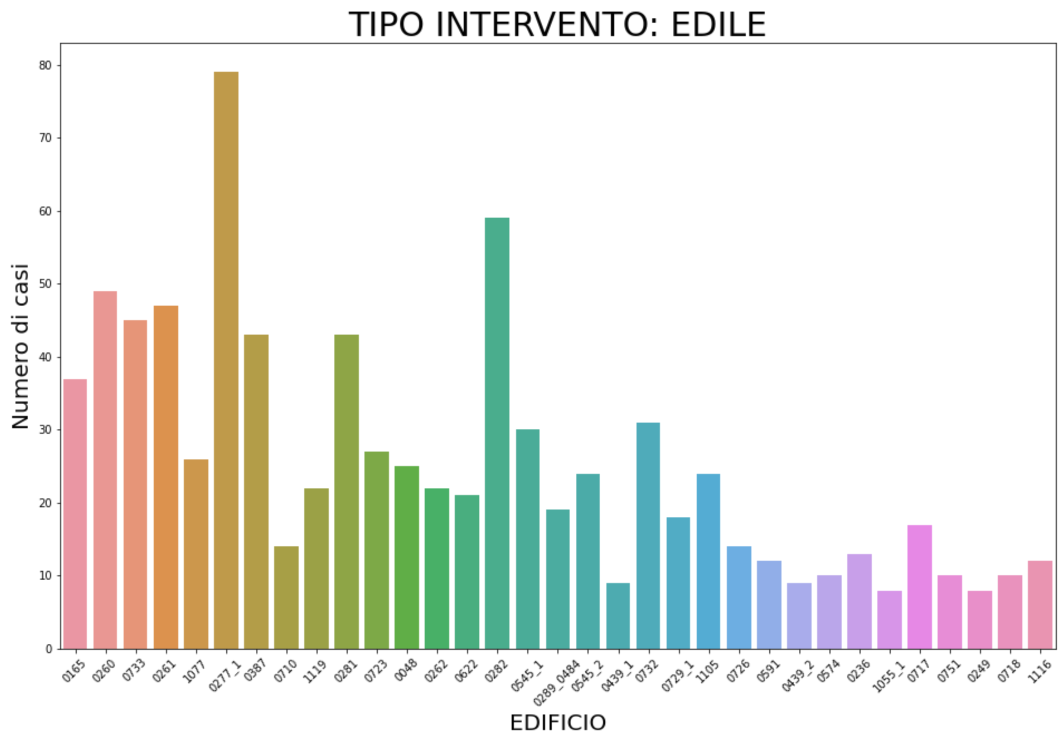
| TIPO DI INTERVENTO | NUM. INTERVENTI | % |
|---|---|---|
| ELETTRICO | 4473 | 35,3 |
| FABBRO/FALEGNAME | 2931 | 23,2 |
| IDROSANITARIO | 2487 | 19,7 |
| SPECIALI | 1241 | 9,8 |
| EDILE | 837 | 6,6 |
| AREE ESTERNE | 268 | 2,1 |
| ELEVATORI | 154 | 1,2 |
| FOGNARIO | 140 | 1,1 |
| ESTINTORI/IDRANTI | 124 | 1,0 |
| TOTALE | 12655 | 100,0 |

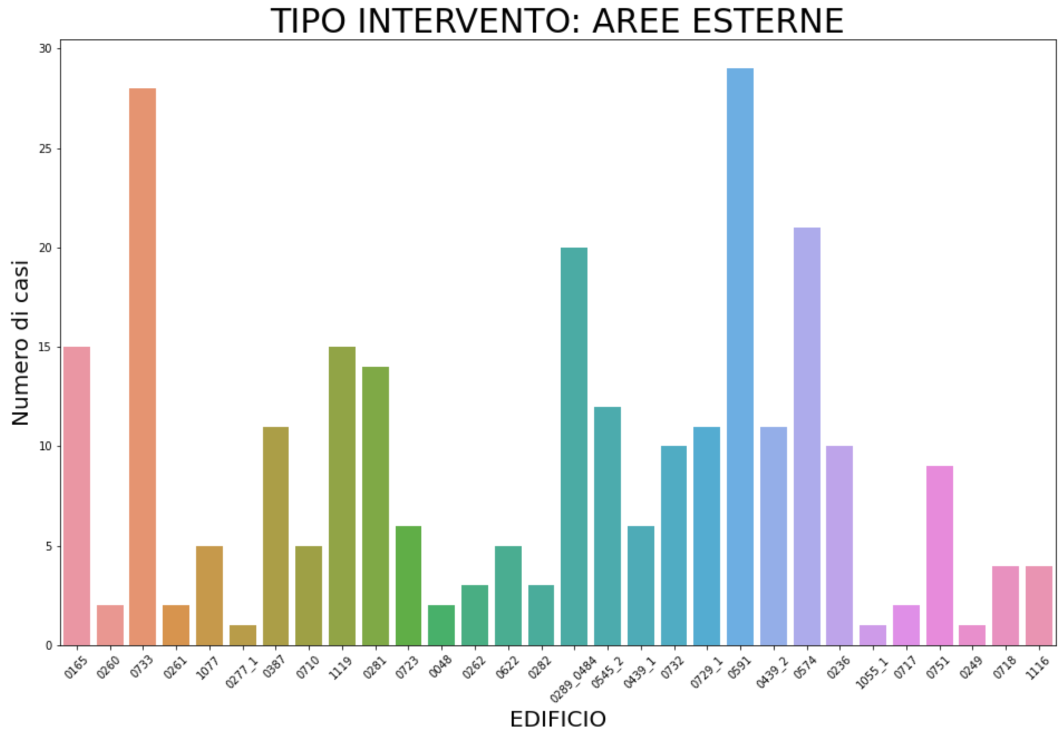
Le tre tipologie di intervento preponderanti, cioè Elettrico, Fabbro/Falegname e Idrosanitario, costituiscono il 78,2% del totale delle segnalazioni per i casi significativi.

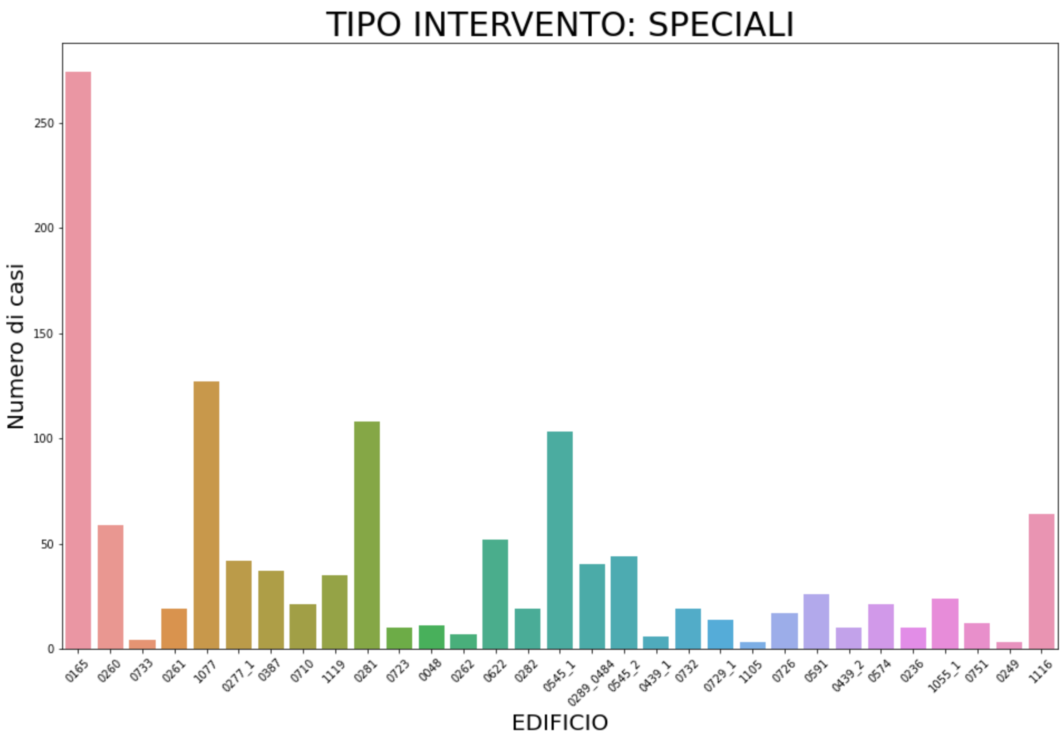

TIPO INTERVENTO: IDROSANITARIO
Numero di casi
0
50
100
150
200
250
300
0165 0260 0733 0261 1077 0277_1 0387 0710 1119 0281 0723 0048 0262 0622 0282 0545_1 0289_0484 0545_2 0439_1 0732 0729_1 1105 0726 0591 0439_2 0574 0236 1055_1 0717 0751 0249 0718 1116
EDIFICIO

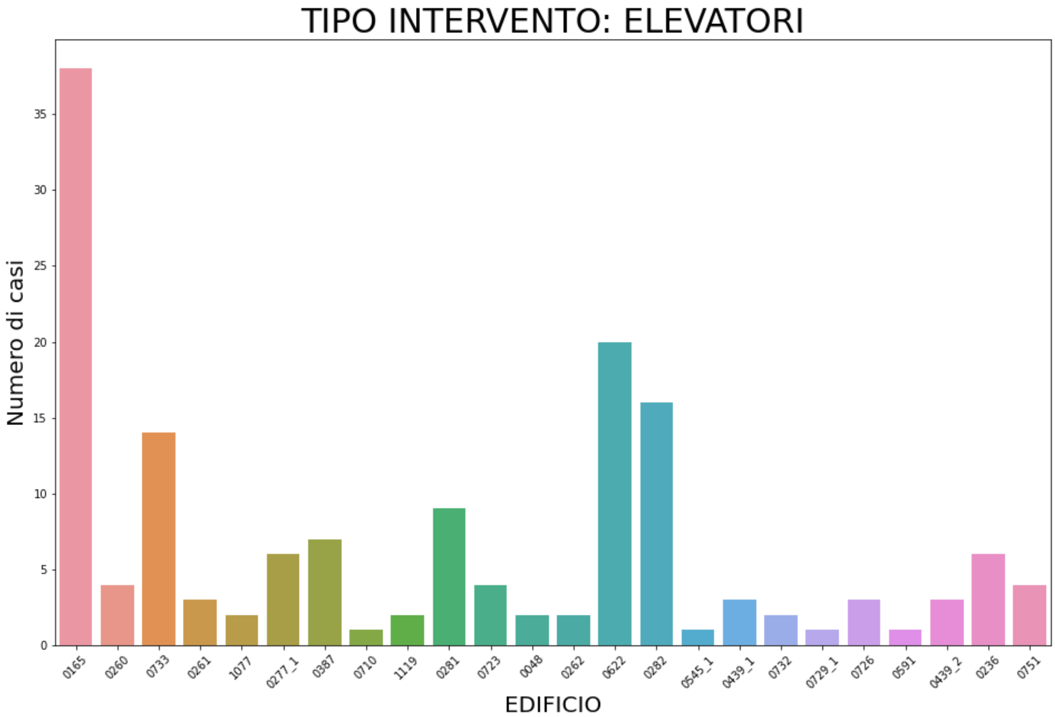

TIPO INTERVENTO: FABBRO/FALEGNAME
Numero di casi
0
50
100
150
200
250
300
350
0165 0260 0733 0261 1077 0277_1 0387 0710 1119 0281 0723 0048 0262 0622 0282 0545_1 0289_0484 0545_2 0439_1 0732 0729_1 1105 0726 0591 0439_2 0574 0236 1055_1 0717 0751 0249 0718 1116
EDIFICIO

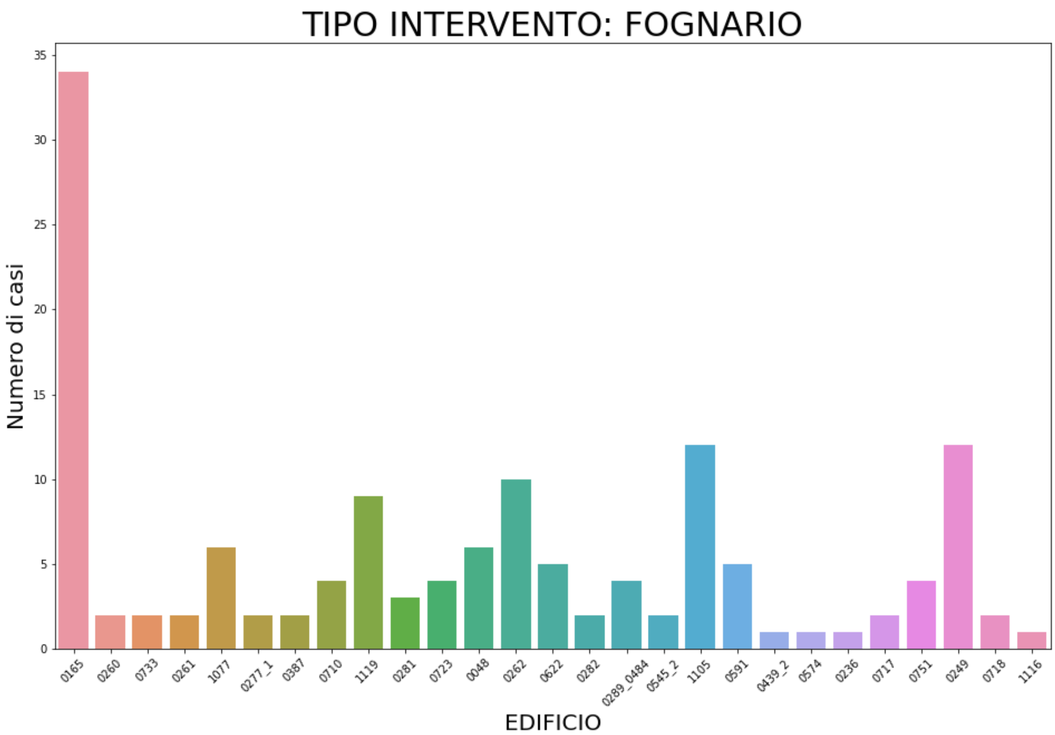

TIPO INTERVENTO: ELETTRICO
Numero di casi
EDIFICIO
0165
0260
0733
0261
1077
0277_1
0387
0710
1119
0281
0723
0048
0262
0622
0282
0545_1
0289_0484
0545_2
0439_1
0732
0729_1
1105
0726
0591
0439_2
0574
0236
1055_1
0717
0751
0249
0718
1116


TIPO INTERVENTO: EDILE
Numero di casi
EDIFICIO
0165
0260
0733
0261
1077
0277_1
0387
0710
1119
0281
0723
0048
0262
0622
0282
0545_1
0289_0484
0545_2
0439_1
0732
0729_1
1105
0726
0591
0439_2
0574
0236
1055_1
0717
0751
0249
0718
1116


TIPO INTERVENTO: AREE ESTERNE
Numero di casi
EDIFICIO
0165
0260
0733
0261
1077
0277_1
0387
0710
1119
0281
0723
0048
0262
0622
0282
0289_0484
0545_2
0439_1
0732
0729_1
0591
0439_2
0574
0236
1055_1
0717
0751
0249
0718
1116


TIPO INTERVENTO: SPECIALI
Numero di casi
EDIFICIO
0165
0260
0733
0261
1077
0277_1
0387
0710
1119
0281
0723
0048
0262
0622
0282
0545_1
0289_0484
0545_2
0439_1
0732
0729_1
1105
0726
0591
0439_2
0574
0236
1055_1
0751
0249
1116


TIPO INTERVENTO: ELEVATORI
Numero di casi
EDIFICIO
0
5
10
15
20
25
30
35
0165
0260
0733
0261
1077
0277_1
0387
0710
1119
0281
0723
0048
0262
0622
0282
0545_1
0439_1
0732
0729_1
0726
0591
0439_2
0236
0751


TIPO INTERVENTO: FOGNARIO
Numero di casi
EDIFICIO
0
5
10
15
20
25
30
35
0165
0260
0733
0261
1077
0277_1
0387
0710
1119
0281
0723
0048
0262
0622
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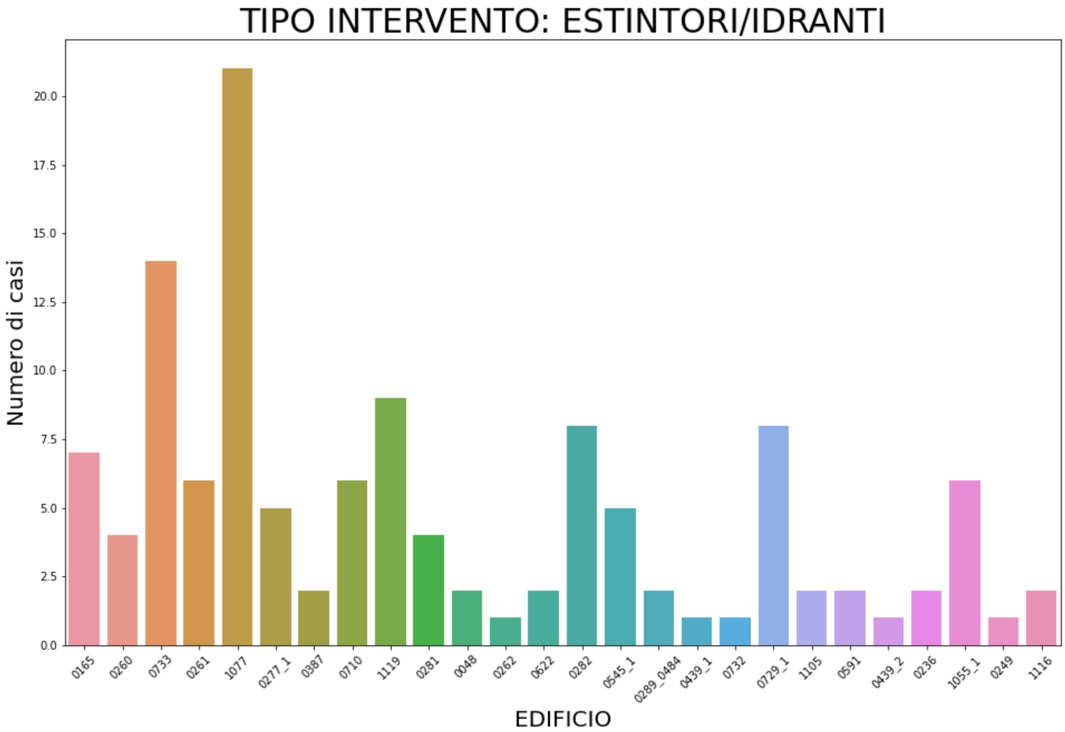
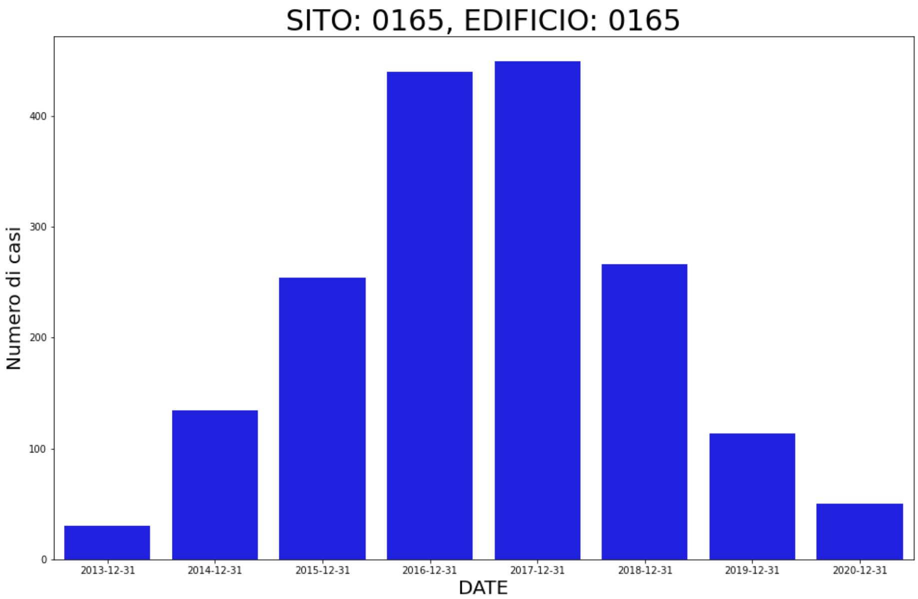
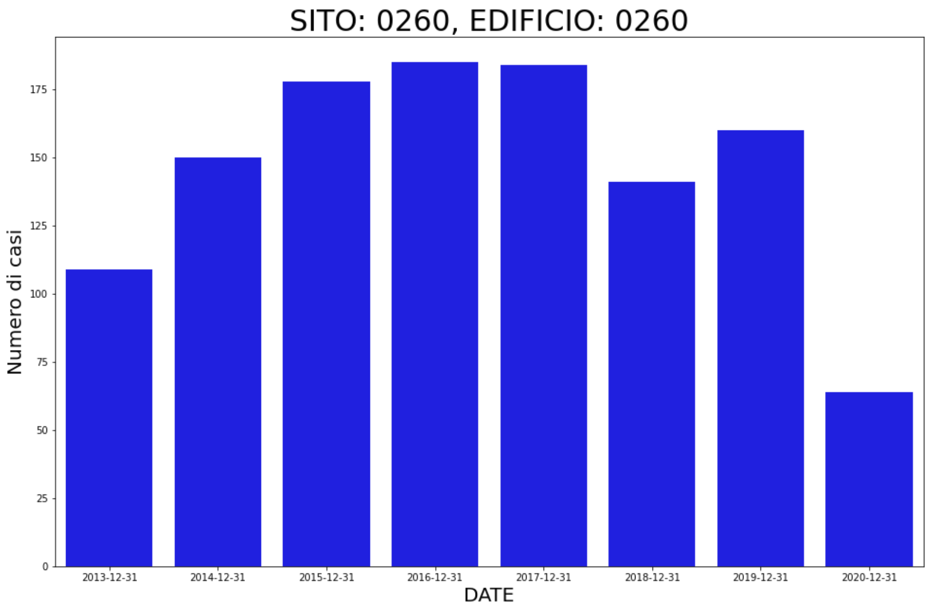
0236
0717
0751
0249
0718
1116

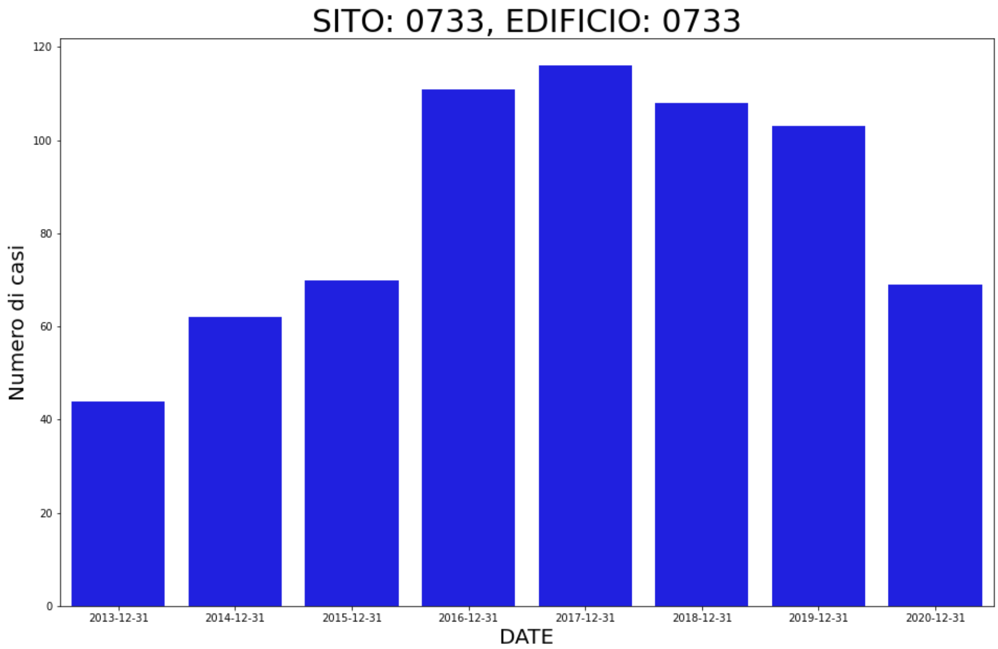

TIPO INTERVENTO: ESTINTORI/IDRANTI
Numero di casi
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
0165
0260
0733
0261
1077
0277_1
0387
0710
1119
0281
0048
0262
0622
0282
0545_1
0289_0484
0439_1
0732
0729_1
1105
0591
0439_2
0236
1055_1
0249
1116
EDIFICIO

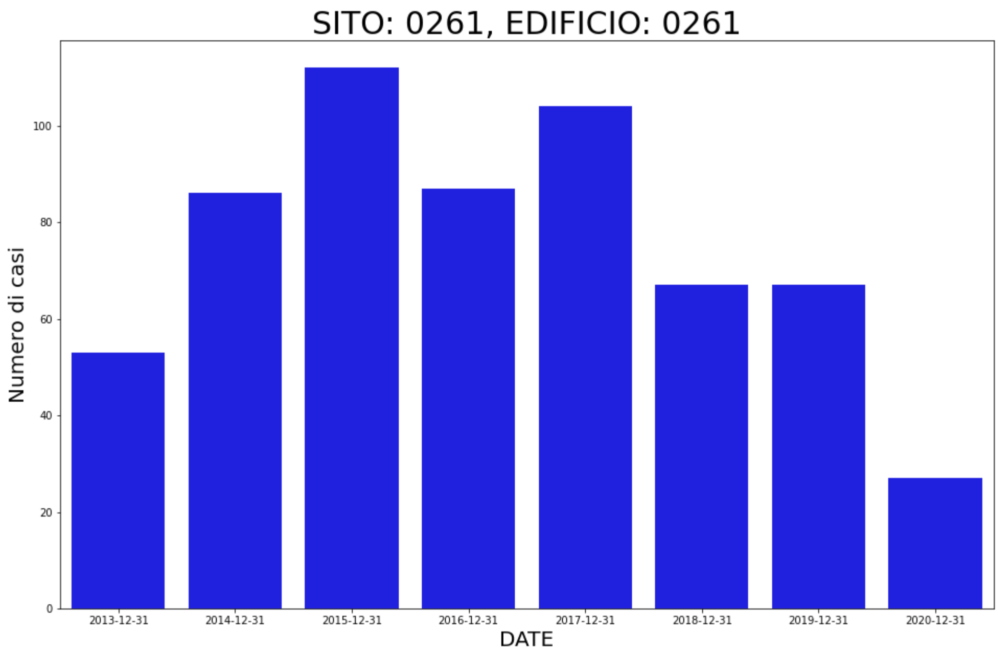
# 6 Analisi puntuale delle segnalazioni dei casi significativi nell'arco del tempo

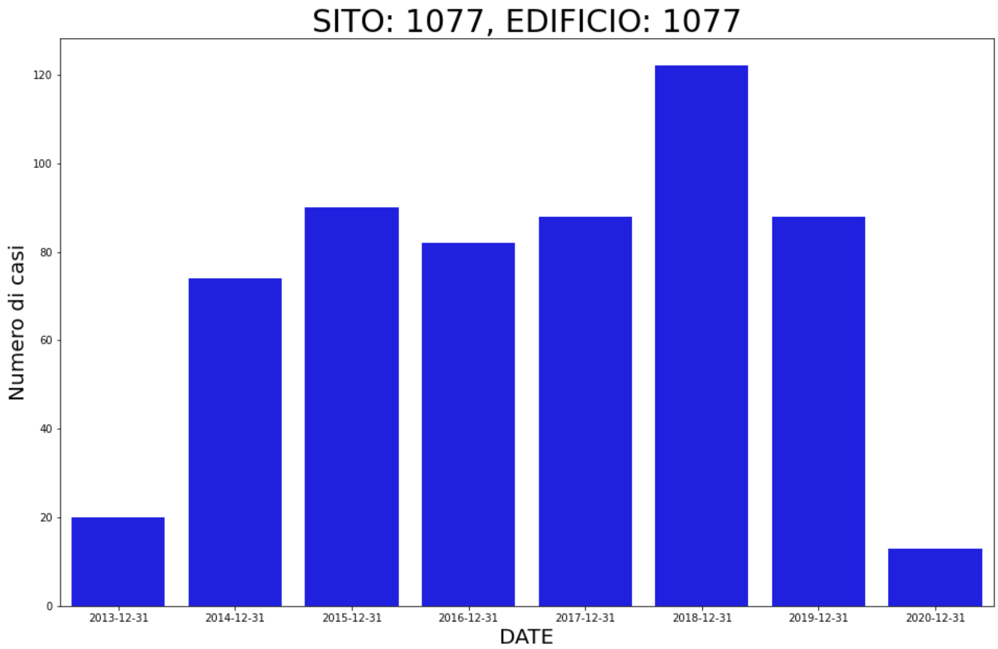
I seguenti grafici mostrano gli andamenti nel tempo delle richieste di intervento dei casi significativi per i sette anni considerati. I dati dell'anno 2013 si riferiscono al periodo maggio-dicembre, mentre per il 2020 al periodo gennaio-settembre.

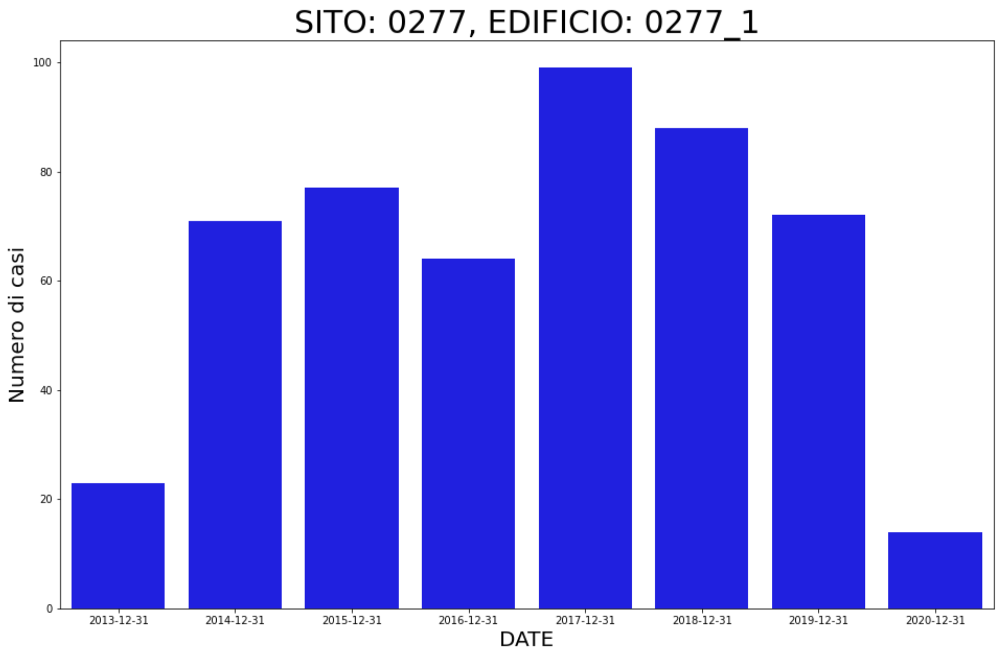


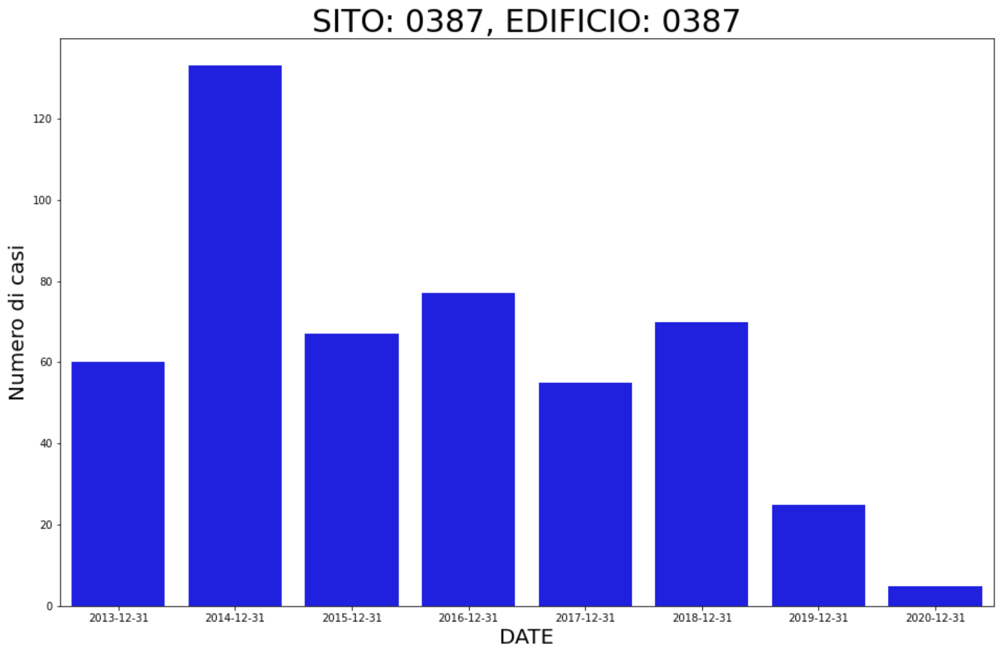




SITO: 0733, EDIFICIO: 0733
Numero di casi
0
20
40
60
80
100
120
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31
DATE

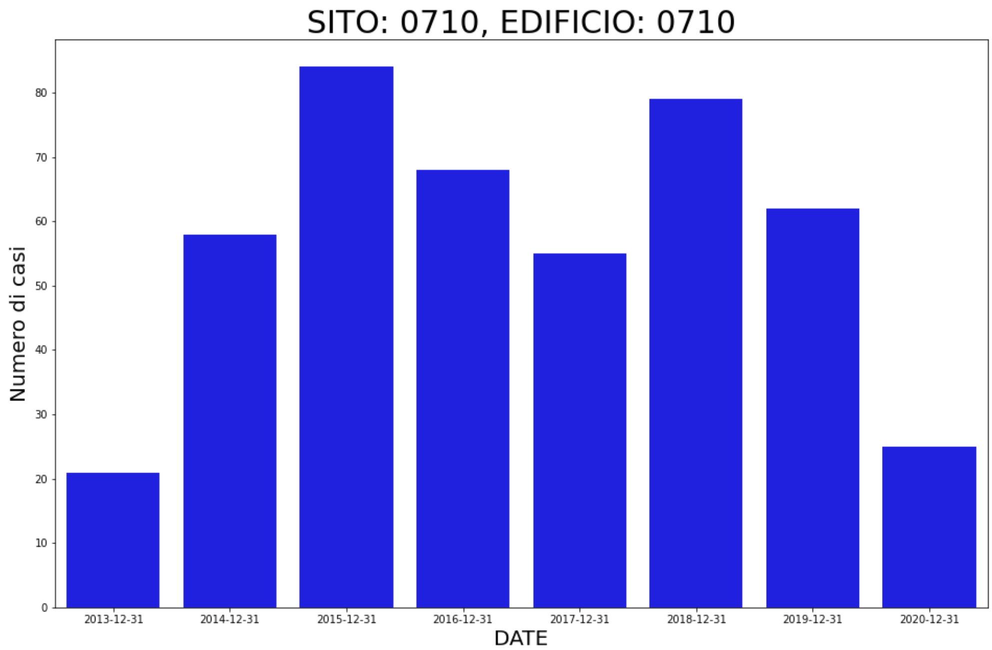

SITO: 0261, EDIFICIO: 0261
Numero di casi
0
20
40
60
80
100
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31
DATE


SITO: 1077, EDIFICIO: 1077
Numero di casi
0
20
40
60
80
100
120
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31
DATE

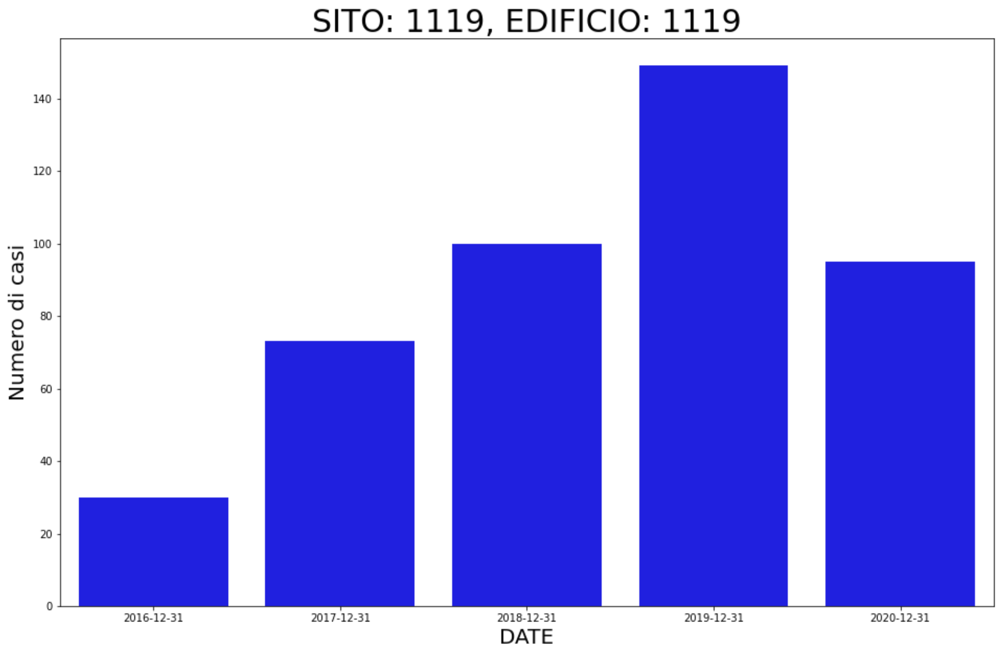

SITO: 0277, EDIFICIO: 0277_1
Numero di casi
0
20
40
60
80
100
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31
DATE

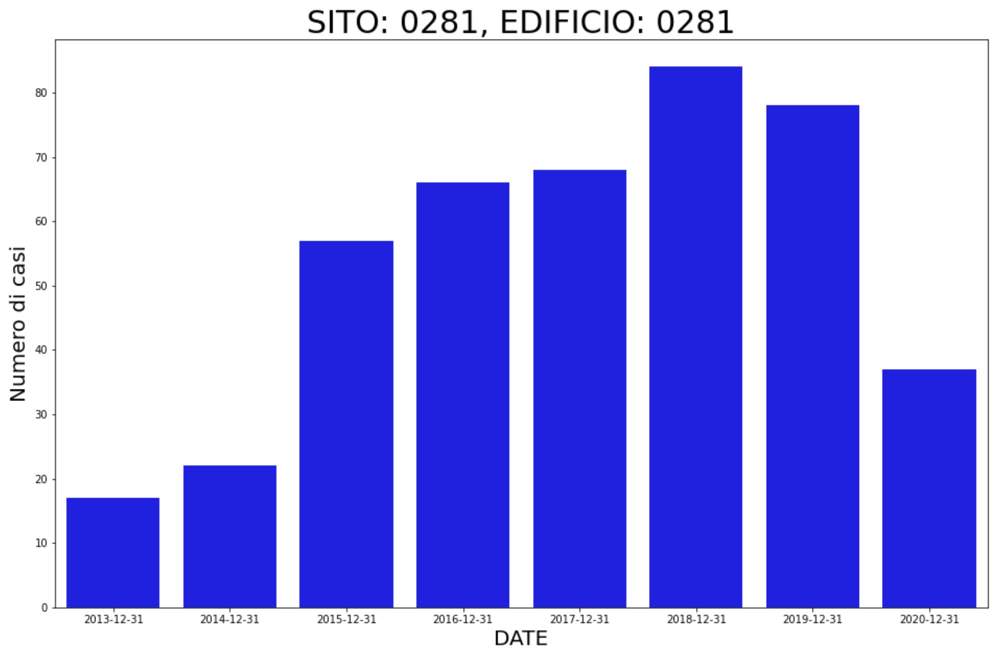


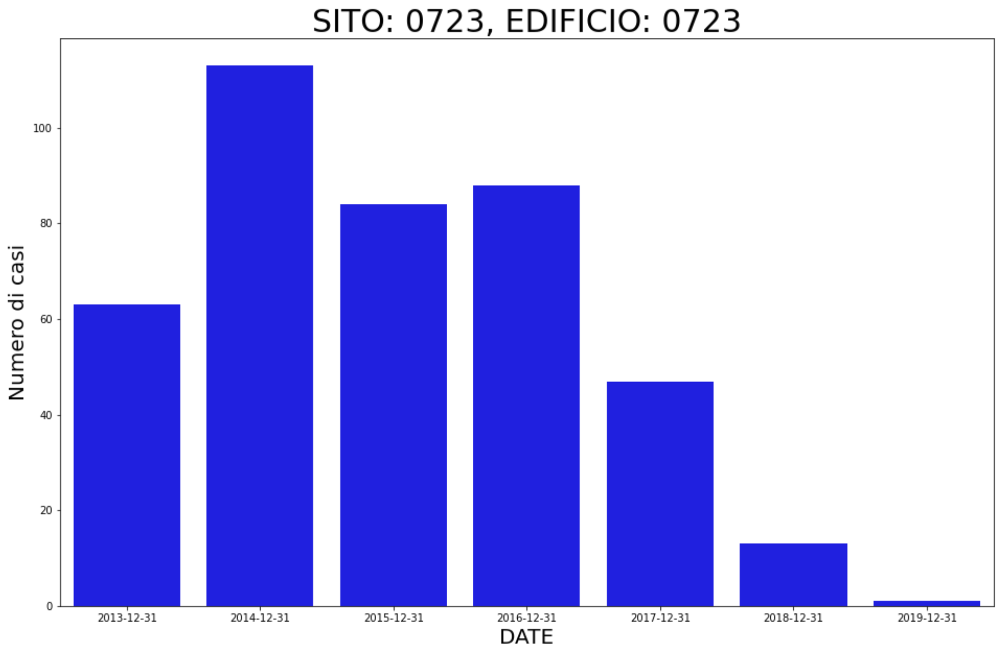
SITO: 0387, EDIFICIO: 0387
Numero di casi
DATE
0
20
40
60
80
100
120
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31

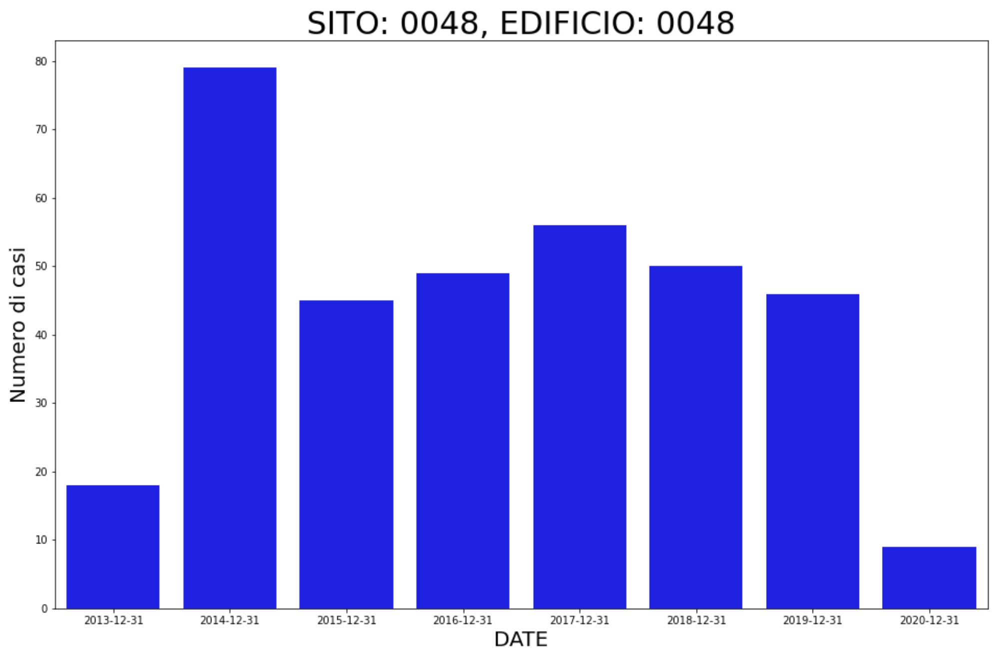



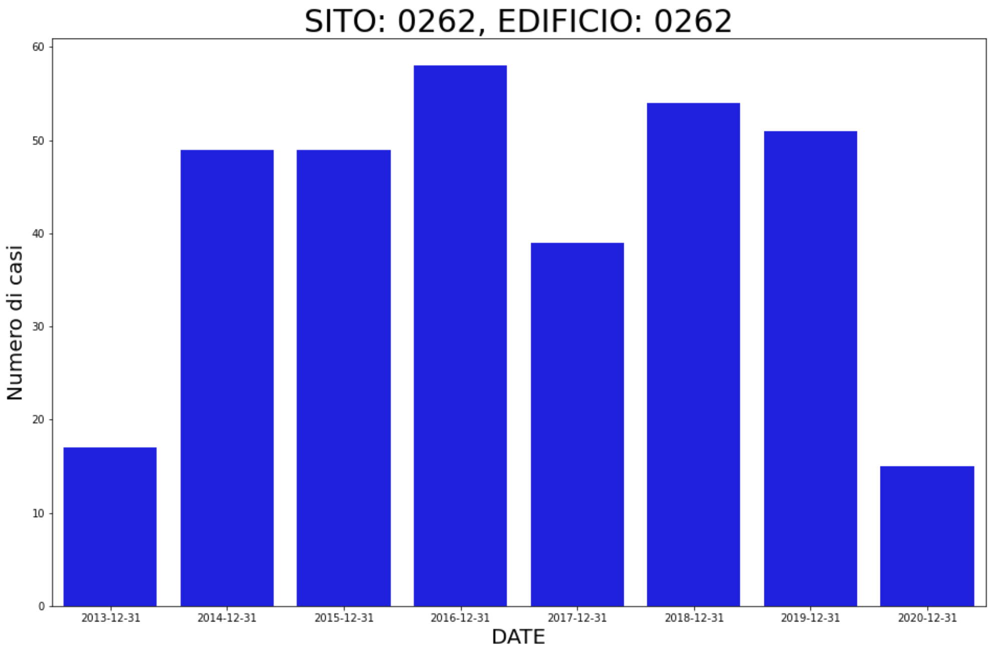
SITO: 0710, EDIFICIO: 0710
Numero di casi
DATE
0
10
20
30
40
50
60
70
80
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31

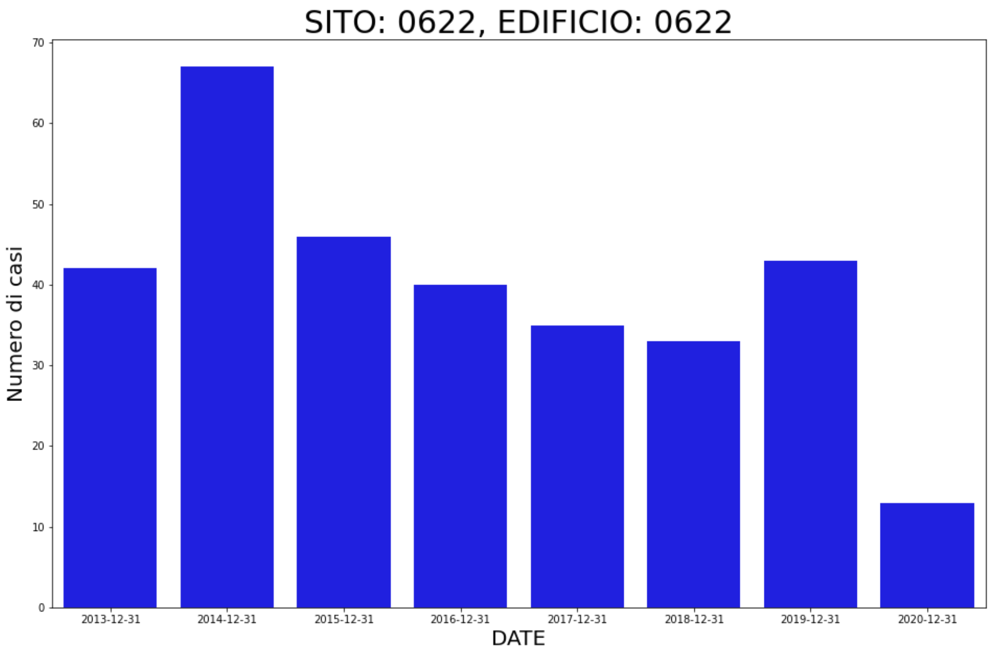

SITO: 1119, EDIFICIO: 1119
Numero di casi
0
20
40
60
80
100
120
140
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31
DATE

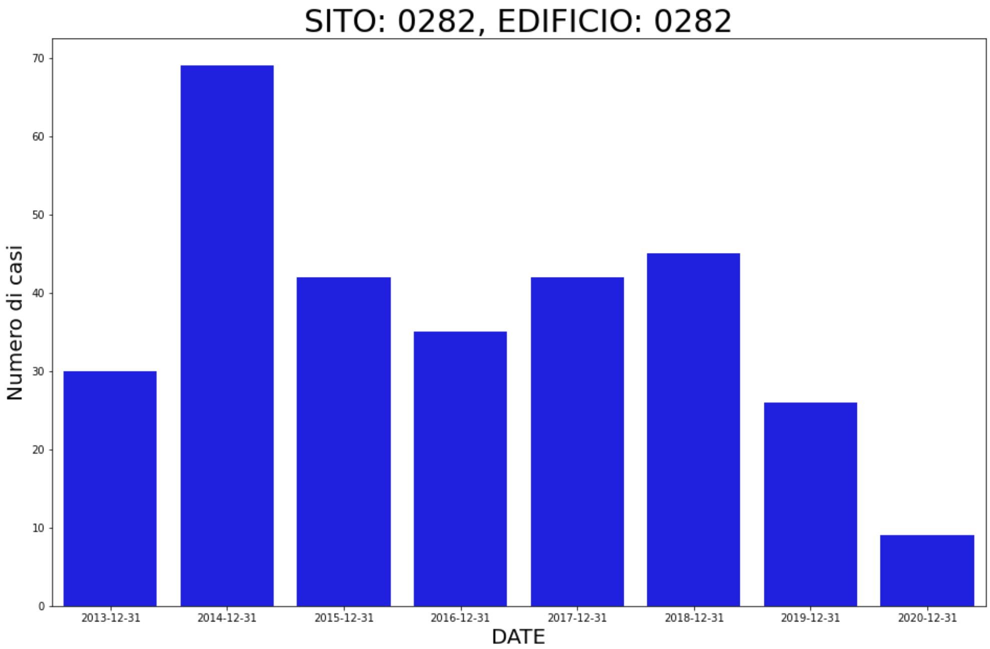

SITO: 0281, EDIFICIO: 0281
Numero di casi
0
10
20
30
40
50
60
70
80
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31
DATE


SITO: 0723, EDIFICIO: 0723
Numero di casi
0
20
40
60
80
100
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
DATE


SITO: 0048, EDIFICIO: 0048
Numero di casi
0
10
20
30
40
50
60
70
80
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31
DATE


SITO: 0262, EDIFICIO: 0262
Numero di casi
0
10
20
30
40
50
60
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31
DATE


SITO: 0622, EDIFICIO: 0622
Numero di casi
0
10
20
30
40
50
60
70
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31
DATE


SITO: 0282, EDIFICIO: 0282
Numero di casi
DATE
0
10
20
30
40
50
60
70
2013-12-31
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2015-12-31
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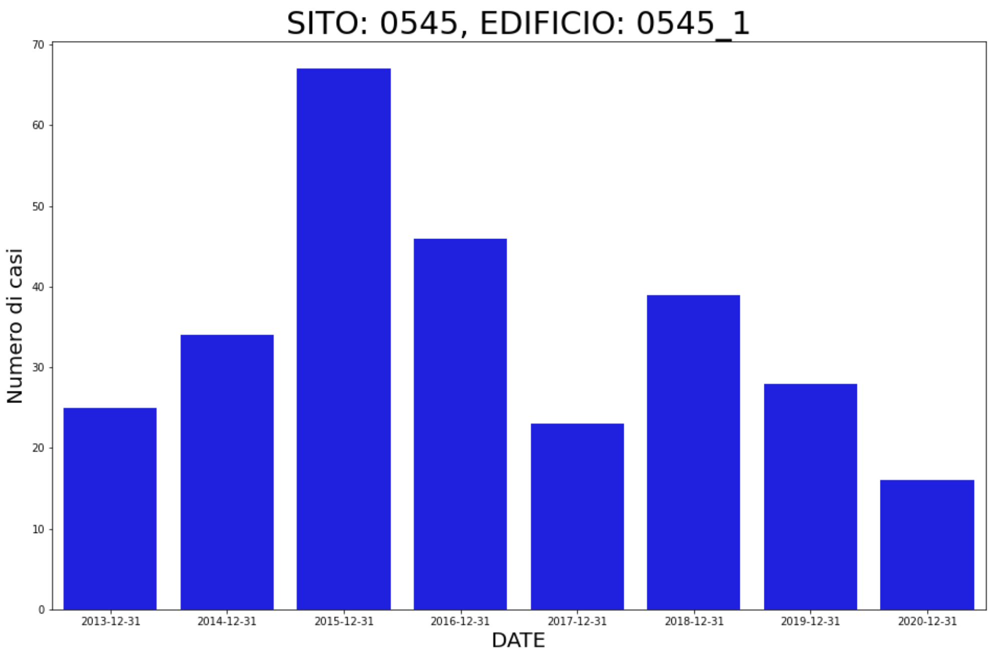
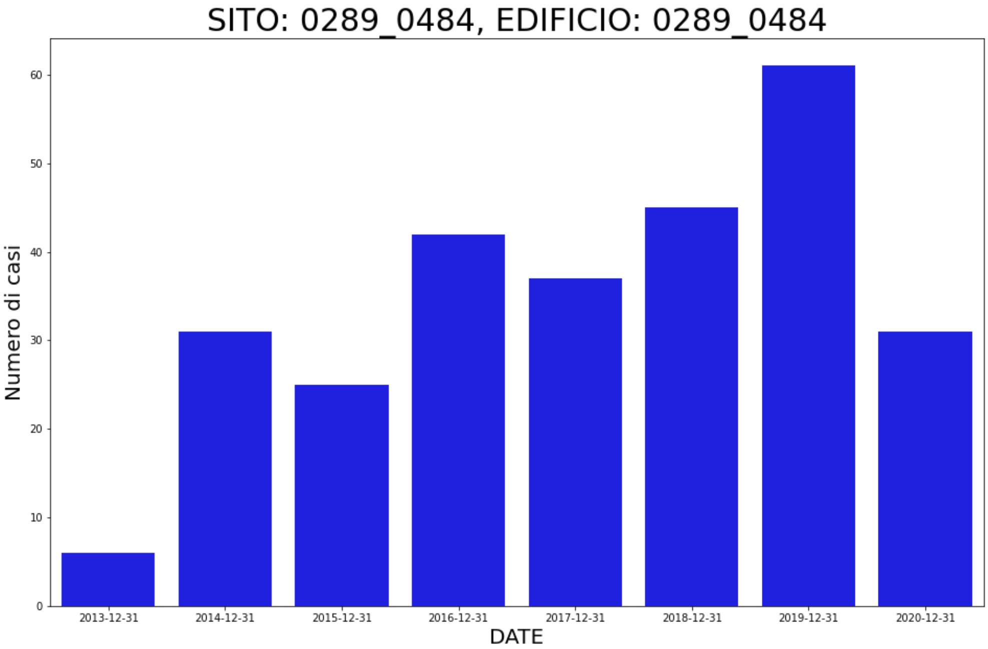
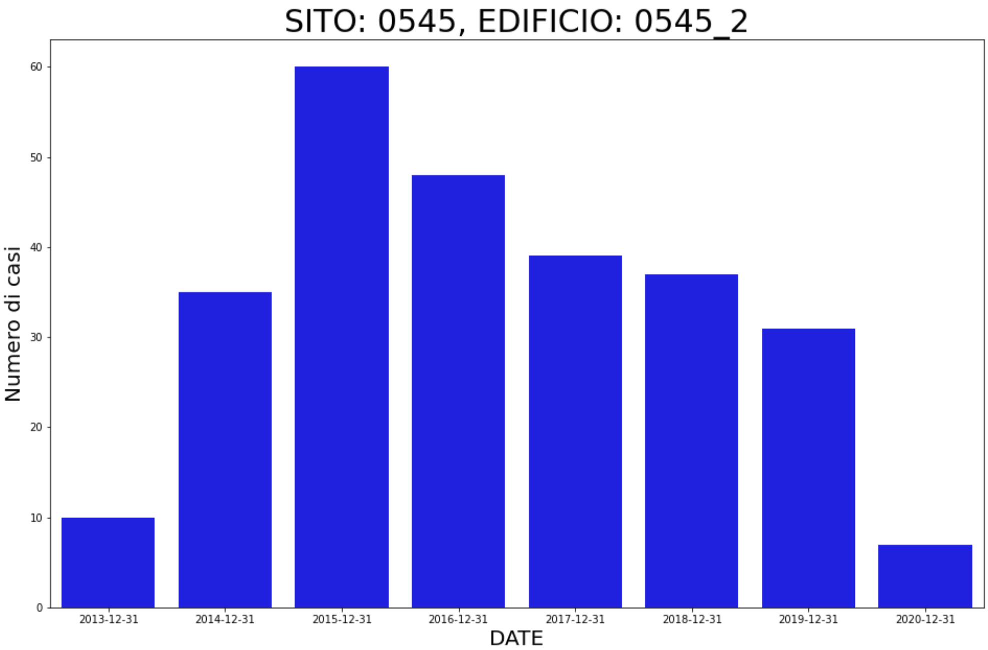
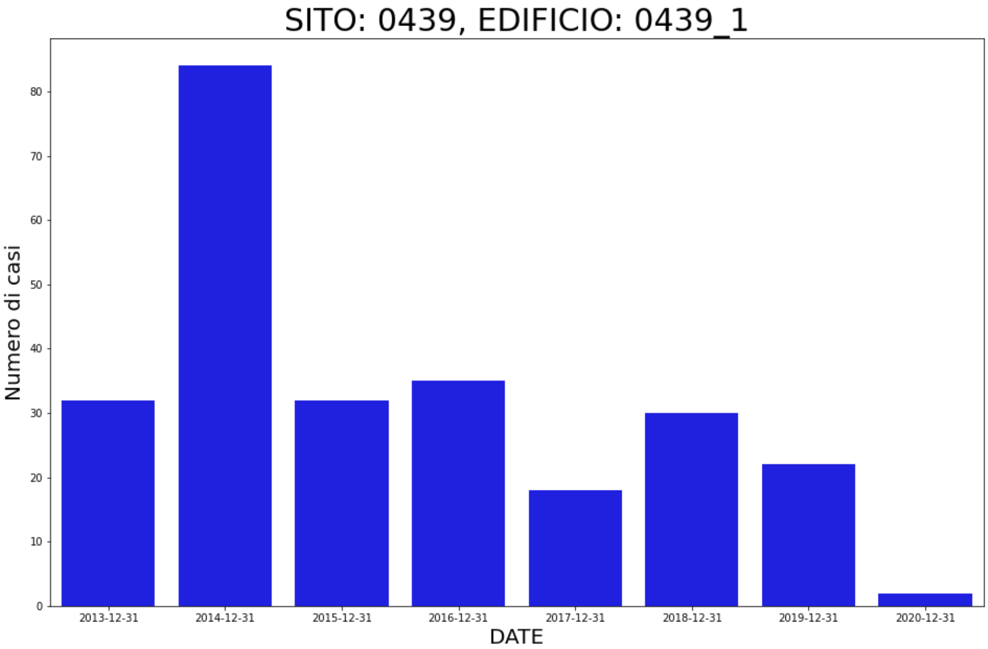
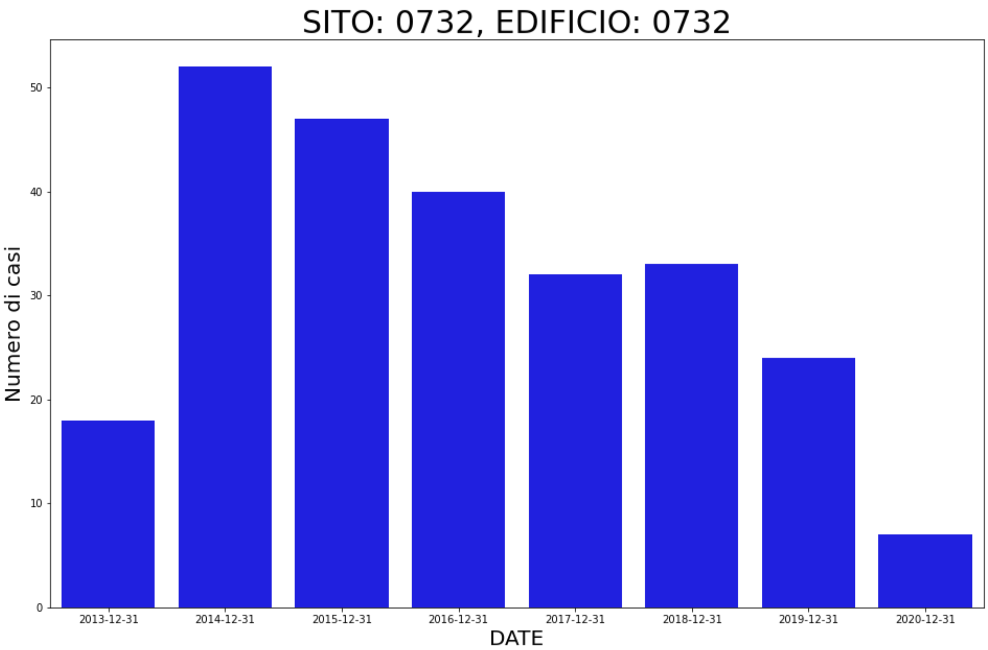
2019-12-31
2020-12-31


SITO: 0545, EDIFICIO: 0545_1
Numero di casi
DATE
0
10
20
30
40
50
60
70
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31


SITO: 0289_0484, EDIFICIO: 0289_0484
Numero di casi
0
10
20
30
40
50
60
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31
DATE


SITO: 0545, EDIFICIO: 0545_2
Numero di casi
0
10
20
30
40
50
60
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31
DATE


SITO: 0439, EDIFICIO: 0439_1
Numero di casi
0
10
20
30
40
50
60
70
80
2013-12-31
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31
DATE


SITO: 0732, EDIFICIO: 0732
Numero di casi
0
10
20
30
40
50
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2016-12-31
2017-12-31
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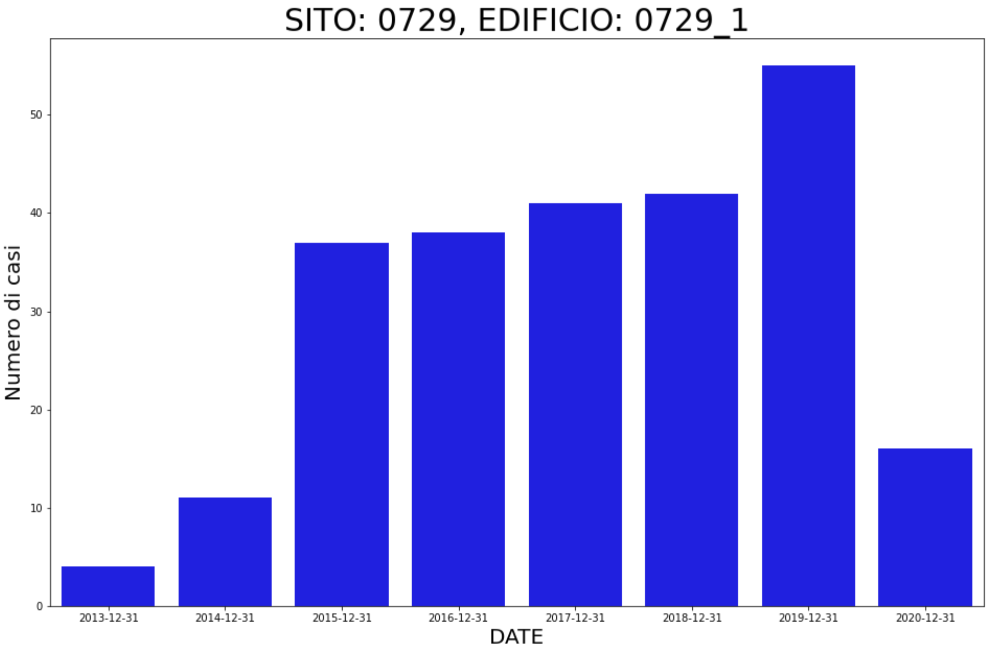
2020-12-31
DATE


SITO: 0729, EDIFICIO: 0729_1
Numero di casi
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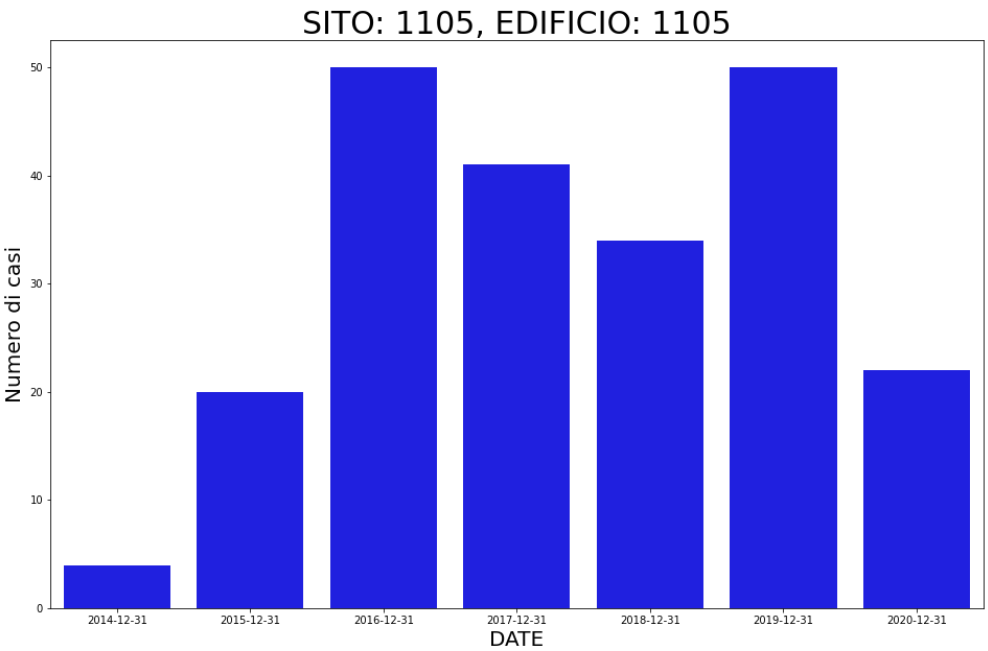
2019-12-31
2020-12-31
DATE


SITO: 1105, EDIFICIO: 1105
Numero di casi
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2014-12-31
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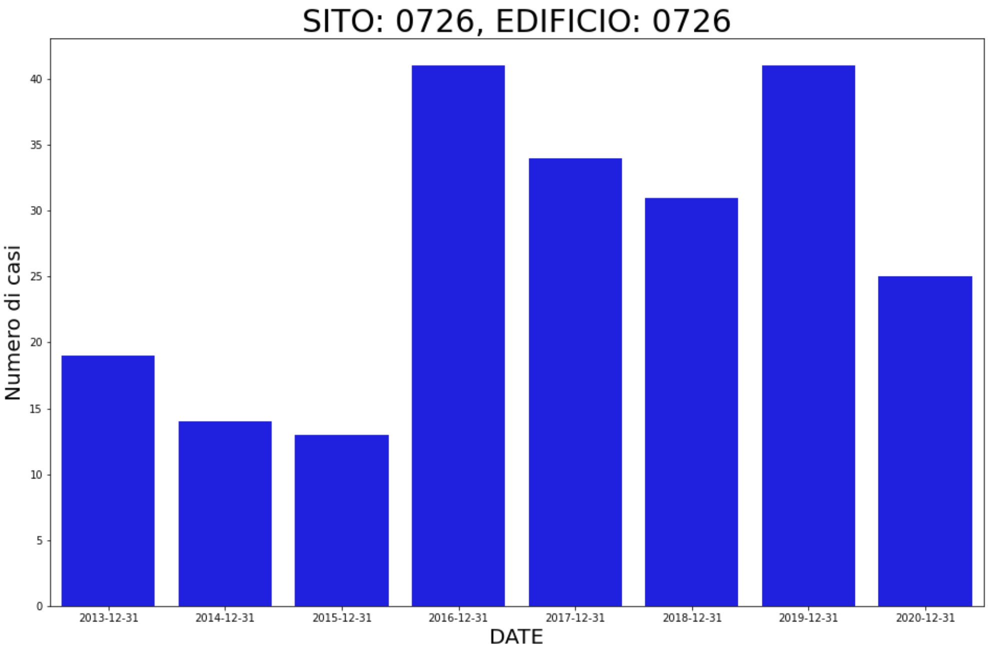
2019-12-31
2020-12-31
DATE


SITO: 0726, EDIFICIO: 0726
Numero di casi
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2013-12-31
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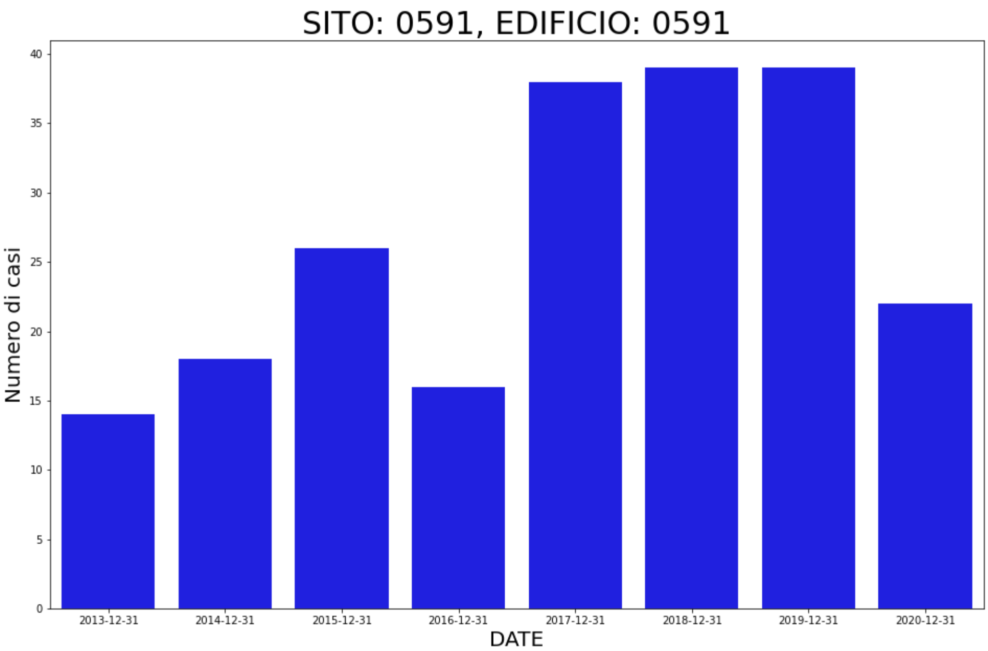
2019-12-31
2020-12-31
DATE


SITO: 0591, EDIFICIO: 0591
Numero di casi
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25
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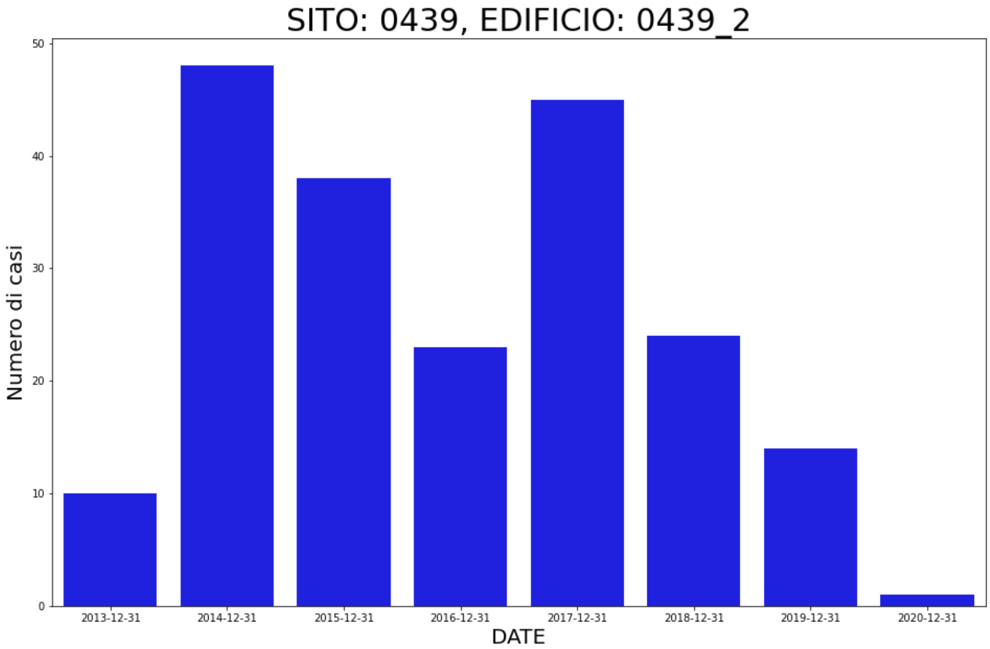
2020-12-31
DATE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Numero di casi
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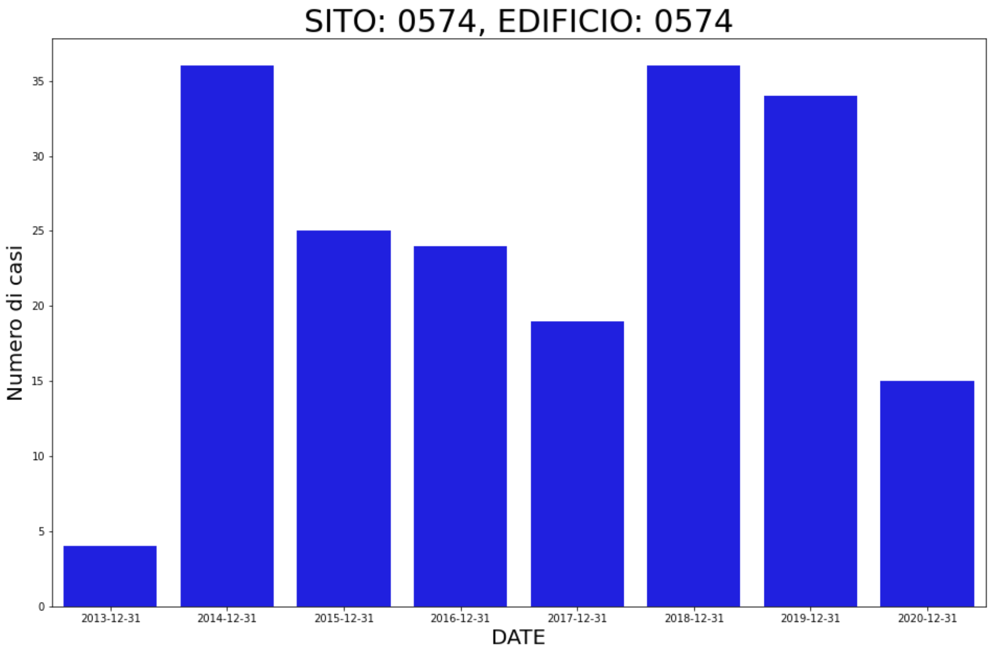
2019-12-31
2020-12-31


SITO: 0574, EDIFICIO: 0574
Numero di casi
DATE
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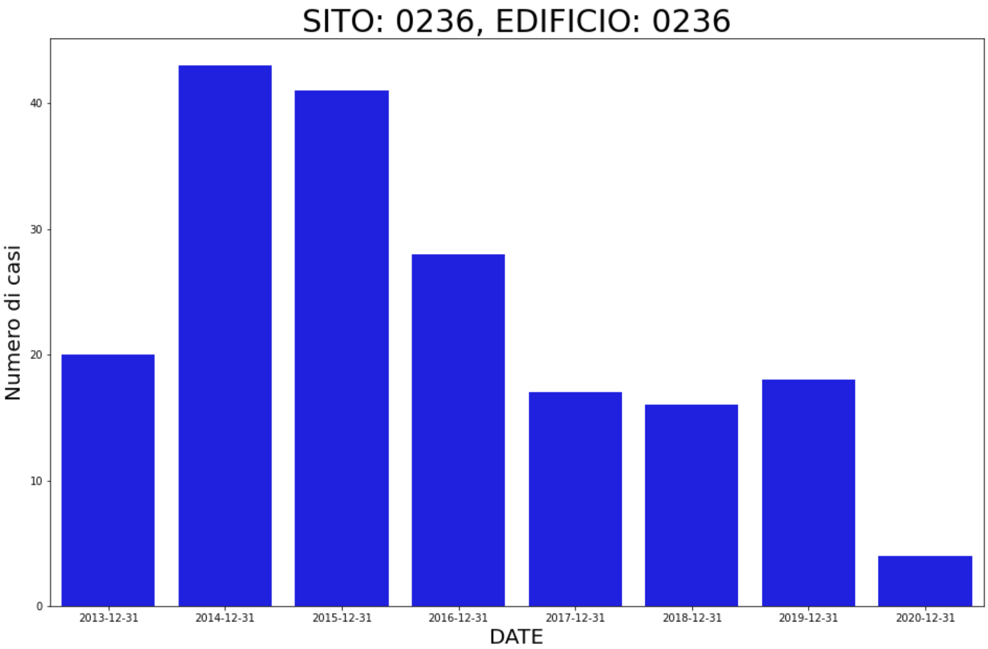
2020-12-31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2013-12-31
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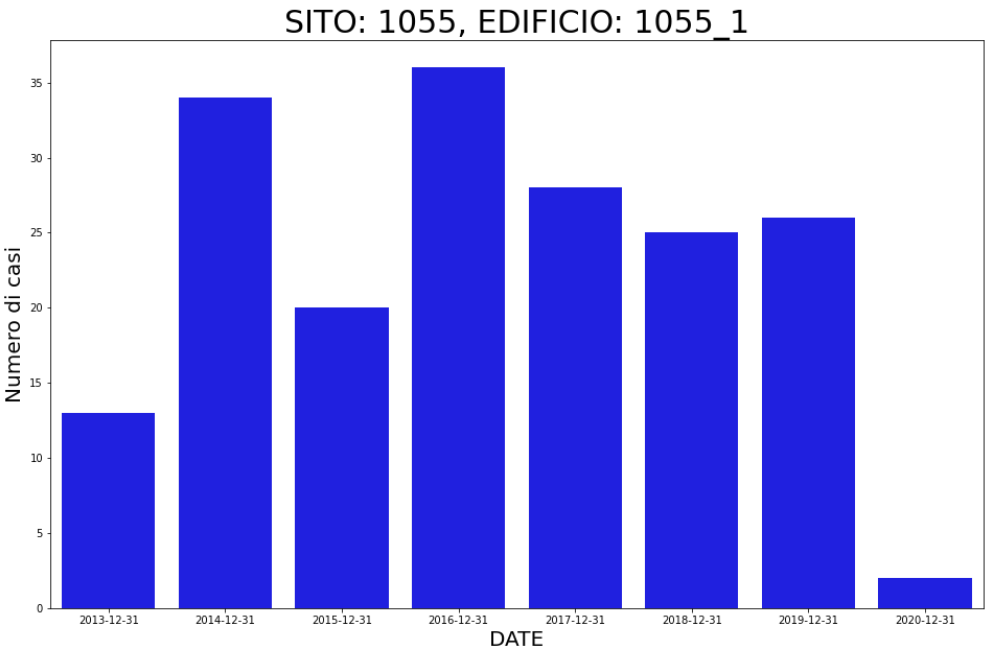
2019-12-31
2020-12-31
DATE


SITO: 1055, EDIFICIO: 1055_1
Numero di casi
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5
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15
20
25
30
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2013-12-31
2014-12-31
2015-12-31
2016-12-31
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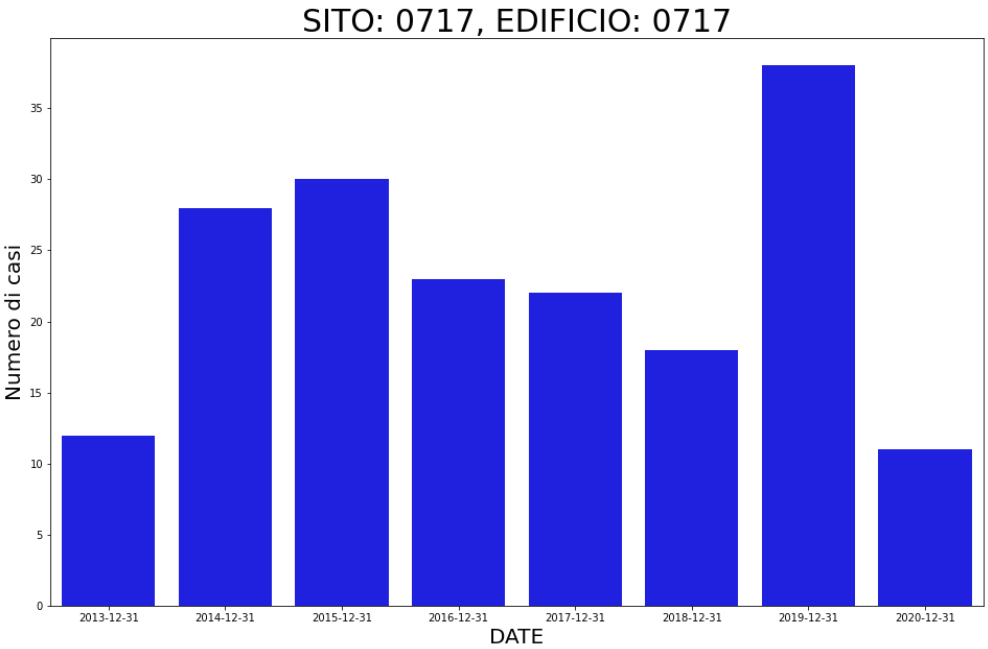
2019-12-31
2020-12-31
DATE


SITO: 0717, EDIFICIO: 0717
Numero di casi
DATE
2013-12-31
2014-12-31
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2016-12-31
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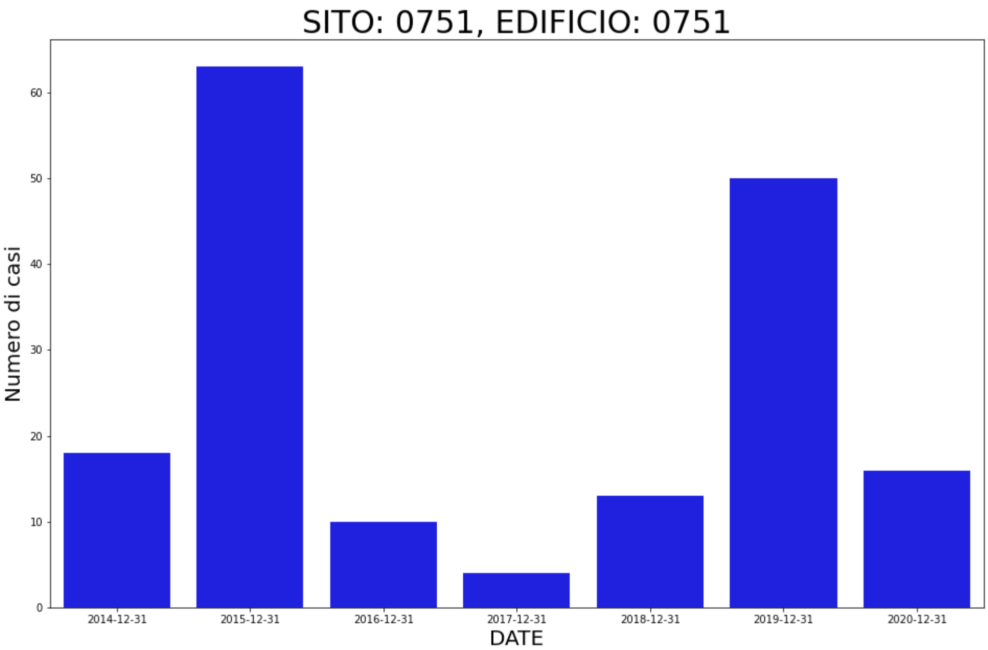
2019-12-31
2020-12-31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Numero di casi
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2015-12-31
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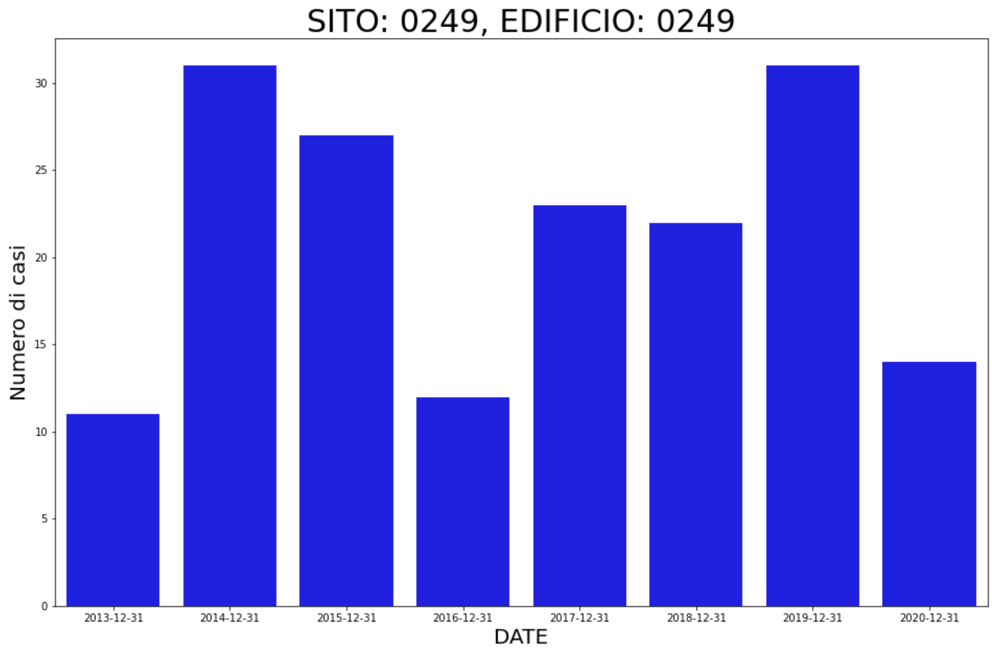
2020-12-31



SITO: 0249, EDIFICIO: 0249
Numero di casi
0
5
10
15
20
25
30
2013-12-31
2014-12-31
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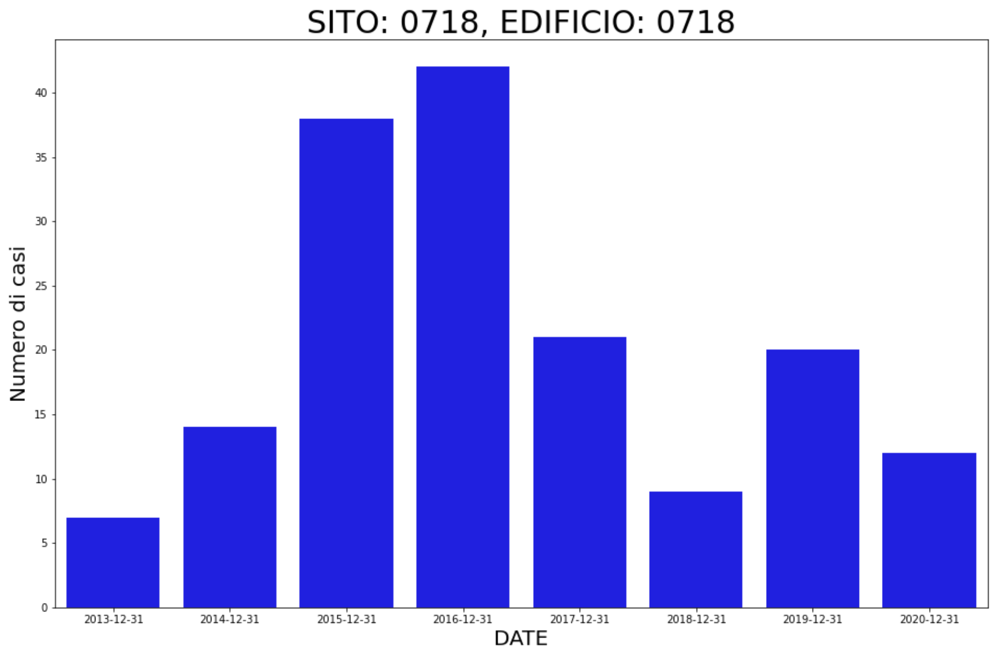
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31
DATE

SITO: 0718, EDIFICIO: 0718
Numero di casi
0
5
10
15
20
25
30
35
40
2013-12-31
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2015-12-31
2016-12-31
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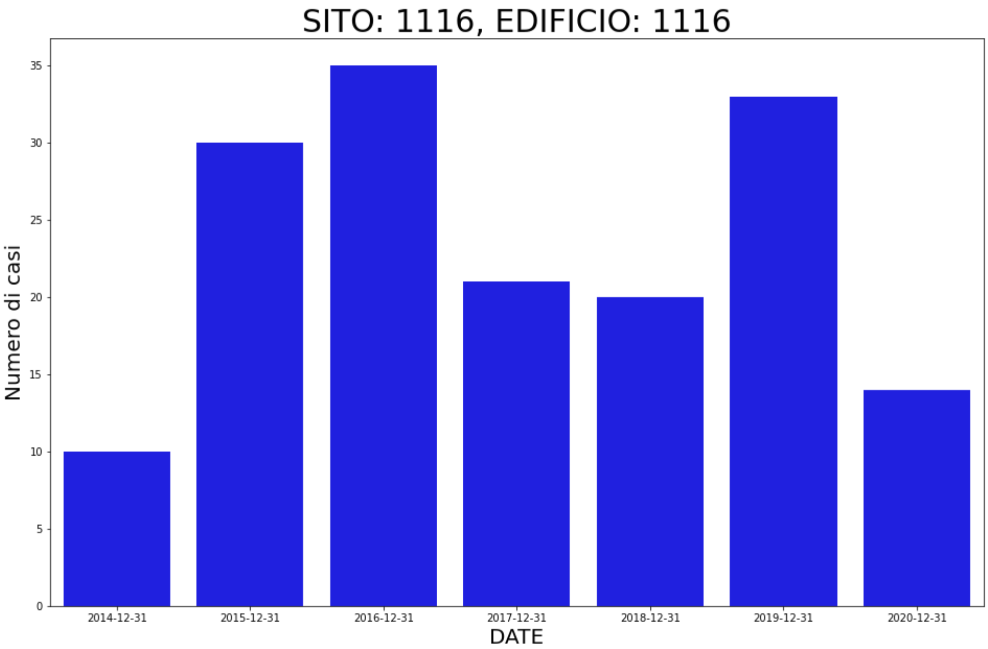
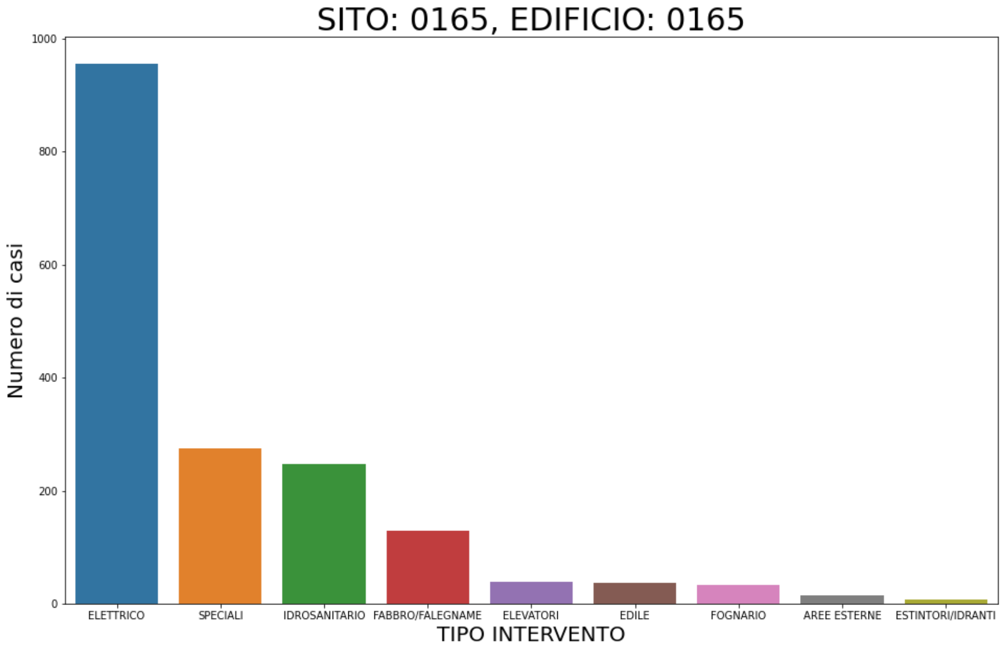
2019-12-31
2020-12-31
DATE

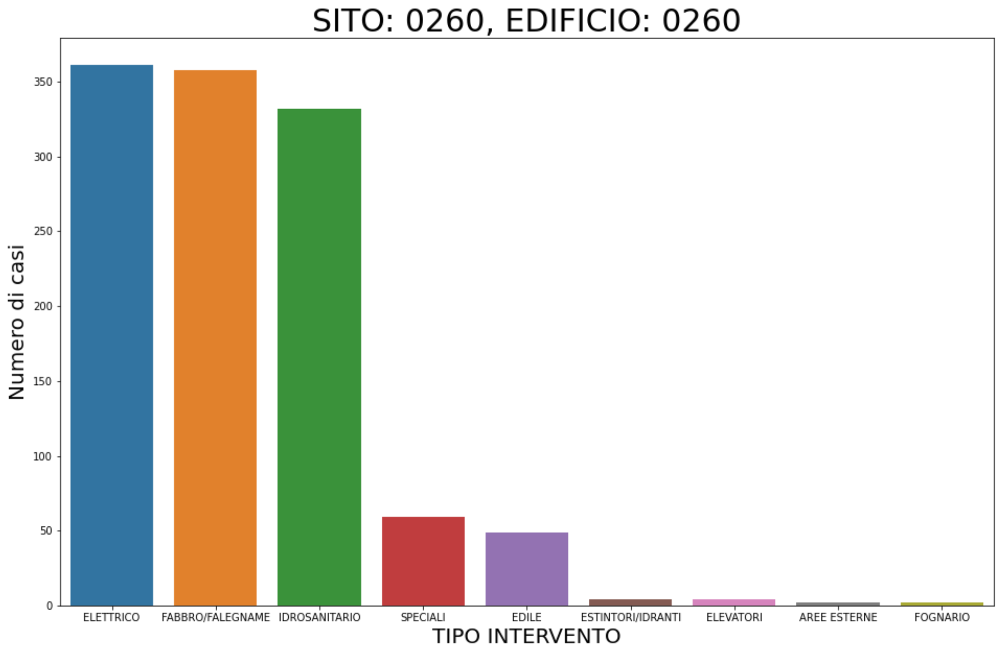


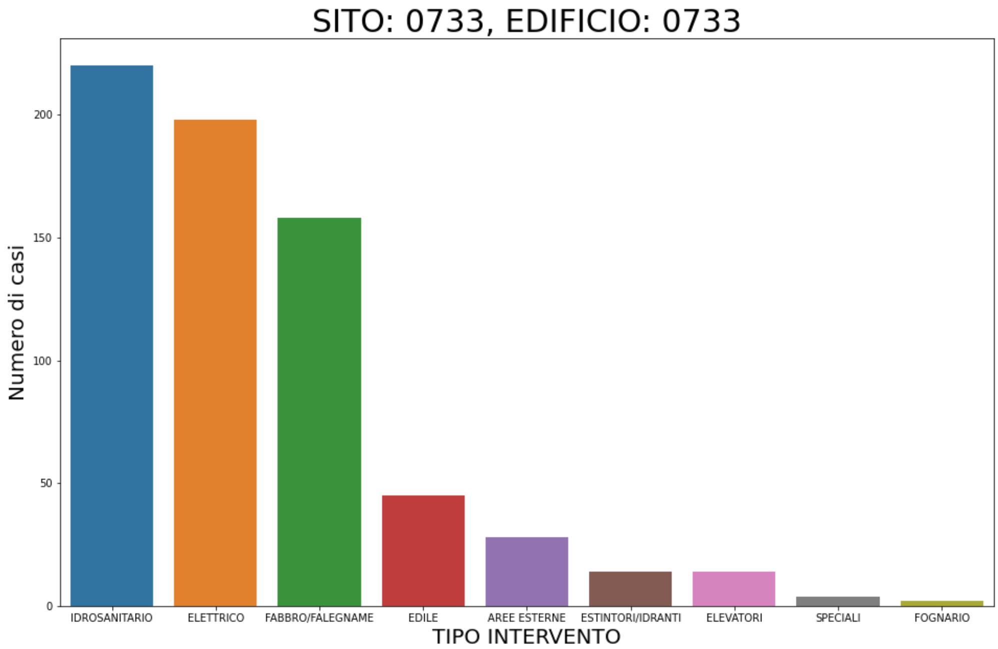
SITO: 1116, EDIFICIO: 1116
Numero di casi
DATE
0
5
10
15
20
25
30
35
2014-12-31
2015-12-31
2016-12-31
2017-12-31
2018-12-31
2019-12-31
2020-12-31

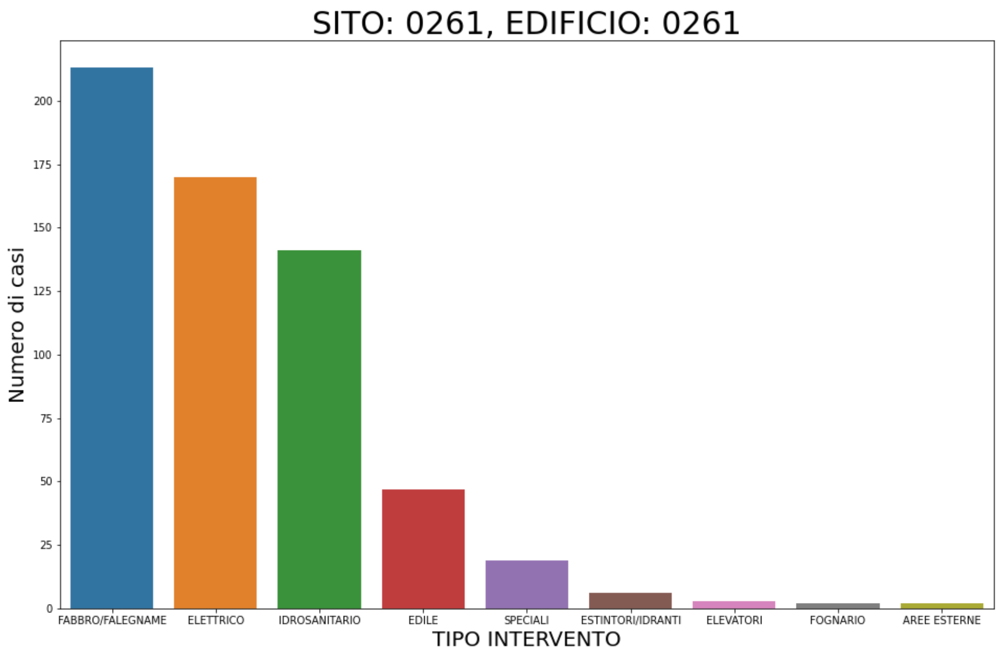
# 7 Analisi puntuale delle segnalazioni dei casi significativi per tipo di intervento

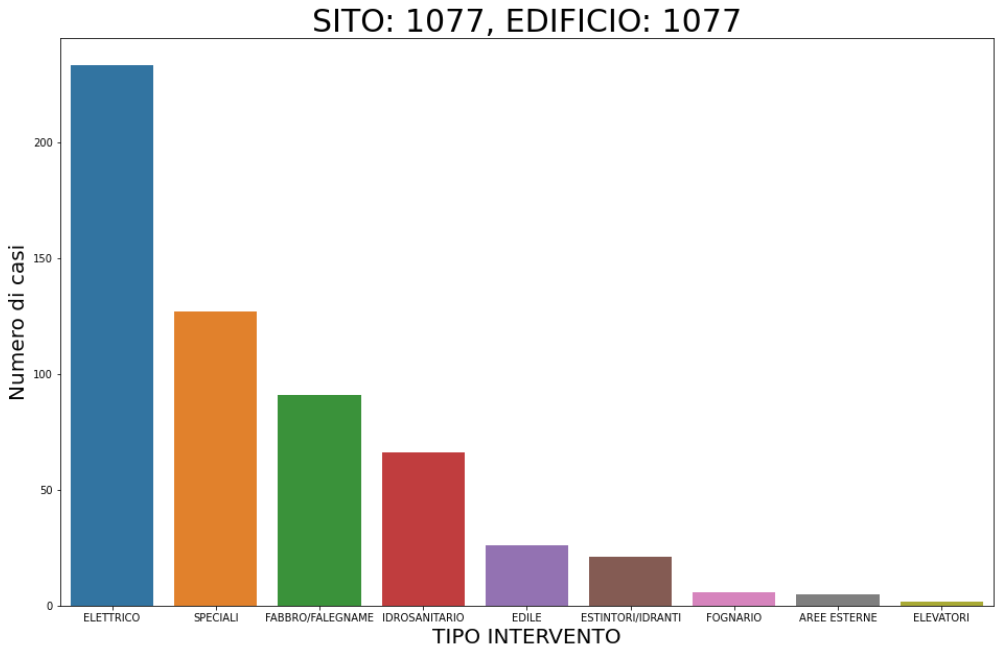
I seguenti grafici mostrano in modo puntuale gli andamenti delle richieste di intervento per tipologia di intervento, edificio per edificio dei casi significativi nei sette anni considerati.

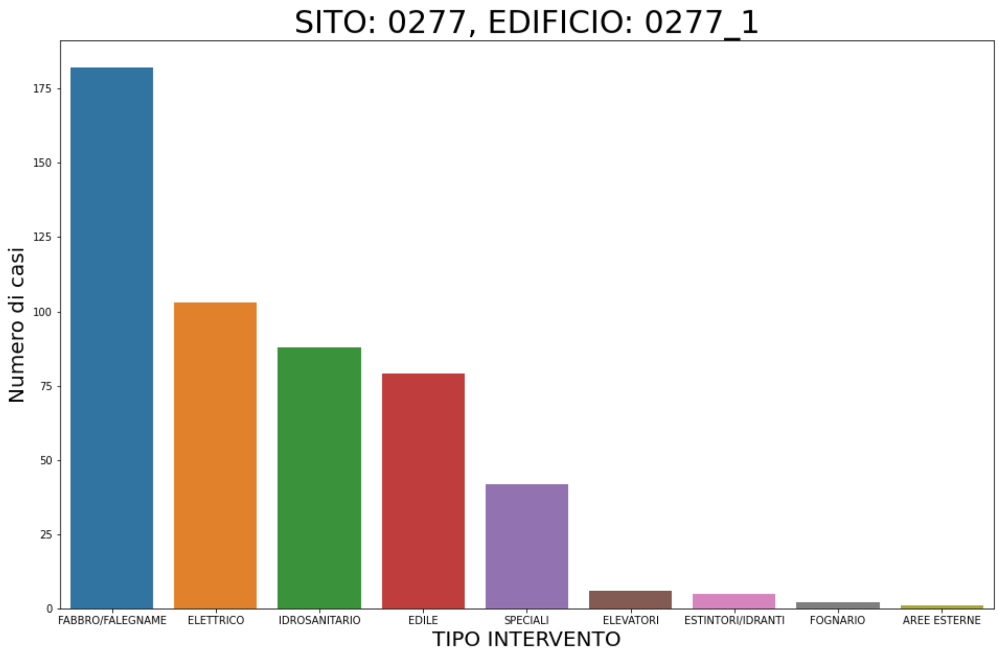


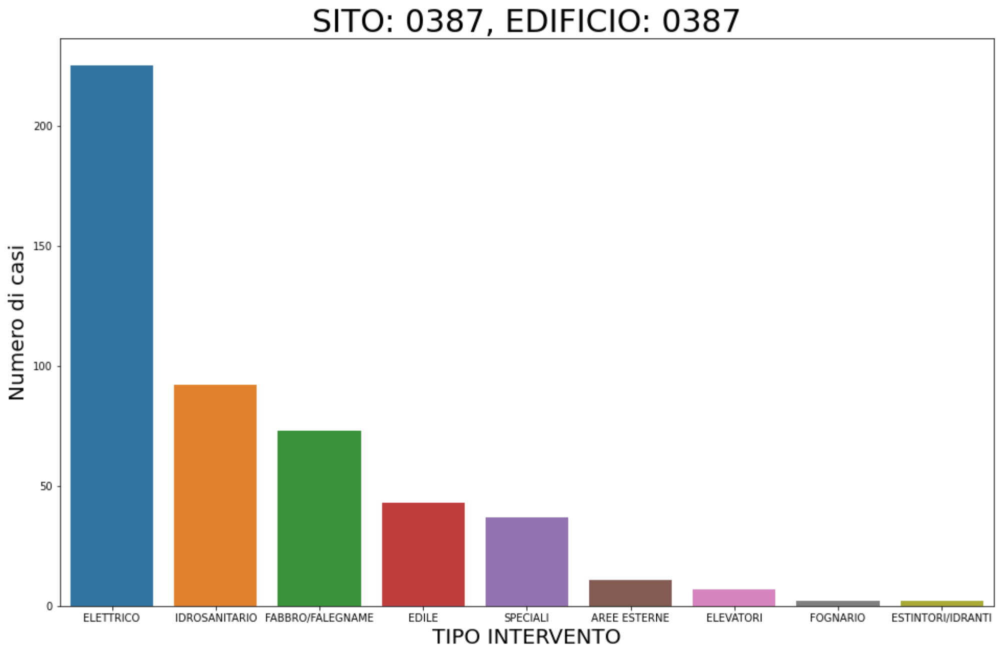



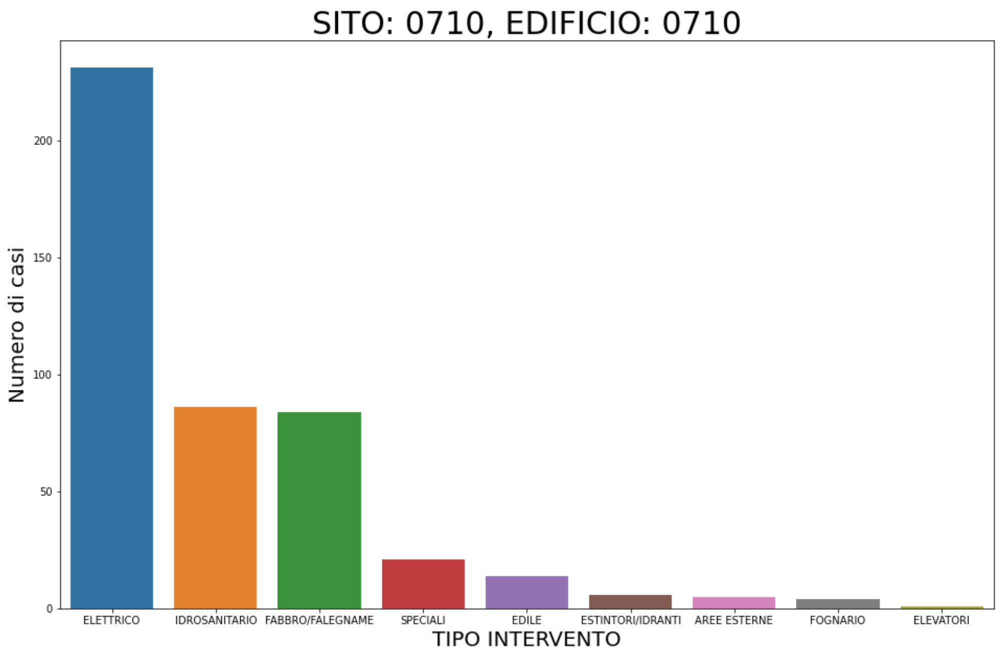

SITO: 0733, EDIFICIO: 0733
Numero di casi
0
50
100
150
200
IDROSANITARIO
ELETTRICO
FABBRO/FALEGNAME
EDILE
AREE ESTERNE
ESTINTORI/IDRANTI
ELEVATORI
SPECIALI
FOGNARIO
TIPO INTERVENTO

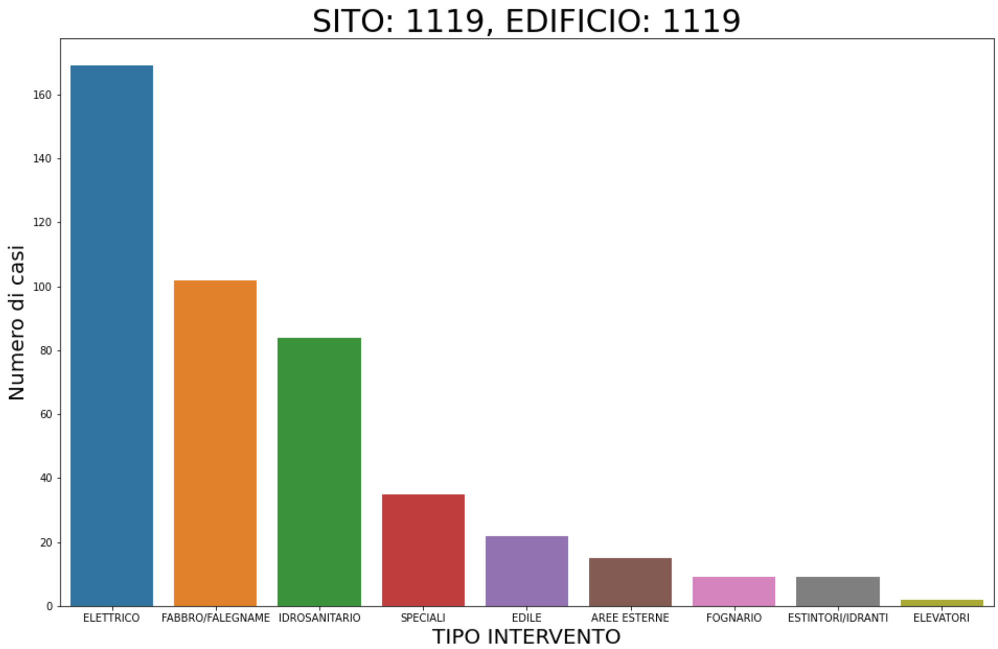

SITO: 0261, EDIFICIO: 0261
Numero di casi
0
25
50
75
100
125
150
175
200
FABBRO/FALEGNAME
ELETTRICO
IDROSANITARIO
EDILE
SPECIALI
ESTINTORI/IDRANTI
ELEVATORI
FOGNARIO
AREE ESTERNE
TIPO INTERVENTO

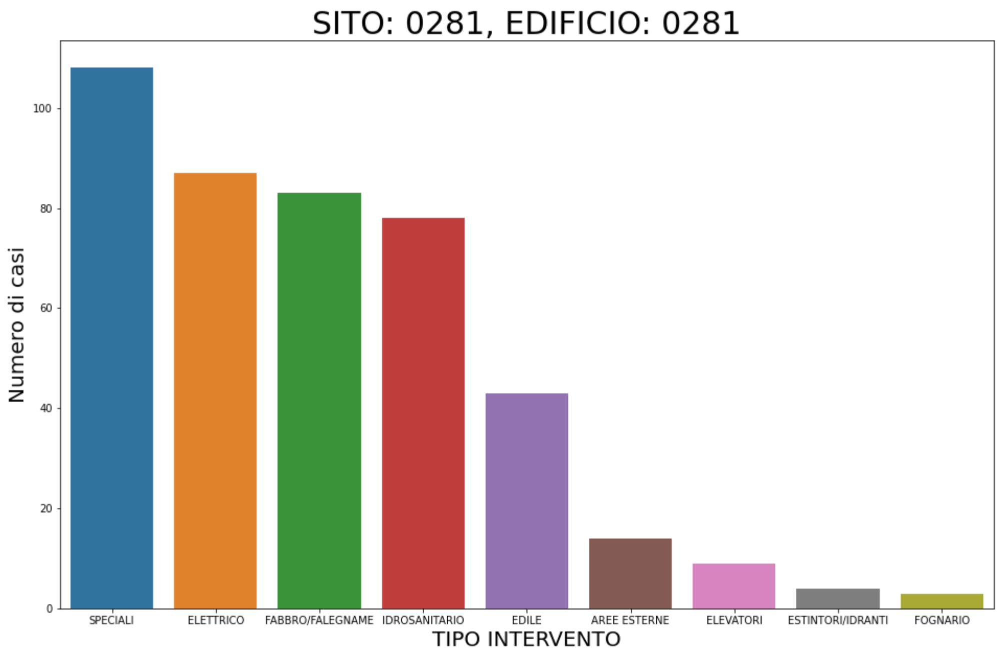

SITO: 1077, EDIFICIO: 1077
Numero di casi
0
50
100
150
200
ELETTRICO
SPECIALI
FABBRO/FALEGNAME
IDROSANITARIO
EDILE
ESTINTORI/IDRANTI
FOGNARIO
AREE ESTERNE
ELEVATORI
TIPO INTERVENTO

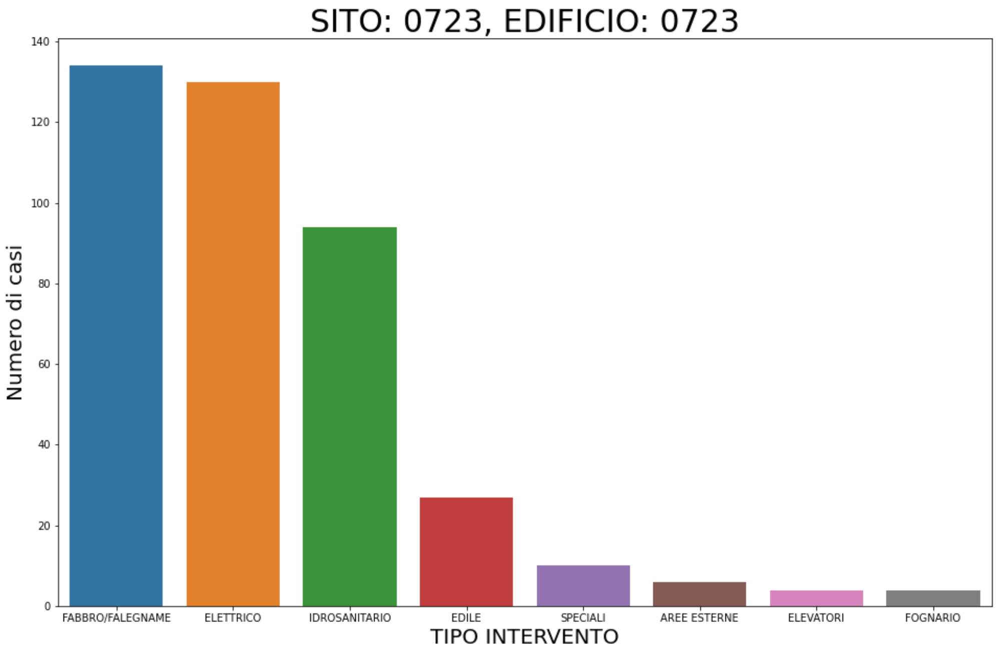

SITO: 0277, EDIFICIO: 0277_1
Numero di casi
0
25
50
75
100
125
150
175
FABBRO/FALEGNAME
ELETTRICO
IDROSANITARIO
EDILE
SPECIALI
ELEVATORI
ESTINTORI/IDRANTI
FOGNARIO
AREE ESTERNE
TIPO INTERVENTO

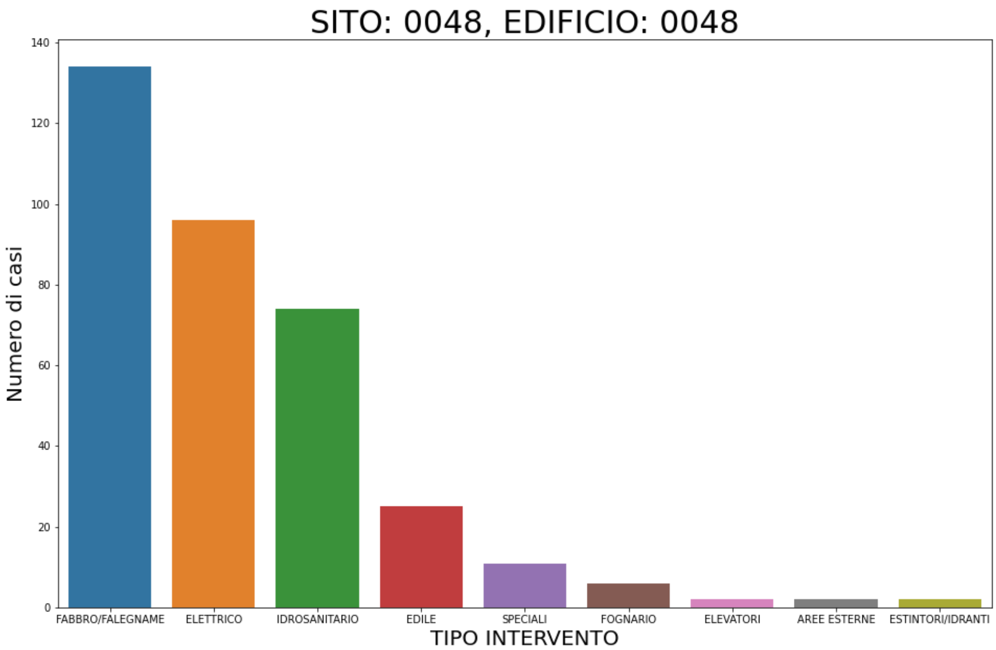

SITO: 0387, EDIFICIO: 0387
Numero di casi
0
50
100
150
200
ELETTRICO
IDROSANITARIO
FABBRO/FALEGNAME
EDILE
SPECIALI
AREE ESTERNE
ELEVATORI
FOGNARIO
ESTINTORI/IDRANTI
TIPO INTERVENTO

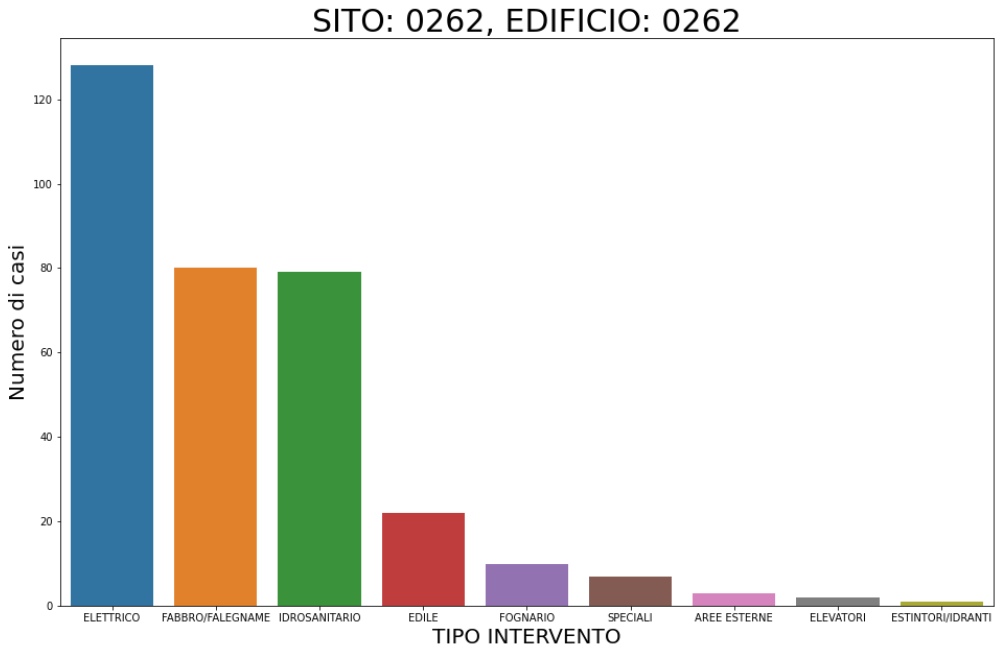

SITO: 0710, EDIFICIO: 0710
Numero di casi
0
50
100
150
200
ELETTRICO
IDROSANITARIO
FABBRO/FALEGNAME
SPECIALI
EDILE
ESTINTORI/IDRANTI
AREE ESTERNE
FOGNARIO
ELEVATORI
TIPO INTERVENTO

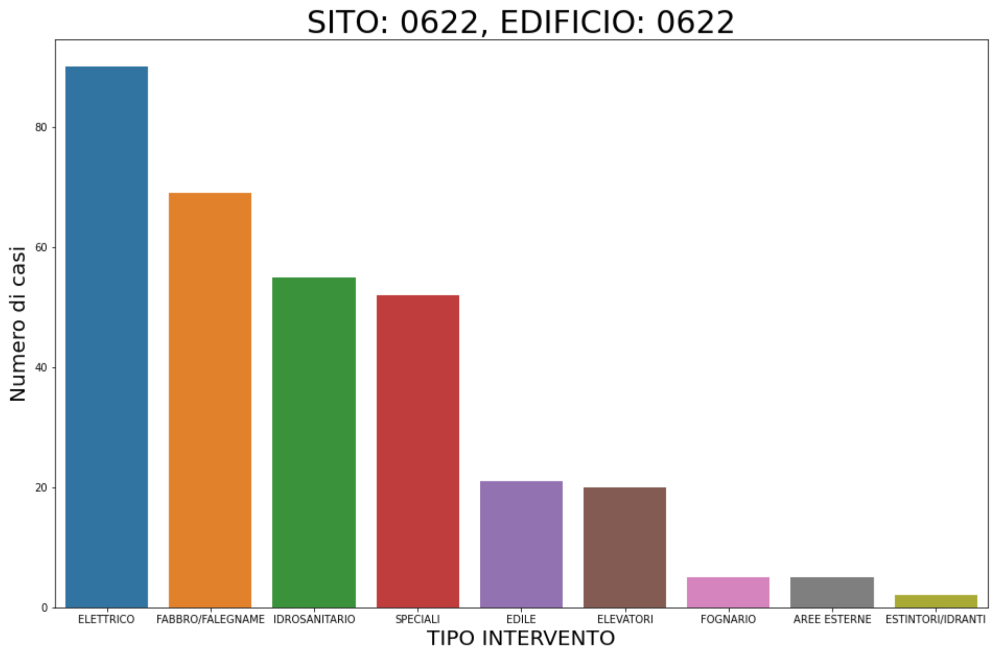

SITO: 1119, EDIFICIO: 1119
Numero di casi
0
20
40
60
80
100
120
140
160
ELETTRICO
FABBRO/FALEGNAME
IDROSANITARIO
SPECIALI
EDILE
AREE ESTERNE
FOGNARIO
ESTINTORI/IDRANTI
ELEVATORI
TIPO INTERVENTO


SITO: 0281, EDIFICIO: 0281
Numero di casi
0
20
40
60
80
100
SPECIALI
ELETTRICO
FABBRO/FALEGNAME
IDROSANITARIO
EDILE
AREE ESTERNE
ELEVATORI
ESTINTORI/IDRANTI
FOGNARIO
TIPO INTERVENTO


SITO: 0723, EDIFICIO: 0723
Numero di casi
140
120
100
80
60
40
20
0
FABBRO/FALEGNAME
ELETTRICO
IDROSANITARIO
EDILE
SPECIALI
AREE ESTERNE
ELEVATORI
FOGNARIO
TIPO INTERVENTO


SITO: 0048, EDIFICIO: 0048
Numero di casi
140
120
100
80
60
40
20
0
FABBRO/FALEGNAME
ELETTRICO
IDROSANITARIO
EDILE
SPECIALI
FOGNARIO
ELEVATORI
AREE ESTERNE
ESTINTORI/IDRANTI
TIPO INTERVENTO


SITO: 0262, EDIFICIO: 0262
Numero di casi
0
20
40
60
80
100
120
ELETTRICO
FABBRO/FALEGNAME
IDROSANITARIO
EDILE
FOGNARIO
SPECIALI
AREE ESTERNE
ELEVATORI
ESTINTORI/IDRANTI
TIPO INTERVENTO


SITO: 0622, EDIFICIO: 0622
Numero di casi
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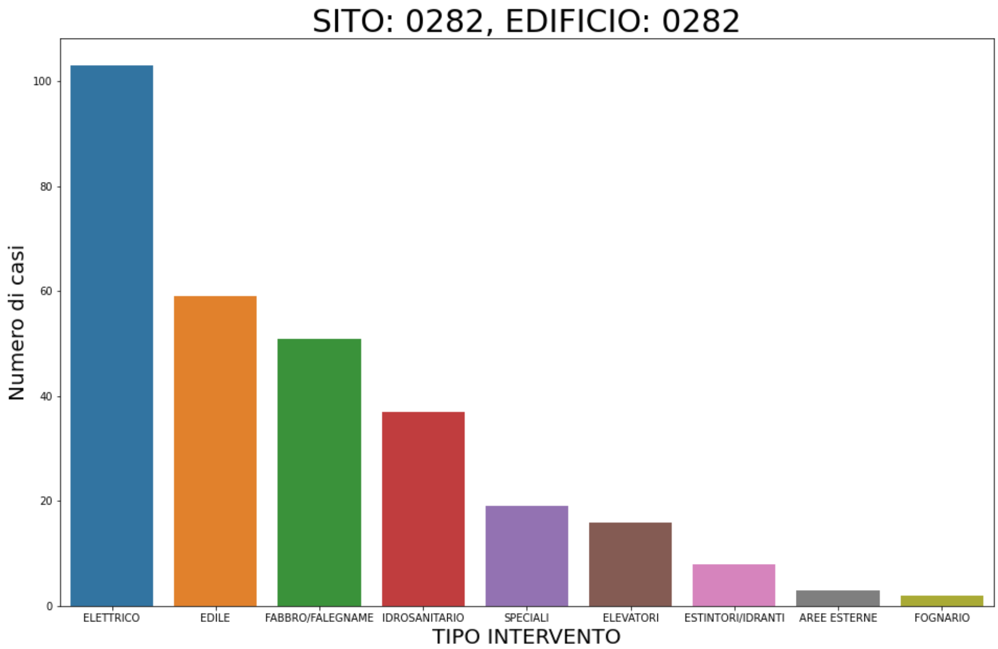
20
40
60
80
ELETTRICO
FABBRO/FALEGNAME
IDROSANITARIO
SPECIALI
EDILE
ELEVATORI
FOGNARIO
AREE ESTERNE
ESTINTORI/IDRANTI
TIPO INTERVENTO


SITO: 0282, EDIFICIO: 0282
Numero di casi
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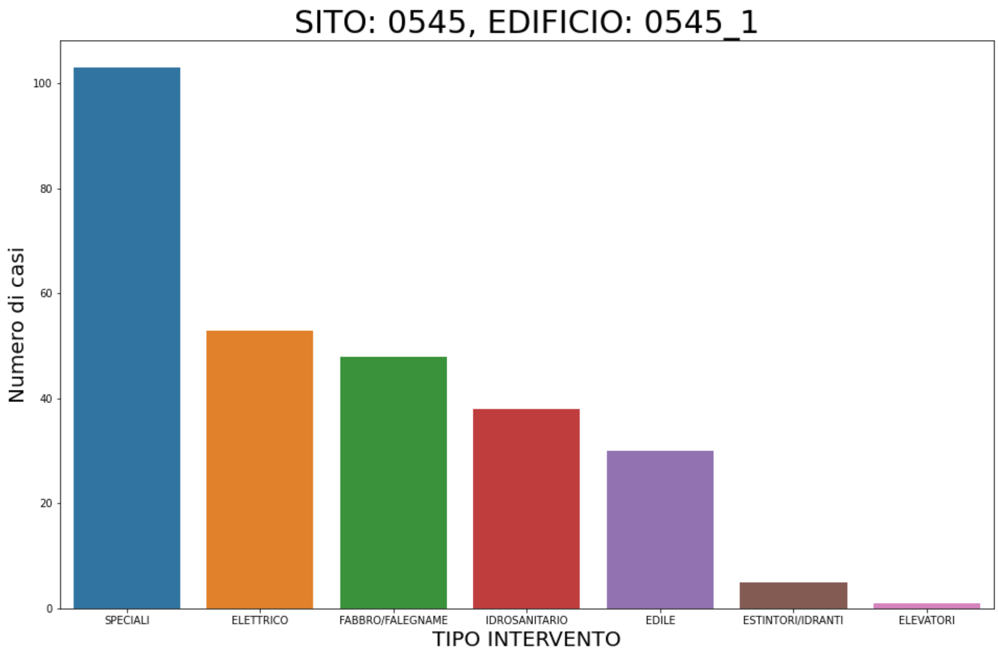
20
40
60
80
100
ELETTRICO
EDILE
FABBRO/FALEGNAME
IDROSANITARIO
SPECIALI
ELEVATORI
ESTINTORI/IDRANTI
AREE ESTERNE
FOGNARIO
TIPO INTERVENTO


SITO: 0545, EDIFICIO: 0545_1
Numero di casi
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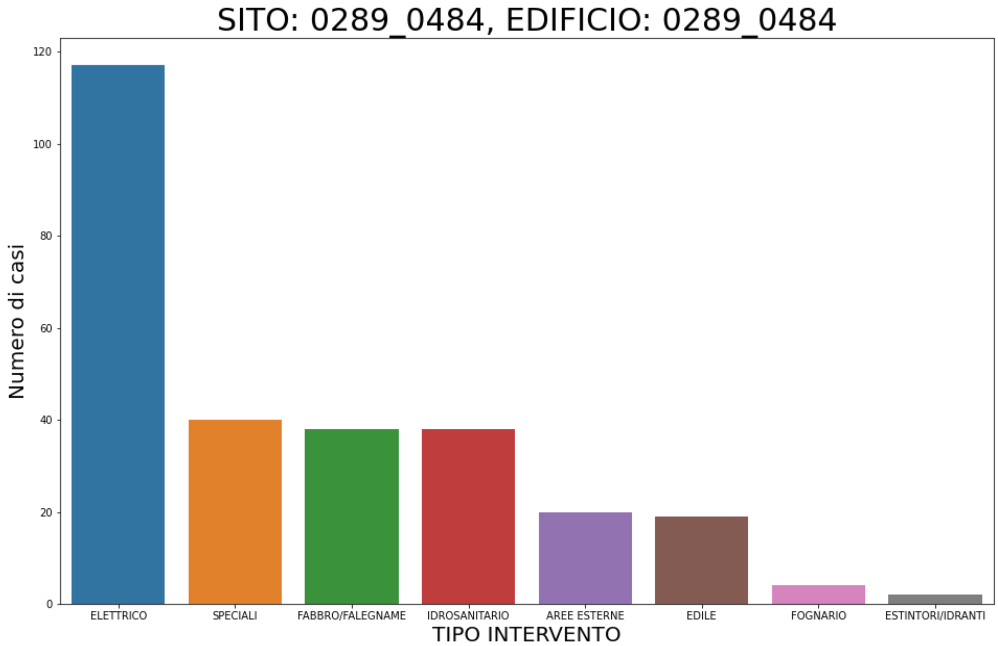
20
40
60
80
100
SPECIALI
ELETTRICO
FABBRO/FALEGNAME
IDROSANITARIO
EDILE
ESTINTORI/IDRANTI
ELEVATORI
TIPO INTERVENTO


SITO: 0289_0484, EDIFICIO: 0289_0484
Numero di casi
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60
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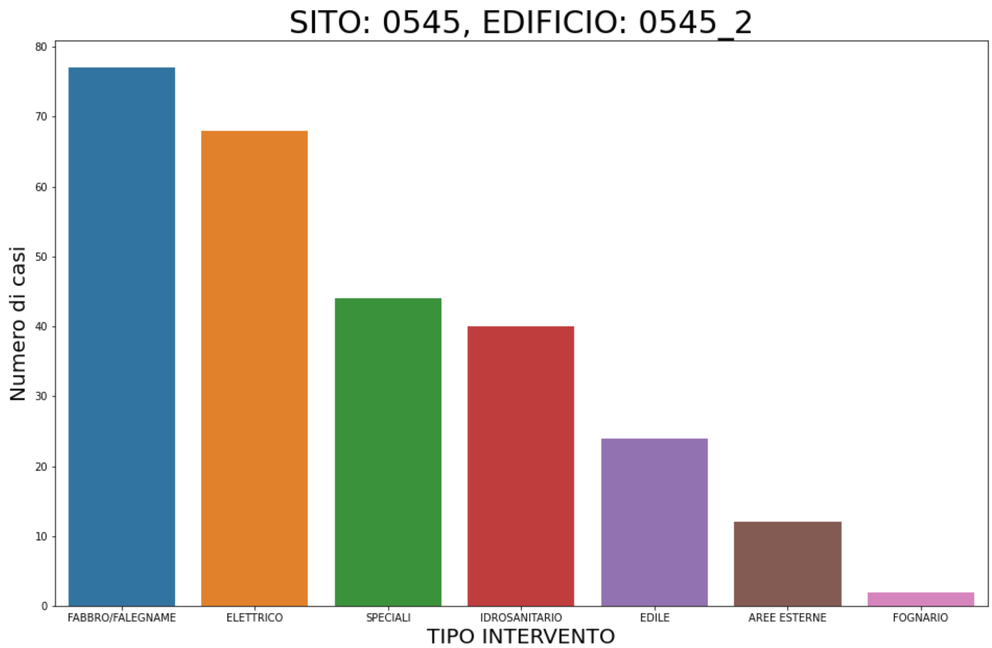
100
120
ELETTRICO
SPECIALI
FABBRO/FALEGNAME
IDROSANITARIO
AREE ESTERNE
EDILE
FOGNARIO
ESTINTORI/IDRANTI
TIPO INTERVENTO


SITO: 0545, EDIFICIO: 0545_2
Numero di casi
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60
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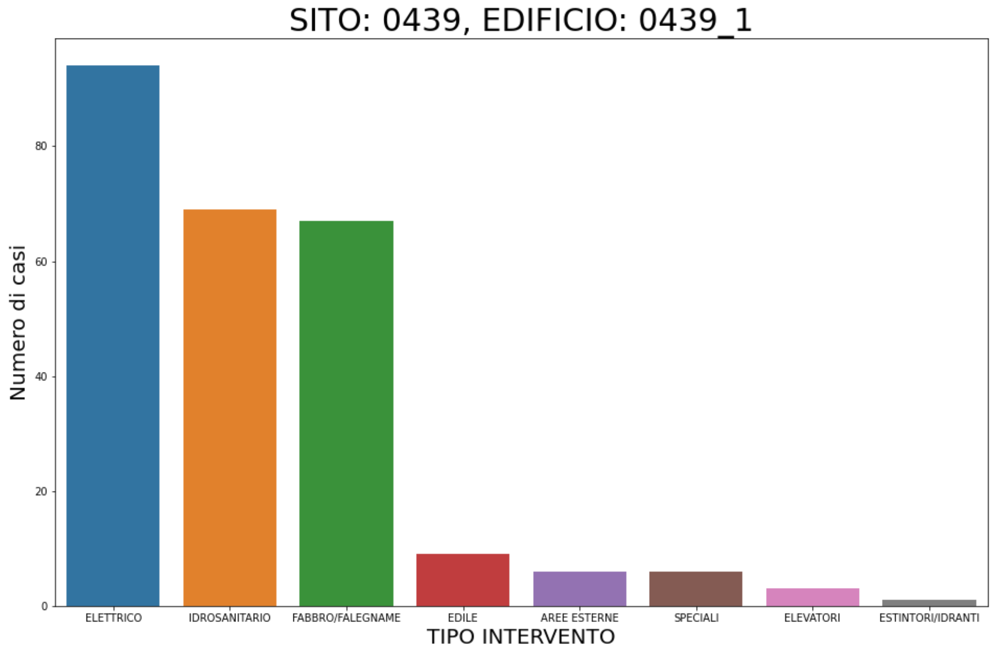
FABBRO/FALEGNAME
ELETTRICO
SPECIALI
IDROSANITARIO
EDILE
AREE ESTERNE
FOGNARIO
TIPO INTERVENTO


SITO: 0439, EDIFICIO: 0439_1
Numero di casi
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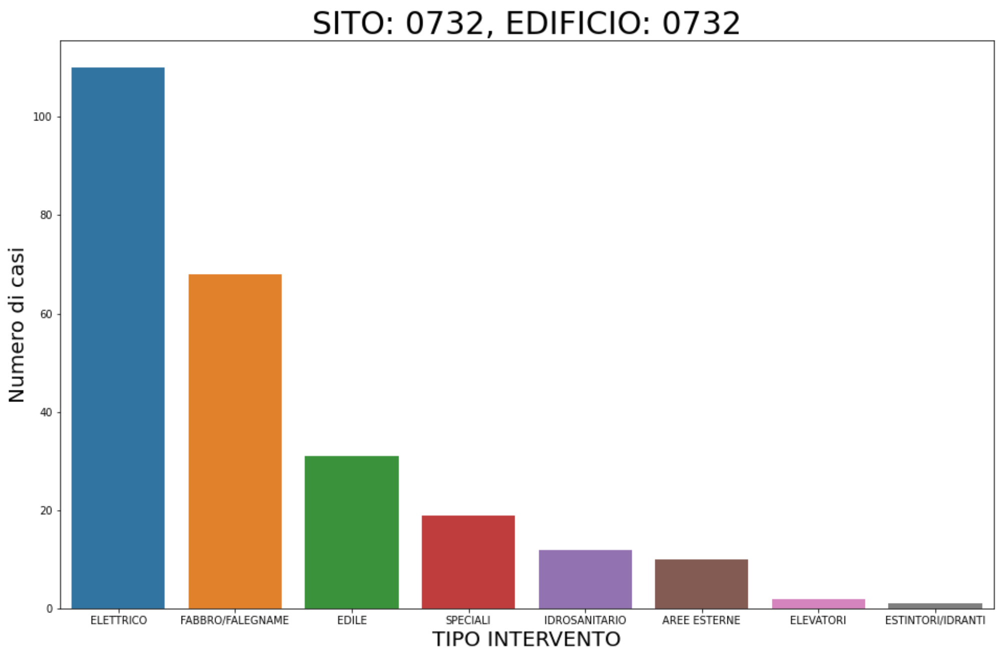
40
60
80
ELETTRICO
IDROSANITARIO
FABBRO/FALEGNAME
EDILE
AREE ESTERNE
SPECIALI
ELEVATORI
ESTINTORI/IDRANTI
TIPO INTERVENTO


SITO: 0732, EDIFICIO: 0732
Numero di casi
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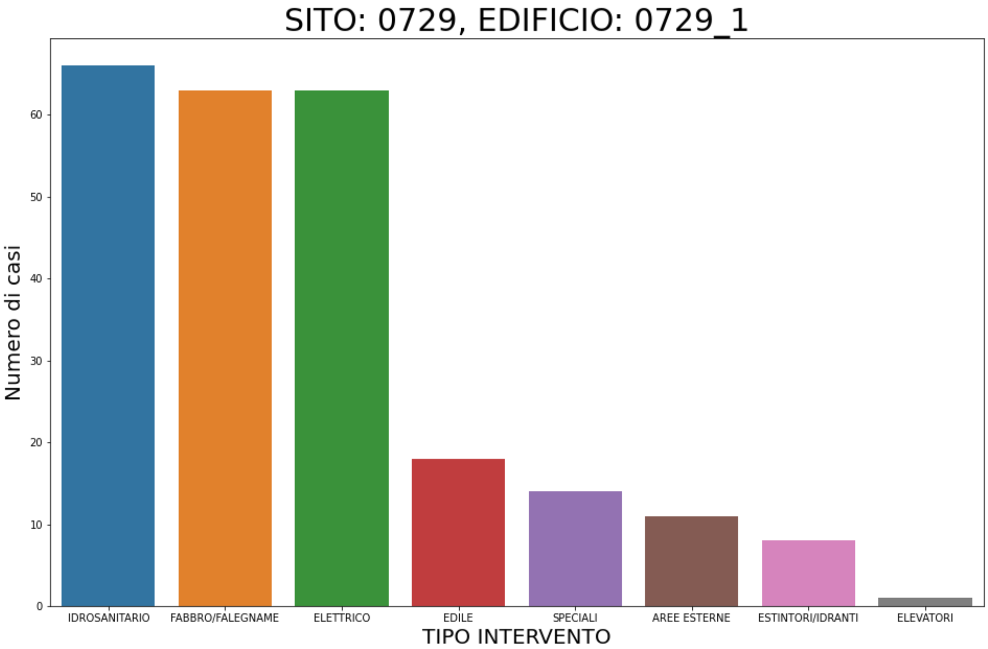
40
60
80
100
ELETTRICO
FABBRO/FALEGNAME
EDILE
SPECIALI
IDROSANITARIO
AREE ESTERNE
ELEVATORI
ESTINTORI/IDRANTI
TIPO INTERVENTO


SITO: 0729, EDIFICIO: 0729_1
Numero di casi
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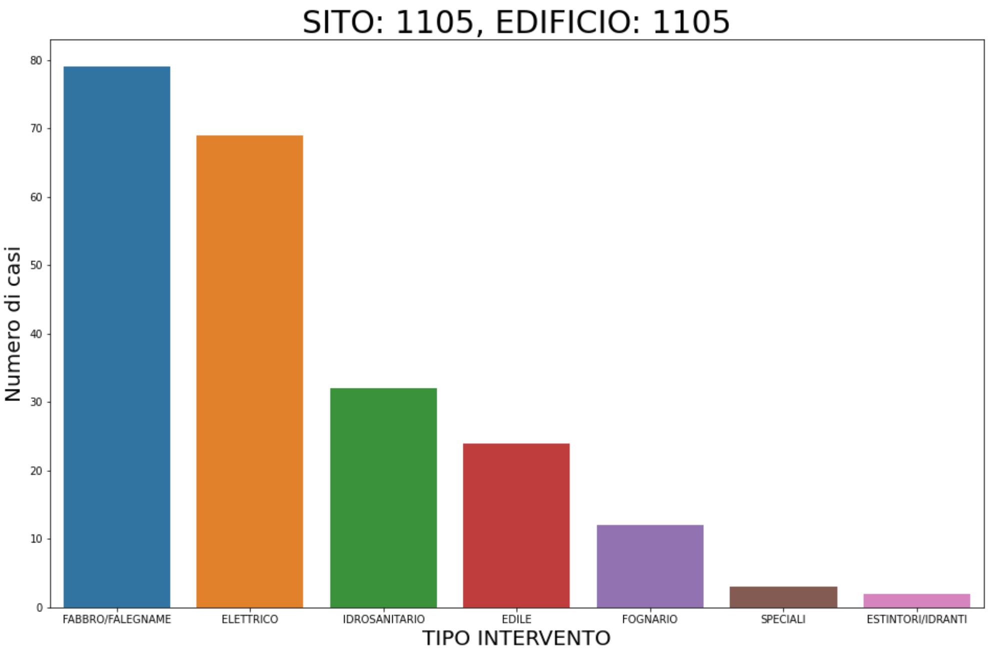
20
30
40
50
60
IDROSANITARIO
FABBRO/FALEGNAME
ELETTRICO
EDILE
SPECIALI
AREE ESTERNE
ESTINTORI/IDRANTI
ELEVATORI
TIPO INTERVENTO


SITO: 1105, EDIFICIO: 1105
Numero di casi
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10
20
30
40
50
60
70
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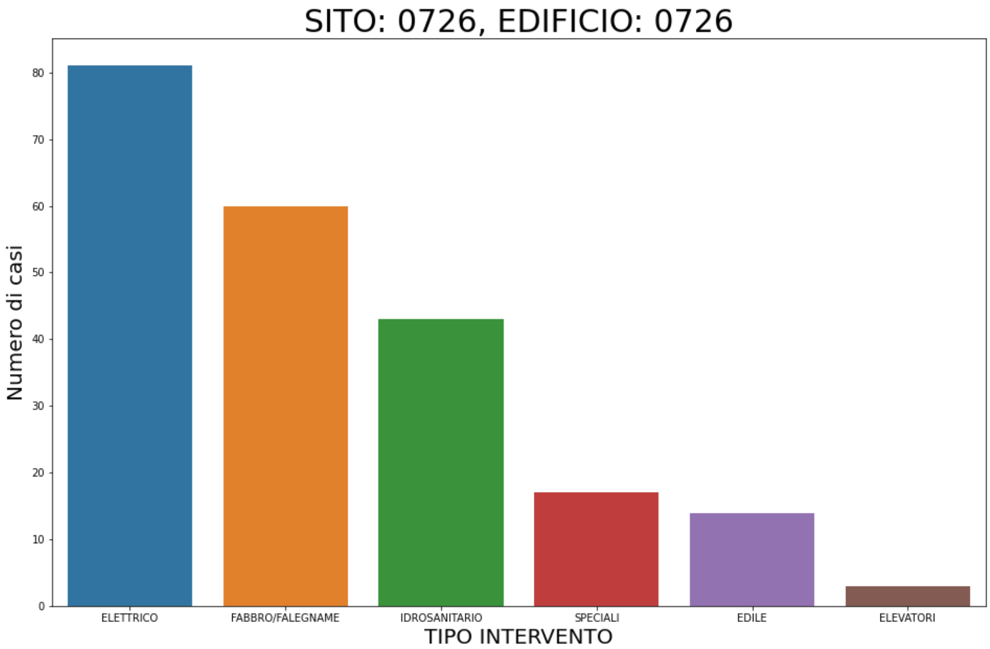
FABBRO/FALEGNAME
ELETTRICO
IDROSANITARIO
EDILE
FOGNARIO
SPECIALI
ESTINTORI/IDRANTI
TIPO INTERVENTO


SITO: 0726, EDIFICIO: 0726
Numero di casi
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10
20
30
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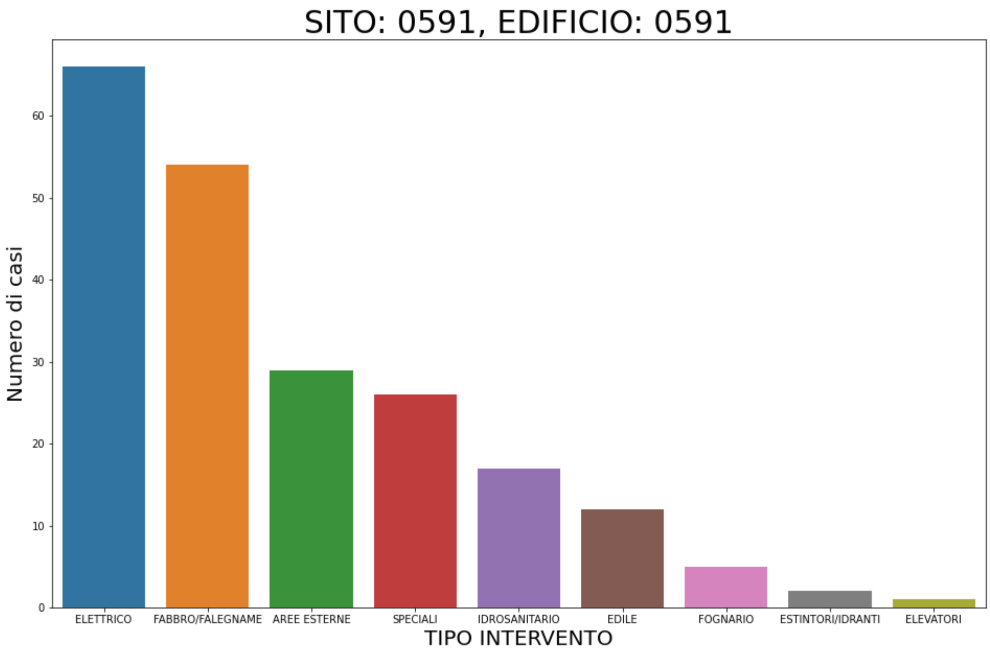
ELETTRICO
FABBRO/FALEGNAME
IDROSANITARIO
SPECIALI
EDILE
ELEVATORI
TIPO INTERVENTO


SITO: 0591, EDIFICIO: 0591
Numero di casi
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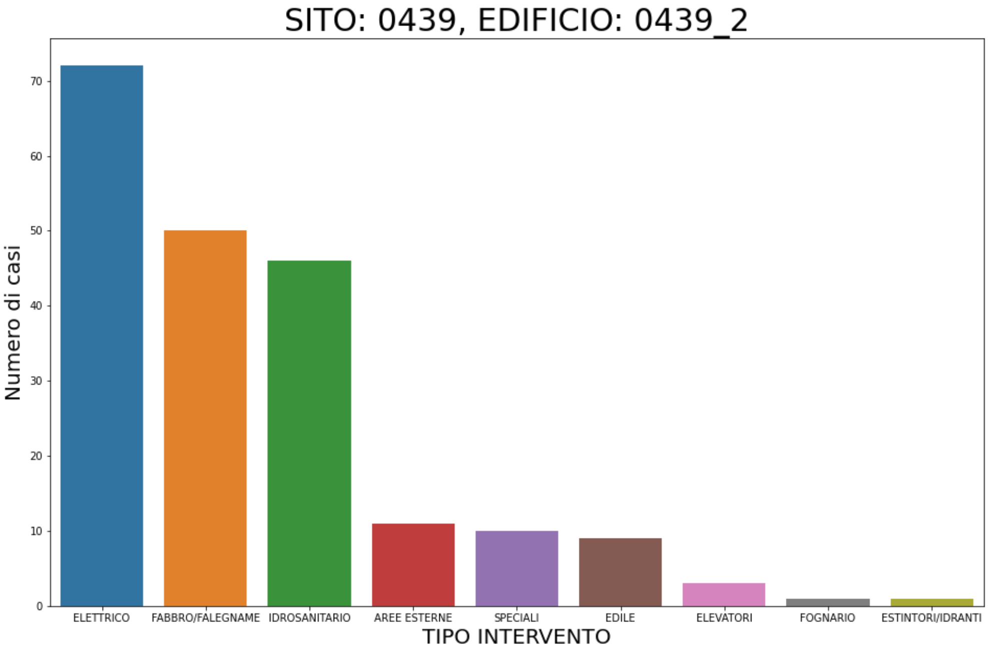
10
20
30
40
50
60
ELETTRICO
FABBRO/FALEGNAME
AREE ESTERNE
SPECIALI
IDROSANITARIO
EDILE
FOGNARIO
ESTINTORI/IDRANTI
ELEVATORI
TIPO INTERVENTO


SITO: 0439, EDIFICIO: 0439_2
Numero di casi
0
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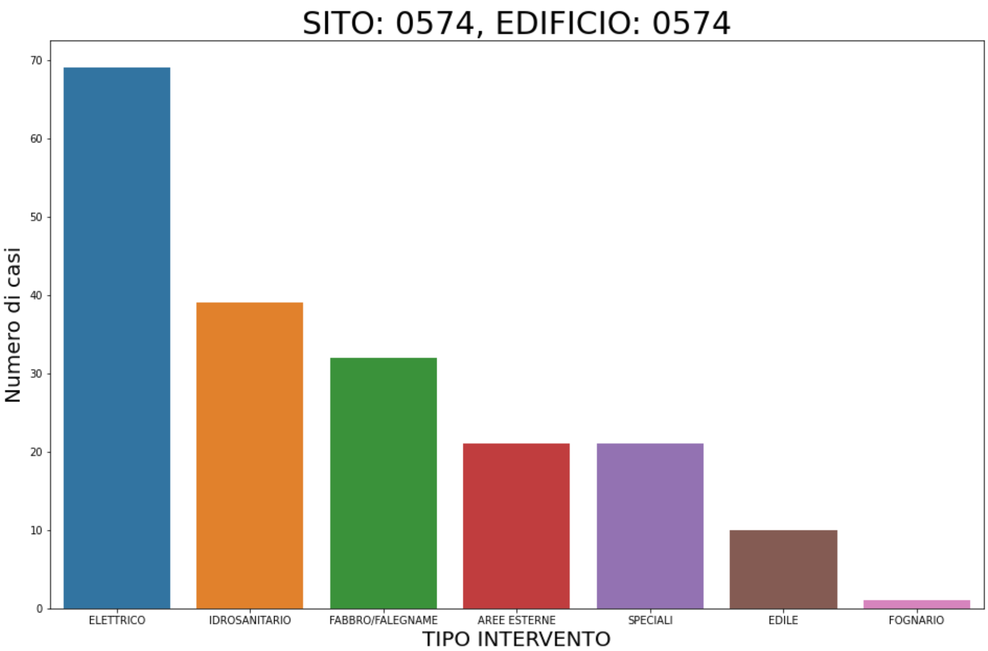
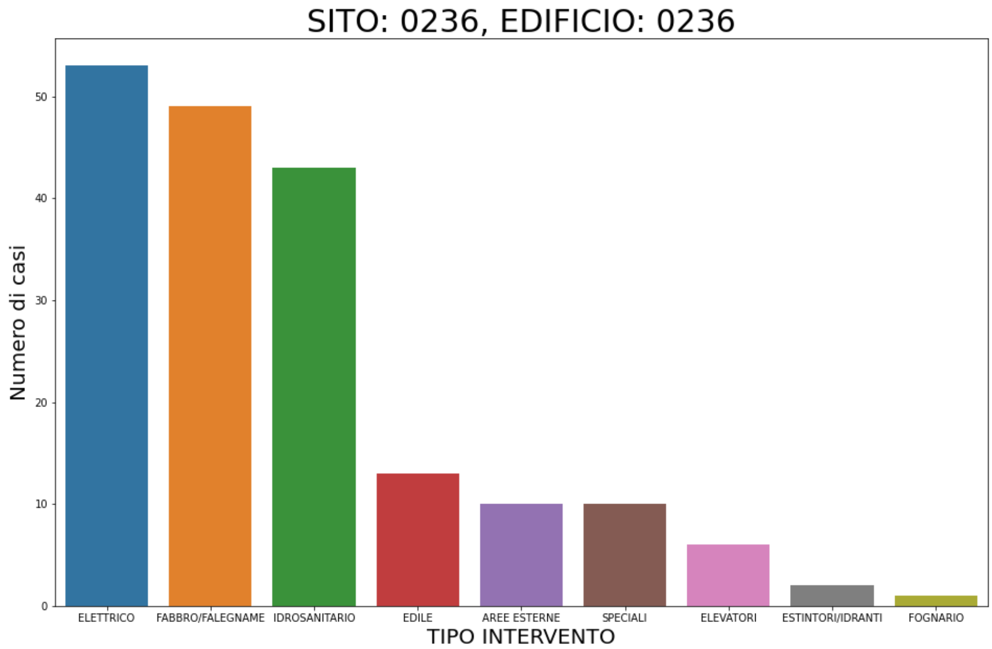
20
30
40
50
60
70
ELETTRICO
FABBRO/FALEGNAME
IDROSANITARIO
AREE ESTERNE
SPECIALI
EDILE
ELEVATORI
FOGNARIO
ESTINTORI/IDRANTI
TIPO INTERVENTO


SITO: 0574, EDIFICIO: 0574
Numero di casi
0
10
20
30
40
50
60
70
ELETTRICO
IDROSANITARIO
FABBRO/FALEGNAME
AREE ESTERNE
SPECIALI
EDILE
FOGNARIO
TIPO INTERVENTO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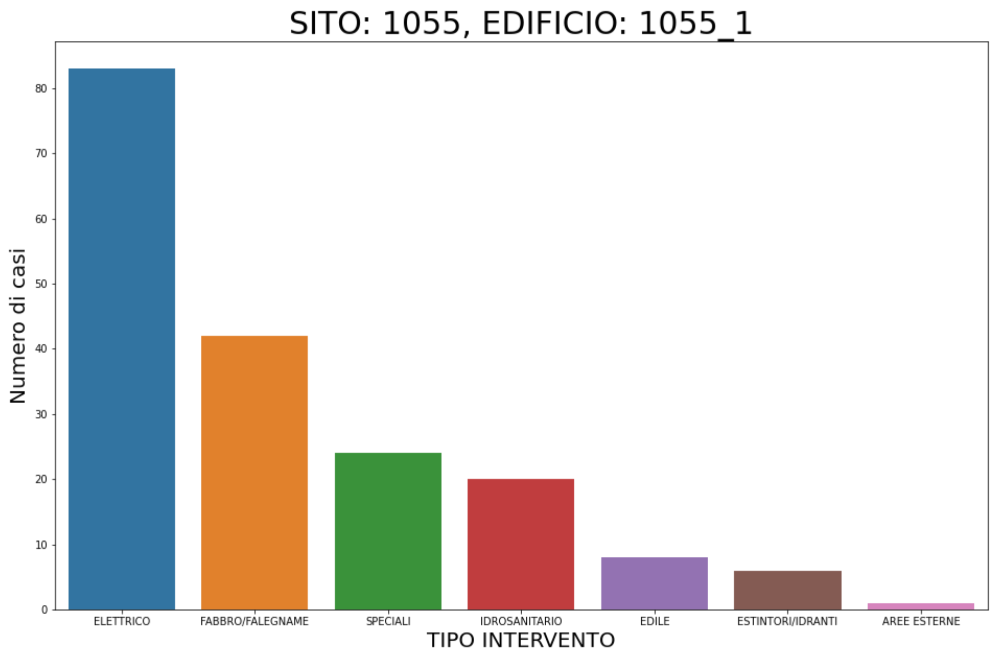
FABBRO/FALEGNAME
IDROSANITARIO
EDILE
AREE ESTERNE
SPECIALI
ELEVATORI
ESTINTORI/IDRANTI
FOGNARIO
TIPO INTERVENTO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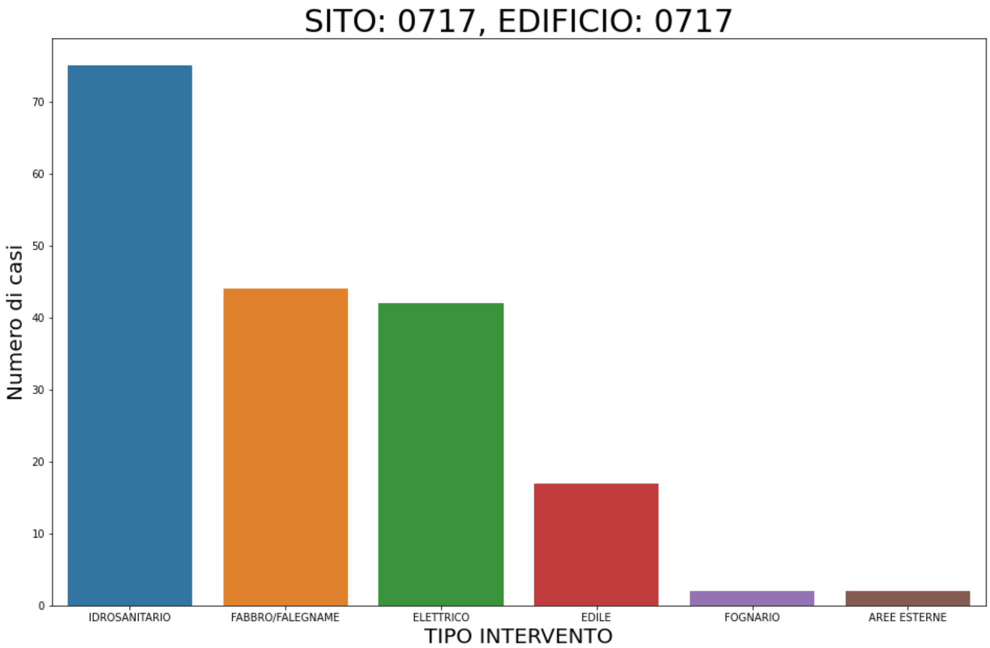
FABBRO/FALEGNAME
SPECIALI
IDROSANITARIO
EDILE
ESTINTORI/IDRANTI
AREE ESTERNE
TIPO INTERVENTO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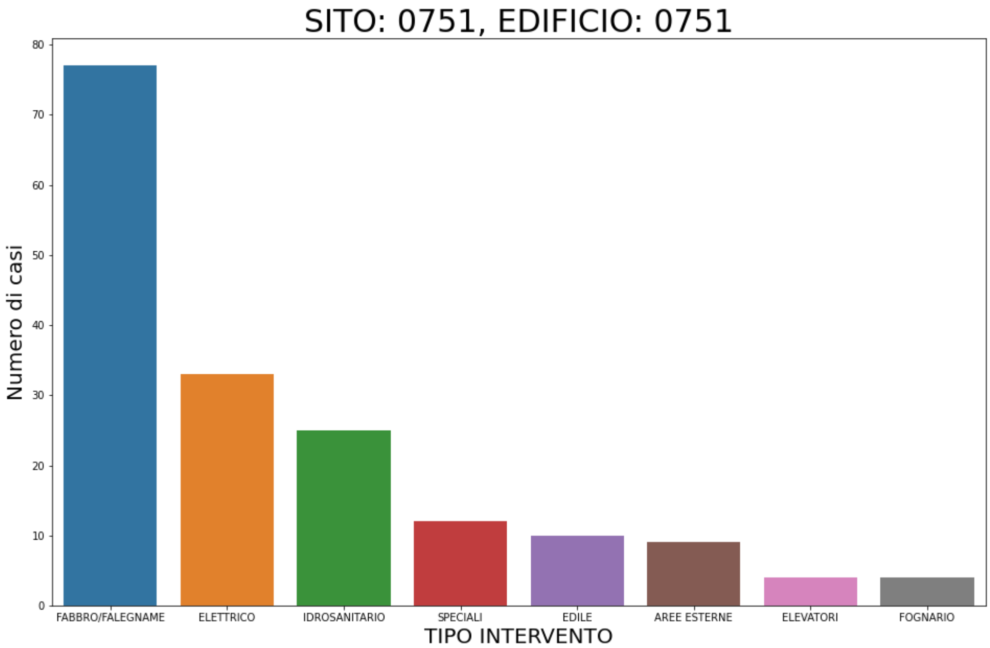
FABBRO/FALEGNAME
ELETTRICO
EDILE
FOGNARIO
AREE ESTERNE
TIPO INTERVENTO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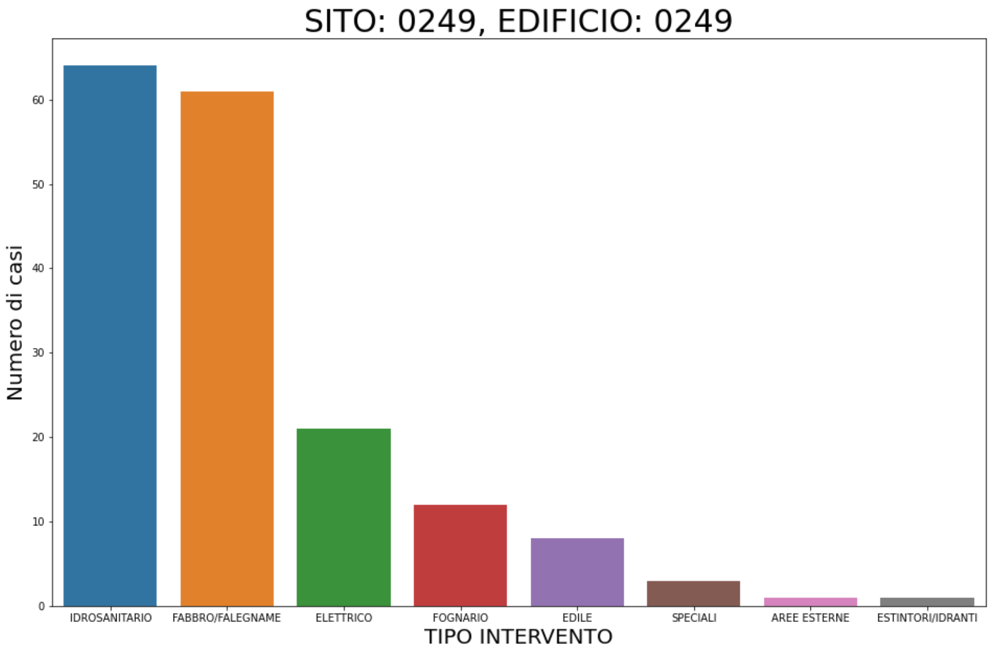
ELETTRICO
IDROSANITARIO
SPECIALI
EDILE
AREE ESTERNE
ELEVATORI
FOGNARIO
TIPO INTERVENTO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Numero di casi
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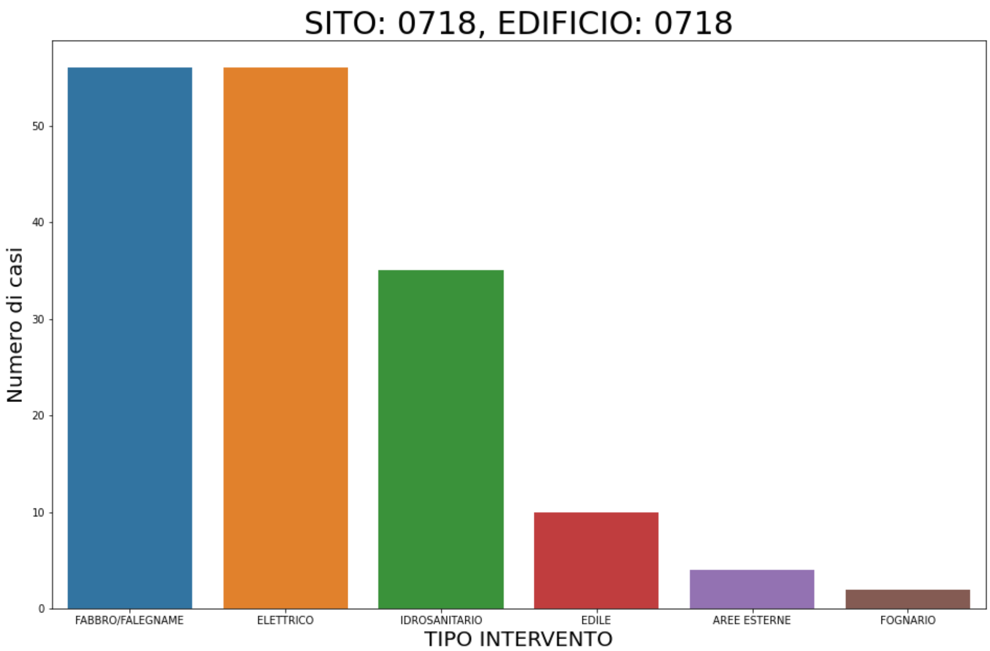
FABBRO/FALEGNAME
ELETTRICO
FOGNARIO
EDILE
SPECIALI
AREE ESTERNE
ESTINTORI/IDRANTI
TIPO INTERVENTO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Numero di casi
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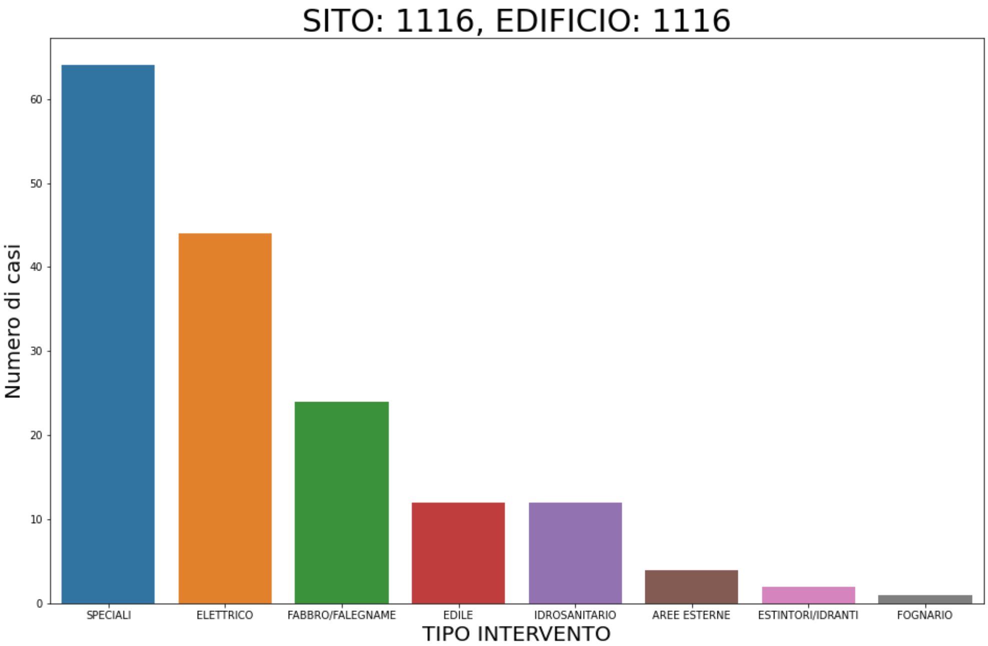
ELETTRICO
IDROSANITARIO
EDILE
AREE ESTERNE
FOGNARIO
TIPO INTERVENTO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Numero di casi
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SPECIALI
ELETTRICO
FABBRO/FALEGNAME
EDILE
IDROSANITARIO
AREE ESTERNE
ESTINTORI/IDRANTI
FOGNARIO
TIPO INTERVENTO

## Conclusioni

Il carico di segnalazioni di intervento negli edifici e impianti gestiti dal Comune di Trieste necessita di un'analisi complessiva che possa integrare i dati delle segnalazioni per fornire confronti utili a future indagini e azioni di intervento migliorativo.

Il report ha riassunto i principali risultati che emergono dall'analisi dei dati contenuti nel database del sistema gestionale Floora del Comune di Trieste partendo da maggio 2013 fino a settembre 2020.

Il grafico di analisi degli edifici e impianti ha mostrato un andamento ad iperbole, in cui per la maggior parte degli elementi (85,6%) sono state inviate segnalazioni di intervento inferiori alle 150 volte nel periodo di riferimento considerato. I casi significativi, cioè gli elementi con almeno 150 segnalazioni di intervento, rappresentato il 14,4% del totale degli elementi che per contro hanno richiesto il 74,7% del totale degli interventi.

Si evidenzia che gli edifici 0260 e 0165 hanno ricevuto rispettivamente il doppio e il triplo delle richieste di intervento rispetto al terzo edificio per numero di richieste di intervento nell'arco di tempo considerato.

Si evidenzia che le richieste di manutenzione non sono direttamente proporzionali alla cubatura dell'edifici. Infatti, si è rilevato nell'analisi delle richieste di manutenzione dei casi significativi rispetto alla cubatura che gli edifici 1105, 0249, 0729_1, 0717, 0718, 1055_1 e 0545_1 hanno un valore pari o superiore all'edificio 0165, cioè quello con più richieste di manutenzione.

Si evidenzia nell'analisi delle priorità di intervento che rispetto al totale di segnalazioni dei casi significativi le richieste con priorità routine sono il 60%, con priorità urgente sono il 29% e con priorità massima urgenza sono l'11%.

Le tre tipologie di intervento preponderanti, cioè Elettrico, Fabbro/Falegname e Idrosanitario, costituiscono il 78,2% del totale delle segnalazioni per i casi significativi.

## Appendix B

This part of the dissertation includes the public tender documents prepared for the local administration of the Municipality of Trieste following the process described in the Sub-section 4.3. In particular, EIR for two buildings in different phases of construction were produced, including the project “Magazzino 26 - Museo del Mare” and the project “Palazzo Biserini”.

Referring to the first project, a EIR for the for the execution of works was developed. With reference to the second project, a EIR for the definitive and executive planning was produced.

These documents were produced in Italian for the practical utility of the local administration.

# CAPITOLATO INFORMATIVO

# SPECIFICHE TECNICHE DI GESTIONE INFORMATIVA

PROCEDURA APERTA AI SENSI DELL'ART. 60 DEL D.LGS. 50/2016 E S.M.I. PER LA PROGETTAZIONE DEFINITIVA ED ESECUTIVA DEGLI INTERVENTI DI RIQUALIFICAZIONE DI:

CODICE OPERA 21097. PALAZZO BISERINI DI PIAZZA HORTIS n. 4 - COMUNE DI TRIESTE (TS)

# Sommario

# PREMESSA

I contenuti del presente Capitolato Informativo (CI) si riferiscono al progetto di riqualificazione del Palazzo Biserini di Piazza Hortis n.4 a Trieste (TS).

Il presente documento contiene i requisiti minimi per la produzione, gestione e trasmissione di dati, informazioni e contenuti informativi per lo svolgimento delle opere attraverso l'uso di metodi e strumenti elettronici specifici quali la modellazione per l'edilizia e le infrastrutture (art. 23, c.13, D.Lgs. 50/2016).

Il presente documento è da intendersi esteso all'intera catena di fornitura dell'appaltatore principale (subappaltatori, fornitori ,ecc) nell'adempimento delle attività di produzione, gestione e trasmissione dei contenuti informativi.

# 1 SCOPO DEL DOCUMENTO

Il CI costituisce l'atto propedeutico ed indispensabile alla redazione dell'offerta di Gestione Informativa (oGI - precontract BIM Execution Plan), che a sua volta illustra la metodologia che il concorrente intende utilizzare per soddisfare ogni specifica sezione del presente CI.

Lo scopo del presente documento è quello di fornire al BIM Manager offerente, un template di partenza che include i contenuti minimi per la redazione dell'Offerta di Gestione Informativa. Il concorrente, rispondendo ad ogni specifica sezione del CI, descrive come intende garantire la rispondenza a quanto richiesto dalla Stazione Appaltante. In tale offerta, il concorrente può ampliare e approfondire quanto proposto, fatto salvo il soddisfacimento dei requisiti minimi richiesti nel CI. In caso di aggiudicazione, l'Affidatario consoliderà e renderà esecutivo quanto offerto nel oGI in fase di gara nel Piano di Gestione Informativa (pGI - BIM Execution Plan) concordato con la Stazione Appaltante che diverrà parte integrante del contratto.

## 1.1 Priorità strategiche generali

La richiesta, da parte della Stazione Appaltante, dell'uso di metodi e strumenti elettronici specifici, quali quelli di modellazione per l'edilizia e le infrastrutture, è finalizzato al raggiungimento delle priorità strategiche ritenute rilevanti per il perseguimento dei seguenti obiettivi generali:

- elevata qualità complessiva delle opere progettate e realizzate;
- maggior efficienza dei processi decisionali supportati da informazioni strutturate, precise, tempestive, nonché aggiornate ed attendibili lungo tutto il ciclo di vita dell'opera;
- mitigazione del rischio di varianti in corso d'opera grazie ad un maggior coordinamento della progettazione multidisciplinare.

## 1.2 Obiettivi di progetto

In relazione alle priorità strategiche sopra descritte, per questo specifico progetto, la Stazione Appaltante ha individuato i seguenti obiettivi:

- disporre sempre di informazioni precise, aggiornate e facilmente reperibili;

• favorire un ambiente di lavoro collaborativo che faciliti il coordinamento della progettazione multidisciplinare (infrastrutture, architettura, strutture, impianti);

• produzione degli elaborati di progettazione e di un unico Modello di Dati federato contente tutte le informazioni inerenti alla progettazione Definitiva/Esecutiva che risulti essere attendibile e utile per le successive fasi di direzione e esecuzione lavori.

## 1.3 Livello di prevalenza contrattuale

La produzione, il trasferimento e la condivisione dei contenuti del progetto avverranno attraverso supporti informativi digitali in un ambiente di condivisione dei Dati - ACDat, pur permanendo la prevalenza contrattuale della documentazione consegnata con formattazione PDF oppure PDF/A corredati da "firma digitale" (come previsto dal disciplinare di gara) di tutti gli elaborati oggetto dell'incarico.

## 1.4 Acronimi e glossario

Di seguito si riportano i principali termini utilizzati nel prosieguo della trattazione ed in generale per ciò che concerne l'applicazione dei sistemi informativi alla realizzazione delle opere edilizie.

| | TERMINI | DEFINIZIONI |
|---|---|---|
| **4 D** | Quarta dimensione | Simulazione dell'opera e dei suoi elementi in funzione del tempo |
| **5 D** | Quinta dimensione | Simulazione dell'opera e dei suoi elementi in funzione del costo |
| **6 D** | Sesta dimensione | Simulazione dell'opera e dei suoi elementi in funzione dell'uso, gestione, manutenzione e dismissione |
| **7 D** | Settima dimensione | Simulazione dell'opera e dei suoi elementi in funzione della sostenibilità (economica, ambientale, energetica) |
| **AIM** | Asset Information Model | Modello federato dell'opera costruita contenente tutti i dati necessari per gestire, mantenere e far funzionare il bene realizzato |
| **AIR** | Asset Information Requirements | Requisiti informativi in relazione all'utilizzo del cespite immobile (asset) |
| **ACDat** | Ambiente di condivisione dei dati (Piattaforma collaborativa digitale) | Ambiente di raccolta, conservazione e condivisione dei dati relativi ai modelli digitali di un'opera gestiti attraverso specifici flussi di lavoro |
| **ACDoc** | Archivio di condivisione dei documenti | Archivio di raccolta, conservazione e condivisione di copie di modelli ovvero di |

| | TERMINI | DEFINIZIONI |
|---|---|---|
| | | documenti non digitali |
| **ACDat Manager** | Coordinatore dei flussi informative - CDE Manager | Figura deputata alla gestione della piattaforma di condivisione ACdat (CDE) |
| **BIM** | Building Information Model | Rappresentazione digitale di caratteristiche fisiche e funzionali di un oggetto |
| **DBC –**<br>**BIM Coordinator Disciplinare** | Coordinatore dei flussi informativi disciplinari di commessa | Figura deputata al coordinamento delle attività di sviluppo dei modelli digitali in interfaccia tra BIM Manager e BIM Specialist |
| **PBC – BIM Coordinator di Progetto** | Coordinatore dei flussi informativi di commessa | Figura deputata al coordinamento delle attività di sviluppo dei modelli digitali in interfaccia tra BIM Manager e i coordinatori disciplinari |
| **BM –**<br>**BIM Manager** | Gestore dei processi digitali | Figura deputata alla pianificazione, gestione e verifica dei flussi di lavori interni al metodo BIM |
| **BSD –**<br>**BIM Specialist** | Operatore avanzato della gestione e della modellazione informativa | Figura deputata alla corretta programmazione e creazione degli oggetti e dei modelli digitali disciplinari |
| **CI (EIR)** | Capitolato Informativo | Esplicitazione delle esigenze e dei requisiti informativi richiesti dal Committente agli Affidatari |
| **GIS** | Geographic Information System | Sistemi informativi geografici |
| **IFC** | Industry Foundation Classes | Schema sviluppato e rilasciato dall'organizzazione no-profit Building SMART per la condivisione dati tra applicativi proprietari |
| **LC1** | Coordinamento di primo livello | Attività di analisi e controllo delle informazioni all'interno di un singolo modello disciplinare prima del rilascio all'esterno |
| **LC2** | Coordinamento di secondo livello | Attività riferita al coordinamento dei dati di modello tra due o più discipline (clash detection & code detection) |
| **LC3** | Coordinamento di terzo | Attività legate alla soluzione di interferenze ed incoerenze tra dati / informazioni / |

| | TERMINI | DEFINIZIONI |
|---|---|---|
| | livello | contenuti informativi non generati da modelli virtuali compiuti (BIM Authoring) |
| **LOD** | Livello di sviluppo oggetti digitali | Livello di approfondimento dei dati e delle informazioni degli oggetti digitali contenuti nei modelli |
| **LOG** | Livello di sviluppo geometrico | Livello di sviluppo degli Oggetti - attributi Geometrici |
| **LOI** | Livello di sviluppo informativo | Livello di sviluppo degli Oggetti - attributi Informativi |
| **LOIN** | Livello di fabbisogno informativo | Struttura di riferimento che definisce l'estensione e la rilevanza dell'informazione |
| **MVD** | Model View Definition | Strumento attraverso cui definire quali caratteristiche del modello IFC devono essere condivise |
| **oGI (BEP pre-contract)** | offerta di Gestione Informativa | Esplicitazione e specifica della gestione informativa offerta dall'Affidatario in risposta al CI |
| **OIR** | Requisiti informativi dell'Organizzazione | Obiettivi dell'Organizzazione (azienda o ente pubblico) |
| **pGI (BEP post-contract)** | piano di Gestione Informativa | Pianificazione operativa della gestione informativa attuata dall'Affidatario dopo l'affidamento del contratto |
| **LV1** | Livello di verifica 1 | Attività di verifica interna formale corretta modalità di produzione, consegna e gestione delle informazioni in relazione a quanto indicato nel Capitolato Informatico e nel pGI |
| **LV2** | Livello di verifica 2 | Attività di verifica interna di tipo sostanziale, volta ad accertare la leggibilità, tracciabilità e coerenza delle informazioni contenute nei vari modelli (es.: report di clash detection, verifica dei LOD etc.) |
| **LV3** | Livello di verifica 3 | Attività di validazione di modelli ed elaborati da parte del Committente, eventualmente supportato da un soggetto terzo |
| **WBS** | Work Breakdown Structure | Scomposizione funzionale/spaziale dell'opera |

| GLOSSARIO | SIGNIFICATO DEI TERMINI |
|---|---|
| **Analisi incoerenze** | Model e Code Checking. Analisi delle possibili incoerenze informative di elementi, modelli ed elaborati in rapporto a normative, regole e procedure |
| **Analisi interferenze geometriche** | Clash Detection. Analisi delle possibili interferenze geometriche presenti tra elementi, modelli ed elaborati |
| **As Built** | Elaborati che descrivono l'opera come è stata effettivamente costruita |
| **Clash Detection** | Analisi delle possibili incoerenze geometriche tra oggetti e/o modelli digitali |
| **Contenuto informativo** | Insieme di informazioni organizzate secondo un determinato scopo ai fini della comunicazione sistematica di una pluralità di conoscenze all'interno di un processo |
| **Dato** | Elemento conoscitivo tangibile, elementare, interpretabile all'interno di un processo di comunicazione attraverso regole e sintassi preventivamente condivise. |
| **Elaborato Informativo** | (Elaborato) Veicolo informativo di rappresentazione di prodotti e processi del settore costruzioni. |
| **Elaborato tradizionale** | Veicolo informativo in formato cartaceo o digitale, contenente rappresentazioni grafiche 2D. |
| **Formato aperto** | Formato file basato su specifiche sintassi di dominio pubblico il cui utilizzo è aperto e accessibile senza necessità di disporre di particolari applicazioni software tecnologiche specifiche. |
| **Formato proprietario** | Formato di file basato su specifiche sintassi di dominio non pubblico il cui utilizzo è limitato a specifiche condizioni d'uso stabilite dal proprietario del formato |
| **Informazione** | Insieme di dati organizzati secondo un determinato scopo ai fini della comunicazione di una conoscenza all'interno di un processo. |
| **Interferenze** | Collisione geometrica tra oggetti presenti nei modelli sia della stessa disciplina sia in modelli di discipline differenti. |
| **Libreria di oggetti** | Ambiente digitale per la raccolta organizzata e la condivisione di oggetti per modelli grafici. |
| **Milestone** | Principali tappe riferite alle Fasi del BIM |
| **Model Checking** | Analisi delle possibili incoerenze tra modelli in relazione a regole e/o regolamenti e geometriche |
| **Model User** | Utilizzatore delle informazioni digitali. Figura autorizzata ad accedere alle informazioni digitali di progetto |

| GLOSSARIO | SIGNIFICATO DEI TERMINI |
| --- | --- |
| **Modello federato** | Virtualizzazione dell'opera o suoi elementi in funzione di una aggregazione (stabile o temporanea) di più modelli singoli |
| **Modello di dati** | Opera Digitale costituita da Dati Grafici e Dati non Grafici, quindi da Informazioni Grafiche e non Grafiche. |
| **Modello di progetto** | Virtualizzazione per oggetti di un'opera od un complesso di opere "in divenire" o di una modificazione di un'opera od un complesso di opere già "in essere" |
| **Modello di rilievo** | Virtualizzazione per oggetti, in un dato tempo, dello stato di fatto di un'opera od un complesso di opere "in essere" (rilievo, as-built, ecc.) |
| **Modello informativo** | Veicolo informativo di virtualizzazione di prodotti e processi del settore delle costruzioni |
| **Modello singolo** | Virtualizzazione dell'opera o suoi elementi in funzione di una disciplina o di uno specifico uso del modello |
| **Parametrico** | Organizzazione di un insieme di dati per relazioni logiche o concettuali in funzione di uno o più parametri |
| **Piattaforma di Collaborazione** | Piattaforma Software dotata di strumenti che agevolano il lavoro collaborativo tra utenti che concorrono alla progettazione/esecuzione/conduzione del medesimo Progetto. Costituisce l'ambiente protetto per l'archiviazione, gestione e distribuzione dell'intero Modello di Dati. |
| **Repository** | Insieme di directory necessarie ad accogliere la documentazione di Progetto e i Modello di Dati organizzate tenendo conto delle discipline e dei mandati. |
| **Scheda informativa** | Raccolta e archiviazione strutturata di informazioni sociali, ambientali, tecniche, economiche e giuridiche, redatte in un ordine prestabilito, secondo certe modalità e per determinati scopi. Raccolta per livelli di attributi informativi non geometrici |
| **Struttura di progetto** | Si definisce "Struttura di Progetto" la scomposizione del Modello di Dati in più parti, realizzata tenendo conto del tipo di Opera, dei limiti tecnologici e degli aspetti contrattuali. |
| **Template** | Modello predefinito che adeguatamente formattato consente di ottenere una Base Dati univoca al variare del Modello di Dati o dei Prodotti Digitali. |
| **Uniclass** | "Unified Classification for the Construction Industry", è un sistema di classificazione sviluppato dall'NBS (UK) |
| **Uniformat** | Sistema di classificazione degli oggetti alternativo all'UniClass di origine Statunitense |

# 2 RIFERIMENTI NORMATIVI

Si elencano di seguito tutti i richiami normativi specifici connessi presi come riferimento per il presente Capitolato Informativo:

- UNI 11337-1:2017 "Edilizia e opere di ingegneria civile - Gestione digitale dei processi informativi delle costruzioni - Parte 1: Modelli, elaborati e oggetti informativi per prodotti e processi
  Parte 4: Evoluzione e sviluppo informativo di modelli, elaborati e oggetti
  Parte 5: Flussi informativi nei processi digitalizzati
  Parte 6: Linea guida per la redazione del capitolato informativo
  Parte 7: Requisiti di conoscenza, abilità e competenza delle figure coinvolte nella gestione e nella modellazione informativa
- UNI EN ISO 16739:2016 Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries – ISO 16739:2005 (IFC2X3) - ISO 16739:2013 (IFC4)
- Decreto MIT n. 560 del 1.12.2017 Modalità e i tempi di progressiva introduzione, da parte delle stazioni appaltanti, delle amministrazioni concedenti e degli operatori economici, dell'obbligatorietà dei metodi e strumenti elettronici specifici, quali quelli di modellazione per l'edilizia e le infrastrutture, nelle fasi di progettazione, costruzione e gestione delle opere e relative verifiche.
- ISO 19650-1:2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling -- Part 1: Concepts and principles
- ISO 19650-2:2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling -- Part 2:Delivery phase of the assets
- UNI EN 17412-1:2021 Livello di Fabbisogno Informativo – Parte 1: Concetti e principi

# 3 SEZIONE TECNICA

Questa sezione stabilisce i requisiti tecnici delle informazioni in termini di hardware, software, infrastrutture tecnologiche, protocollo di scambio dei dati, sistemi di coordinate, specifiche per l'inserimento degli oggetti, sistemi di classificazione degli oggetti e competenze richieste per lo svolgimento delle prestazioni di cui all'oggetto.

Il concorrente specificherà nella oGI ogni elemento utile a descrivere come intende soddisfare i requisiti minimi descritti in questa sezione oltre a dettagliare eventuali specifiche migliorie.

## 3.1 Caratteristiche tecniche e prestazionali dell'infrastruttura hardware e software

### *3.1.1 Infrastruttura hardware*

Il concorrente dichiara che le unità e le caratteristiche tecniche della dotazione hardware attualmente in suo possesso e che intende mettere a disposizione per lo svolgimento della prestazione richiesta sia adeguata all'elaborazione di modelli e allo scambio di informazioni e che garantisca un corretto livello di sicurezza.

Di seguito sono riportate le caratteristiche principali da tenere in considerazione dagli offerenti.

| N° UNITA` | TIPOLOGIA | CARATTERISTICA TECNICA | VALORE PRESTAZIONALE |
|---|---|---|---|
| | Workstation fissa | Processore | |
| | | RAM | |
| | | Sistema Operativo | |
| | | Monitor-Scheda grafica | |
| | Workstation mobile (cantiere) | Processore | |
| | | RAM | |
| | | Sistema Operativo | |
| | | Monitor-Scheda grafica | |
| | Unità di backup | Memoria di archiviazione | |
| | Trasmissione dati | Rete | |
| | | Server | |

Nella propria oGI l'affidatario dovrà specificare quali saranno le caratteristiche tecniche dell'infrastruttura messa a disposizione.

### *3.1.2 Infrastruttura software*

Il concorrente dichiara che la tipologia software attualmente in suo possesso e che intende mettere a disposizione per lo svolgimento della prestazione è basata su piattaforme interoperabili a mezzo di formati aperti non proprietari, in grado di leggere, scrivere e gestire, oltre al formato proprietario, anche i file in formato aperto *.ifc.

Il concorrente dichiara di fornire un ambiente di condivisione dei dati (ACDat) con le caratteristiche riportate nel capitolo 4.7, garantendone la piena fruibilità del Committente (Read/Write/Download), con adeguato numero di accessi fino al termine dell'incarico.

Nella propria oGI l'affidatario dovrà specificare quali saranno le caratteristiche tecniche dell'infrastruttura messa a disposizione.

Di seguito è riportato una tabella di esempio per gli ambiti di specializzazione dei software.

| AMBITO | DISCIPLINA/ATTIVITA` | SISTEMA SOFTWARE | VERSIONE |
|---|---|---|---|
| Es: BIM Authoring | Modellazione | Revit | 2022 |
| Gestione documentazione (ACDat) | … | | |
| Clash Detection | … | | |
| … | | | |

L'aggiudicatario è tenuto a usare software dotati di regolare contratti di licenza d'uso.

## 3.2 Fornitura e scambio dei dati

### *3.2.1 Formati da utilizzare*

Nella propria oGI l'affidatario dovrà specificare l'estensione dei file in formato proprietario e aperto che intende utilizzare, in assonanza con l'infrastruttura software dichiarata.

Di seguito è riportato una tabella di esempio.

| VEICOLI INFORMATIVI / OBIETTIVI | FORMATO PROPRIETARIO | FORMATO APERTO |
|---|---|---|
| Es: Modelli informativi (BIM Authoring) | .rvt (2020.2) | .ifc 2x3 Coordination View 2.0 |
| Elaborati digitali grafici | … | ….. |
| Elaborati digitali documentali | … | |
| Computo | | |
| Elaborati digitali multimediali | | |
| Verifica ed analisi interferenze geometrice | | |
| Schede Informative | | |
| ….. | …… | ….. |

## 3.3 Sistema di coordinate e specifiche di riferimento

### *3.3.1 Coordinate condivise*

Al fine di ottenere dei modelli con un sistema di coordinate coerente, gli stessi devono essere programmati con i medesimi settaggi e condividere lo stesso Punto di Origine. La localizzazione dell'opera e/o del sito sul modello deve essere fissata alla corretta longitudine e latitudine o altro punto di riferimento definito. Il Nord effettivo della localizzazione dell'opera e/o del sito sul modello deve inoltre essere impostato correttamente. Tutti i modelli prodotti devono utilizzare un sistema "coordinate condivise" o sistemi analoghi.

L'Affidatario nell'oGI e successivamente nel pGI dovrà esplicitare come intende soddisfare i requisiti minimi descritti in questa sezione e dettagliare eventuali specifiche migliorie.

Si richiede di eseguire un rilievo GPS per poi poter georeferenziare il modello e coordinarlo con il punto di origine.

Di seguito è riportato una tabella di esempio delle principali coordinate e specifiche di riferimento.

| SPECIFICA | DESCRIZIONE |
|---|---|
| Origine = Coincidente con Project Base Point | |
| Rotazione del Nord di Progetto | |
| Unità di Misura (Sistema metrico) | |
| Sistema di riferimento (datum) | |

#### *3.3.2 Template di modello*

Per garantire la coerenza tra i vari modelli disciplinari, tutti i modelli dovranno essere sviluppati da un medesimo template di progetto, in cui saranno precaricati tutti i parametri comuni alle varie discipline tra i quali in particolare:

- parametri per la compilazione del cartiglio e organizzazione del browser di progetto
- parametri di classificazione
- parametri di WBS
- parametri finalizzati all'esportazione IFC
- parametri per gli attributi previsti dal LOIN
- famiglie di annotazioni grafiche

Ogni nuovo modello disciplinare dovrà condividere:

- sistema di coordinate (internal origin, base point e survey point)
- griglie e piani di riferimento primari
- livelli comuni

##### *3.3.2.1 Fasi*

È previsto l'utilizzo delle due fasi di default Existing e New Construction. Tutti gli elementi dei modelli facenti parte lo stato di fatto preesistente sono attribuiti alla fase Existing mentre gli elementi relativi allo stato di progetto sono attribuiti alla fase New Construction. Tramite override grafici delle fasi deve essere possibile distinguere gli elementi esistenti e gli elementi di nuova costruzione.

### 3.4 Specifica per l'inserimento di oggetti

Il Concorrente dovrà rispettare per i principali elementi tecnici le seguenti modalità di inserimento e/o i vincoli rispetto ai principali sistemi di riferimento spaziali definiti nel modello stesso. L'Affidatario nell'oGI e successivamente nel pGI dettaglierà eventuali specifiche migliorie.

| Oggetto | Specifica |
| --- | --- |
| **Tutte le discipline** | Tutti gli elementi saranno associati al livello di riferimento in cui giacciono al netto di eccezioni relative a necessità funzionali di modellazione. |
| **Architettura** | Tutti gli elementi architettonici devono essere associati al livello di riferimento su cui giacciono. |
| **Strutture** | Tutte le strutture portanti verticali (setti) saranno associate al livello di riferimento in cui giacciono e limitate superiormente dall'intradosso della trave o del solaio sovrastante, inferiormente dall'estradosso della trave o del solaio sottostante.<br><br>Tutte le travi a vista, volte e altri elementi portanti che delimitano lo spazio architettonico saranno associate al livello di riferimento inferiore rispetto a quello in cui giacciono e limitate superiormente dall'intradosso del solaio sovrastante.<br><br>Travi in cemento, quali travi ricalate o nervature di solette sono assimilabili al solaio strutturale, limitate superiormente dall'estradosso del solaio strutturale e quindi associate al piano che sorreggono.<br><br>Orditure secondarie o elementi strutturali discreti (es: arcarecci di copertura) senza valore architettonico sono assimilabili al pacchetto di solaio strutturale. |
| **Impianti** | Tutte le attrezzature e relative distribuzioni impiantistiche saranno modellate in relazione al piano di calpestio del piano di riferimento con offset relativo al netto di eccezioni relative a necessità funzionali di modellazione. |
| **Muri / Partizioni verticali** | Le altezze devono essere definite mediante livelli, tranne nel caso di muri ad altezza non collegata, ad esempio parapetti. I muri devono essere suddivisi per piano, salvo il caso in cui l'estensione multipiano costituisca reale intento progettuale.<br><br>Tutte le partizioni verticali esterne saranno associate al livello di riferimento in cui giacciono e limitate superiormente dall'estradosso del solaio sovrastante ed inferiormente dall'estradosso del solaio sottostante.<br><br>Tutte le partizioni verticali interne saranno associate al livello di riferimento in cui giacciono e limitate superiormente dall'intradosso del solaio sovrastante ed inferiormente dall'estradosso del solaio sottostante o dal massetto/sottofondo a seconda della tecnologia edilizia.<br><br>Tutti i muri avranno associata la funzione corretta (interior, exterior, etc) e qualora siano elementi architettonici portanti (es: muratura) saranno catalogati come tali tramite parametro "Structural" e conseguente |

| Oggetto | Specifica |
|---|---|
| | parametro IFC “LoadBearing” (entrambi booleani). |
| **Pavimenti / Partizioni Orizzontali** | I livelli principali saranno riferiti allo strato di Finitura del piano di calpestio. In caso di scomposizione tra finitura e massetto, questi ultimi avranno offset negativo associato.<br><br>Tutti gli strati di finitura dei solai posti all’intradosso saranno associati al livello/ambiente a loro sovrastante. |
| **Controsoffitti** | I controsoffitti saranno associati al livello/ambiente a loro sottostante. |
| **Coperture inclinate** | Le chiusure orizzontali inclinate saranno associate al livello di gronda principale del manufatto, minimizzando il numero di livelli. |
| **Locali/Vani**<br><br>**(rooms/spaces)** | Definire posizione e altezza in riferimento ai livelli. Accertarsi che gli elementi delimitino correttamente il locale, in modo da avere la corretta definizione dei volumi. I locali devono avere la corretta fase associata.<br><br>Nei modelli impiantistici è suggerito creare i vani e recepire la codifica dei locali architettonici. Qualora suddivisi in sottodiscipline è sufficiente che solo un modello contenga i vani (es. Ventilazione e Illuminazione oppure il modello di coordinamento disciplinare). |
| **Elementi impiantistici a pavimento** | Gli elementi impiantistici a pavimento dovranno essere riferiti allo stesso livello del pavimento su cui l’oggetto è posto. È consentito un offset da tale livello nel caso di oggetti inseriti al di sotto o al di sopra del pavimento stesso. |
| **Elementi Impiantistici a controsoffitto** | Gli elementi impiantistici inseriti nel controsoffitto dovranno essere riferiti allo stesso livello del pavimento sottostante il controsoffitto in oggetto. |
| **Modelli collegati** | I modelli collegati dovranno avere sistemi di coordinate coerenti tra di loro, garantendo l’identificazione corretta della loro posizione relativa. |
| **Sito** | La superficie del terreno dovrà essere modellata per intero a partire dagli oggetti del rilievo topografico e non dovrà subire rototraslazioni. Gli edifici esistenti che vogliono essere rappresentati nel profilo dovranno essere modellati come solidi (masse) a partire dalle polilinee di base rilevate. |

### 3.5 Sistemi di classificazione e denominazione degli oggetti;

Gli oggetti costituenti il/i modello/i informativi grafici, organizzati in singoli elementi e/o parti, gruppi, blocchi ed assiemi dovranno riportare una univoca classificazione e codifica. Si richiede all'Operatore l'adozione di un sistema di classificazione degli elementi. Si suggerisce l'uso degli standard internazionali come Uniclass o Omniclass.
Nella propria oGI l'affidatario dovrà descrivere il sistema di classificazione degli elementi scelto.

### 3.6 Competenze ed esperienze dell'Aggiudicatario

L'Aggiudicatario è responsabile del soddisfacimento dei requisiti di formazione specifica in ambito di gestione informativa BIM all'interno della propria organizzazione. I livelli di esperienza, conoscenza e competenza del concorrente devono essere idonei a soddisfare i requisiti minimi necessari per attuare una gestione digitale dei processi informativi del progetto. Il concorrente deve inoltre possedere una figura di "BIM Manager del Team di Progettazione" che dovrà organizzare e dirigere tutti gli aspetti legati alla gestione informativa della progettazione, interfacciandosi con il BIM Manager della Stazione Appaltante.

E' richiesto che il concorrente descriva in questa sezione dell'oGI alcuni progetti significativi, in ambito BIM, realizzati e seguiti dal BIM Manager del Team di Progettazione, fornendo le seguenti informazioni minime:

| n. | Anno | Progetto | Importo opera | Ruolo svolto | Usi ed Obiettivi del modello |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| .. | | | | | |

# 4 SEZIONE GESTIONALE

### 4.1 Obiettivi e Usi del Modello in Relazione alle Fasi del Processo

Gli usi del modello minimi suddivisi per fase progettuale sono sintetizzati nella seguente tabella.

**MODEL USES**

| rif | Progettazione Esecutiva | Realizzazione | Consegna (Handover) |
|---|---|---|---|
| 0 | SITE MODELING | | |
| 1 | DESIGN REVIEWS | | |
| 2 | COORDINAMENTO 3D | | |
| 3 | | PROGETTAZIONE DEI SISTEMI COSTRUTTIVI | |
| 4 | | RECORD MODELING (AS BUILT) | |
| 5 | | | PROGRAMMAZIONE DELLA GESTIONE E MANUTENZIONE (6D) |

Di seguito si descrivono gli obbiettivi del servizio relativamente agli usi del modello sopra identificati:

| FASE | OBIETTIVI DI FASE | MODELLI | USI DEL MODELLO |
|---|---|---|---|
| *CONOSCITIVA*<br><br>RESTITUZIONE RILIEVO | Per una corretta valutazione e storicizzazione degli interventi da realizzare si ritiene importante realizzare un modello dello stato preesistente (Stato di Fatto) ottenuto dal rilievo CAD fornito. | • ARC/STR | SITE MODELING (0) |
| *TECNOLOGICA*<br><br>PROGETTAZIONE ESECUTIVA | Valutazione ed analisi delle soluzioni progettuali. Fornirsi di modello coordinato multidisciplinare e aggiornabile, definendo ogni elemento del progetto esecutivo tale che sia identificato in forma, tipologia, qualità e dimensione. Generazione degli elaborati grafici e della documentazione di progetto. | • COO<br>• ARC<br>• STR<br>• MEP | DESIGN REVIEWS (1)<br>COORDINAMENTO 3D (2) |

## 4.2 Definizione degli elaborati informativi richiesti

In relazione alla generazione degli elaborati informativi grafici, l'Affidatario dichiara che gli elaborati rispettino le origini e collegamenti come illustrato nella seguente tabella.

| ELABORATI | DISCIPLINA | ORIGINE | NOTE |
|---|---|---|---|
| **Inquadramento Territoriale, Struttura del Progetto, Planimetria Aree di Intervento** | Generali | Da modello o integrate nel modello | |
| **Piante, Sezioni, Prospetti rilievo geometrico** | Rilievo | Da modello | |
| **Piante, Sezioni, Prospetti rilievo degrado e quadro fessurativo** | Rilievo | Da modello o integrate nel modello | |
| **Planimetrie, Piante, Layout funzionali, Arredi** | Progetto Architettonico | Da modello | |
| **Sezioni e Prospetti** | Progetto Architettonico | Da modello | |
| **Planimetrie, Piante, Sezioni Prospetti** | Tavole Comparative | Da modello o integrate nel modello | |
| **Dettagli Costruttivi** | Tutte le discipline | Da modello o integrate nel modello | |
| **Piante e sezioni interventi strutturali nuova costruzione** | Progetto Strutturale | Da modello | |
| **Interventi strutturali sull'esistente (aperture e consolidamenti)** | Progetto Strutturale | Da modello | |
| **Documentazione Impianti: riscaldamento, condizionamento,** | Impianti Meccanici | Da modello o integrate nel | |

| ELABORATI | DISCIPLINA | ORIGINE | NOTE |
|---|---|---|---|
| **idrico-sanitario, distribuzione generale, idrico sanitario** | | modello | |
| **Documentazione Impianti: distribuzione e FM, impianti speciali, illuminazione** | Impianti Elettrici | Da modello o integrate nel modello | |
| **Piani della Sicurezza** | Coordinamento Sicurezza | Da modello o integrate nel modello | |
| **Piante, Sezioni Antincendio** | Prevenzioni Incendi | Da modello o integrate nel modello | Compilazione parametri REI su porte e nuovi divisori |
| **Computi Metrici Estimativi** | Generali Amministrativi | Tradizionale | |
| **Specifiche Tecniche** | Generali | Esterne | Da collegare al modello tramite codici o URL in fase di handover (consegna dei lavori) |

Inoltre, diventerà allegato integrante del pGI, l'elenco di tutti gli elaborati da produrre (estratti da modello e non) rispettivamente codificati in accordo allo standard del Committente, che verrà fornito in fase di aggiudicazione gara con il contenuto minimo costituito da quelli previsti in contratto, nel Capitolato Speciale d'Appalto e dalla normativa vigente in materia.

In ogni caso l'Affidatario è tenuto a produrre elaborati grafici cartacei (di estrazione o non dai modelli) inerenti tutta la documentazione completa del progetto e secondo specifiche richieste del Committente.

## 4.3 Livello di sviluppo degli oggetti e delle schede informative

Il livello di sviluppo degli oggetti che compongono i modelli grafici (LOD) definisce quantità e qualità del loro contenuto informativo ed è funzionale al raggiungimento degli obiettivi delle fasi a cui il modello si riferisce. Il livello di sviluppo di un oggetto va considerato come risultante della sommatoria delle informazioni di tipo geometrico e non-geometrico, (normativo, economico ecc.) che possono essere rappresentate in forma grafica 2D e 3D ed in forma alfanumerica (4D tempo, 5D costi, ecc.). La scala di riferimento dei livelli di sviluppo degli oggetti è presa dalla UNI 11337 - parte 4.

I livelli definiti dalla norma UNI 11337:

- LOD A oggetto simbolico
- LOD B oggetto generico
- LOD C oggetto definito
- LOD D oggetto dettagliato
- LOD E oggetto specifico
- LOD F oggetto eseguito
- LOD G oggetto aggiornato.

Tale scala va considerata come riferimento, poiché il LOD è un concetto che si applica ad una singola istanza e nello stesso modello i vari elementi potrebbero avere dei gradi di dettaglio differenti.

Pertanto l'Aggiudicatario nella consapevolezza della specificità dell'intervento, inteso nella sua globalità, potrà proporre contenuti informativi aggiuntivi e specifici del progetto. Ai fini esemplificativi e non esaustivi si riporta di seguito i LOD previsti:

| | **PROGETTO ESECUTIVO** |
|---|---|
| **Modello** | **LOD** |
| ***Esistente*** | |
| Elementi Strutturali Esistenti | C |
| Elementi Architettonici Esistenti | C |
| Impianti Esistenti | C |
| ***Nuova Costruzione*** | |
| Modello Strutturale | C |
| Modello Architettonico | D |
| Modello Aree Esterne | C |
| Modello Meccanico HVAC | D |
| Modello Meccanico Idr. Sani. Antincendio | C/D |
| Modello Elettrici | C/D |

Partendo dai LOD indicati nella tabella precedente, l'affidatario dovrà predisporre il contenuto dei modelli in base alle schede informative che sintetizzano il livello di fabbisogno informativo necessario a soddisfare gli obiettivi dei Model Use.

Nelle schede informative, per ogni obiettivo (purpose) e fase, sono quindi specificate le seguenti caratteristiche:

**Livello geometrico** (Geometrical Information):

- forma (Detail): semplice, definita, complessa
- dimensionalità (Dimensionality): 0D (posizione puntuale, conteggio) 1D (lunghezza), 2D (superficie), 3D (geometria 3D)
- posizione (Location): effettiva, di progetto (relativa)
- parametricità (Parametric behaviour): non richiesta, parziale (operazioni base come estrusioni), totale (multiparametrica)
- aspetto (Appereance): simbolica, schemi colore, per materiali, realistica, etc

**Livello alfanumerico** (alphanumerical information):

- identificazione (Identification): parametri identificativi
- contenuto informativo (Information Content): parametri qualitativi e quantitativi, attributi prestazionali, dati manutentivi

**Livello documentale** (Documentation)

- documentazione relazionata

In questo modo sarà più facile verificare la compliance del modello, piuttosto che l'interpretazione dei LOD alfanumerici che forniscono solo un riferimento per una commessa generica, evitando informazioni non necessarie allo scopo del modello BIM, il cosiddetto "spreco" informativo.

## 4.4 Ruoli e responsabilità ai fini informativi

Il concorrente deve identificare e specificare il soggetto che ricoprirà il ruolo di gestore delle informazioni (BIM Manager) e il soggetto che ricoprirà il ruolo di coordinatore delle informazioni (BIM Coordinator).

Viene di seguito presentata una tabella esemplificativa dei requisiti richiesti, che il concorrente deve riportare completata in sede di oGI:

| FASE | Ruolo | Nome | Cognome | Società (sede) | e-mail |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |

L'affidatario dovrà quindi presentare nella oGI l'organigramma dei soggetti coinvolti nelle attività di modellazione e di gestione informativa e delle relazioni tra di essi. L'affidatario dovrà inoltre esplicitare come la sua struttura informativa si interfaccerà con quella della Stazione Appaltante.

## 4.5 Strutturazione e organizzazione della modellazione digitale

L'organizzazione dei modelli dovrà essere identificata in base alle discipline di progetto e rispetto alla fase di processo cui fanno riferimento.

Nella propria oGI l'affidatario dovrà specificare l'organizzazione dei modelli utilizzata.

### *4.5.1 Nomenclatura e codifica dei modelli*

Di seguito è riportato a titolo di esempio una tipologia di organizzazione.

Un esempio del nome dei file costituenti il modello BIM di progetto è così determinato:

| n° Progetto | | Fase progettuale | | Disciplina | | Opera | | Tipo di file/elaborato | Progressivo |
|---|---|---|---|---|---|---|---|---|---|
| **21097** | **_** | **3** | **_** | **ARC** | **_** | **A** | **_** | **M3** | **001** |

Dove:

- Codice Progetto è il codice di progetto definito dal Committente

- Fase — è un codice di una cifra identificativo della fase progettuale

  0 = stato di fatto (rilievo)
  1 = studio di fattibilità tecnica ed economica
  2 = progetto definitivo
  3 = progetto esecutivo
  4 = progetto costruttivo / DL
  5 = as-built

- Codice Disciplina — vale

  COO per il coordinamento

  ARC per la componente architettonica

  FUR per la componente arredi e attrezzature

  STR per la componente strutturale

  MEP per la componente impiantistica MEP congiunta

  ELE per la componente elettrica

  MEC per la componente meccanica (ventilazione, condizionamento, plumbing)

  EXW per le opere esterne

  EXS edifici del contesto esistente e paesaggio

  FPR per il progetto antincendio

  OHS per il progetto accantieramento e sicurezza

  SUR per i file di rilievo (CAD 3D)

- Codice Opera — è il codice identificativo del corpo di fabbrica da definirsi progetto per progetto (1cifra)

  0 identifica i file di coordinamento generale

  A, B, C, …Z identifica il corpo A, B, C, …Z, AA,…,ZZ

- Tipo di file/elaborato vale: — è un codice di due cifre identificativo del tipo di file e per i file BIM

  M3 per i file di modellazione

  M2 per il modelli di contenuti bidimensionali (impaginazione, sheet model)

  MC per i file di coordinamento (contenitori)

- Progressivo — è un codice di tre cifre progressivo, da utilizzare nel caso ci sia la necessità di ulteriore scomposizione del modello (esempio interrato e fuori terra, facciate o per sub-discipline condizionamento, idrico-sanitario, etc). In caso contrario varrà sempre 001.

**CODIFICA LIVELLI:**

| CODICE | DESCRIZIONE |
|---|---|
| GF_ | Piano di Campagna (se diverso da P0) |
| 00_ | Piano Terra |
| 01_ | Primo Piano |
| 02_ | Secondo Piano |
| 03_ | Terzo Piano |
| 04_ | Quarto Piano |
| -1_ | Piano Interrato - 1 |
| -2_ | Piano Interrato - 2 |
| M1_ | Primo Piano Mezzanino |
| M2_ | Secondo Piano Mezzanino |

| AMBITO SPAZIALE | DISCIPLINA | MODELLO | CONTENUTO |
|---|---|---|---|
| INTERO BENE | COO | 21097_3_COO_0_M3001 | Modello di coordinamento interdisciplinare |
| FABBRICATO | ARC | 21097_3_ARC_A_M3001 | Modello Architettonico |
| | STR | 21097_3_STR_A_M3001 | Modello opere Strutturali (nuove costruzioni) |
| | MEP | 21097_3_MEC_A_M3001<br>21097_3_ELE_A_M3001 | Modello impianti Meccanici Modello impianti Elettrici e speciali |

### *4.5.2 Programmazione temporale della modellazione e del processo informativo*

L’Affidatario dovrà programmare e realizzare le attività di modellazione in una tempistica coerente con quella legata alla contrattualizzazione. In nessun caso le tempistiche legate alla realizzazione dei modelli ed all’estrazione dagli stessi delle informazioni e degli elementi dovranno modificare o rallentare le procedure di realizzazione dell’opera ed adempimento connessi).
Il mancato rispetto delle tempistiche dell’attività informativa che dovesse riflettersi sull’andamento dell’appalto e generare ritardi verrà considerato un ritardo nella progettazione delle opere per esclusiva causa dell’Affidatario e troverà applicazione secondo quanto previsto in Contratto ed in Capitolato Speciale d’Appalto in materia.

Nella oGI e successivamente nel pGI si richiede all’affidatario di esplicitare un programma dove si possano evincere le frequenze di:

- Condivisione dei modelli verso la Committenza (consegne intermedie)

- Riunioni di coordinamento
- Periodi di verifica e validazione dei modelli

#### *4.5.3 Dimensione massima dei file di modellazione*

Per supportare l'accesso e l'uso agevole dell'informazione alla Stazione Appaltante è necessario che i modelli messi in condivisione non superino i **150 MB.** Qualora il rispetto di tale vincolo comporti svantaggi di gestione informativa tale limite può essere portato a **200 MB** giustificandone i motivi.

### 4.6 Politiche per la tutela e sicurezza del contenuto informativo

Tutte le informazioni di progetto dovranno essere trattate con riserbo e sicurezza e non possono essere rese pubbliche senza uno specifico consenso della Committenza. Tutta la catena di fornitura deve adottare tali politiche per la tutela e la sicurezza del contenuto informativo. L'Affidatario dovrà tenere in considerazione le norme tecniche in materia di sicurezza, oltre alla legislazione vigente, al fine di garantire la disponibilità, l'integrità e la riservatezza del contenuto informativo digitale all'interno del processo. Tutte le informazioni riguardanti la modellazione informativa saranno conservate e scambiate in un ambiente di condivisione dei dati (Acdat).

**Richieste aggiuntive in materia di sicurezza**

In aggiunta ai criteri generali identificati tramite gli strumenti normativi, vengono individuate le indicazioni specifiche necessarie al fine di garantire il rispetto dei principi espressi dalle suddette norme. Si riportano di seguito le specifiche necessarie:

- salvataggio con backup dei dati per l'archiviazione su supporto fisso esterno con cadenza prefissata;

- garanzia di salvataggio di numero di copie sufficienti, da archiviarsi secondo precise indicazioni del committente;

- redazione di una scheda informativa digitale identificativa da allegare al modello grafico informativo al momento del caricamento nell'archivio di condivisione dei dati (ACDat), da parte dell'affidatario, all'interno della quale dovrebbero essere riportati gli scopi, l'identità del modellatore delle informazioni e una breve descrizione del modello stesso; Nota Tale scheda è redatta al fine di poter sempre stabilire, sia da committente sia dall'affidatario, le responsabilità delle figure professionali associate ai modelli pubblicati.

### 4.7 Modalità di condivisione dei dati, dei modelli, dei documenti e degli elaborati

Sarà onere dell'Aggiudicatario predisporre un ambiente di condivisione dei dati con le caratteristiche di seguito riportate, garantendone la piena fruibilità del Committente con adeguato numero di accessi sino alla conclusione dell'incarico.

L'Aggiudicatorio sarà anche responsabile della conservazione e mantenimento della copia di tutte le informazioni di progetto in una risorsa sicura e stabile all'interno della propria organizzazione.

L'ambiente di condivisione dei dati, così come previsto dalla UNI 11337:2017 – parti 1 e 5, sarà la piattaforma informatica a supporto del corretto flusso di informazioni tra i diversi soggetti partecipanti alla realizzazione dell'opera di cui all'oggetto. In particolare, con riferimento all'ambiente di condivisione dei dati (ACDat), dovranno essere garantiti i seguenti obiettivi minimi:

- accessibilità dell'ACDat tramite server web, regolamentata con differenti tipologie di accesso ai dati in termini di permessi per garantire l'accesso alle figure coinvolte nel processo e la possibilità di consultazione ed estrazione della copia dei documenti, degli elaborati, nonché dei modelli ivi presenti nello stato di pubblicazione;

- garanzia di sicurezza e riservatezza dell'archivio (ACDat), in riferimento alle modalità di gestione dei dati in esso contenuti;

- tracciabilità dei dati e versioni dei documenti digitali/modelli e delle operazioni effettuate con successione storica delle revisioni apportate a tali dati;

Inoltre si richiede all'Affidatario:

- aggiornamento continuo durante gli stadi e le fasi del processo dell'archivio di condivisione dati (ACDat), in relazione al continuo sviluppo degli elaborati/modelli/documenti digitali contenuti;

- implementazione, nella piattaforma utilizzata quale ACDat, di una interfaccia per la visualizzazione e l'eventuale commento (markups e isses) dei modelli federati;

- consultazione attraverso l'ACDat dei modelli e/o dei documenti tramite dispositivi mobile;

In ogni caso, l'ACDat fornisce solo un supporto alla comunicazione tra le parti, ma NON sostituisce in nessun modo le tradizionali comunicazioni previste dalla norma in vigore.

#### *4.7.1 Struttura delle cartelle di progetto*

L'affidatario dovrà utilizzare una struttura dell'ACDat rispetto alle 4 aree canoniche (Lavorazione– Condivisione – Pubblicazione – Archiviazione – ISO19650) o nel caso più granulare rispetto alle 4 aree canoniche.

Nella propria oGI l'affidatario dovrà dettagliare a riguardo della struttura dell'ACDat:

- la struttura gerarchica e i nomi delle cartelle condivise con gli altri attori;

- le politiche di accesso;

- le responsabilità della struttura e degli accessi.

### 4.8 Modalità di programmazione e gestione dei contenuti informativi di eventuali collaboratori

Quanto descritto nel presente Capitolato dovrà essere rispettato anche da eventuali collaboratori. La verifica dei dati, delle informazioni e dei contenuti informativi prodotti da tali collaboratori è condotta dall'Affidatario, in relazione alla specifica fase di progettazione.

L'affidatario dovrà specificare nell´oGI il flusso e la procedura di validazione per i vari livelli di verifica, definendo:

- le modalità con cui i modelli, gli oggetti e/o gli elaborati vengono sottoposti a validazione in merito alla loro emissione, controllo degli errori e nuove necessità di coordinamento;

• i contenuti informativi oggetto di una periodica revisione;

• la frequenza con cui i contenuti informativi sono soggetti a revisione, non inferiore alle scadenze definite da progetto.

## 4.9 Procedure di coordinamento e verifica dei modelli

L'Affidatario dovrà svolegere le procedure di validazione per i modelli, gli oggetti e gli elaborati, con riferimento alla norma UNI 11337:5.

Ai modelli dovrà essere allegata una scheda descrittiva delle principali attività svolte e delle principali problematiche eventualmente riscontrate. L'Affidatario dovrà eseguire il controllo delle interferenze e delle incoerenze sia intra che interdisciplinari e provvedere alla pubblicazione dei report con il risultato delle analisi (i report e i modelli correlati dovranno essere consegnati alla Stazione Appaltante) nell'ACDat. La verifica di coordinamento dei modelli grafici dovrà essere eseguita in via automatizzata attraverso specifici software.

L'Aggiudicatario dovrà aggiornare il modello in accordo con il progredire dei lavori e consegnare alla stazione appaltante il modello ad ogni step intermedio programmato in accordo con il Capitolato Speciale d'Appalto o comunque secondo le richieste della Stazione Appaltante.

Al fine delle verifiche intermedie verranno programmate delle riunioni di coordinamento in cui si verificheranno le implementazioni e gli aggiornamenti fatti sui modelli.

## 4.10 Processo di analisi e risoluzione delle interferenze e delle incoerenze informative

Qualora l'analisi dei risultati in seguito ad un controllo *Modello vs Modello* risultasse di difficile gestione, il Project BIM Coordinator può suddividere i test di interferenza al fine di:

- rendere più agevole l'identificazione di tutte le intersezioni;
- assegnare tolleranze più o meno restrittive a seconda delle tipologie di elementi;
- evitare i falsi positivi tramite esclusioni di elementi dai set di selezione;
- stabilire le strategie di azione più idonee alla risoluzione delle criticità.

La priorità deve essere gestita all'interno dei software di controllo tramite commenti, tag, priorità ed eventualmente esportate e condivise verso gli altri software di BIM Authoring o piattaforma di collaborazione tramite il formato BCF (BIM Collaboration Format).

Il committente richiede la redazione di un documento riassuntivo per l'attività di risoluzione delle incoerenze e interferenze.

Le comunicazioni relative alle modalità in oggetto possono essere gestite attraverso le funzionalità degli ACDat.

Si riportano di seguito esempi di informazioni richieste:

- risoluzione avvenuta delle incoerenze e/o interferenze rilevate all'interno dei modelli o degli oggetti, o degli elaborati informativi;

- assegnazione della risoluzione di ogni singola interferenza degli oggetti o dei modelli ai modellatori responsabili delle informazioni;

- eventuale determinazione di nuova riunione, nel momento in cui le interferenze/incoerenze siano relative a più discipline, quindi coinvolgano più modellatori delle informazioni all'interno della stessa fase processuale

## 4.11 Modalità di archiviazione e consegna finale di modelli

Alla consegna di tutti i Modelli e degli Elaborati, compresi i modelli informativi in formato proprietario e in formato aperto, la proprietà degli stessi si intende trasferita in via esclusiva alla Stazione Appaltante, ivi compresi eventuali diritti. In particolare quanto prodotto dall'Affidatario resterà di piena ed assoluta proprietà della Stazione Appaltante la quale, potrà utilizzarlo come crede, come pure integrarlo nel modo e con i mezzi che riterrà opportuni con tutte quelle varianti ed aggiunte che, a suo insindacabile giudizio, saranno riconosciute necessarie, senza che l'affidatario possa sollevare eccezioni di sorta. Con la sottoscrizione del Piano di Gestione Informativa, l'Affidatario autorizza la Stazione Appaltante all'utilizzo e alla pubblicazione dei dati e delle informazioni presenti nei modelli prodotti per finalità anche diverse da quelle previste dal presente incarico. L'utilizzo dei dati sopra indicati da parte dell'Affidatario è consentito previa espressa autorizzazione da parte della Stazione Appaltante.

# CAPITOLATO INFORMATIVO

# SPECIFICHE TECNICHE DI GESTIONE INFORMATIVA

PROCEDURA APERTA AI SENSI DELL'ART. 60 DEL D.LGS. 50/2016 E S.M.I. PER L'AFFIDAMENTO DELL'ESECUZIONE DEI LAVORI DI RISTRUTTURAZIONE EDILIZIA E COORDINAMENTO DELLA SICUREZZA IN FASE DI ESECUZIONE DEL NUOVO MUSEO DEL MARE DEL POLO MUSEALE DEL PORTO VECCHIO-COMUNE DI TRIESTE (TS)

# Sommario

# PREMESSA

I contenuti del presente Capitolato Informativo si riferiscono al progetto del nuovo Museo del Mare del Polo Museale del Porto Vecchio a Trieste (TS).

Qualora il concorrente intenda svolgere l'esecuzione delle opere attraverso l'uso di metodi e strumenti elettronici specifici quali la modellazione per l'edilizia e le infrastrutture (art. 23, c.13, D.Lgs. 50/2016), il presente documento, denominato Capitolato Informativo:

- contiene i requisiti minimi per la produzione, gestione e trasmissione di dati, informazioni e contenuti informativi;
- costituisce il documento propedeutico alla stesura dell'offerta di Gestione Informativa e del piano di Gestione Informativa che diverrà parte integrante del contratto d'appalto;
- è da intendersi esteso all'intera catena di fornitura dell'appaltatore principale (subappaltatori, fornitori,ecc) nell'adempimento delle attività di produzione, gestione e trasmissione dei contenuti informativi.

# 1 SCOPO DEL DOCUMENTO

Lo scopo del presente documento (CI) è quello di fornire agli offerenti, una serie di linee guida da seguire nel caso in cui il concorrente intenda svolgere l'esecuzione delle opere attraverso l'uso di metodi e strumenti elettronici specifici quali la modellazione per l'edilizia e le infrastrutture (art. 23, c.13, D.Lgs. 50/2016). Il concorrente accettando le condizioni imposte dal capitolato si impegna a soddisfare tutti i suoi punti.

Il CI intende fornire al BIM Manager offerente un template di partenza che include i contenuti minimi per la redazione dell'Offerta di Gestione Informativa. Il concorrente, rispondendo ad ogni specifica sezione del CI, descrive come intende garantire la rispondenza a quanto richiesto dalla Stazione Appaltante. In tale offerta, il concorrente può ampliare e approfondire quanto proposto, fatto salvo il soddisfacimento dei requisiti minimi richiesti nel CI. In caso di aggiudicazione, l'Affidatario consoliderà e renderà esecutivo quanto offerto nel oGI in fase di gara nel Piano di Gestione Informativa (pGI - BIM Execution Plan) concordato con la Stazione Appaltante che diverrà parte integrante del contratto.

## 1.1 Priorità strategiche generali

La richiesta, da parte della Stazione Appaltante, dell'uso di metodi e strumenti elettronici specifici, quali quelli di modellazione per l'edilizia e le infrastrutture, è finalizzato al raggiungimento delle priorità strategiche ritenute rilevanti per il perseguimento dei seguenti obiettivi generali:

• maggior controllo sui costi di gestione e razionalizzazione degli stessi;

• reperibilità tempestiva e attendibilità delle informazioni utili per la gestione dell'opera nella successiva fase di esercizio;

• maggior efficienza dei processi decisionali supportati da informazioni strutturate e quindi facilmente e tempestivamente reperibili, nonché aggiornate ed attendibili lungo tutto il ciclo di vita dell'opera;

• mitigazione del rischio di varianti in corso d'opera grazie ad un maggior coordinamento della progettazione multidisciplinare.

## 1.2 Obiettivi di progetto

In relazione alle priorità strategiche sopra descritte, per questo specifico progetto, la Stazione Appaltante ha individuato i seguenti obiettivi:

• disporre sempre di informazioni precise, aggiornate e facilmente reperibili;

• garantire un controllo reale ed affidabile sui costi di progetto preventivati;

• determinare in ogni dettaglio le fasi di esecuzione del lavoro da realizzare, il relativo costo previsto, il cronoprogramma e l'impatto sulle attività;

• determinare il livello di definizione di ogni elemento del progetto tale che ogni oggetto risulti essere attendibile e utile per le fasi di direzione e esecuzione lavori, nonché per l'esercizio dell'opera;

• favorire un ambiente di lavoro collaborativo che faciliti il coordinamento della progettazione multidisciplinare (infrastrutture, architettura, strutture, impianti) ed esecuzione;

• generare un database informativo solido e robusto.

## 1.3 Livello di prevalenza contrattuale

La produzione, il trasferimento e la condivisione dei contenuti del progetto avverranno attraverso supporti informativi digitali in un ambiente di condivisione dei Dati - ACDat, pur permanendo la prevalenza contrattuale della documentazione consegnata con formattazione PDF oppure PDF/A corredati da "firma digitale" (come previsto dal disciplinare di gara) di tutti gli elaborati oggetto dell'incarico.

## 1.4 Acronimi e glossario

Di seguito si riportano i principali termini utilizzati nel prosieguo della trattazione ed in generale per ciò che concerne l'applicazione dei sistemi informativi alla realizzazione delle opere edilizie.

| | TERMINI | DEFINIZIONI |
|---|---|---|
| **4 D** | Quarta dimensione | Simulazione dell'opera e dei suoi elementi in funzione del tempo |
| **5 D** | Quinta dimensione | Simulazione dell'opera e dei suoi elementi in funzione del costo |
| **6 D** | Sesta dimensione | Simulazione dell'opera e dei suoi elementi in funzione dell'uso, gestione, manutenzione e dismissione |
| **7 D** | Settima dimensione | Simulazione dell'opera e dei suoi elementi in funzione della sostenibilità (economica, ambientale, energetica) |
| **AIM** | Asset Information Model | Modello federato dell'opera costruita contenente tutti i dati necessari per gestire, |

| | TERMINI | DEFINIZIONI |
|---|---|---|
| | | mantenere e far funzionare il bene realizzato |
| **AIR** | Asset Information Requirements | Requisiti informativi in relazione all'utilizzo del cespite immobile (asset) |
| **ACDat** | Ambiente di condivisione dei dati (Piattaforma collaborativa digitale) | Ambiente di raccolta, conservazione e condivisione dei dati relativi ai modelli digitali di un'opera |
| **ACDoc** | Archivio di condivisione dei documenti | Archivio di raccolta, conservazione e condivisione di copie di modelli ovvero di documenti non digitali |
| **ACDat Manager** | Coordinatore dei flussi informative - CDE Manager | Figura deputata alla gestione della piattaforma di condivisione ACdat (CDE) |
| **BIM** | Building Information Modeling | Rappresentazione digitale di caratteristiche fisiche e funzionali di un oggetto |
| **DBC –**<br>**BIM Coordinator Disciplinare** | Coordinatore dei flussi informativi disciplinari di commessa | Figura deputata al coordinamento delle attività di sviluppo dei modelli digitali in interfaccia tra BIM Manager e BIM Specialist |
| **PBC – BIM Coordinator di Progetto** | Coordinatore dei flussi informativi di commessa | Figura deputata al coordinamento delle attività di sviluppo dei modelli digitali in interfaccia tra BIM Manager e i coordinaotri disciplinari |
| **BM –**<br>**BIM Manager** | Gestore dei processi digitali | Figura deputata alla pianificazione, gestione e verifica dei flussi di lavori interni al metodo BIM |
| **BSD –**<br>**BIM Specialist** | Operatore avanzato della gestione e della modellazione informativa | Figura deputata alla corretta programmazione e creazione degli oggetti e dei modelli digitali disciplinari |
| **CI (EIR)** | Capitolato Informativo | Esplicitazione delle esigenze e dei requisiti informativi richiesti dal Committente agli Affidatari |
| **GIS** | Geographic Information System | Sistemi informativi geografici |
| **IFC** | Industry Foundation Classes | Codifica sviluppata e rilasciata dall'organizzazione no-profit Building SMART per la condivisione dati tra applicativi proprietari |
| **LC1** | Coordinamento di primo | Attività di analisi e controllo delle informazioni all'interno di un singolo modello disciplinare |

| | TERMINI | DEFINIZIONI |
|---|---|---|
| | livello | prima del rilascio all'esterno |
| **LC2** | Coordinamento di secondo livello | Attività riferita al coordinamento dei dati di modello tra due o più discipline (clash detection & code detection) |
| **LC3** | Coordinamento di terzo livello | Attività legate alla soluzione di interferenze ed incoerenze tra dati / informazioni / contenuti informativi non generati da modelli virtuali compiuti (BIM Authoring) |
| **LOD** | Livello di sviluppo oggetti digitali | Livello di approfondimento dei dati e delle informazioni degli oggetti digitali contenuti nei modelli |
| **LOG** | Livello di sviluppo geometrico | Livello di sviluppo degli Oggetti - attributi Geometrici |
| **LOI** | Livello di sviluppo informativo | Livello di sviluppo degli Oggetti - attributi Informativi |
| **LOIN** | Livello di fabbisogno informativo | Struttura di riferimento che definisce l'estensione e la rilevanza dell'informazione |
| **MVD** | Model View Definition | Strumento attraverso cui definire quali caratteristiche del modello devono essere condivise |
| **oGI (BEP pre-contract)** | offerta di Gestione Informativa | Esplicitazione e specifica della gestione informativa offerta dall'Affidatario in risposta al CI |
| **OIR** | Requisiti informativi dell'Organizzazione | Obiettivi dell'Organizzazione (azienda o ente pubblico) |
| **pGI (BEP post-contract)** | piano di Gestione Informativa | Pianificazione operativa della gestione informativa attuata dall'Affidatario dopo l'affidamento del contratto |
| **LV1** | Livello di verifica 1 | Attività di verifica interna formale corretta modalità di produzione, consegna e gestione delle informazioni in relazione a quanto indicato nel Capitolato Informatico e nel pGI |
| **LV2** | Livello di verifica 2 | Attività di verifica interna di tipo sostanziale, volta ad accertare la leggibilità, tracciabilità e coerenza delle informazioni contenute nei vari modelli (es.: report di clash detection, verifica dei LOD etc.) |
| **LV3** | Livello di verifica 3 | Attività di validazione di modelli ed elaborati da parte del Committente, eventualmente |

| | TERMINI | DEFINIZIONI |
|---|---|---|
| | | supportato da un soggetto terzo |
| **WBS** | Work Breakdown Structure | Scomposizione funzionale/spaziale dell'opera |

| GLOSSARIO | SIGNIFICATO DEI TERMINI |
|---|---|
| **Analisi incoerenze** | Model e Code Checking. Analisi delle possibili incoerenze informative di elementi, modelli ed elaborati in rapporto a normative, regole e procedure |
| **Analisi interferenze geometriche** | Clash Detection. Analisi delle possibili interferenze geometriche presenti tra elementi, modelli ed elaborati |
| **As Built** | Elaborati che descrivono l'opera come è stata effettivamente costruita |
| **Clash Detection** | Analisi delle possibili incoerenze geometriche tra oggetti e/o modelli digitali |
| **Contenuto informativo** | Insieme di informazioni organizzate secondo un determinato scopo ai fini della comunicazione sistematica di una pluralità di conoscenze all'interno di un processo |
| **Dato** | Elemento conoscitivo tangibile, elementare, interpretabile all'interno di un processo di comunicazione attraverso regole e sintassi preventivamente condivise. |
| **Elaborato Informativo** | (Elaborato) Veicolo informativo di rappresentazione di prodotti e processi del settore costruzioni. |
| **Elaborato tradizionale** | Veicolo informativo in formato cartaceo o digitale, contenente rappresentazioni grafiche 2D. |
| **Formato aperto** | Formato file basato su specifiche sintassi di dominio pubblico il cui utilizzo è aperto e accessibile senza necessità di disporre di particolari applicazioni software tecnologiche specifiche. |
| **Formato proprietario** | Formato di file basato su specifiche sintassi di dominio non pubblico il cui utilizzo è limitato a specifiche condizioni d'uso stabilite dal proprietario del formato |
| **Informazione** | Insieme di dati organizzati secondo un determinato scopo ai fini della comunicazione di una conoscenza all'interno di un processo. |
| **Interferenze** | Collisione geometrica tra oggetti presenti nei modelli sia della stessa disciplina sia in modelli di discipline differenti. |
| **Libreria di oggetti** | Ambiente digitale per la raccolta organizzata e la condivisione di oggetti per modelli grafici. |
| **Milestone** | Principali tappe riferite alle Fasi del BIM |

| GLOSSARIO | SIGNIFICATO DEI TERMINI |
|---|---|
| **Model Checking** | Analisi delle possibili incoerenze tra modelli in relazione a regole e/o regolamenti e geometriche |
| **Model User** | Utilizzatore delle informazioni digitali. Figura autorizzata ad accedere alle informazioni digitali di progetto |
| **Modello aggregato / federato** | Virtualizzazione dell'opera o suoi elementi in funzione di una aggregazione (stabile o temporanea) di più modelli singoli |
| **Modello di dati** | Opera Digitale costituita da Dati Grafici e Dati non Grafici, quindi da Informazioni Grafiche e non Grafiche che descrivono in modo più o meno particolareggiato l'Opera Reale. |
| **Modello di progetto** | Virtualizzazione per oggetti di un'opera od un complesso di opere "in divenire" o di una modificazione di un'opera od un complesso di opere già "in essere" |
| **Modello di rilievo** | Virtualizzazione per oggetti, in un dato tempo, dello stato di fatto di un'opera od un complesso di opere "in essere" (rilievo, as-built, ecc.) |
| **Modello informativo** | Veicolo informativo di virtualizzazione di prodotti e processi del settore delle costruzioni |
| **Modello singolo** | Virtualizzazione dell'opera o suoi elementi in funzione di una disciplina o di uno specifico uso del modello |
| **Parametrico** | Organizzazione di un insieme di dati per relazioni logiche o concettuali in funzione di uno o più parametri |
| **Piattaforma di Collaborazione** | Piattaforma Software dotata di strumenti che agevolano il lavoro collaborativo tra utenti che concorrono alla progettazione/esecuzione/conduzione del medesimo Progetto. Costituisce l'ambiente protetto per l'archiviazione, gestione e distribuzione dell'intero Modello di Dati. |
| **Repository** | Insieme di directory necessarie ad accogliere la documentazione di Progetto e i Modello di Dati organizzate tenendo conto delle discipline e dei mandati. |
| **Scheda informativa** | Raccolta e archiviazione strutturata di informazioni sociali, ambientali, tecniche, economiche e giuridiche, redatte in un ordine prestabilito, secondo certe modalità e per determinati scopi. Raccolta per livelli di attributi informativi non geometrici |
| **Struttura di progetto** | Si definisce "Struttura di Progetto" la scomposizione del Modello di Dati in più parti, realizzata tenendo conto del tipo di Opera, dei limiti tecnologici e degli aspetti contrattuali. |
| **Template** | Modello predefinito che adeguatamente formattato consente di ottenere una Base Dati univoca al variare del Modello di Dati o dei Prodotti Digitali. |
| **Uniclass** | "Unified Classification for the Construction Industry", è un sistema di |

| GLOSSARIO | SIGNIFICATO DEI TERMINI |
| --- | --- |
| | classificazione sviluppato dall'NBS (UK) |
| **Uniformat** | Sistema di classificazione degli oggetti alternativo all'UniClass di origine Statunitense |
| **Veicolo informativo** | Mezzo di trasmissione di contenuti informativi. Nel settore delle costruzioni si suddividono in veicoli di rappresentazione (elaborati informativi) e veicoli di virtualizzazione (modelli informativi) |

# 2 RIFERIMENTI NORMATIVI

Si elencano di seguito tutti i richiami normativi specifici connessi presi come riferimento per il presente Capitolato Informativo:

- UNI 11337-1:2017 "Edilizia e opere di ingegneria civile - Gestione digitale dei processi informativi delle costruzioni - Parte 1: Modelli, elaborati e oggetti informativi per prodotti e processi
  Parte 4: Evoluzione e sviluppo informativo di modelli, elaborati e oggetti
  Parte 5: Flussi informativi nei processi digitalizzati
  Parte 6: Linea guida per la redazione del capitolato informativo
  Parte 7: Requisiti di conoscenza, abilità e competenza delle figure coinvolte nella gestione e nella modellazione informativa
- UNI EN ISO 16739:2016 Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries – ISO 16739:2005 (IFC2X3) - ISO 16739:2013 (IFC4)
- Decreto MIT n. 560 del 1.12.2017 Modalità e i tempi di progressiva introduzione, da parte delle stazioni appaltanti, delle amministrazioni concedenti e degli operatori economici, dell'obbligatorietà dei metodi e strumenti elettronici specifici, quali quelli di modellazione per l'edilizia e le infrastrutture, nelle fasi di progettazione, costruzione e gestione delle opere e relative verifiche.
- ISO 19650-1:2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling -- Part 1: Concepts and principles
- ISO 19650-2:2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling -- Part 2:Delivery phase of the assets
- UNI EN 17412-1:2021 Livello di Fabbisogno Informativo – Parte 1: Concetti e principi

# 3 SEZIONE TECNICA

Questa sezione stabilisce i requisiti tecnici delle informazioni in termini di hardware, software, infrastrutture tecnologiche, protocollo di scambio dei dati, sistemi di coordinate, specifiche per l'inserimento degli oggetti, sistemi di classificazione degli oggetti e competenze richieste per le attività di esecuzione dei lavori di cui all'oggetto.

Il concorrente specificherà nella oGI ogni elemento utile a descrivere come intende soddisfare i requisiti minimi descritti in questa sezione oltre a dettagliare eventuali specifiche migliorie.

## 3.1 Caratteristiche tecniche e prestazionali dell'infrastruttura hardware e software

### *3.1.1 Infrastruttura hardware*

Il concorrente deve dichiarare la dotazione hardware attualmente in suo possesso e che intende mettere a disposizione per l'esecuzione della prestazione richiesta. La dotazione deve essere adeguata all'elaborazione di modelli e allo scambio di informazioni e deve garantire un corretto livello di sicurezza.

Nella propria oGI il concorrente dovrà specificare quali saranno le caratteristiche tecniche dell'infrastruttura messa a disposizione.

| N° UNITA` | TIPOLOGIA | CARATTERISTICA TECNICA | VALORE PRESTAZIONALE |
|---|---|---|---|
| | Workstation fissa | Processore | |
| | | RAM | |
| | | Sistema Operativo | |
| | | Monitor-Scheda grafica | |
| | Workstation mobile (cantiere) | Processore | |
| | | RAM | |
| | | Sistema Operativo | |
| | | Monitor-Scheda grafica | |
| | Unità di backup | Memoria di archiviazione | |
| | Trasmissione dati | Rete | |

### *3.1.2 Infrastruttura software*

Il concorrente dichiara che la tipologia software attualmente in suo possesso e che intende mettere a disposizione per l'esecuzione della prestazione sono basati su piattaforme interoperabili a mezzo di formati aperti non proprietari, in grado di leggere, scrivere e gestire, oltre al formato proprietario, anche i file in formato aperto *.ifc.

Il concorrente dichiara di fornire un ambiente di condivisione dei dati (ACDat) con le caratteristiche riportate nel capitolo 4.9, garantendone la piena fruibilità del Committente (Read/Write/Download), con adeguato numero di accessi che tengano in considerazione anche della Direzione Lavori, sino alla consegna e collaudo dell'opera.

L'aggiudicatario è tenuto a usare software dotati di regolare contratti di licenza d'uso.

Nella propria oGI il concorrente dovrà specificare quali saranno le caratteristiche tecniche dell'infrastruttura messa a disposizione.

| AMBITO | DISCIPLINA/ATTIVITA` | SISTEMA SOFTWARE | VERSIONE |
|---|---|---|---|
| Es: BIM Authoring | Modellazione costruttiva | Revit | 2022 |
| Gestione documentazione | … | | |
| Clash Detection | … | | |
| … | | | |

## 3.2 Formati di fornitura dati messi a disposizione inizialmente dal committente

Al fine di garantire agli offerenti un supporto alle analisi in fase della gara, la Stazione Appaltante fornisce in fase di gara il modello informativo dello stato di fatto del Polo Museale del Porto Vecchio in formato *.ifc (MVD 2x3 Coordination view 2.0).

Inoltre, al fine di garantire un elevato livello di contenuti informativi e consistenza dei dati, e per agevolare le attività di modellazione, all'atto della consegna dei lavori la Stazione Appaltante fornirà all'Aggiudicatario sia il modello informativo dello stato di fatto del Polo Museale del Porto Vecchio in formato *.rvt (versione 2020) e *.ifc (MVD 2x3 Coordination view 2.0) e sia il modello informativo del Polo Museale del Porto Vecchio creato nella fase di progettazione esecutiva in formato *.rvt (versione 2020) e *.ifc (MVD 2x3 Coordination view 2.0).

Tali modelli sono messi a disposizione come supporto alla modellazione e la Stazione Appaltante non si prende la responsabilità della sicurezza delle informazioni in essi contenute. Nel caso in cui l'aggiudicatario decidesse di acquisire tali modelli come punto di partenza, sarà ritenuto responsabile di tutte le informazioni in essi contenute.

## 3.3 Fornitura e scambio dei dati

### *3.3.1 Formati da utilizzare*

Nella propria oGI il concorrente dovrà specificare l'estensione dei file in formato proprietario e aperto che intende utilizzare, in assonanza con l'infrastruttura software dichiarata.

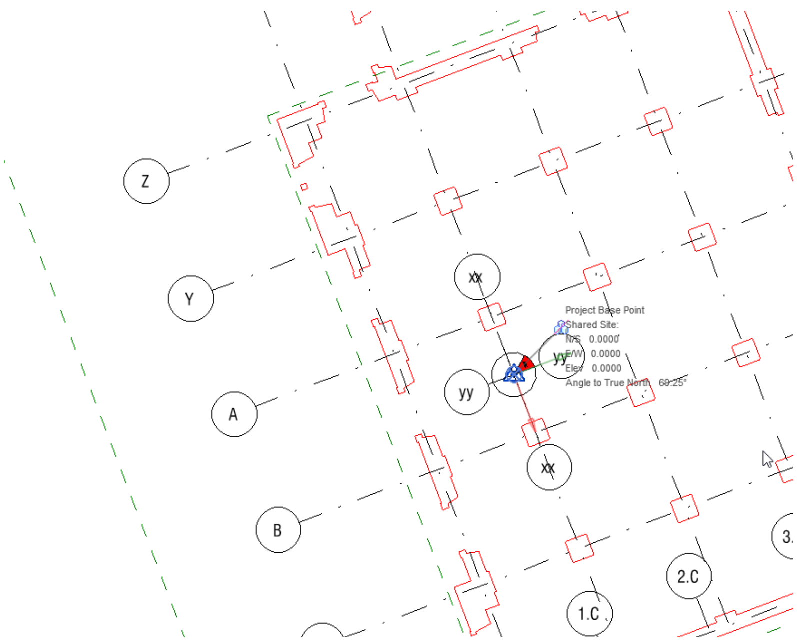
| VEICOLI INFORMATIVI / OBIETTIVI | FORMATO PROPRIETARIO | FORMATO APERTO |
|---|---|---|
| Modelli informativi (BIM Authoring) | | |
| Elaborati digitali grafici | | |
| Elaborati digitali documentali | | |
| Computo | | |
| Elaborati digitali multimediali | | |
| Schede Informative | | |
| Contabilità dei lavori (per la parte di competenza dell'aggiudicatorio) | | |
| Cronoprogramma | | |
| Verifica e analisi delle interferenze geometriche | | |

### 3.4 Sistema di coordinate e specifiche di riferimento

Al fine di ottenere dei modelli con un sistema di coordinate coerente, gli stessi devono essere programmati con i medesimi settaggi e condividere lo stesso Punto di Origine. La localizzazione dell'opera e/o del sito sul modello deve essere fissata alla corretta longitudine e latitudine o altro punto di riferimento definito. Il Nord effettivo della localizzazione dell'opera e/o del sito sul modello deve inoltre essere impostato correttamente. Tutti i modelli prodotti devono utilizzare un sistema "coordinate condivise" o sistemi analoghi.

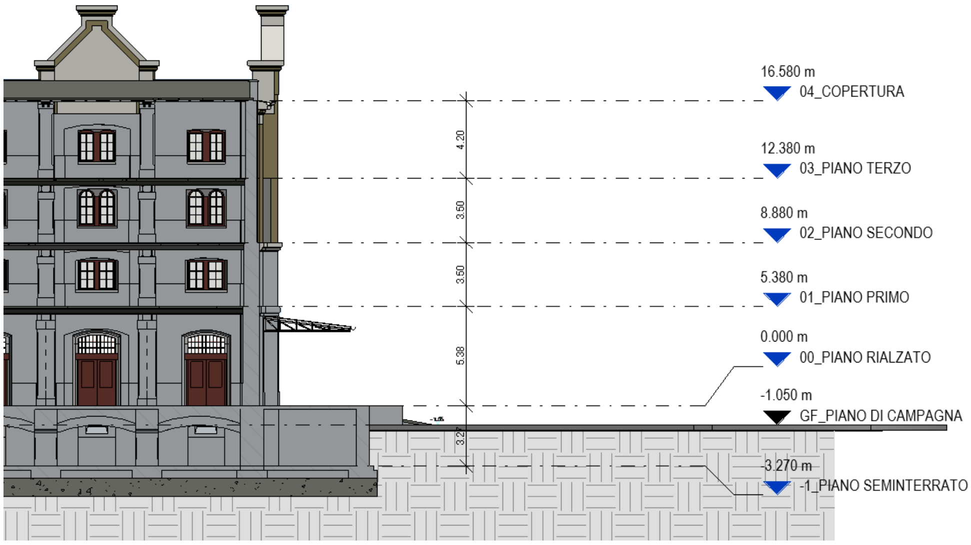
Si richiede di eseguire un rilievo GPS per poi poter georeferenziare il modello e coordinarlo con il punto di origine.

| | |
|---|---|
| Origine = Coincidente con Project Base Point coincide con asse di simmetria corpo centrale (asse A/B) e asse 2S (prima file di colonne) | N/S: 0 (rispetto ad internal origin)<br>E/W: 0 (rispetto ad internal origin)<br>Elevation: 0 (rispetto ad internal origin) = Finito del livello P0<br>*Nei modelli di coordinamento L'origine, Project Base e Survey dovranno coincidere con un caposaldo identificato.* |
| Rotazione del Nord di Progetto | il nord di Progetto viene pianificato in base alla geometria dei manufatti e della messa in tavola degli stessi.<br>69°14'48'' a OVEST (antiorario) (circa 69°,25) |
| Unità di Misura (Sistema metrico) | Metro per modelli Architettonico e Strutturale<br>Millimetro/Metro per i modelli Impiantistici |
| Sistema di riferimento (datum) | Gauss-Boaga o WGS84 |



### *3.4.1 Livelli di progetto*

| **LIVELLI** | **quota estradosso finito** **m** |
|---|---|
| **04_COPERTURA** | 16.58 |
| **03_PIANO TERZO** | 12.38 |
| **02_PIANO SECONDO** | 8.88 |
| **01_PIANO PRIMO** | 5.38 |
| **00_PIANO TERRA (rialzato)** | 0.00 |
| **-1_PIANO SEMINTERRATO** | -3.27 |
| **GF_PIANO DI CAMPAGNA (strada)** | -1.05 |




### *3.4.2 Sistemi di codifica livelli, viste e abachi*

**CODIFICA LIVELLI:**

| CODICE | DESCRIZIONE |
|---|---|
| GF_ | Piano di Campagna (se diverso da P0) |
| 00_ | Piano Terra |
| 01_ | Primo Piano |
| 02_ | Secondo Piano |
| 03_ | Terzo Piano |
| 04_ | Quarto Piano |
| -1_ | Piano Interrato - 1 |
| -2_ | Piano Interrato - 2 |
| M1_ | Primo Piano Mezzanino |
| M2_ | Secondo Piano Mezzanino |

### 3.5 Specifica per l'inserimento di oggetti

Il Concorrente dovrà rispettare per i principali elementi tecnici le seguenti modalità di inserimento e/o i vincoli rispetto ai principali sistemi di riferimento spaziali definiti nel modello stesso.

| Oggetto | Specifica |
|---|---|
| **Tutte le discipline** | Tutti gli elementi saranno associati al livello di riferimento in cui giacciono al netto di eccezioni relative a necessità funzionali di modellazione. |
| **Architettura** | Tutti gli elementi architettonici devono essere associati al livello di riferimento su cui giacciono. |
| **Strutture** | Tutte le strutture portanti verticali (setti) saranno associate al livello di riferimento in cui giacciono e limitate superiormente dall'intradosso della trave o dall'estradosso del solaio sovrastante, inferiormente dall'estradosso della trave o del solaio sottostante.<br><br>Tutte le travi a vista, volte e altri elementi portanti che delimitano lo spazio architettonico saranno associate al livello di riferimento inferiore rispetto a quello in cui giacciono e limitate superiormente dall'intradosso del solaio sovrastante.<br><br>Travi in cemento, quali travi ricalate o nervature di solette sono assimilabili al solaio strutturale, limitate superiormente dall'estradosso del solaio strutturale e quindi associate al piano che sorreggono.<br><br>Orditure secondarie o elementi strutturali discreti (es: arcarecci di copertura) senza valore architettonico sono assimilabili al pacchetto di solaio strutturale. |
| **Impianti** | Tutte le attrezzature e relative distribuzioni impiantistiche saranno modellate in relazione al piano di calpestio del piano di riferimento con offset relativo al netto di eccezioni relative a necessità funzionali di modellazione. |
| **Muri / Partizioni verticali** | Le altezze devono essere definite mediante livelli, tranne nel caso di muri ad altezza non collegata, ad esempio parapetti. I muri devono essere suddivisi per piano, salvo il caso in cui l'estensione multipiano costituisca reale intento progettuale.<br><br>Tutte le partizioni verticali esterne saranno associate al livello di riferimento in cui giacciono e limitate superiormente dall'estradosso del solaio sovrastante ed inferiormente dall'estradosso del solaio sottostante.<br><br>Tutte le partizioni verticali interne saranno associate al livello di riferimento in cui giacciono e limitate superiormente dall'intradosso del solaio sovrastante ed inferiormente dall'estradosso del solaio sottostante o dal |

| Oggetto | Specifica |
| --- | --- |
| | massetto/sottofondo a seconda della tecnologia edilizia. Tutti i muri avranno associata la funzione corretta (interior, exterior, soffit, etc) e qualora siano elementi architettonici portanti (es: muratura) saranno catalogati come tali tramite parametro “Structural” e conseguente parametro IFC “LoadBearing” (entrambi booleani). |
| **Pavimenti / Partizioni Orizzontali** | I livelli principali saranno riferiti allo strato di Finitura del piano di calpestio. In caso di scomposizione tra finitura e massetto, questi ultimi avranno offset negativo associato.<br><br>Tutti gli strati di finitura dei solai posti all’intradosso saranno associati al livello/ambiente a loro sovrastante. |
| **Controsoffitti** | I controsoffitti saranno associati al livello/ambiente a loro sottostante. |
| **Coperture inclinate** | Le chiusure orizzontali inclinate saranno associate al livello di gronda principale del manufatto, minimizzando il numero di livelli. |
| **Locali/Vani**<br><br>**(rooms/spaces)** | Definire posizione e altezza in riferimento ai livelli. Accertarsi che gli elementi delimitino correttamente il locale, in modo da avere la corretta definizione dei volumi. I locali devono avere la corretta fase associata.<br><br>Nei modelli impiantistici è suggerito creare i vani e recepire la codifica dei locali architettonici. Qualora suddivisi in sottodiscipline è sufficiente che solo un modello contenga i vani (es. Ventilazione e Illuminazione oppure il modello di coordinamento disciplinare). |
| **Elementi impiantistici a pavimento** | Gli elementi impiantistici a pavimento dovranno essere riferiti allo stesso livello del pavimento su cui l’oggetto è posto. È consentito un offset da tale livello nel caso di oggetti inseriti al di sotto o al di sopra del pavimento stesso. |
| **Elementi Impiantistici a controsoffitto** | Gli elementi impiantistici inseriti nel controsoffitto dovranno essere riferiti allo stesso livello del pavimento sottostante il controsoffitto in oggetto. |
| **Modelli collegati** | I modelli collegati dovranno avere sistemi di coordinate coerenti tra di loro, garantendo l’identificazione corretta della loro posizione relativa. |
| **Sito** | La superficie del terreno dovrà essere modellata per intero a partire dagli oggetti del rilievo topografico e non dovrà subire rototraslazioni. Gli edifici esistenti che vogliono essere rappresentati nel profilo dovranno essere modellati come solidi (masse) a partire dalle polilinee di base rilevate. |

### 3.6 Sistemi di classificazione e denominazione degli oggetti;

Gli oggetti costituenti il/i modello/i informativi grafici, organizzati in singoli elementi e/o parti, gruppi, blocchi ed assiemi dovranno riportare una univoca classificazione e codifica. Si richiede all'Operatore l'adozione di un sistema di classificazione degli elementi. Si suggerisce l'uso degli standard internazionali come Uniclass o Omniclass.
Nella propria oGI l'affidatario dovrà descrivere il sistema di classificazione degli elementi scelto.

### 3.7 Competenze ed esperienze dell'Aggiudicatario

L'Aggiudicatario è responsabile del soddisfacimento dei requisiti di formazione specifica in ambito di gestione informativa BIM all'interno della propria organizzazione. I livelli di esperienza, conoscenza e competenza del concorrente devono essere idonei a soddisfare i requisiti minimi necessari per attuare una gestione digitale dei processi informativi del progetto. Il concorrente deve inoltre possedere una figura di "BIM MANAGER DELL' ESECUTORE" che dovrà organizzare e dirigere tutti gli aspetti legati alla gestione informativa della realizzazione dell'opera, interfacciandosi con il BIM MANAGER DEL TEAM DI PROGETTAZIONE e con il BIM MANAGER DELLA STAZIONE APPALTANTE.

Nella propria oGI l'affidatario dovrà specificare i progetti significativi, in ambito BIM, realizzati e seguiti dal BIM MANAGER DELL' ESECUTORE individuato fornendo le seguenti informazioni minime:

| n. | Anno | Progetto | Importo opera | Ruolo svolto | Usi ed Obiettivi del modello |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| .. | | | | | |

# 4 SEZIONE GESTIONALE

### 4.1 Obiettivi e Usi del Modello in Relazione alle Fasi del Processo

Gli usi del modello minimi suddivisi per fase progettuale sono sintetizzati nella seguente tabella.

MODEL USES

<table>
<tr><th>rif</th><th>Realizzazione</th><th>Consegna (Handover)</th></tr>
<tr><td>1</td><td>DESIGN REVIEWS (VARIANTI)</td><td></td></tr>
<tr><td>2</td><td>COORDINAMENTO 3D (VARIANTI)</td><td></td></tr>
<tr><td>3</td><td>PROGETTAZIONE DEI SISTEMI COSTRUTTIVI</td><td></td></tr>
<tr><td>4</td><td>COORDINAMENTO (4D)</td><td></td></tr>
<tr><td>5</td><td>QUANTITY TAKE-OFF ANALYSIS (5D)</td><td></td></tr>
<tr><td>6</td><td colspan="2">RECORD MODELING (AS BUILT)</td></tr>
<tr><td>7</td><td></td><td>PROGRAMMAZIONE DELLA GESTIONE E MANUTENZIONE</td></tr>
</table>

Di seguito si descrivono gli obbiettivi del servizio relativamente agli usi del modello sopra identificati:

| FASE | OBIETTIVI DI FASE | MODELLI | USI DEL MODELLO |
|---|---|---|---|
| REALIZZATIVA<br><br>PROGETTAZIONE COSTRUTTIVA | Supporto all'ingegnerizzazione di tutti gli interventi previsti nelle precedenti fasi di progettazione o di varianti dovute al manifestarsi di condizioni impreviste | • COO<br>• ARC<br>• STR<br>• MEP<br>• | DESIGN REVIEW (1)<br>PROGETTAZIONE SISTEMI COSTRUTTIVI (3) |
| | Coordinamento interdisciplinare delle interferenze | • COO<br>• ARC<br>• STR<br>• MEP | COORDINAMENTO 3D (2) |
| | Monitoraggio delle fasi di lavoro e della relativa cantierizzazione con particolare riguardo per le attività di coordinamento della sicurezza in fase di esecuzione | • COO<br>• ARC<br>• STR<br>• MEP | COORDINAMENTO 4D (4) |
| | Monitoraggio e verifica materiali, quantità e costi | • COO<br>• ARC<br>• STR<br>• MEP | QUANTITY TAKE-OFF ANALYSIS (5D) (5) |
| | Restituzione modello aggiornato dell'interventi realizzati | • ARC<br>• STR<br>• MEP | RECORD MODELING (6) |
| | Redazione dei Piani di manutenzione dell'opera integrati con il modello | • MEP<br>• FUR | PROGRAMMAZIONE DELLA GESTIONE E MANUTENZIONE (7) |
| GESTIONALE<br><br>COLLAUDO E CONSEGNA | Fornirsi di modello coordinato multidisciplinare e aggiornabile in fase di gestione dell'opera. | • COO<br>• ARC<br>• STR<br>• MEP | PROGRAMMAZIONE DELLA GESTIONE E MANUTENZIONE (8) |

## 4.2 Definizione degli elaborati informativi richiesti

In relazione alla generazione degli elaborati informativi grafici (costruttivo, asbuilt) l'Affidatario dichiara che gli elaborati rispettino le origini e collegamenti come illustrato nella seguente tabella.

| ELABORATI | ORIGINE | NOTE |
|---|---|---|
| **Planimetrie, Piante, Sezioni Prospetti** | Da modello | |
| **Dettagli Costruttivi** | Da modello | |
| **Cronoprogramma 4D** | Collegato al modello | |
| **Cronoprogramma finanziario 5D** | Collegato al modello | |
| **Specifiche Tecniche** | | Da collegare al modello tramite codici o URL in fase di handover |
| **Disegni e misure di contabilità** | Collegato al modello | |

Inoltre, diventerà allegato integrante del pGI, l'elenco di tutti gli elaborati da produrre (estratti da modello e non) rispettivamente codificati in accordo allo standard del Committente, che verrà fornito in fase di aggiudicazione gara.

In ogni caso l'Affidatario è tenuto a produrre elaborati grafici cartacei (di estrazione o non dai modelli) inerenti tutta la documentazione completa del progetto as built e secondo specifiche richieste del Committente.

### 4.3 Livello di sviluppo degli oggetti e delle schede informative

Il livello di sviluppo degli oggetti che compongono i modelli grafici (LOD) definisce quantità e qualità del loro contenuto informativo ed è funzionale al raggiungimento degli obiettivi delle fasi a cui il modello si riferisce. Il livello di sviluppo di un oggetto va considerato come risultante della sommatoria delle informazioni di tipo geometrico e non-geometrico, (normativo, economico ecc.) che possono essere rappresentate in forma grafica 2D e 3D ed in forma alfanumerica (4D tempo, 5D costi, ecc.). La scala di riferimento dei livelli di sviluppo degli oggetti è presa dalla UNI 11337 - parte 4. Tale scala va considerata come riferimento.

Si riporta di seguito i LOD previsti sia nella fase precedente che nella presente fase:

| | FASE | | |
|---|---|---|---|
| | PROGETTO ESECUTIVO | PROGETTO COSTRUTTIVO / ESECUZIONE | CONSEGNA (AS BUILT) |
| Modello | LOD | | |
| Esistente | | | |
| Elementi Strutturali Esistenti | C | - | G |
| Elementi Architettonici Esistenti | C | - | G |
| Nuova Costruzione | | | |
| Modello Strutturale | C | D | F |
| Modello Architettonico | C/D | D | F |
| Modello Aree Esterne | C | C/D | F |
| Modello Meccanico HVAC | C/D | D/E | F |
| Modello Meccanico Idr. Sani. Antincendio | C/D | D/E | F |
| Modello Elettrici | C/D | D/E | F |

I LOD in questione sono da ritenersi generici, poiché il LOD è un concetto che si applica ad una singola istanza e nello stesso modello i vari elementi potrebbero avere dei gradi di dettaglio differenti.

Partendo dai LOD indicati nella tabella precedente, l'affidatario dovrà predisporre il contenuto dei modelli in base alle schede informative (ALLEGATO: Tabelle LOIN) che sintetizzano il livello di fabbisogno informativo necessario a soddisfare gli obiettivi dei Model Use.

Le tabelle fornite si basano sui concetti espressi dalla norma UNI EN 17412 -1 (2021) che definisce il cosiddetto LOIN (Level of Information Need) introdotto dalla UNI 19650.

Nell'allegato (ALLEGATO: Tabelle LOIN) vengono individuate tutte le caratteristiche ed informazioni che i modelli devono contenere in fase di consegna.

In sintesi, dovranno essere indicate con precisione le caratteristiche geometriche quali forma, aspetto dimensione, ubicazione e orientamento geometrico degli elementi e/o parti costituenti lo stato dei luoghi e delle opere realizzate, e le caratteristiche alfanumeriche quail identificazione e contenuti informativi (parametri qualitativi e quantitativi, attributi prestazionali, dati manutentivi). Gli oggetti costituenti il modello informativo grafico contengono inoltre idonei parametri che permettono l'inserimento di riferimenti esterni di tipo ipertestuale alla documentazione tecnica di dettaglio, (certificazioni, dettagli costruttivi, piani di manutenzione ecc.)

## 4.4 Ruoli e responsabilità ai fini informativi

Il concorrente deve identificare e specificare il soggetto che ricoprirà il ruolo di gestore delle informazioni (BIM Manager) e il soggetto che ricoprirà il ruolo di coordinatore delle informazioni (BIM Coordinator).

Il concorrente deve presentare l'organigramma dei soggetti coinvolti nelle attività di modellazione e di gestione informativa e delle relazioni tra di essi.

| FASE | Ruolo | Nome | Cognome | Società (sede) | e-mail |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |

Il concorrente dovrà inoltre esplicitare come la sua struttura informativa si interfaccerà con quella della Stazione Appaltante.

## 4.5 Caratteristiche informative di modelli, oggetti e/o elaborati messi a disposizione dalla committenza

La Committenza metterà a disposizione dei soggetti ammessi alla procedura di gara la documentazione del progetto esecutivo in formato non editabile (pdf) e il modello informativo dello stato di fatto del Polo Museale del Porto Vecchio in formato *.ifc (MVD 2x3 Coordination view 2.0).

La Committenza metterà a disposizione solo dell'Affidatario del servizio la documentazione del progetto esecutivo in formato non editabile (pdf) ed editabile (e.g. dwg). Saranno inoltre forniti solo all'Aggiudicatario, unicamente come supporto all'avvio dell'attività di modellazione (Varianti e As-Built), sia il modello informativo dello stato di fatto del Polo Museale del Porto Vecchio in formato *.rvt (versione 2020) e *.ifc (MVD 2x3 Coordination view 2.0) che il modello informativo del Polo Museale del Porto Vecchio creato nella fase di progettazione esecutiva in formato *.rvt (versione 2020) e *.ifc (MVD 2x3 Coordination view 2.0). Si precisa che il modello di progetto che sarà fornito non è stato utilizzato per l'estrazione degli elaborati grafici posti a base di gara.

Le caratteristiche dei modelli dello stato di fatto e di progetto esecutivo sono indicate nella matrice dei LOD e nelle schede informative LOIN ( vedi ALLEGATO: Tabelle LOIN).

Rimane obbligo dell'Affidatario procedere al rilievo dello stato dei luoghi per l'avvio della modellazione, ovvero la redazione dei modelli informativi as-built per la fase di collaudo secondo il progetto esecutivo (posto a base di gara) e costruttivo (aggiornamenti in fase di esecuzione delle opere).

## 4.6 Strutturazione e organizzazione della modellazione digitale

L'organizzazione dei modelli dovrà essere identificata in base alle discipline di progetto e rispetto alla fase di processo cui fanno riferimento.

Nella propria oGI l'affidatario dovrà specificare l'organizzazione dei modelli utilizzata.

Di seguito è riportato a titolo di esempio una tipologia di organizzazione.

### *4.6.1 Nomenclatura dei modelli*

Un esempio del nome dei file costituenti il modello BIM di progetto è così determinato:

| n° Progetto | | Fase progettuale | | Disciplina | | Opera | | Tipo di file/elaborato | Progressivo |
|---|---|---|---|---|---|---|---|---|---|
| **4968** | **_** | **4** | **_** | **ARC** | **_** | **A** | **_** | **M3** | **001** |

Dove:

- Codice Progetto — è il codice di progetto definito dal Committente
- Fase — è un codice di una cifra identificativo della fase progettuale

  0 = stato di fatto (rilievo)
  1 = studio di fattibilità tecnica ed economica
  2 = progetto definitivo
  3 = progetto esecutivo
  4 = progetto costruttivo / DL
  5 = as-built
- Codice Disciplina — vale

  COO per il coordinamento

  ARC per la componente architettonica

  FUR per la componente arredi e attrezzature

  STR per la componente strutturale

MEP per la componente impiantistica MEP congiunta

ELE per la componente elettrica

MEC per la componente meccanica (ventilazione, condizionamento, plumbing)

EXW per le opere esterne

EXS edifici del contesto esistente e paesaggio

FPR per il progetto antincendio

OHS per il progetto accantieramento e sicurezza

SUR per i file di rilievo (CAD 3D)

- Codice Opera — è il codice identificativo del corpo di fabbrica da definirsi progetto per progetto (1cifra)

  0 identifica i file di coordinamento generale

  A, B, C, …Z identifica il corpo A, B, C, …Z, AA,…,ZZ

- Tipo di file/elaborato — è un codice di due cifre identificativo del tipo di file e per i file BIM vale:

  M3 per i file di modellazione

  M2 per il modelli di contenuti bidimensionali (impaginazione, sheet model)

  MC per i file di coordinamento (contenitori)

- Progressivo — è un codice di tre cifre progressivo, da utilizzare nel caso ci sia la necessità di ulteriore scomposizione del modello (esempio interrato e fuori terra, facciate o per sub-discipline condizionamento, idrico-sanitario, etc). In caso contrario varrà sempre 001.

| AMBITO SPAZIALE | DISCIPLINA | MODELLO | CONTENUTO |
|---|---|---|---|
| INTERO BENE | COO | 4968_5_COO_0_M3001 | Modello di coordinamento interdisciplinare |
| FABBRICATO (Magazzino 26) | ARC | 4968_5_ARC_A_M3001 | Modello Architettonico e sistemazioni est |

| AMBITO SPAZIALE | DISCIPLINA | MODELLO | CONTENUTO |
|---|---|---|---|
| | STR | 4968_5_STR_A_M3001 | Modello opere Strutturali (nuove costruzioni) |
| | MEP | 4968_5_MEC_A_M3001<br>4968_5_ELE_A_M3001 | Modello impianti Meccanici Modello impianti Elettrici e speciali |

### *4.6.2 Programmazione temporale della modellazione e del processo informativo*

Il concorrente dovrà esplicitare nella sua oGI la programmazione delle sue attività di modellazione mediante stesura di un cronoprogramma della modellazione coerente in relazione ad obiettivi della modellazione (capitolo 4.1).

In particolare, tale pianificazione dovrà essere coerente con la consegna e collaudo finale dell’opera prevedendo step intermedi per la verifica e confronto con il Committente e altri soggetti che la Committenza riterrà opportuno coinvolgere per la verifica e validazione della documentazione finale (Collaudatori ecc.).

Nella oGI e successivamente nel pGI si richiede all’affidatario di esplicitare un programma dove si possano evincere le frequenze di:

- Condivisione dei modelli verso la Committenza (consegne intermedie)
- Relazione tra SAL e Modellazione As-built
- Riunioni di coordinamento
- Periodi di verifica e validazione dei modelli

### *4.6.3 Coordinamento modelli*

Al fine delle verifiche intermedie verranno programmate delle riunioni di coordinamento in cui si verificheranno le implementazioni e gli aggiornamenti fatti sui modelli.

Ai modelli dovrà essere allegata una scheda descrittiva delle principali attività svolte e delle principali problematiche eventualmente riscontrate. L’Affidatario dovrà eseguire il controllo delle interferenze e delle incoerenze sia intra che interdisciplinari e provvedere alla pubblicazione dei report nell’ACDat. Potranno essere utilizzati strumenti differenti per il monitoraggio delle stesse a seconda dell’ambito di analisi. In particolare, l’Affidatario dovrà provvedere alla risoluzione delle interferenze e delle incoerenze dei singoli modelli disciplinari prima della pubblicazione degli stessi lavorando direttamente nell’ambiente di model authoring o alternativamente appoggiandosi a procedure interne di controllo mediante terze parti. Attraverso l’ACDat si provvederà quindi al monitoraggio del processo di risoluzione delle stesse.

### *4.6.4 Dimensione massima dei file di modellazione*

Per supportare l'accesso e l'uso agevole dell'informazione alla Stazione Appaltante è necessario che i modelli messi in condivisione non superino i **150 MB.** Qualora il rispetto di tale vincolo comporti svantaggi di gestione informativa tale limite può essere portato a **200 MB** giustificandone i motivi.

## 4.7 Politiche per la tutela e sicurezza del contenuto informativo

Tutte le informazioni di progetto dovranno essere trattate con riserbo e sicurezza e non possono essere rese pubbliche senza uno specifico consenso della Committenza. Tutta la catena di fornitura deve adottare tali politiche per la tutela e la sicurezza del contenuto informativo. L'Affidatario dovrà tenere in considerazione le norme tecniche in materia di sicurezza, oltre alla legislazione vigente, al fine di garantire la disponibilità, l'integrità e la riservatezza del contenuto informativo digitale all'interno del processo. Tutte le informazioni riguardanti la modellazione informativa saranno conservate e scambiate in un ambiente di condivisione dei dati (Acdat).

## 4.8 Proprietà del modello e dei contenuti informativi digitalizzati

Alla consegna di tutti i Modelli e degli Elaborati, la proprietà degli stessi si intende trasferita in via esclusiva alla Stazione Appaltante, ivi compresi eventuali diritti. In particolare quanto prodotto dall'Affidatario resterà di piena ed assoluta proprietà della Stazione Appaltante la quale, potrà utilizzarlo come crede, come pure integrarlo nel modo e con i mezzi che riterrà opportuni con tutte quelle varianti ed aggiunte che, a suo insindacabile giudizio, saranno riconosciute necessarie, senza che l'affidatario possa sollevare eccezioni di sorta. Con la sottoscrizione del Piano di Gestione Informativa, l'Affidatario autorizza la Stazione Appaltante all'utilizzo e alla pubblicazione dei dati e delle informazioni presenti nei modelli prodotti per finalità anche diverse da quelle previste dal presente incarico. L'utilizzo dei dati sopra indicati da parte dell'Affidatario è consentito previa espressa autorizzazione da parte della Stazione Appaltante.

## 4.9 Modalità di condivisione dei dati, dei modelli, dei documenti e degli elaborati

Sarà onere dell'Aggiudicatario predisporre un ambiente di condivisione dei dati con le caratteristiche di seguito riportate, garantendone la piena fruibilità del Committente con adeguato numero di accessi che tengano in considerazione anche della Direzione Lavori, sino alla consegna e collaudo dell'opera.

L'Aggiudicatorio sarà anche responsabile della conservazione e mantenimento della copia di tutte le informazioni di progetto in una risorsa sicura e stabile all'interno della propria organizzazione.

L'ambiente di condivisione dei dati, così come previsto dalla UNI 11337:2017 – parti 1 e 5, sarà la piattaforma informatica a supporto del corretto flusso di informazioni tra i diversi soggetti partecipanti alla realizzazione dell'opera di cui all'oggetto. In particolare, con riferimento all'ambiente di condivisione dei dati (ACDat), dovranno essere garantiti i seguenti obiettivi minimi:

- accessibilità dell'ACDat tramite server web, regolamentata con differenti tipologie di accesso ai dati in termini di permessi per garantire l'accesso alle figure coinvolte nel processo e la possibilità di consultazione ed estrazione della copia dei documenti, degli elaborati, nonché dei modelli ivi presenti nello stato di pubblicazione;

- garanzia di sicurezza e riservatezza dell'archivio (ACDat), in riferimento alle modalità di gestione dei dati in esso contenuti;

- tracciabilità dei dati e versioni dei documenti digitali/modelli e delle operazioni effettuate con successione storica delle revisioni apportate a tali dati;

Inoltre si richiede all'Affidatario:

- aggiornamento continuo da parte dell'affidatario, durante gli stadi e le fasi del processo, dell'archivio di condivisione dati (ACDat), in relazione al continuo sviluppo degli elaborati/modelli/documenti digitali contenuti;

- implementazione, nella piattaforma utilizzata quale ACDat, di una interfaccia per la visualizzazione e l'eventuale commento (markups e isses) dei modelli federati;

- consultazione attraverso l'ACDat dei modelli e/o dei documenti tramite dispositivi mobile;

In ogni caso, l'ACDat fornisce solo un supporto alla comunicazione tra le parti, ma NON sostituisce in nessun modo le tradizionali comunicazioni previste dalla norma in vigore.

#### *4.9.1 Struttura delle cartelle di progetto*

L'affidatario dovrà utilizzare una struttura dell'ACDat rispetto alle 4 aree canoniche (Lavorazione– Condivisione – Pubblicazione – Archiviazione – ISO19650) o nel caso più granulare rispetto alle 4 aree canoniche.

Nella propria oGI l'affidatario dovrà dettagliare a riguardo della struttura dell'ACDat:

- la struttura gerarchica e i nomi delle cartelle condivise con gli altri attori;

- le politiche di accesso;

- le responsabilità della struttura e degli accessi.

### 4.10 Modalità di programmazione e gestione dei contenuti informativi di eventuali subfornitori e/o sub-esecutori

Quanto descritto nel presente Capitolato e come consolidato nel pGI, dovrà essere rispettato anche da eventuali sub-esecutori. La verifica dei dati, delle informazioni e dei contenuti informativi prodotti da tali sub-esecutori è condotta dall'Affidatario, in relazione alla specifica fase di realizzazione.

L'affidatario dovrà specificare nell´oGI il flusso e la procedura di validazione per i vari livelli di verifica, definendo:

• le modalità con cui i modelli, gli oggetti e/o gli elaborati vengono sottoposti a validazione in merito alla loro emissione, controllo degli errori e nuove necessità di coordinamento;

• i contenuti informativi oggetto di una periodica revisione;

• la frequenza con cui i contenuti informativi sono soggetti a revisione, non inferiore agli Stati di Avanzamento dei Lavori come definiti da progetto o richiesti dalla Direzione dei lavori.

### 4.11 Procedure di coordinamento e verifica dei modelli

L'Affidatario dovrà svolegere le procedure di validazione per i modelli, gli oggetti e gli elaborati, con riferimento alla norma UNI 11337:5.

La verifica di coordinamento dei modelli grafici dovrà essere eseguita in via automatizzata attraverso specifici software. A seguito della verifica dovranno essere redatti opportuni report con il risultato delle analisi (i report e i modelli correlati dovranno essere consegnati alla Stazione Appaltante).

Nella fase di realizzazione (progetto costruttivo) dovranno essere risolte tutte le collisioni significative (cioè esclusi i casi di falsi positivi o collisioni risolvibili in fase di cantiere) che potrebbero insorgere durante questa fase di modellazione.

L'Aggiudicatario dovrà aggiornare il modello in accordo con il progredire dei lavori e consegnare alla stazione appaltante il modello ad ogni SAL programmato in accordo con il Capitolato Speciale d'Appalto o comunque secondo le richieste della Stazione Appaltante.

## 4.12 Modalità di gestione della programmazione (4D)

Nella presente sezione il committente richiede all'affidatario di gestire i dati di programmazione, la schedulazione delle risorse e altro dell'intervento tramite l'utilizzo di strumenti che possano essere collegati ai modelli grafici.

Al fine di pianificare e controllare le attività per la realizzazione del servizio, l'aggiudicatario dovrà predisporre un sistema di riferimento basato su WBS (Work Breakdown Structure) create dalle milestone relative allo specifico intervento, in funzione delle fasi in cui esso si articola, in accordo col committente, che permetterà di analizzare i dati quantitativi relativi alla pianificazione e all'effettivo avanzamento della progettazione, dei lavori e delle attività propedeutiche all'esecuzione delle lavorazioni. Il modello informativo dovrà essere quindi impostato prevedendo tale suddivisione. Si dovrà predisporre un collegamento degli Oggetti 3D del modello alle relative attività della WBS, così da creare una corrispondenza opportuna tra il modello e il programma dei lavori.

## 4.13 Modalità di gestione informativa economica (5D)

Nella presente sezione il committente richiede all'affidatario di gesitre i dati di costo dell'intervento tramite l'utilizzo di strumenti che possano essere collegati ai modelli grafici.

Il modello informativo dovrà essere sviluppato prevedendo la suddivisione delle opere, in maniera da consentire aggregazioni e/o disaggregazioni secondo la suddivisione per WBS, e dovrà essere sviluppato ad un livello di definizione tale che ogni elemento sia identificato in forma, tipologia, qualità, dimensione e prezzo. Ad ogni oggetto del modello informativo dovranno essere associati parametri coerenti con la WBS completa delle voci di computo in modo da garantirne una univoca correlazione.

## 4.14 Modalità di archiviazione e consegna finale di modelli

Una volta superata la verifica di congruenza con lo stato di fatto, tutti i dati, le informazioni e i contenuti informativi verranno archiviati nella directory Archiviazione garantendone l'accessibilità alla Stazione Appaltante, almeno sino alla fine dell´incarico, momento in cui l´Affidatario è tenuto a consegnare alla Stazione Appaltante una copia dei dati, delle informazioni e dei contenuti informativi ivi contenuti, compresi i modelli informativi in formato proprietario e in formato aperto. Al termine dei lavori, i dati, le informazioni e i contenuti informativi diventano proprietà della Stazione Appaltante. In particolare, quanto prodotto dall'Affidatario resterà di piena ed assoluta proprietà della Stazione Appaltante la quale, pur nel rispetto del diritto di autore, potrà utilizzarlo come crede, come pure integrarlo nel modo e con i mezzi che riterrà più opportuni con tutte quelle varianti ed aggiunte che, a suo insindacabile giudizio, saranno riconosciute necessarie, senza che l'affidatario possa sollevare eccezioni di sorta. Con la sottoscrizione del Piano di Gestione Informativa, l'Affidatario autorizza la Stazione appaltante l'utilizzo e alla pubblicazione dei dati e delle informazioni presenti nei modelli prodotti per finalità anche diverse da quelle previste dal presente incarico. L'uso dei dati sopra indicati da parte dell'affidatario è consentito previa espressa autorizzazione da parte della Stazione Appaltante.