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DIGITAL TRANSITION OF THE BUILT
ENVIRONMENT – AN INFORMATION SYSTEM
FOR REAL ESTATE MANAGEMENT IN PUBLIC
ITALIAN UNIVERSITIES

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Author
Daniele Accardo

Tutors

Prof. Giuseppe Martino Di Giuda

Prof. Lavinia Chiara Tagliabue

The Coordinator of the PhD Program

Prof. Stefano Bresciani

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TESI PRESENTATA DA:

Daniele Accardo

SUPERVISORI:

Prof. Giuseppe Martino Di Giuda
Prof. Lavinia Chiara Tagliabue

COORDINATORE DEL DOTTORATO:

Prof. Stefano Bresciani

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Abstract

The Architecture, Engineering, Construction, and Operation (AECO) sector is responsible for approximately 40% of global emissions, as well as the exploitation of resources and the generation of waste. Therefore, to limit emissions and reduce the use of new resources, it is necessary to reconsider the traditional approach to the construction industry, land use and construction management.

In this context, numerous countries have enacted new regulations with the objective of making the AECO sector more sustainable. The European Union has established common targets for the reduction of energy consumption and carbon dioxide emissions. The simultaneous increase in the availability of digital tools and the accumulation of large amounts of data offers the AECO sector, which is one of the least digitised in the world, the opportunity to support the necessary energy transition with new tools and technologies.

The concept of the campus as a living laboratory has been embraced by many universities, which have encouraged experimentation on campus. This is because universities contribute significantly to the global environmental footprint and because, often like small cities, they are the ideal laboratory for testing new solutions. A Campus as Living Lab is defined as an integrated organisational, technological and socio-economic approach in which a university uses its assets and facilities to investigate, test or demonstrate innovative technologies or services by, with and for their community. Consequently, university campuses represent optimal settings for piloting sustainability initiatives.

The objective of this research is the design and development of an information system for strategic decision support in the context of the case study of the University of Turin, while also evaluating the impact of introducing a new digital tool on processes and organisational structure to facilitate a successful digital transition.

In the case of public universities, organisational units are frequently decentralised and often managed as separate entities. This has resulted in a highly fragmented data landscape, with data sources being managed and stored in different ways in different parts of the organisation. This fragmentation has led to the emergence of data silos, comprising individual databases, repositories or systems that are not connected, making it difficult to access data and perform holistic analysis.

In response to these challenges, an Information System was developed using the Design Science Research Methodology. The system was designed with the objective of addressing some of the identified organisational problems and to assist facility management and maintenance operations. Additionally, it was developed to oversee teaching and workspace allocation. The construction of such a platform necessitates the integration of disparate data sets to generate actionable insights for decision-makers through the utilisation of Business Intelligence tools.

The consequences of the introduction of a new Asset Information Management System (AIMS) for the large building stock of the University of Turin, integrating different information (BIM, GIS, maintenance, occupancy, timetables, sensor data, etc.) are then investigated. In order to study the optimal implementation method and the impact on the current processes, an analysis was carried out on the University of Turin's Enterprise architecture in its initial state, proposing then a new architecture developed using the modelling language ArchiMate.

The result is a meticulous examination of extant processes and a novel Reference Architecture that considers business requirements, information systems and associated applications, and the requisite technological infrastructure for implementing the AIMS. Therefore, significant disruption to current practices can be avoided, while proposing solutions for the management of the transitional phase towards the new approach, including guidelines to support the success of the change.

Keywords: Information System, Asset Management, Facility Management, Building Information Modelling (BIM), Business Intelligence (BI), Enterprise Architecture, Organisational Change Management.

Sommario

Il settore Architettura, Ingegneria e Costruzioni è responsabile di circa il 40% delle emissioni globali, oltre che dello sfruttamento di materie prime e della generazione di rifiuti. Per limitare le emissioni e ridurre l'uso di nuove risorse, è necessario riconsiderare l'approccio tradizionale all'industria delle costruzioni, all'uso del territorio e alla gestione degli edifici.

In questo contesto, numerosi Paesi hanno emanato nuove normative con l'obiettivo di rendere il settore AEC più sostenibile. L'Unione Europea ha stabilito obiettivi comuni per la riduzione del consumo energetico e delle emissioni di anidride carbonica. Il contemporaneo aumento della disponibilità di strumenti digitali e l'accumulo di grandi quantità di dati offre al settore AEC, che è uno dei meno digitalizzati al mondo, l'opportunità di sostenere la necessaria transizione energetica con nuovi strumenti e tecnologie.

Il concetto di campus come laboratorio vivente è stato abbracciato da molte università, che hanno incoraggiato la sperimentazione nei campus. Questo perché le università contribuiscono in modo significativo all'impronta ambientale globale e perché, spesso come le piccole città, sono il laboratorio ideale per testare nuove soluzioni. Il Campus come Living Lab è definito come un approccio organizzativo, tecnologico e socioeconomico integrato in cui l'Università utilizza i propri beni e le proprie strutture per studiare e testare tecnologie o servizi innovativi per la propria comunità. Di conseguenza, i campus universitari rappresentano un ambiente ottimale per la sperimentazione di iniziative di sostenibilità.

L'obiettivo di questa ricerca è l'ideazione e lo sviluppo di un sistema informativo per il supporto alle decisioni strategiche nel contesto del caso di studio dell'Università di Torino, valutando anche l'impatto dell'introduzione del nuovo strumento digitale sui processi e sulla struttura organizzativa per facilitare una transizione digitale di successo.

Nel contesto delle università pubbliche, le unità organizzative sono spesso decentrate e gestite come entità separate. Questo ha portato ad un panorama di dati molto frammentato, con fonti di dati gestite e archiviate in modi diversi in diverse aree dell'organizzazione. Questa frammentazione ha portato alla nascita di silos di dati, che comprendono singoli database, archivi o sistemi non collegati tra loro, rendendo difficile l'accesso ai dati e l'esecuzione di analisi olistiche.

In risposta a queste sfide, è stato sviluppato un sistema informativo utilizzando la metodologia di ricerca "design science". Il sistema è stato progettato con l'obiettivo di risolvere alcuni dei problemi organizzativi individuati e di assistere la gestione degli edifici e le operazioni di manutenzione. Inoltre, è stato sviluppato per supervisionare l'allocazione degli spazi di lavoro e delle aule per le attività didattiche. La costruzione di una piattaforma di questo tipo richiede l'integrazione di insiemi di dati eterogenei

per generare informazioni utili ai decisori attraverso l'uso di strumenti di business intelligence.

Vengono successivamente analizzate le conseguenze dell'introduzione di un nuovo Asset Information Management System (AIMS) per il grande patrimonio edilizio dell'Università di Torino, che integri diverse informazioni (BIM, GIS, manutenzione, occupazione, orari, dati dei sensori, ecc. Per studiare il metodo di implementazione ottimale e l'impatto sui processi attuali, è stata condotta un'analisi sulla Enterprise Architecture dell'Università di Torino nel suo stato iniziale, proponendo poi una nuova Architettura sviluppata utilizzando il linguaggio di modellazione ArchiMate.

Il risultato è un esame meticoloso dei processi esistenti e una nuova Architettura di Riferimento che considera i requisiti di business, i sistemi informativi e le applicazioni associate, nonché l'infrastruttura tecnologica necessaria per l'implementazione dell'AIMS. Pertanto, è possibile evitare di alterare in modo significativo le pratiche attuali, proponendo al contempo soluzioni per la gestione della fase di transizione verso il nuovo approccio, comprese le linee guida per sostenere il successo del cambiamento.

Keywords: Sistemi Informativi, Asset Management, Facility Management, Building Information Modelling (BIM), Business Intelligence (BI), Enterprise Architecture, Gestione del cambiamento organizzativo.

List of Abbreviations

A

AECO	Architecture, Engineering, Construction and Operation
AM	Asset Management
AMS	Asset Management System
AIMS	Asset Information Management System

B

BIM	Building Information Modelling
BI	Business Intelligence
BPM	Business Process Management
BPMS	Business Process Management System
BS	Building and Sustainability Directorate

C

CM	Change Management
CUD	Centralised University Database

D

DAT	Data Analysis Team
DS	Design Science
DSR	Design Science Research
DSRM	Design Science Research Methodology
DTs	Digital Twins

E

EA	Enterprise Architecture
ESS	Educational and Student Services Directorate
ESG	Environmental Social and Governance

G

GIS	Geographic Information System
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H

HR	Human Resources Directorate
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I

ICT	Information Systems, Portal and E-learning Directorate
IM	Information Management
IRs	Information Requirements
IS	Information System
IT	Information Technology

O

O&M	Operation and Maintenance
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R

RA	Reference Architecture
REM	Real Estate Management

S

SPFM	Security, Property and Facility Management Directorate
SSM	Soft Systems Methodology
SDGs	Sustainable Development Goals

T

TOGAF	The Open Group Architecture Framework
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U

UCD User Centred Design

V

VPL Visual Programming Language

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1

CHAPTER

Introduction

The objective of this chapter is to introduce the background and the principal issues that will be discussed and analysed in the subsequent chapters, as well as to offer a general overview of the research field.

1.1 Building stock management

Managing building stock within organizations has become a significant focus in the last few years. Several factors underscore the critical importance of real estate management. Primary among these are concerns related to energy consumption and carbon dioxide emissions, with buildings accounting for approximately 40% of energy use and 30-35% of emissions [1]. Indeed, Cities and governments worldwide grapple with the impacts of climate change that presents multifaceted challenges requiring innovative solutions in building management. Public organizations are increasingly tasked with reducing greenhouse gas emissions, improving energy efficiency, and ensuring the resilience of infrastructure against extreme weather events.

The United Nations Sustainable Development Goals (SDGs) provide a comprehensive framework for addressing these challenges. Specifically, SDG 11 (Sustainable Cities and Communities) [2] and SDG 13 (Climate Action) [3] emphasize the importance of sustainable building practices and climate resilience in urban development. Public organizations play a pivotal role in localizing these goals by implementing strategies that promote sustainable infrastructure and community resilience. The integration of ambient intelligence and data-driven management systems can enhance decision-making processes, enabling public organizations to effectively monitor and control environmental impacts. Additionally, space management issues, which became particularly evident during the COVID-19 pandemic, have gained new dimensions with the advent of agile working policies [4]. Furthermore, recent conflicts in Europe and worldwide have disrupted logistics and material supply chains, leading to increased energy prices [5]. Consequently, effective management of various aspects of real estate assets - such as space utilization, energy consumption, and emissions - has

become essential for both public and private institutions with extensive property portfolios.

1.1.1 Asset Management and Facility Management

In the context of managing substantial portfolios of real estate, both Asset Management (AM) and Facility Management (FM) assume pivotal roles, though with distinct focal points and responsibilities. A comprehensive knowledge of these roles and their distinctions is indispensable for optimising the value and functionality of real estate assets.

The term "Asset Management" is used in the context of real estate to describe the strategic oversight of property investments, with the objective of maximizing returns and ensuring long-term value appreciation. The term AM is defined as a unified approach to extract value from asset systems. Following the establishment of its definition by the International Organization for Standardization in ISO 55000 [6], the term AM gained significant traction in the industry.

The role of the asset manager is to make investment decisions, conduct market research and manage financial performance. The overarching objective of asset management is to enhance the market value of the properties within a portfolio, thereby increasing the returns to the owner [7],[8]. Such activities include the regular inspection and assessment of the building's condition, the development of maintenance plans, the implementation of energy efficiency measures, and the monitoring of financial performance and investment returns [9],[10].

Summarizing, key responsibilities of an asset manager for public buildings and universities are as follows:

- *Investment Strategy*: Develop and implement strategies for acquiring, maintaining, and disposing of university properties to optimize the institution's resources and support its educational mission.
- *Market Analysis*: Conduct thorough research and analysis of the real estate market to forecast trends and identify opportunities that align with the university's strategic goals.
- *Financial Management*: Oversee budgeting, cash flow management, and financial reporting to ensure that university properties contribute positively to the institution's financial health.
- *Risk Mitigation*: Minimize risks associated with managing university properties, such as market fluctuations, regulatory changes, and potential disruptions in campus operations.

Several studies have been conducted to explore the applications of AM in various industries, including the construction industry [11]–[13]. These studies have highlighted the potential benefits of adopting asset management practices in construction, such as improving project planning and scheduling, optimizing maintenance strategies, enhancing asset performance and reliability, minimizing downtime and disruptions, and optimizing resource allocation. Furthermore, the digitalization of AM has appeared as a significant trend in the construction industry. This trend involves the use of digital technologies, such as Building Information Modelling (BIM), Internet of Things (IoT) devices, and data analytics, to collect and

analyse data about building assets in real-time [13].

Facility management (FM) is a pivotal aspect of building stock management. Effective FM is vital for guaranteeing the seamless operation and upkeep of buildings, as well as enhancing the overall quality of life for occupants. [14]. FM encompasses a variety of services, including security, cleaning, repair and maintenance and general management. The provision of these services is crucial for ensuring the functionality and safety of the building, as well as for creating a pleasant living or working environment for occupants. The field of facility management is concerned with the operational aspects of maintaining and enhancing the physical environment of real estate properties. The role of the facility manager is to ensure that buildings and their systems are safe, efficient, and compliant with regulations. In contrast to asset management, facility management is more operational and service oriented [15].

The following duties are of particular importance for facility managers:

- *Oversight of building systems*: including heating, ventilation, air conditioning (HVAC), lighting, and security, with the aim of ensuring optimal operational efficiency;
- *Space Management*: devise and implement strategies to optimise the utilisation of space within buildings, thereby enhancing functionality and user comfort;
- *Safety and Compliance*: ensure compliance with health, safety, and environmental regulations;
- *Cost Management*: reduce operational costs through the implementation of energy-efficient practices and process improvements.

The Table 1 shows a summary of the main differences between Asset Management and Facility Management in terms of primary focus, scope, objective, responsibility.

Table 1: Differences between Asset Management and Facility Management.

Aspect	Asset Management	Facility Management
Primary Focus	Maximizing investment returns and property value	Ensuring operational efficiency and safety of facilities
Scope	Financial performance and strategic investment	Day-to-day operations and maintenance of physical assets
Objective	Increase net worth through strategic asset handling	Improve workplace environment and operational effectiveness
Responsibility	Financial analysis, market research, risk management	Maintenance, compliance, space planning

Eventually, the effective management of large real estate portfolios hinges on the integration of both AM and FM strategies. The objective of AM is to guarantee the

financial viability and strategic alignment of properties with the investment goals of the organisation. FM, on the other hand, is concerned with ensuring operational efficiency and users' satisfaction.

The importance of AM in the context of large real estate portfolios concentrate on financial performance and strategic growth, asset management facilitates the maximisation of returns and ensures the long-term appreciation of property values [16].

The importance of FM lies in its ability to maintain the physical and operational aspects of properties, thereby ensuring users satisfaction, operational efficiency, and compliance with regulations, which in turn supports the asset's value [17].

In conclusion, while AM and FM have distinct roles, they are complementary in managing large real estate portfolios. Together, they ensure that properties are both financially rewarding and operationally sound, contributing to the overall success of real estate investments.

In addition to the operational and environmental aspects, building stock management is also of great importance for ensuring the long-term financial sustainability of real estate assets. With the increasing focus on sustainable practices and ESG standards, real estate asset managers and institutional investors are under pressure to demonstrate responsible and efficient management of building stock.

Moreover, the evolving nature of work patterns, particularly in the aftermath of the global pandemic caused by the SARS-CoV-2 virus, has prompted a revaluation of space management strategies. The transition towards remote work and flexible office arrangements has highlighted the necessity for adaptable and multifunctional spaces within buildings. This, in turn, has implications for facility management, as the necessity for dynamic and responsive building environments becomes increasingly apparent.

As the intricacies and interconnections within the domain of building stock management continue to expand, it is of paramount importance for stakeholders to adopt comprehensive and forward-thinking approaches to address the multifaceted challenges and opportunities inherent to this field.

1.1.2 University Campus Management

One area in which the application of AM and FM has been explored is in the field of university campus management [18]. The implementation of AM and FM practices enables universities to effectively manage their extensive campus buildings and infrastructure.

The management of university campuses is a complex field of application that involves addressing a variety of challenges and implementing best practices to ensure efficient and sustainable operations. The existing literature on this subject explores the different types of campuses and the specific issues they face, with a particular focus on the European context.

In the European context, as well as in many other parts of the world, the three most common types of university campus are as follows:

- *Traditional campus*: these campuses are typically situated in suburban or rural areas and are confronted with several challenges, including those related to infrastructure maintenance, sustainability and resource allocation. The

management of large physical spaces and the assurance of accessibility and safety represent significant concerns. Research conducted by [19] underscores the importance of sustainable practices in traditional campus settings, emphasising the necessity for the implementation of comprehensive sustainability indicators and dimensions.

- *Urban campus*: city centres present several challenges, including space constraints, high operational costs and the need to integrate with the urban environment. Additional issues include transportation, noise and pollution. [20] discuss the potential for urban campuses to adopt integrated environmental management practices to address these issues effectively.
- *Virtual campus*: the advent of online education has led to a notable increase in the prevalence of virtual campuses. These institutions must address several challenges, including ensuring the reliability of their digital infrastructure, protecting their systems from cyber threats and providing students with equitable access to technology. In their study, [21] examine the integration of technology in higher education, underscoring the necessity for faculty training and support to optimise digital learning environments.

The present study is concerned with the management of public real estate assets and, as a consequence, it is not within the scope of this investigation to consider the case of virtual campuses. Nevertheless, an analysis of the first two types of campuses reveals that they share common challenges: sustainability, integration of new technologies, and student management. In terms of sustainability practices, universities are increasingly emphasising issues such as carbon footprint reduction and the implementation of green building standards. A systematic review by [20] emphasises the importance of sustainability in campus management, and highlights the necessity for a holistic approach to environmental stewardship.

Regarding the technological aspect, it is of paramount importance to integrate technology into the delivery of education and the operations of academic campuses. This encompasses the administration of IT infrastructure, the assurance of cybersecurity, and the provision of assistance for digital learning environments. The research conducted by [22] highlights the difficulties encountered by higher education institutions in developing intelligent campuses with the objective of improving efficiency and productivity.

Finally, regarding students, universities are required to manage diverse student populations, which necessitates the implementation of strategies that address issues of equity, inclusion, and support for international students. The utilisation of big data analytics is becoming a key approach to personalise student services and enhance outcomes [23].

In examining the existing literature on the most effective initiatives implemented in the European context, several noteworthy examples emerge. A considerable number of European universities have established themselves as pioneers in the field of sustainability, implementing comprehensive strategies aimed at reducing energy consumption and promoting environmental stewardship. The study by [24] presents a model of sustainable university management, elucidating the factors that influence the implementation of sustainability practices. The formation of collaborative relationships with private enterprises has proven to be an effective strategy for the improvement of campus facilities and services, particularly in urban contexts where spatial and resource

constraints are prevalent [25]. European universities have invested in robust IT systems to support both administrative functions and academic activities, ensuring seamless operations and enhancing the student experience [26]. It is common practice for universities in Europe to engage with their local communities through the implementation of outreach programmes and the formation of strategic partnerships. This approach serves to foster a sense of belonging and mutual benefit between the university and the local community [27].

In conclusion, the management of university campuses entails the resolution of a multitude of challenges that are distinctive to each campus type. European universities have exhibited efficacious management practices through a concentration on sustainability, technology integration, and community engagement. These endeavours not only augment the operational efficacy of campuses but also facilitate their role as pioneers in education and innovation.

1.2 Digital transition of built environment

The built environment is undergoing a substantial digital transition. This shift is driven by the necessity to enhance efficiency, sustainability, and competitiveness in response to global challenges such as climate change and urbanisation. To understand digital transition, it is necessary to introduce three key concepts: digitisation, digitalisation, and digital transformation. An understanding of these concepts is essential for stakeholders seeking to leverage digital technologies to improve the built environment use and management [28].

Digitisation “is the process of changing from analogue to digital form” [29]. It concerns the transformation of an object from an analogue to a digital format (e.g., a paper document is transformed into a digital format). This encompasses the conversion of tangible blueprints into digital formats and the utilisation of tools such as BIM for the capture and administration of data pertinent to construction projects. The digitisation of data facilitates enhanced accessibility, accuracy and efficiency, thereby enabling stakeholders to make informed decisions in a timely manner. As indicated in [30] digitisation represents a fundamental aspect of the digital transformation of the construction industry. In the context of enterprise, digitisation is a crucial process for dealing with analogue information and “paper-based” (i.e., analogue) procedures. However, it is essential to recognise that it is the information that is being digitised, not the procedures themselves. This is where digitalisation becomes a significant factor.

Digitalisation means leveraging digital technologies to manage processes in an innovative way to secure new opportunities for value creation (e.g., ensuring a better customer experience, creating new sources of revenue) as well as efficiency improvements. Digitalisation therefore also leverages digitisation and, more generally, digital technologies, but has a broader scope. It is not limited to the simple scanning of documents but concerns a profound rethinking of processes. The process of digitalisation entails the incorporation of digital technologies into existing operational procedures and in the AECO sector, this encompasses the utilisation of digital tools to optimise construction workflows, enhance project management, and facilitate improved collaboration among stakeholders. The digitalisation of processes can result in notable enhancements in productivity, safety and sustainability, due to the real-time sharing of data and the capacity for prompt decision-making. A review of the literature in [31] indicates that digital technologies can facilitate sustainability across the various stages of the construction lifecycle.

Digital transformation is quite distinct from digitalisation and goes beyond. Digital transformation is the utilisation of digital technology to effect a transformation in the operational processes of an organisation, encompassing all levels of the organisational structure. It is the progression of business processes and models to capitalise on the opportunities afforded by digital technology. This encompasses alterations to the way employees perform their duties, the methods by which customers are provided with services, and the operational procedures of the company. Digital transformation represents a further evolution of digitisation and digitalisation, whereby digital technology is harnessed to effect a comprehensive transformation of business operations. The concept of digital transformation implies a comprehensive alteration in how the built environment functions. It necessitates a reconsideration of business models, processes, and strategies with a view to optimally exploiting digital

technologies. This transformation necessitates a cultural shift within organisations, with an emphasis on collaboration, innovation and a customer-centric approach. [32] demonstrates how digital transformation is reshaping the construction industry, enabling green innovation and sustainability.

1.2.1 New digital tools in the AECO Sector

The advent of recent technologies and the concomitant increase in the volume of data has precipitated significant transformations across a range of sectors, including transport, manufacturing, and automotive, among others. Despite the pervasive adoption of digital tools across most sectors, the AECO sector remains one of the least digitised [33].

A review of the literature reveals that certain technologies are indeed contributing to the gradual transformation of this reality. These include Building Information Modelling (BIM), Geographic Information Systems (GIS) and the Internet of Things (IoT).

It is evident that the role of governments can facilitate the success of digitalisation. The primary rationale for the introduction of Building Information Modelling (BIM) into construction processes is often its gradual imposition through its application in public works. In order to achieve the effective digital implementation of processes, it is essential that governments and institutions develop and implement strategies that are tailored to their specific needs and able to adapt to changing circumstances [34],[35].

The European Directive 2004/18/EC, which was subsequently superseded by the Directive 2014/24/EU in 2014, constituted the foundation for the introduction of BIM and digitalisation in numerous European countries. This enabled Member States to "require the use of specific electronic tools, such as electronic simulation tools for building information or similar tools." (Art. 22, paragraph 4) through the implementation of dedicated legislative measures.

In Italy, the directive was implemented through Legislative Decree (L.D.) No. 50/2016 [36], otherwise known as the "Contracts Code". This was followed by the Ministerial Decree (M.D.) No. 560/2017 [37], which implemented the aforementioned L.D. No. 50/2016. The recent L.D. No. 36/2023 [38] replaced the aforementioned L.D. No. 50/2016, reinforcing the importance of digitalisation throughout the entire procurement lifecycle. This decree outlines the gradual, mandatory introduction of Building Information Modelling (BIM) in public procurement, requiring public clients to establish an "Organizational Act" involving a comprehensive plan for staff training, hardware and software acquisition and maintenance for digital decision-making and information management processes. It emphasises the importance of an organisational framework structuring the control and management of information and related aspects throughout the asset lifecycle. Moreover, the new Contracts Code was preceded by the M.D. No. 312/2021, which stated that information models should be accompanied by decision-support workflows.

1.2.2 BIM and GIS

Building Information Modelling (BIM) was developed with the objective of enabling the management of all phases of a building project, from the initial design and construction stages to the subsequent maintenance and eventual decommissioning. This is achieved through the use of parametric models and the incorporation of relevant data [39]. The ability of Building Information Modelling (BIM) to facilitate collaboration and information sharing between different stakeholders is seen as a further benefit in the construction industry, contributing to greater efficiency [40]. BIM was also defined as "the digital representation of the physical and functional characteristics of a facility". In this regard, it can be seen to function as a shared knowledge resource for information pertaining to a given facility, thereby providing a reliable basis for decision-making throughout the facility's life cycle, from its inception onwards [41].

BIM models can gather a multitude of data pertinent to the construction industry, including geometric characteristics such as measurements and topological attributes such as the relationships between building elements. Additionally, they can store semantic data, which encompasses the codes associated with the various elements and the properties of the materials used in the construction process [42]. The incorporation of information into the BIM model allows for rapid visualisation, interrogation and spatial positioning within both two-dimensional and three-dimensional contexts. This facilitates enhanced decision-making through the utilisation of insights derived from the model [43].

It can be reasonably deduced that if information is correctly incorporated into the BIM model, the model can be utilised effectively during the O&M phase. Furthermore, the implementation of Building Information Modelling (BIM) for asset and facility management yields additional advantages, including enhanced customer service, reduced expenditure and time through more effective planning, and greater data consistency [44].

A Geographic Information System (GIS) enables the examination of spatial data using customised parameters that encompass both spatial and non-spatial attributes. It provides access to extensive data repositories stored within a relational database [45]. Geographic information systems (GIS) have emerged as a means of acquiring, safeguarding, retrieving, transforming, examining, and replicating spatial data at the territorial level [46].

Geographic information systems (GIS) have become an indispensable tool for facility management, enabling professionals to efficiently manage and analyse spatial data pertinent to building operations and maintenance activities [47]. Moreover, the utilisation of GIS facilitates the visualisation of data on cartographic representations, thereby optimising the decision-making process through the provision of a spatial context [48]. The utilisation of spatial context allows for the identification of patterns, the optimisation of space utilisation and the assessment of the impact of location on facility management operations. Furthermore, GIS can be integrated with other FM systems, such as IoT and BIM, to create a comprehensive and holistic management approach.

1.2.3 GeoBIM

BIM and GIS are undoubtedly behind the most promising methodologies and technologies in the AECO sector. The applications of methodologies and technologies exploiting these have been manifold in the field of building digitisation and land management. In addition to their separate applications, the joint use of these technologies (i.e., GeoBIM) has been the subject of investigation and application since 2010, with the objective of exploiting the characteristics of both. This integration is capable of supporting data integration, urban management and strategic decision making [49], offering a wide range of benefits and practical applications [50].

Nevertheless, there remains a degree of incompatibility between BIM and GIS. Although both systems employ information models, their utilisation of these models is distinct, exhibiting varying degrees of granularity [51]. The structure of a geodatabase is designed to manage and analyse spatial data, organizing information into feature classes, raster datasets, and tables that support spatial relationships and geographic queries. In contrast, BIM databases focus on detailed building components and their relationships, using parametric models to represent physical and functional characteristics of structures. Thus, while BIM facilitates information management (IM) at the micro-level, offering detailed descriptions of individual buildings and components, GIS extends this capability to the macro-level, providing information about the surrounding districts and buildings [52]. The principal strength of GeoBIM is its capacity to facilitate digital asset management (AM) at varying levels of detail, from the micro-scale of individual asset components to the territorial macro-scale. However, the inherent disparities in levels of detail and information pose challenges to BIM-GIS integration. These challenges encompass several aspects, including user interfaces, spatial dimensions, coordinate systems, standardised levels of detail, geometric and semantic representations, granularity levels, information storage, and access methods. A substantial body of research has been dedicated to the topic of BIM-GIS interoperability, with encouraging outcomes [53].

In accordance with the findings of [54], the principal challenges can be summarised as follows:

- *Standardisation and alignment of data:* the objective is to guarantee that all items and data are integrated in a seamless manner and adhere to the specified feature class requirements. These requirements encompass a range of aspects, including georeferencing, accuracy, geometric and semantic representation, and level of detail.
- *Ability of different software systems to communicate and work together:* the structuring of metadata in a clear and comprehensive manner facilitates its correct utilisation across a range of software platforms. The adoption of open standards such as Industry Foundation Classes (IFC) for BIM and CityGML for GIS could facilitate interoperability and consistency across diverse datasets, thereby streamlining the process of converting datasets into a uniform format [55]. Of the numerous open standards currently in use, IFC and CityGML are arguably the two most widely employed.
- *Common guidelines:* It is recommended that the adoption of GeoBIM models be encouraged among stakeholders, as opposed to the utilisation of BIM and GIS in isolation. This approach has the potential to minimise data loss during information exchanges.

Furthermore, three relevant domains in which the application of GeoBIM is appropriate are planning and design (P&D), operations and maintenance (O&M), and the demolition phase [56].

The benefits of integrating BIM and GIS for streamlining IM across the entire lifecycle enhancing decision-making in the pre-construction phase are emphasised in [57]. Other research has pointed out that during the O&M phase, activities such as AM and FM benefit significantly from BIM-GIS integration by improving risk management and prevention, energy management, and security management [50],[58]–[61].

Despite the potential benefits and the necessity for “location and spatial links” [62], the limited exploration of GeoBIM within the AM domain was highlighted by [63]. This is partly due to the extensive and varied data requirements with diverse levels of detail, which present challenges in both acquisition and storage. Trying to solve the issue, an innovative method for condition assessment within the development of a GeoBIM model was proposed, demonstrating positive outcomes in data gathering, visualization, and analysis. This approach enriches AM decision-making processes [63].

Regarding the demolition phase, GeoBIM can optimize material disposal management, thereby mitigating environmental impact and reducing costs. Furthermore, the integration of transportation networks and material data from BIM models into GIS systems for waste management presents potential for optimising resources and reducing costs [64].

The issue of data exchange between these systems has been the subject of several studies, which have identified three potential approaches for converting and integrating data within a GeoBIM framework [56]. These are:

- transitioning from BIM and GIS to a third system;
- from BIM to GIS;
- from GIS to BIM.

Of these, the route from BIM to GIS is regarded as the most efficacious, entailing the extraction of data from BIM and their importation into GIS. Similarly, numerous studies have reached a consensus that the combination of ESRI ArcGIS Pro® and Autodesk Revit® represents the most effective and widely adopted authoring solution for achieving BIM-GIS integration [56]. Moreover, [53] have emphasised the close interrelationship between BIM-GIS integration and other domains, including smart cities and Digital Twins development, as well as the IoT and AI [65]. They argue that BIM-GIS integration is regarded as the foundation of Digital Twins, a view supported by other studies [11],[63]. These studies demonstrate how the growing demand for Digital Twins (DTs) can further enhance BIM-GIS integration with complementary technologies, thereby facilitating a comprehensive understanding of how these technologies, when leveraged collectively, can significantly contribute to the advancement of smart cities and smart campuses.

1.2.4 Smart campuses

The extensive implementation of digital technologies and IoT networks in the construction industry is facilitating the realisation of the smart building concept, which in turn is paving the way for the advent of the smart city [66]–[68]. The integration of BIM-GIS and the advent of DTs facilitate the achievement of this goal. The resulting cognitive buildings are designed to autonomously react to environmental changes, thereby creating more resilient, proactive, and sustainable environments [66].

In recent times, a number of universities have adopted the concept of the smart city at the campus scale, with a particular focus on enhancing the still less-investigated O&M phase and providing a more satisfactory user experience and optimal resource utilisation [69]–[72]. It can be argued that university assets could be considered a "little city within a city," comprising a diverse population of users (e.g., students, professors, researchers, external individuals, facility managers, and administrative staff) and a range of services (e.g., classrooms, canteen, library, offices etc.) [73]. This dynamic and variable environment, comprising numerous interconnected elements, presents a significant challenge in terms of effective management [22]. The presence of a diverse range of users with varying objectives and schedules introduces a significant degree of unpredictability, both in typical scenarios and even more so in emergency situations, where the consequent stress of the situation can lead to erratic user behaviour [74].

[62] defines AM as the systematic process of maintaining, upgrading and operating physical assets. In Italian Universities AM and FM is frequently organised on fragmented and inaccessible databases, which are still document-based. This results in incomplete and asymmetrical information, which in turn leads to ineffective decisions and the use of resources in an inefficient manner, particularly during the O&M phase. [71] elucidate that this phase encompasses a period of over fifty years and is inherently challenging to manage due to the necessity for integrated, comprehensive data to be exchanged by a multitude of stakeholders. [75] assert that this phase represents the costliest aspect of the entire asset life cycle. Therefore, the effective management of space in accordance with occupancy patterns, considering user behaviour and the requisite supplies and services, has a significant impact on the usability of a building. In the event of inadequate management, this can result in the wastage of resources and an increase in costs associated with management, operations and maintenance [76]–[78]. It can be reasonably deduced that a dynamic and intelligent Information System, which is based on the principles of Information Management, has the potential to support decision-making processes and provide a more comfortable environment, while simultaneously reducing costs [63],[71],[79]. Nevertheless, the O&M phase is still lacking a comprehensive system for the management of information dispersed across multiple databases, which is particularly pertinent in the context of smart campuses [63],[71].

Despite the existence of numerous studies that have addressed the topic of smart campus development, yielding intriguing results [80], a singular, universally accepted definition of the term remains elusive. However, [81] have identified six principal characteristics that are commonly associated with the concept of a smart campus. These are: context-aware, data-driven, forecasting, immersive, collaborative, and ubiquitous. Therefore, data and their contextualisation are significant, as they facilitate the generation of more valuable information [71],[82] and promote more informed decision-making processes. It is therefore evident that a transition from disparate document-based methodologies to digital collaborative ones is imperative, offering

significant advantages in both the adoption of BIM and the digitalisation of processes [62],[83]–[85]. The development of an optimal IM strategy remains a significant challenge in enabling the transition towards full digital AM and FM. In particular, the creation of effective information protocols is essential to ensure the availability of accurate information in a timely manner, directed to the appropriate subject, and presented in the required format [86]. Furthermore,[87] posits that a comprehensive approach is essential to consider the multifaceted and interrelated elements that shape numerous conventional AM and FM operations (such as maintenance, cleaning, occupancy monitoring, and space optimisation), in addition to the optimal value and the ideal environment for users and owners. The utilisation of a smart campus through the implementation of user-friendly, data-driven and analytical digital tools was demonstrated to facilitate the actualisation of a holistic IM approach, which is beneficial for the optimisation of information flow among the numerous stakeholders involved throughout the complex asset lifecycle. In particular, the BIM-GIS integration and DT has the potential to significantly enhance decision-making processes during the O&M phase, which has yet to be fully investigated [63],[71]. It is noteworthy that many cases developed thus far, at both the international and national levels, have employed a "micro to macro" approach. This entails initiating the process with the BIM model of a single building, which is then utilized as a case study. Subsequently, the model is georeferenced through BIM-GIS integration, extending the procedure to encompass the entire asset [52],[60]. This approach is applicable to minor-sized assets, whereas a similar methodology for larger and more diffuse ones would necessitate years of development, thereby precluding the possibility of enhancements to reduce the environmental footprint and promoting higher resilience and sustainability. For example, [63],[88] employed a "macro to micro" approach, which is preferable when a rapid overview of the asset and its distribution is required in order to ascertain the overall consistency of the necessary interventions and optimisation options. It is important to note that there is no single, universally applicable method; rather, the approach depends on the purpose. In instances where an urgent analysis of the consistency and distribution of the entire asset is required in order to provide a strategic management tool, the "macro to micro" approach should be preferred [52].

1.3 Problem statement, objectives and research questions

The AECO sector is one of the least digitised in the world [89] and the introduction of BIM methodology is often seen by many stakeholders as a regulatory imposition rather than an opportunity to improve asset management [90]. Furthermore, there is a lack of holistic approaches that consider the introduction of BIM methodology and data sharing at an organisational level using information systems in parallel.

As previously outlined, challenges have been identified in the building management phase, particularly when dealing with groups of public buildings that host a multitude of different activities and are markedly distinct from each other in terms of building type. The difficulties encountered in the management phase are primarily attributable to the absence of suitable tools for the stakeholders involved. Furthermore, at the organisational level, there is a lack of a comprehensive view of Asset Management, which results in the compartmentalisation of tasks among various directorates. This situation, which is common within organisations, is also known as organisational silos and has the following disadvantages:

- *an inefficient allocation of resources*: space and assets may be under-utilised in one department while in others there may be an urgent need for more resources;
- *increased costs*: the difficulty in locating assets may lead to unnecessary purchases or unnecessary maintenance;
- *poor strategic planning*: the lack of a clear global vision of the resource situation limits the effectiveness of management decisions.

The aforementioned issues will be further elucidated in the subsequent chapters, where a more comprehensive investigation of the case study will enable the identification of the specific challenges within the organisational structure of the University of Turin.

On a general level, improvements in the management of the operational phase of buildings can bring multiple environmental benefits, such as reduction of greenhouse gases, increased building efficiency, reducing the need for new construction.

In the specific case of universities, or more generally for organisations managing large building portfolios, the value of a solution includes:

- *cost reduction*: a centralised system can help optimise the use of assets, reduce redundancy and improve maintenance planning;
- *improved operational efficiency*: improved and streamlined asset tracking and management processes can save time and reduce administrative burden;
- *improved strategic decision-making*: management has access to accurate, real-time data, enabling better informed decisions;
- *increased transparency*: a centralised system promotes transparency and accountability in Asset Management.

Managing and maintaining up-to-date and readily available data on properties is a long-standing challenge in property management [91]. Property management companies managing large portfolios often deal with distributed properties with different building types, spatial characteristics and use patterns (i.e., how the asset is used in terms of space allocation, occupancy, equipment and time). In this context, university real estate, especially in Italy, presents significant management problems due to

fragmented, incomplete and inaccessible databases, which hinder the accurate identification and optimisation of usage patterns and the standardisation of management processes [92],[93].

The University of Turin is a typical example of an Italian mega-campus that spans urban and suburban areas, acting as a “city within a city” with a large catchment area. This “urban hub” role offers activities beyond the academic, such as museums, exhibitions and events open to the public. These factors lead to management difficulties due to the size and complexity of the university and the diversity of its users (e.g., students, teachers, researchers, administrators, citizens, etc.). The management of such a large campus is complicated, involving historic and modern buildings, different types of buildings and land, and management approaches that vary according to the technical or administrative area under consideration. Furthermore, the management approach has relied heavily on siloed databases managed by different technical and administrative areas, and still relies heavily on document processes. As a result, information is often fragmented, making it difficult to provide accessible, up-to-date and correlated data of different types (such as space size, planned and actual occupancy and equipment) for timely and effective decisions on resource use, space management, quality of service and improvement of user experience. The involvement of internal and external users, such as citizens participating in activities in the urban environment, further complicates the university management processes.

Despite being the fourth largest university in Italy and having a large catchment area, the University of Turin current management practices are fragmented and poorly digitised, leading to a significant information asymmetry between stakeholders. This prevents an accurate understanding of the size and use of the university's assets. As a result, administrators urgently need a timely view of the consistency and distribution of assets across the territory, as well as a management system that is closely linked to the urban space. The management complexity described highlights the need for dynamic and proactive systems for the operation and maintenance (O&M) phase of University of Turin.

Having identified the principal challenges in the field of real estate management within the context of Italian universities, and with reference to the University of Turin, it is now necessary to define the objectives of the research project. Following an assessment of the issues and the availability of new tools, the initial objective is the design of an information system. In particular, the system is designed to address issues related to the management of space and buildings.

The implementation of a digitised, structured, data-driven and accessible management system at various levels, from territories to individual spaces, with consideration of the urban environment, will assist decision-makers in developing a more comprehensive understanding of the stock and utilisation of university heritage. The system should be accessible via a web-based application, which will provide visualisation of the geo-referenced university heritage through queryable 3D maps, combined with BIM models and analysis for monitoring and identification of usage patterns and optimisation potential. The principal objective of the Information System is to enhance information management and decision-making processes by furnishing more accessible, comprehensive and current data that can be disseminated across different levels of accessibility in accordance with the scope of management or the end user. Concurrently, the data management procedures can be delineated and formalised, thereby identifying the organisation's requirements and the nature of the information

exchanges between stakeholders. Even a minor enhancement in management procedures and the curtailment of superfluous resources can produce substantial savings, particularly when one considers that the annual expenditure for the administration of the University of Turin is estimated to be approximately forty millions of Euro.

Additionally, certain targets are the result of strategies that have been identified by the Italian government and those that have been set by University of Turin through its strategic plan. The Italian government has made the utilisation of Building Information Modelling (BIM) mandatory for public works with an estimated value exceeding one million of Euro, effective from first January 2025. Furthermore, it is promoting the integration of BIM in all tenders, irrespective of the financial outlay involved, through the incorporation of bonus criteria (as outlined in Law Decree 36/2023 and Ministerial Decree 312/2022). To facilitate the digital transition of its processes in preparation for this change, the University of Turin has developed its latest strategic plan. At present, the standards for the university's digital transformation process are being defined through the issuance of specific guidelines within the "Organisational Act". This document sets out the guidelines and requirements that University must adhere to in order to adopt digital practices and advanced information systems in the management of its assets. The objective of these guidelines is to guarantee efficiency, transparency and consistency in administrative and decision-making processes.

In order to ascertain the optimal configuration of the information system, it is essential to identify the specific objectives that should be focused on the stakeholders who will be mainly involved and the main recipients of the first results offered by the information system. Based on this analysis, the following figures are proposed, together with an outline of the envisaged use of the information system:

- The University Rector, given his functions, will have access to high-level analytical data and monitor the University's performance metrics. This enables strategic decision-making based on interconnected data. It is also possible for the Rector to request new information dashboards for new issues that emerge in the university context.
- Members of the Academic Senate, considering their competences in the areas of teaching, research, student services, courses, departments and facilities, will be able to view information dashboards on teaching and space utilisation. For topics of particular interest, it will be possible for Senate members or committee members to propose the creation of new information dashboards.
- The members of the Board of Directors, considering the activities of competence, will have at their disposal information dashboards at a strategic level. In particular, they will be able to make use of dashboards concerning the Athenaeum's real estate assets and the use of the Athenaeum's spaces in order to deliberate on the annual and three-year budget, making use of analytical data and metrics that are always up to date.
- The Director General, having responsibility for the overall management and organisation of services, instrumental resources and technical-administrative staff, will have information dashboards with analytical data and metrics that will support him in making decisions at a strategic level. In particular, it will be able to access information dashboards on the size of the University's real estate assets and the use of space in buildings. At the request of the Director General,

it will be possible to create new information dashboards thanks to the database prepared for the operation of the entire Information Management System.

Specific objectives have also been set to support the work of offices dealing with the use and management of spaces. In particular, great attention will have to be paid to the development of information dashboards concerning the use of teaching spaces to support the work of all the organisational units in the various territorial hubs that are responsible for drawing up the timetable of teaching activities. A similar type of information is also thought to be necessary in the case of office space with dashboards that can support managers, department heads and all stakeholders who find themselves having to manage space and assign workstations to their employees.

The main objectives of this research work are therefore to create an information system for strategic decision support and, secondly, to explore how the analysis and improvement of processes can enable a successful digital transition and the implementation of an information system for real estate management in the case of the Italian public administration (particularly in universities).

In the light of the set objectives, the research questions are as follows:

- How to create a decision support system for the management of the university of Turin's real estate assets?
- What are the organisational and process changes following the implementation of a new decision support system for real estate management at the University of Turin?

2

CHAPTER

Literature Review

The objective of this section is to review the existing literature on the research fields of Asset and Facility Management and to intersect the knowledge with the field dealing with Information Systems design. It is also important to understand how Information Systems can be effectively implemented in public organisations, with reference to universities and in the context of real estate management.

To achieve this objective, a scientometric analysis of the literature on the Scopus database was conducted, followed by a traditional literature review to provide additional support and context.

2.1 Science mapping analysis

As a result of the considerations made in the introductory section, two research areas have been identified that need to be intersected to investigate the literature and identify both issues that have already been addressed and those that remain unexplored. Recalling the research questions formulated in section 1.3 , the aim is to find areas of connection as the issue to be investigated appears to be multidisciplinary. Specifically, the formulated questions are:

- How to create a decision support system for the management of the university of Turin's real estate assets?
- What are the organisational and process changes following the implementation of a new decision support system for real estate management at the University of Turin?

It is therefore clear that, to answer these questions, the research areas involved are inherent to Information Systems (IS) and their design in the context of Asset Management (AM) and Facility Management (FM). In addition, it is essential to examine another domain, namely that of Organisations, with a particular focus on the

influence of IS and emerging technologies on public sector organisations management.

To analyse the present scientific literature, a scientometric analysis was performed using several tools and methodologies detailed in the following sections. The literature review process is structured in stages named as the following informative sections: Tools for quantitative research in scientometrics; Database, query methods and article filtering; Scientometric analysis.

2.1.1 Tools for quantitative research in scientometrics

Many tools are now available in the field of quantitative research with the aim of exploiting bibliometric data in various databases. In order to decide which tool to use, studies comparing different tools dedicated to the analysis of science mapping were sought. In particular, [94] has carried out a comprehensive analysis of the subject, combining the retrieved results by [95] and [96] to obtain an overview, which is presented in Table 2.

Table 2: Science mapping tools comparison [94].

		Bibexcel	BiblioShiny	BiblioMaps	CiteSpace	CitNetExplorer	SciMAT	SciTool	VosViewer	Gephi
Network analysis	Thematic	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes
	Author	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes
	Reference	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Other	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes
	Geospatial	Yes	Yes	Yes	Yes			Yes		
Other analysis	Burst detection		Yes		Yes			Yes		
	Spectrogram		Yes							
Map visualization	Network	Yes	Yes	Yes		Yes		Yes	Yes	Yes
	Geospatial	Yes	Yes		Yes			Yes		
	Temporal	Yes	Yes					Yes		
	Cluster	Yes	Yes				Yes			
	Evolution	Yes	Yes							
	Overlay	Yes	Yes				Yes		Yes	
	Density	Yes	Yes				Yes		Yes	
	Tree ring	Yes	Yes		Yes					
	Other	Yes	Yes							Yes

As can be seen from the table, the only software that allows all the considered analyses to be carried out on a single platform is BiblioShiny [97]. Moreover, it is open source and has a web-based interface, which makes it easy to use without requiring advanced

skills. However, VosViewer [98] also has excellent features and the ability to create meaningful visualisations in the field of network analysis. For this scientometric study, BiblioShiny was used to be able to analyse all the metadata within a single interface, and then some network-related visualisations were created with VosViewer.

2.1.2 Database, query methods and article filtering

A fundamental aspect of the preparation of a literature review is the selection of the most appropriate database and query methods. Scopus and Web of Science (WoS) were taken into consideration when choosing the database to be used, as they are recognised as the most comprehensive and reliable in various fields of related research [99]. The choice then fell on the Scopus database for the following reasons:

- Scopus has a broader coverage of scientific literature than WoS [100];
- greater speed in the indexing process by Scopus and thus more recent publications [100];
- other interdisciplinary scientometric studies have identified Scopus as a superior alternative to WoS [101].

Once the database had been selected, a list of keywords had to be identified to fully utilise the analytical potential of the bibliometric data.

Although the subject of investigation is extensive and incorporates a multitude of themes, and given the interdisciplinary nature of the endeavour, the research questions were formulated to concentrate on two specific areas to avoid any ambiguity in the request.

As discussed by [102], every literature review is a survey and every research survey should be guided by the research questions [103]. For this reason, the choice of keywords was guided both by a qualitative literature review and by answering the research questions.

In response to the initial query (i.e., how to create a decision support system for the management of the university of Turin's real estate assets?) the selection of keywords was made with the objective of examining the domain of IS design in the context of real estate management. Specifically, the research was concentrated on the area of decision support systems for the management of the built environment and the innovative technological tools employed. Accordingly, in the broader context of the construction industry, tools that facilitate the digitisation of the built environment, such as the Building Information Modelling (BIM) methodology and Geographic Information System (GIS) technologies, were also included in the macro-area of Information Technology (IT) (Figure 2.1). The search string for the initial research question is thus formulated as follows:

```
((("Construction Management" OR "Asset Management" OR "Facilit* manag*" OR "Operations and Maintenance" OR "Space Management" OR "Built Environment") AND (BIM OR "Building information model*" OR GIS OR "Geographic Information System*" OR "Decision support system*" OR "Information platform*" OR "Asset Management System*" OR "Management System*" OR "Information exchange*" OR "Information system design"))).
```

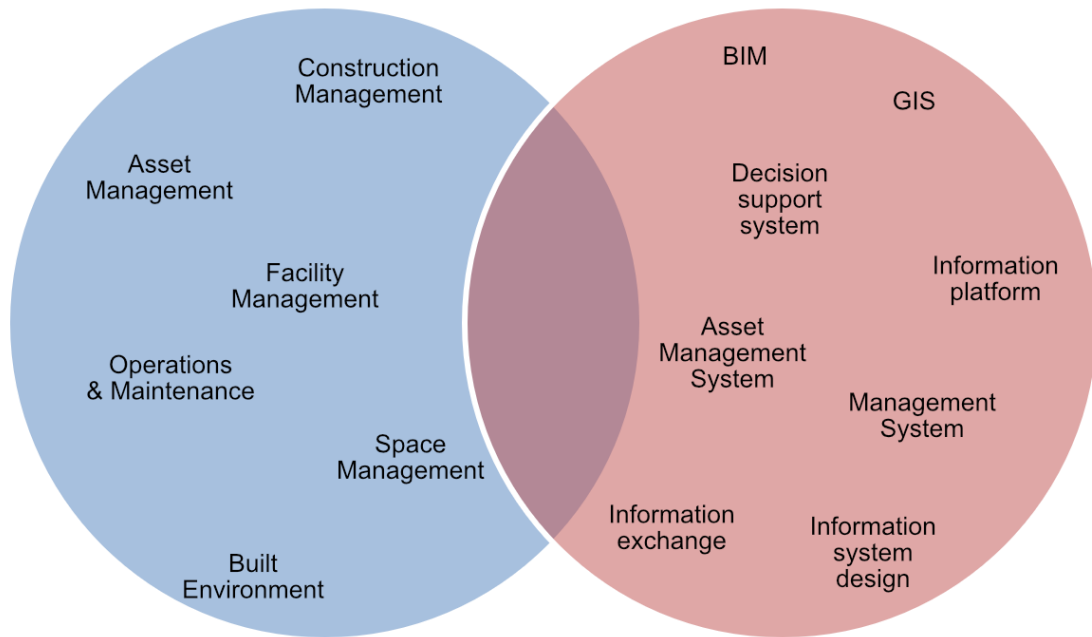


Figure 2.1: Search string for the first research question.

Regarding the second research question (i.e., what are the organisational and process changes following the implementation of a new decision support system for real estate management at the University of Turin?) the choice of keywords was informed by the field of digital transformation and transition in the context of organisations. To ensure an appropriate focus on the question, keywords were included concerning the digital transformation and digitalisation of organisations, as well as the associated processes and change management in the context of the public sector (Figure 2.2).

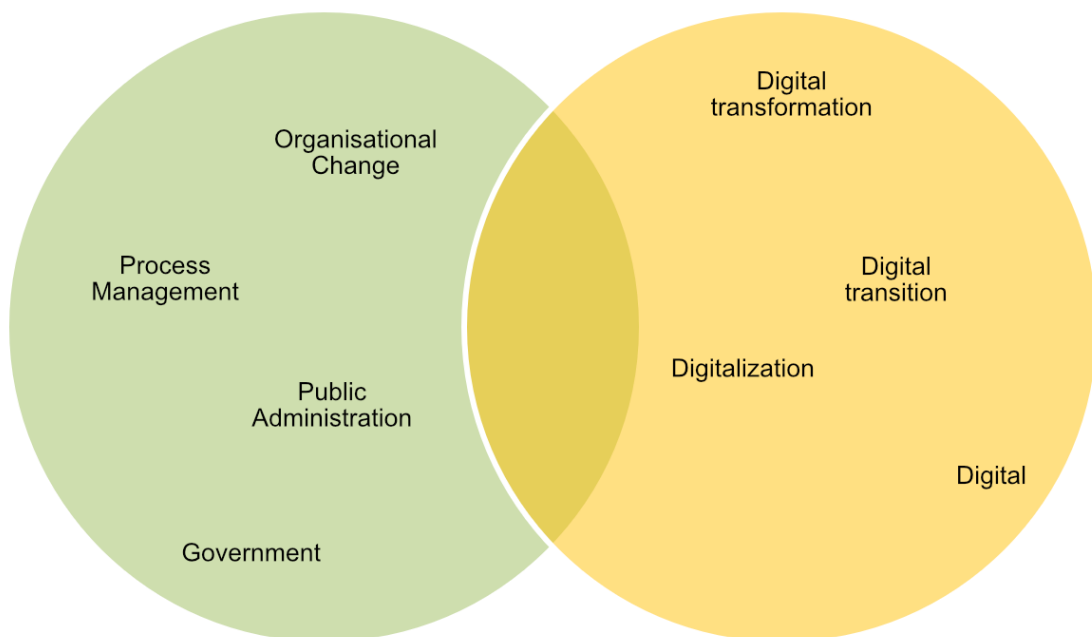


Figure 2.2: Search string for the second research question.

Accordingly, the search string for the second research question was constructed as

follows:

((("Organi*ational Change" OR "Process Management" OR "Public administration*" OR government*) AND ("Digital Transformation*" OR digital* OR "Digital Transition*" OR "Digitali*ation*")). Subsequently, the two keyword strings were intersected in order to ascertain which research works had already investigated the intersection between these fields of knowledge (Figure 2.3). Accordingly, the final string for the Scopus database search is as follows: (("Construction Management" OR "Asset Management" OR "Facilit* manag*" OR "Operations and Maintenance" OR "Space Management" OR "Built Environment") AND (BIM OR "Building information model*" OR GIS OR "Geographic Information System*" OR "Decision support system*" OR "Information platform*" OR "Asset Management System*" OR "Management System*" OR "Information exchange*" OR "Information system design")) AND ((("Organi*ational Change" OR "Process Management" OR "Public administration*" OR government*) AND ("Digital Transformation*" OR digital* OR "Digital Transition*" OR "Digitali*ation*"))).

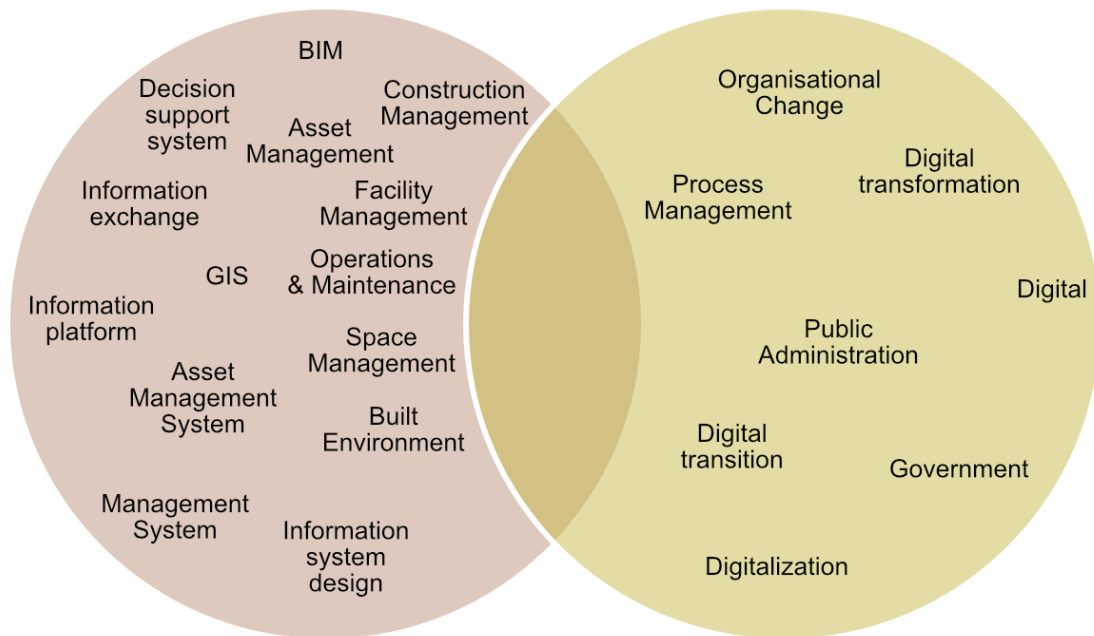


Figure 2.3: Intersection between first and second research string.

The search conducted on the selected database (i.e., Scopus), using the previously constructed string, yielded 620 documents.

The search was conducted within the following fields: article title, keywords and abstract. The first search conducted on the Scopus database yielded articles published between 1989 (the first paper found on the database with the created string) and 2024. Additionally, as no filter was applied to the type of paper, the results encompass a diverse range of origins: conference proceedings, books, book series and journals.

Certain operators were used in the string in order to obtain all relevant articles and to avoid excluding words with different spellings. Boolean operators (i.e., AND, OR) were used to construct the string with the desired combinations. Wildcards (i.e., the asterisk *) were used for some words that may have different spellings or variations depending on the language or desinence.

In order to refine the search and reduce the field of articles to be analysed to the most relevant, some filters were set within the Scopus search interface. In detail, firstly, articles were filtered to consider only those written in English, and then non-journal articles were filtered out, excluding conference proceedings and books (a filter that almost halved the number of papers). In addition, the period considered was limited to the last 20 years, taking into account papers published between 2005 and 2024 (there were only 13 papers between 1989 and 2004). The last filter set concerned the publication phase, which was set only on articles that had been definitively published, excluding 15 papers that were in the press phase in August 2024.

The selection of articles thus resulted in 352 documents from the Scopus database, whose metadata could be downloaded to carry out scientometric analysis. After entering the dataset in BiblioShiny via the web interface, the first information was analysed, as shown in Table 3.

Table 3: Main information about downloaded dataset (BiblioShiny).

MAIN INFORMATION ABOUT DATA	
Timespan	2005:2024
Sources (Journals)	171
Documents	352
Annual Growth Rate %	19,81
Document Average Age	3,42
Average citations per doc	34,14
References	25095
DOCUMENT CONTENTS	
Keywords Plus (ID)	2108
Author's Keywords (DE)	1266
AUTHORS	
Authors	1156
Authors of single-authored docs	27
AUTHORS COLLABORATION	
Single-authored docs	27
Co-Authors per Doc	3,75
International co-authorships %	35,51
DOCUMENT TYPES	
article	296
conference paper	2
data paper	1
review	53

As can be seen from Table 3, the documents resulting from the search have almost twice as many Keywords Plus as the Author's Keywords. In Scopus, Author's Keywords are terms selected by the authors to represent the main topics of their research. These keywords reflect the authors' perspective and help in indexing and retrieving the article in databases. On the other hand, Keywords Plus are generated based on terms that frequently appear in the titles of articles cited within the paper's

references, offering a broader thematic context. The key difference is that Author's Keywords are manually chosen by the authors, while Keywords Plus are algorithmically generated from cited literature. Both types of keywords certainly include within them the keywords chosen for the search string. However, Keywords Plus are much more numerous, and coming from the bibliography of each article, they cover a much broader range of topics. In fact, while among the authors' keywords it is possible to find keywords mostly relevant to those belonging to the created string, Keywords Plus also cover topics far removed from the purpose of this search.

Considering the average number of co-authors per article, it can be observed that it stands at 3.75. This figure indicates that the majority of papers are the result of joint efforts involving several experts with different areas of expertise. Such collaboration is often necessary to address the increasing complexity of modern scientific questions, which require interdisciplinary approaches. Furthermore, the aforementioned average number of co-authors may suggest the existence of a dynamic research environment in which collaborative networks are well developed.

2.1.3 Scientometric analysis

The analysis began by observing the temporal trend of the scientific production concerning the researched topics. As can be seen in Figure 2.4, the topics are present between 2005 and 2024, with a steady increase in production. In particular, the annual growth rate is 19.81%. The first paper identified (published in 2005) within this dataset is entitled “Enterprisewide Spatial Data Integration of Legacy Systems for Asset Management: The Case of the Illinois Department of Transportation” from the University of Illinois and deals with the implementation of a Spatial Information System to aid asset management decision makers at the Illinois Department of Transportation [104]. In particular, the System described makes extensive use of GIS technologies to integrate and link information from different databases.

As can be seen in Figure 2.4, the trend of publications in this research area has always been upwards to date. In fact, the dataset returned 57 papers for the year 2022, 64 papers for the year 2023, and with still 5 months to the end of the year 2024, there are already 62 published articles. A marked increase in scientific production can be seen from 2014 onwards. Until then, digitalisation in the construction world had been little investigated in the context of operation and maintenance. For example, BIM processes were already a reality in many countries for the design of new buildings but were scarcely used for existing buildings or for the maintenance, renovation and deconstruction phases [105].

The most recent papers published in 2023 and 2024 highlight a range of solutions developed in the field of asset management utilising digital tools that have emerged in recent years. For instance, studies in the natural gas pipeline asset management sector have reviewed cases of BIM-GIS integration [106], emphasising the importance of data standardisation. In other instances, data accessibility is facilitated by the deployment of chatbots to enable inquiries, with blockchain technology employed for the upkeep of historical edifices [107].

Additionally, research has been conducted on the design of IS for the management of the built environment from various perspectives [108],[109]. Notwithstanding the existing interest in the subject and the considerable number of publications, the challenge of managing data concerning assets and buildings and their integration and

utilisation by decision-makers persists [110],[111]. In this regard, the necessity of change management aspects for an effective and efficient transition to digitalised asset and facility management has also been investigated recently [112].

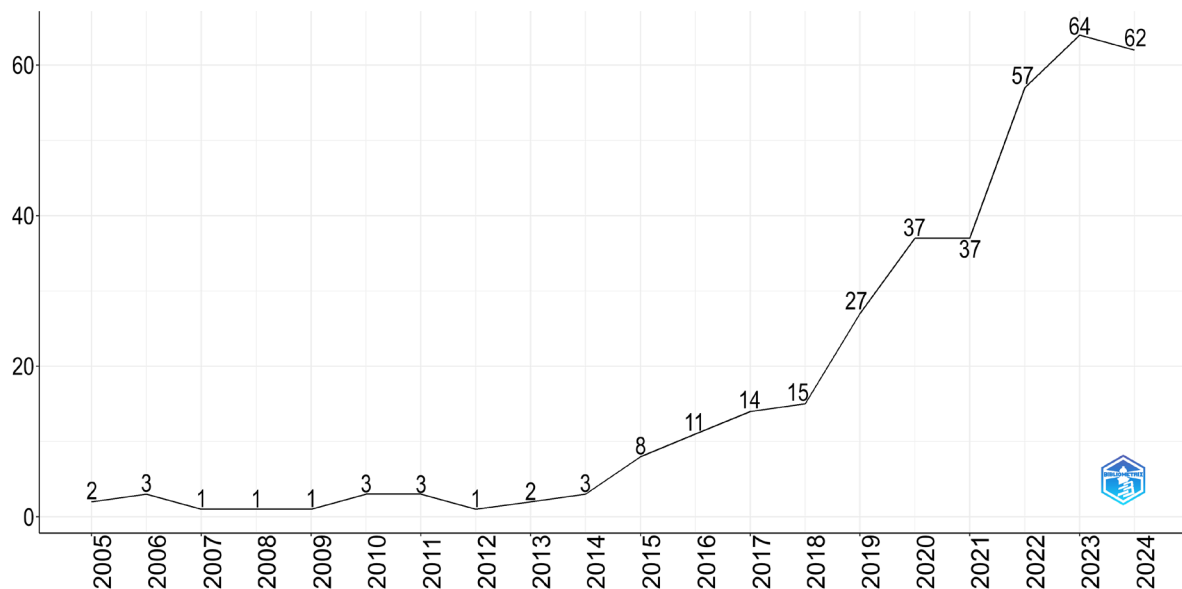


Figure 2.4: Annual Scientific Production (BiblioShiny).

About the trend of average citations per year (Figure 2.5), it can be observed that this does not align with the trend of publications. It is noteworthy that the greatest number of papers within the dataset are concentrated between the years 2015 and 2024. Indeed, between 2005 and 2014, the dataset consistently comprises between one and three papers per year. Additionally, the image illustrates a peak in 2014, which can be attributed to the inclusion of a literature review article [105] that has been cited over 1,500 times.

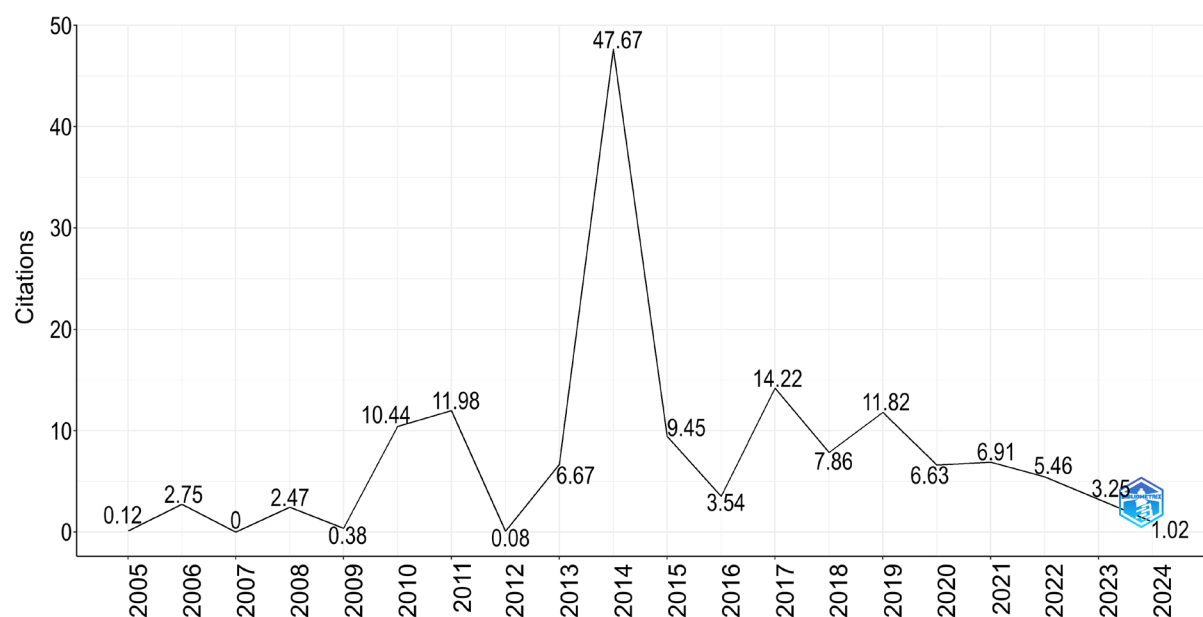


Figure 2.5: Average citations per year (BiblioShiny).

The analysis demonstrates that the majority of the 352 reviewed journal publications were produced in 15 countries, as illustrated in Figure 2.6. Notably, the most active countries are the United Kingdom (251), China (130), Australia (116), the United States of America (86), Italy (62), Malaysia (44), Canada (33), India (32), Spain (27) and Norway (26).

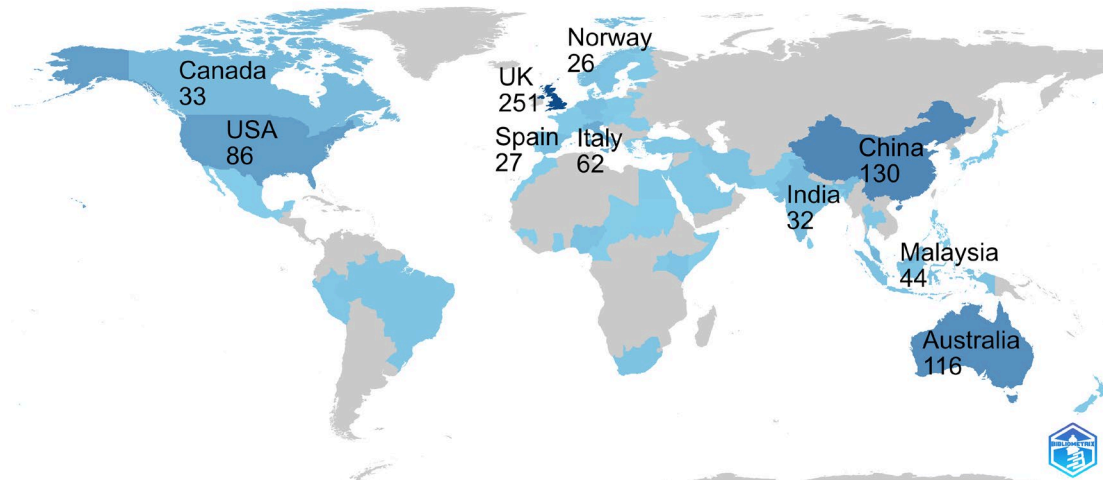


Figure 2.6: Countries' Scientific Production (BiblioShiny).

These figures corroborate the hypothesis that countries with more advanced technology and processes, as well as greater experience in these fields, are more interested in this topic. For instance, in 2015, the UK has proposed the Digital Built Britain strategy, which has enabled the acquisition of substantial knowledge regarding Asset and Facility Management [113].

About the subject areas of the papers in question, the analysis shows that Engineering represents the most prominent area of study, followed by Social Sciences and Computer Science as illustrated in Figure 2.7. The remaining subject areas included: Business, Management and Accounting; Environmental science; Energy; Decision science.

Documents by subject area

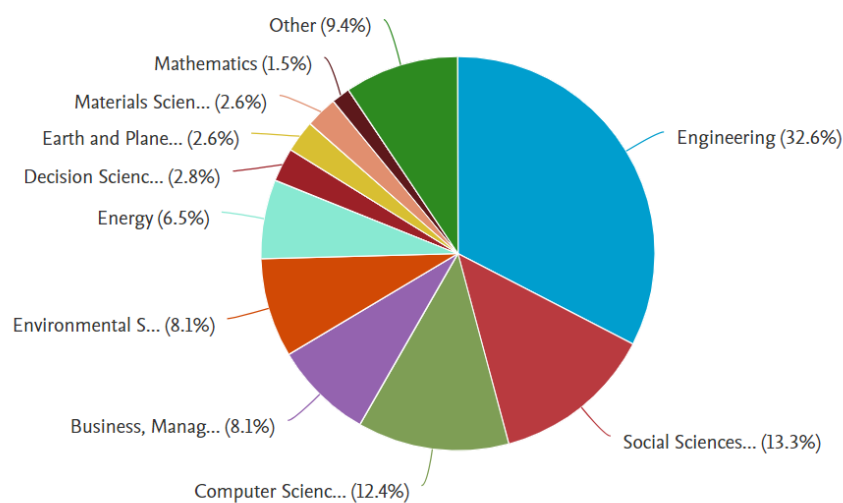


Figure 2.7: Documents by subject area (Scopus).

A further crucial and beneficial avenue of enquiry in the analysis of the knowledge domain under investigation is the examination of the most pertinent sources. The analysis of the most prevalent journals is indeed beneficial for researchers in identifying the most current resources in terms of authors and research groups.

The journals with the highest frequency of occurrence within the analysed dataset are presented in Figure 2.8.

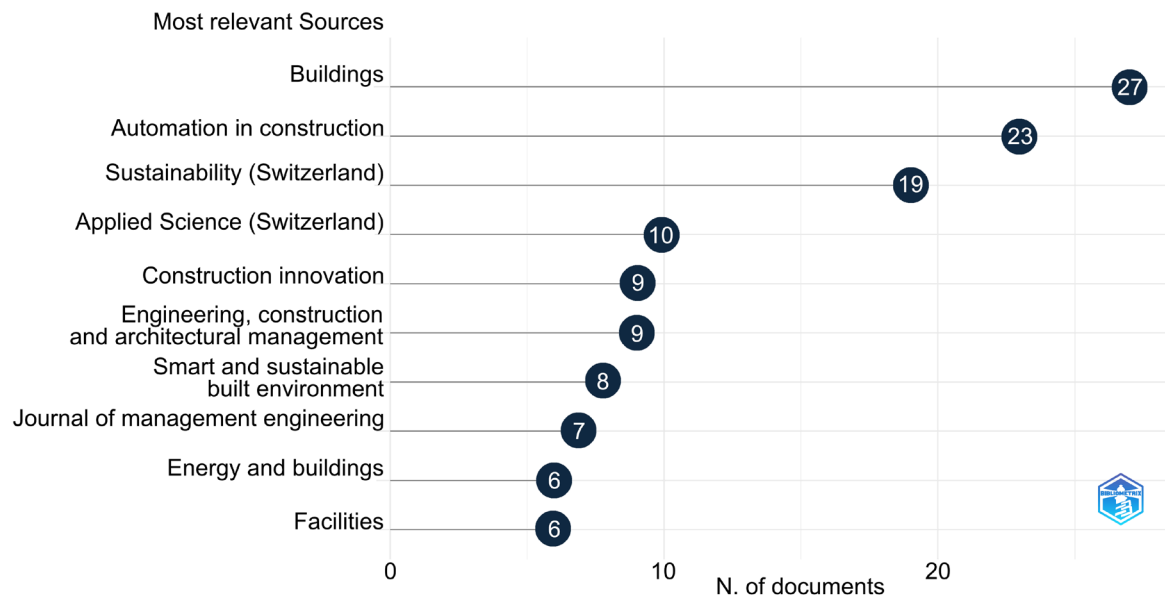


Figure 2.8: Most relevant sources (BiblioShiny).

An additional analysis pertinent to this category of data is illustrated in Figure 2.9. The process entails the identification of core resources through the application of Bradford's law, which describes the dispersion of information within a knowledge domain in accordance with the distribution of citations [114].

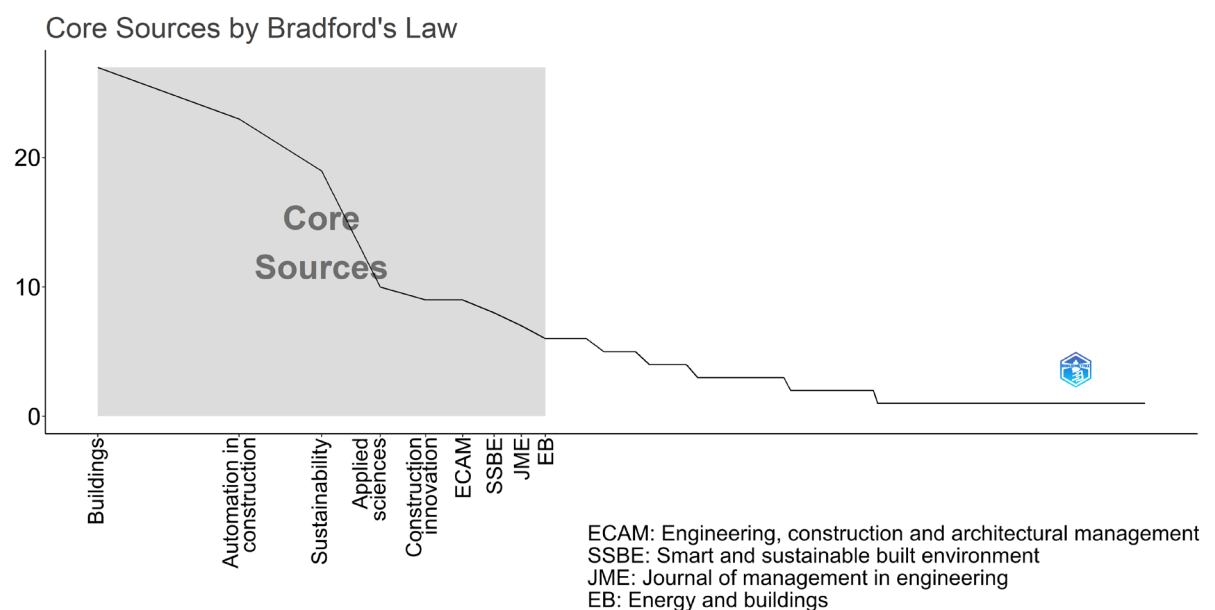


Figure 2.9: Core sources by Bradford's law (BiblioShiny).

In the case of the dataset under investigation, it can be observed that the papers representing the core resource are as follows: *Buildings*; *Automation in Construction*; *Sustainability*; *Applied Sciences*; *Construction Innovation*; *Engineering, Construction and Architectural Management*; *Smart and Sustainable Built Environment*; *Journal of Management in Engineering*; *Energy and Buildings*.

An additional parameter that can be evaluated is the H-index (Figure 2.10), which is defined as follows: “a scientist is assigned an n index if at least n of his published works have been cited at least n times”.

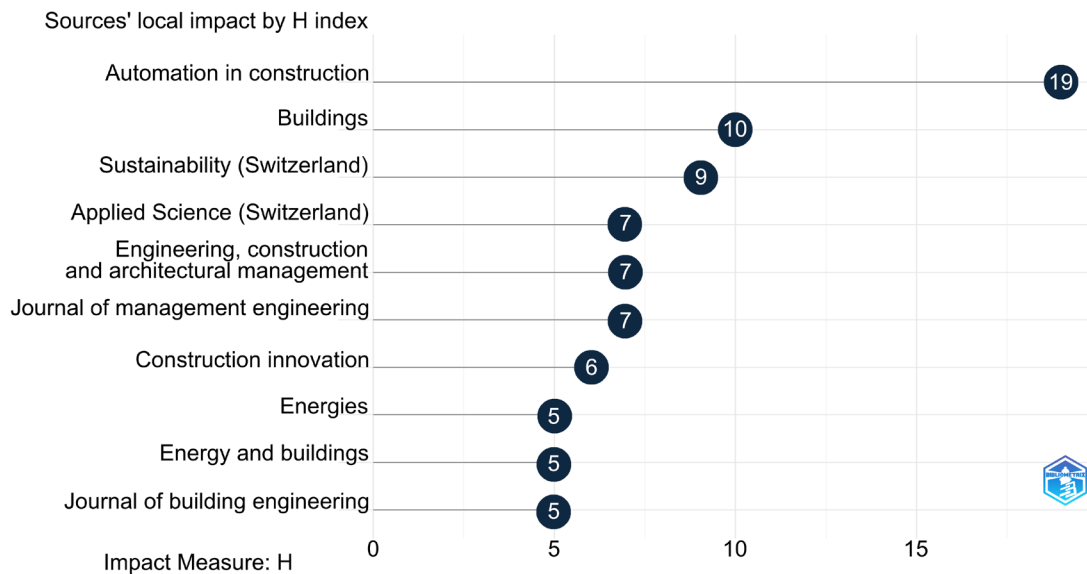


Figure 2.10: Sources' local impact by H index (BiblioShiny).

It should be noted that the n papers included in the calculation of the Hirsch index may be all the papers published by the author in question, or a subset of them. Furthermore, the papers excluded from the calculation may also have no citations at all. It thus follows that an author with m publications may have an H-index of at most m ($n \leq m$).

In the case of the analysed dataset, considering the H index, Automation in construction is the journal with the highest impact. Furthermore, despite the different ranking order, the top seven journals are the same as the core resource group identified with Bradford's law.

The analysis of the top sources is concluded with the presentation of the temporal trends of the top six sources in the graph in Figure 2.11. The analysis revealed a positive trend across all sources, with Automation in construction emerging as the earliest publisher (2010) and Sustainability the latest (2019). However, within a few years, Sustainability is approaching the number of occurrences of the top two (i.e., Automation in construction, Buildings). This data indicates an increasing interest in the topics of operation and maintenance from a sustainability perspective.

The analysis now turns to the most influential authors in the field of knowledge investigated by this analysis. Figure 2.12 shows the number of papers published by the 10 most prominent authors.

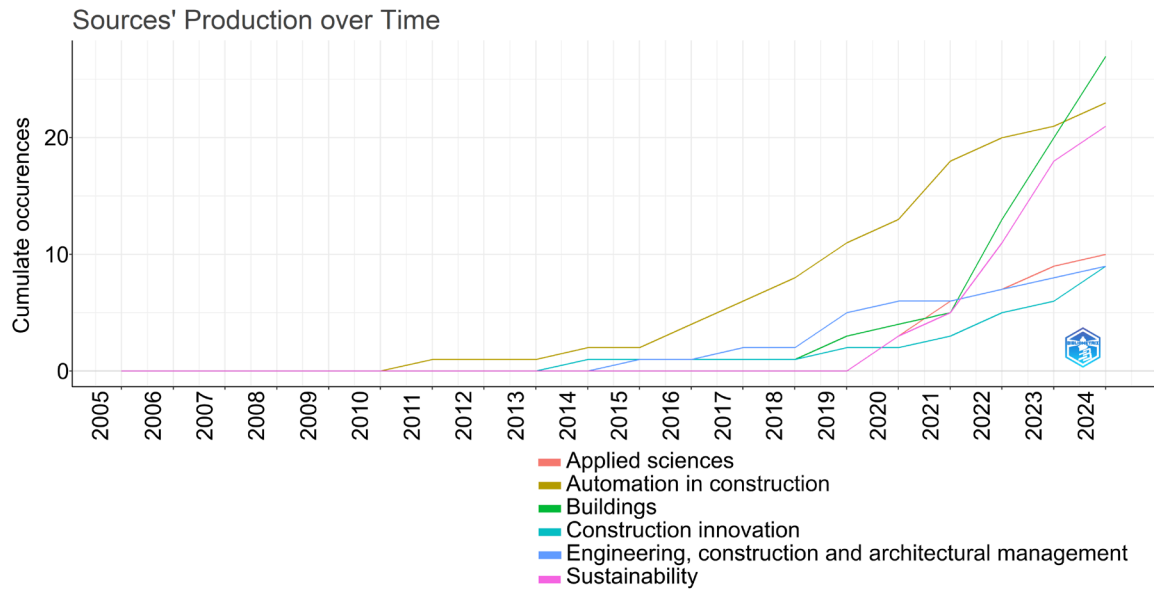


Figure 2.11: Sources' production over time (BiblioShiny).

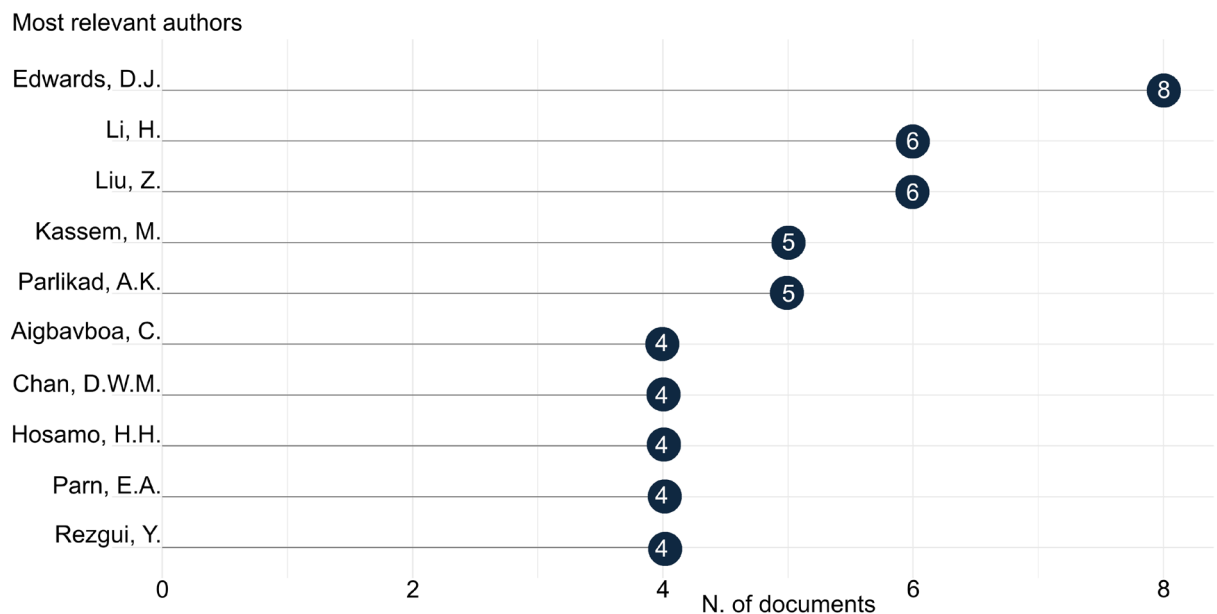


Figure 2.12: Most relevant authors (BiblioShiny).

The most productive authors over the period considered (i.e., 2005-2024) were D.J. Edwards, H. Li, Z. Liu, M. Kassem, A.K. Parlikad.

Again, taking into consideration the 10 most productive authors, productivity over time was also analysed (Figure 2.13). As can be seen from the image, the most productive authors published papers in the most recent years (i.e., between 2017 and 2024) with the exclusion of A.K. Parlikad who stopped in 2021. The most productive authors with most recent papers (in 2024) appear to be D.J. Edwards, Z. Liu, M. Kassem, C. Aigbavboa, D.W.M. Chan and H.H. Hosamo.

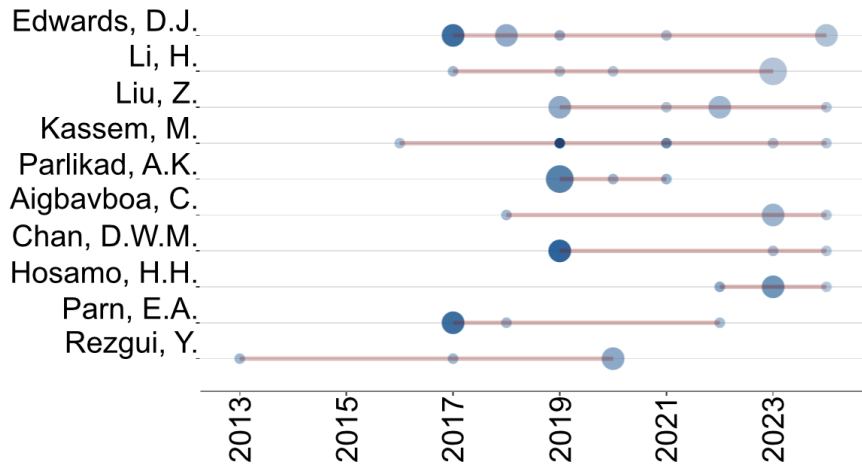


Figure 2.13: Authors' production over time (BiblioShiny).

Finally, depicted in Figure 2.14, the last analysis about authors is proposed, the productivity through Lotka's law. This representation makes it possible to visualise which authors are significant for the investigated research area. In particular, the authors who published more than 3 papers on the investigated topics are 35 while 72 authors published 2 papers. The remaining papers were published by authors who wrote occasionally on the investigated topics as there are 1049 authors with only one published paper.

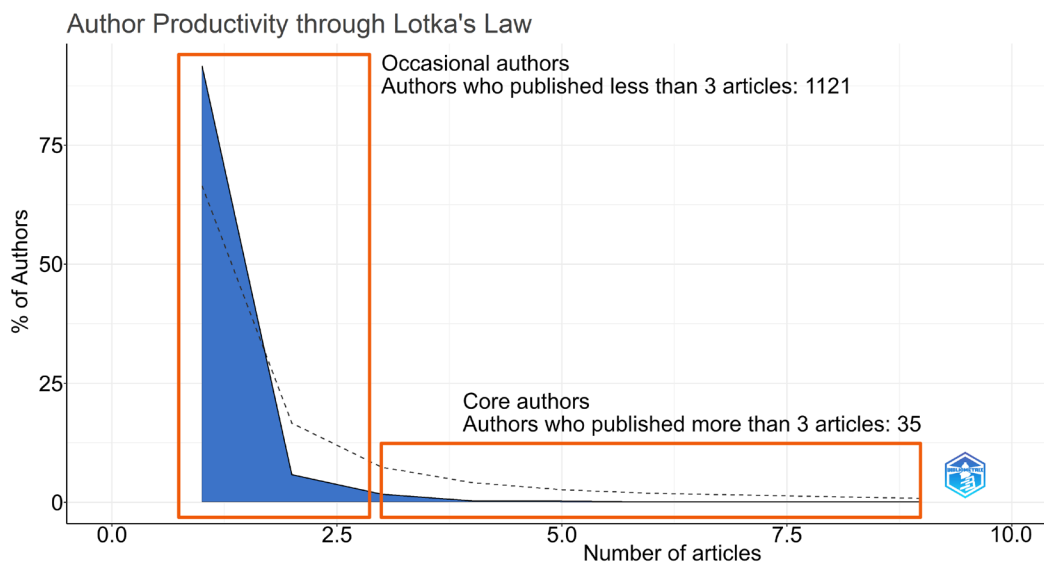


Figure 2.14: Authors' productivity through Lotka's law (BiblioShiny).

Another aspect taken into consideration by the scientometric analysis was the affiliations of the authors of the papers.

Figure 2.15 shows the 10 most frequent affiliations regarding the analysed dataset. In particular, the most represented is The Hong Kong Polytechnic University with 24 articles. From second to fifth position are UK institutions, all of which have between 19 and 21 articles.

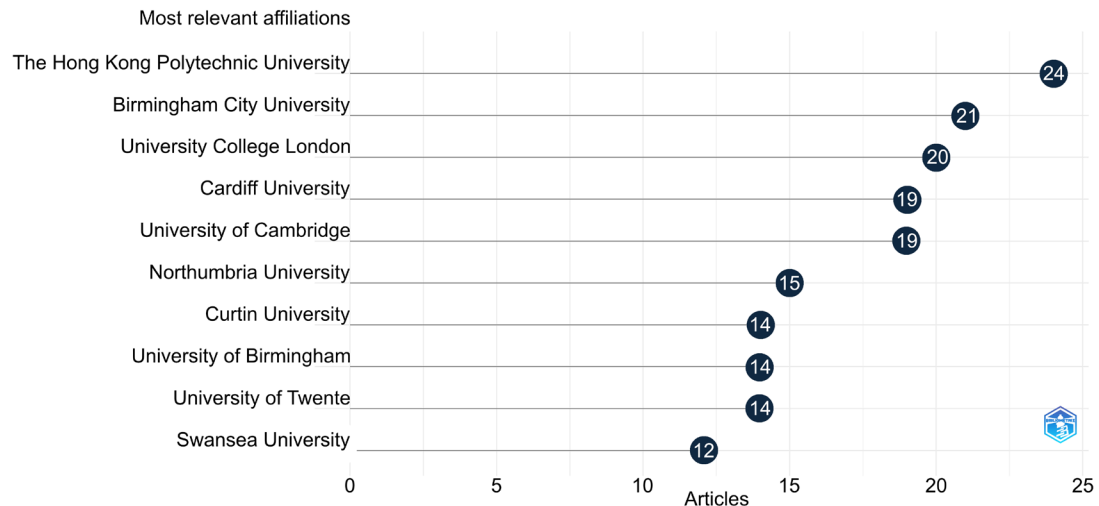


Figure 2.15: most relevant affiliations (BiblioShiny).

Regarding productivity over time, the top 5 results were analysed, which confirm a positive trend in recent years. In Figure 2.16 it can be seen that after 2017 all the universities have had a marked increase in the production of articles on this topic and have all arrived more or less towards a total of 20 articles published in the period 2017-2024.

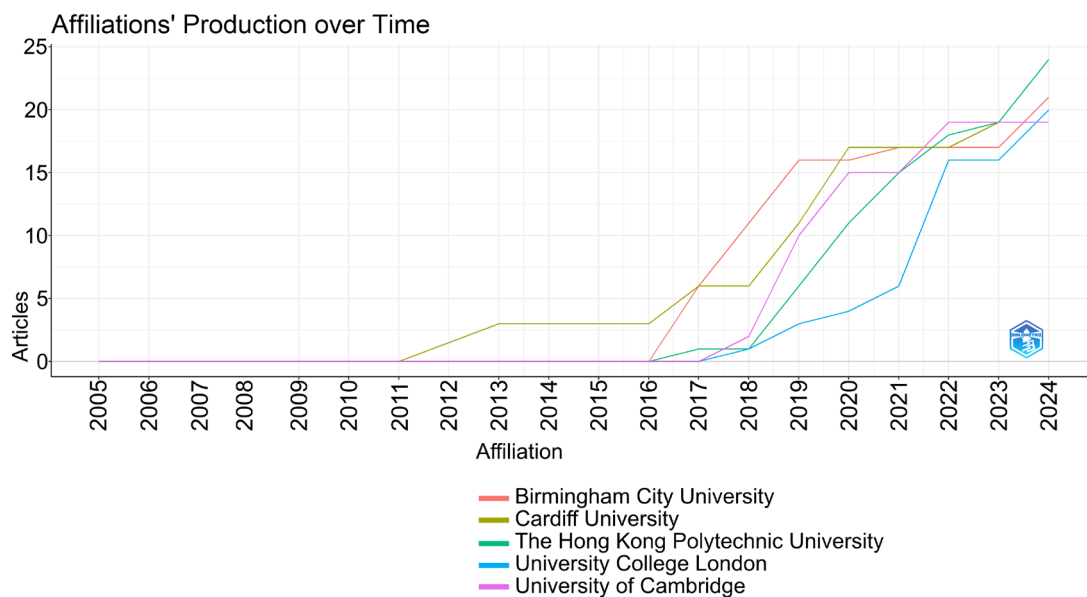


Figure 2.16: Affiliations' production over time (BiblioShiny).

Collaboration between institutions leading to the publication of articles involving several universities from different countries should not be underestimated. A map depicting collaboration between countries is shown in Figure 2.17. The highest frequency of collaborations is between the UK and China with 13 articles, followed by the UK with Australia (8 articles). The third, fourth and fifth collaborations all count five articles and are: China-US; UK-Hong Kong; UK-United Arab Emirates.

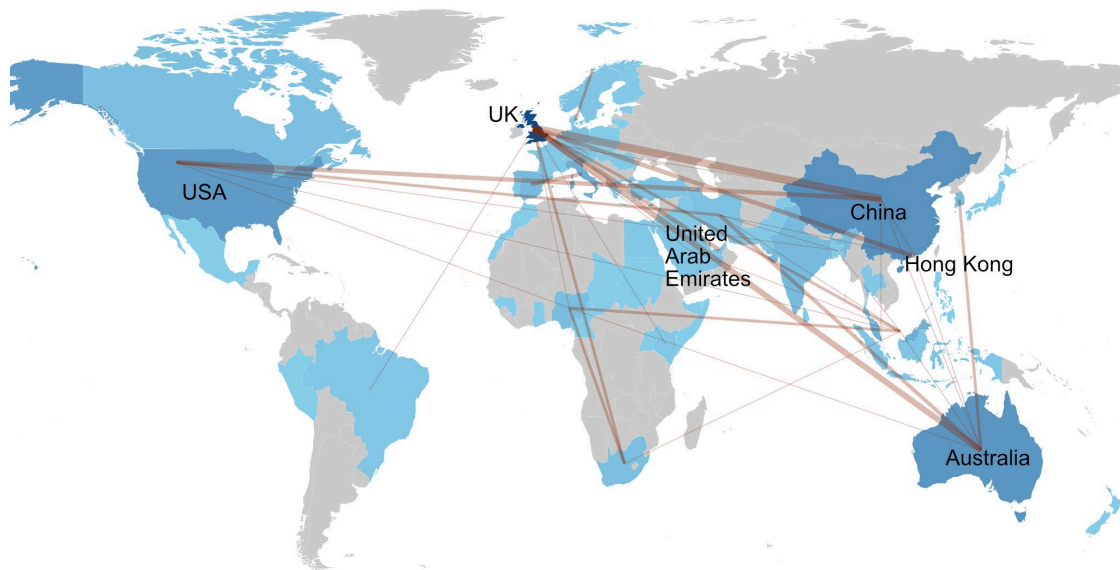


Figure 2.17: Country collaboration map (BiblioShiny).

To visualise the co-authorship network, VosViewer software was used to represent the relationships between authors, also known as the social structure of the research field. The resulting representation can be analysed in Figure 2.18.

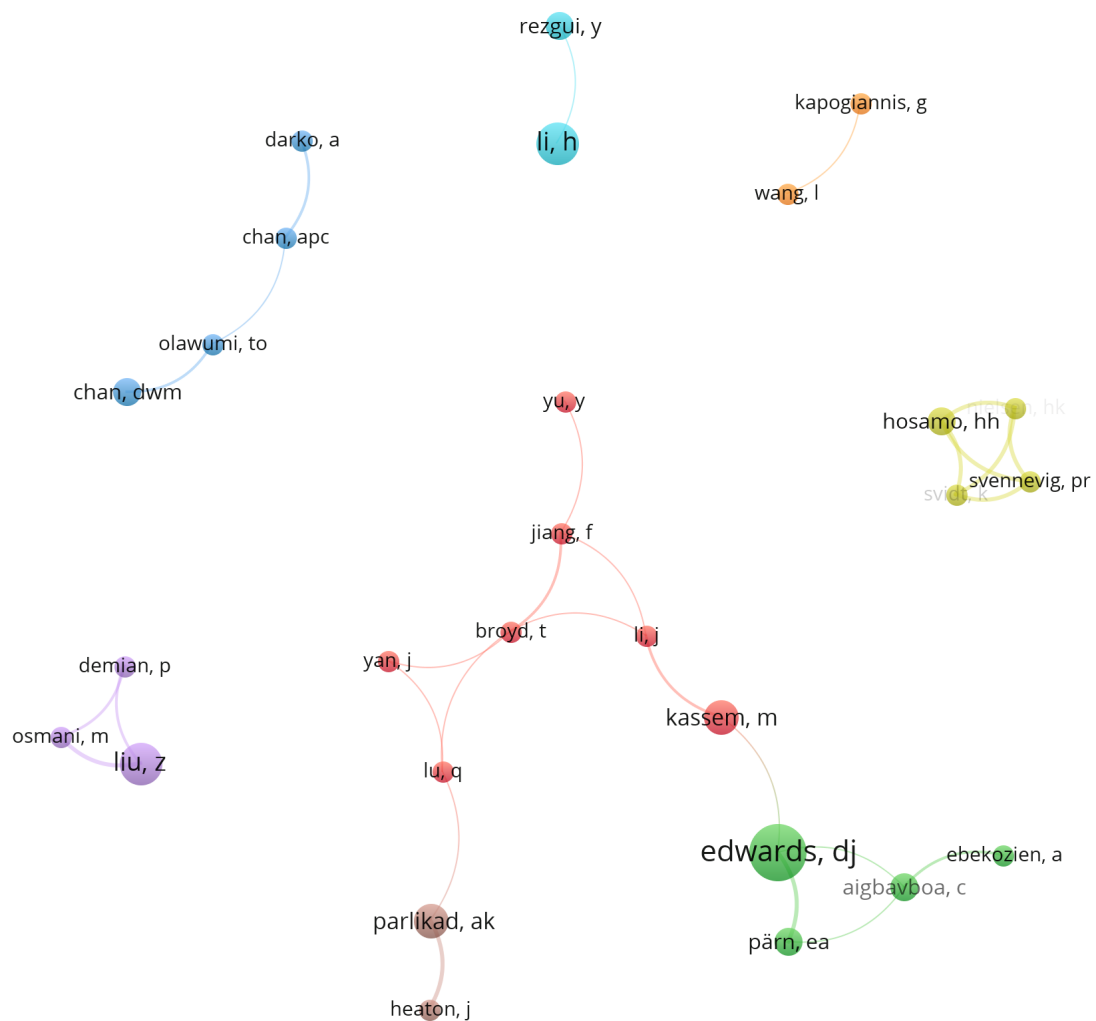


Figure 2.18: Co-authorship analysis (VosViewer).

The analysis concerns co-authorship (i.e., the relatedness of items is determined based on their number of co-authored documents) where the counting method was set to full counting and the minimum number of documents per author was set to 3. Out of a total of 1156 authors, the analysis returned twenty-eight authors.

As can be seen in Figure 2.18, eight clusters were detected, some of which are interconnected. Particularly important are the red, brown and green clusters that also highlight collaborations between different clusters. Of note is the collaboration between D.J. Edwards, M. Kassem and E.A. Parn, who were also among the most authoritative authors on the subject. A.K. Parlikad is present in the brown cluster and is indirectly connected to the green cluster via the red cluster. Other interesting co-authorships including authors who were also in the top 10 are those in the blue cluster with D.W.M. Chan, those in the orange cluster with I. Wang and those in the yellow cluster with H.H. Hosamo.

The last type of analysis performed on the chosen dataset involved the creation of a co-occurrence keywords network map. The VosViewer software was used for this visualisation and the co-occurrences between the authors' keywords were analysed. The keyword network represents the investigated knowledge domain and shows how the keywords are connected.

The VosViewer settings for this analysis concerned the calculation method (set to total calculation method to give equal weight to each keyword) and the threshold (set to a minimum number of co-occurrences of 3).

The initial set of words comprised 1240 keywords, which after setting the threshold dropped to 70 and are displayed in the map in Figure 2.19.

The network graph shows has four clusters (i.e. red, yellow, blue, green) and the lines represent the relationships between the keywords defined by the seventy nodes. The most represented cluster is the red one, which consists of twenty-seven elements. Among these elements, the one with the most occurrences (174) is the keyword BIM which is strongly linked to three other keywords that have comparable occurrences (between 27 and 34): Facility Management, Asset Management and Construction Management. In the red cluster we also find a keyword of interest for the first research question, namely Information Systems. This has seven occurrences and relates to the following eleven keywords: BIM, Asset Management, Facility Management, Knowledge Management, Building, Interoperability, Construction management, Collaboration, Circular Economy, Project Management, Enterprise Architecture.

The second cluster with the most elements is the green one where there are seventeen keywords representing the network nodes. In particular, the most recurrent ones are Sustainability, Blockchain, and the Construction industry. The third cluster (i.e., the blue cluster) has fourteen elements and although it has fewer elements than the green cluster, it has keywords that have many occurrences and connect solidly with the other clusters. For example, the keyword Digital Twin (24 occurrences) connects most with: BIM, Facility Management and Asset Management in the red cluster; built environment and GIS in the yellow cluster; blockchain and sustainability in the green cluster.

Finally, the yellow cluster consists of twelve elements of which Built environment is the keyword with the most occurrences. The strongest links are with the keyword BIM (red cluster), with the keyword Digital Twin (blue cluster) and with the keyword Sustainability (green cluster).

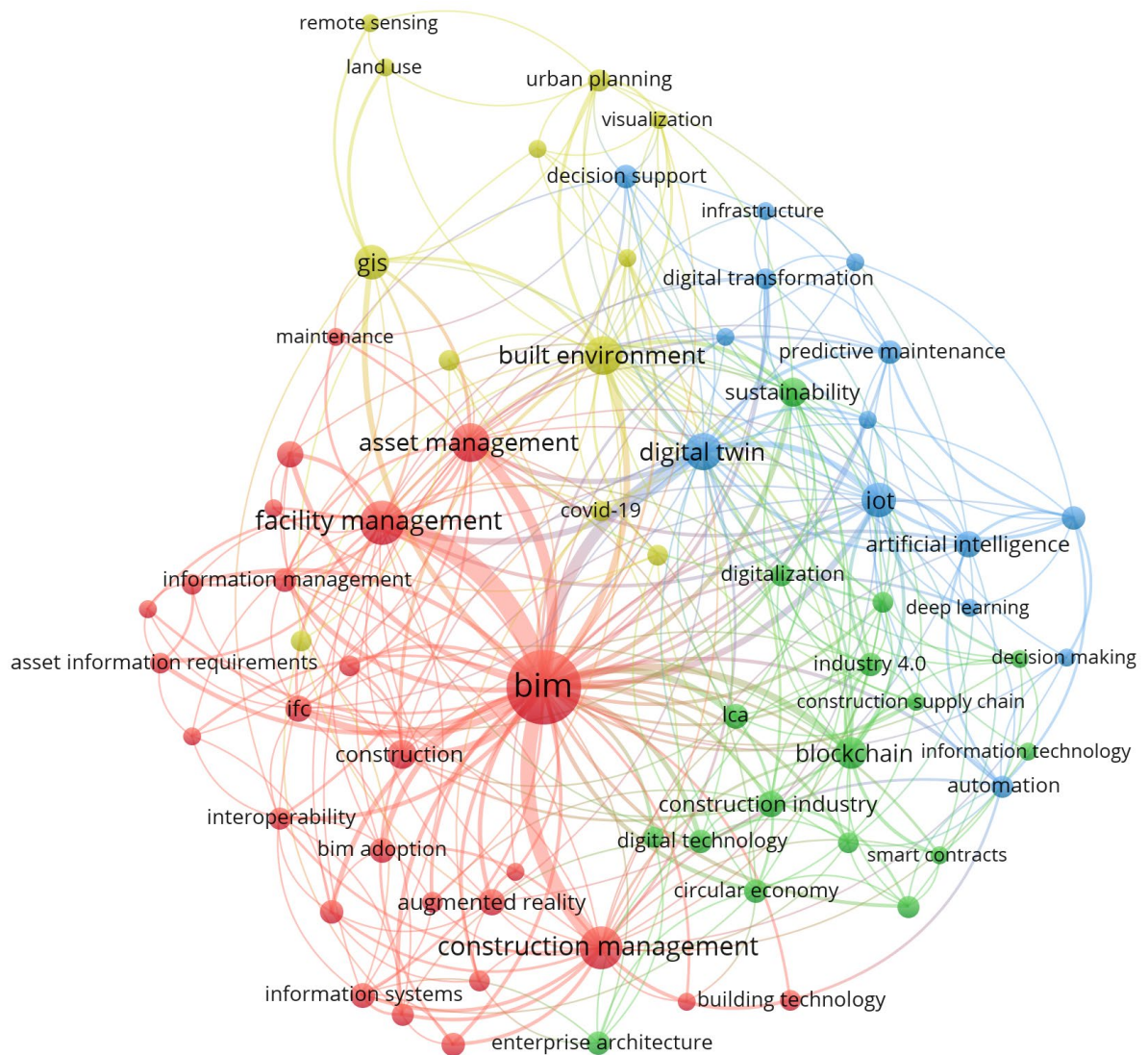


Figure 2.19: Co-Occurrence author keywords network graph (VosViewer).

In conclusion, the keyword analysis allowed to frame the most discussed topics and their connections. The topics of Facility Management, Asset Management and Construction Management are very closely related to the BIM methodology. Among the other technologies that emerged to support strategic decisions, GIS was mentioned several times. A great deal of interest also emerged around the topic of Digital Twins and IoT technology that allows real-time data to be collected from sensors installed in buildings and infrastructure. In the field of Information Systems in the context of the AECO industry, a strong connection with the BIM methodology to facilitate Asset and Facility Management was highlighted, and connections in the field of Enterprise Architecture with BIM and Information Systems were also found.

2.2 Review of the scientific sources of knowledge

2.2.1 Information Systems design

The design of information systems (IS) represents a pivotal area of research, addressing the intricate needs of organisations striving to resolve a multitude of operational and strategic challenges. In the field of IS research, a variety of methodologies are employed to direct the design, development, and implementation of effective Information Technology (IT) solutions within organisations. These methodologies provide structured frameworks that help ensure systems are both technically robust and aligned with organisational objectives. A variety of methodologies are frequently utilised in the design of IS, each with a distinctive focus and approach:

- The Structured Systems Analysis and Design Method (SSADM) is a traditional approach that emphasises a rigorous and structured process for systems analysis and design, often employed in large-scale projects [115];
- The Agile Methodologies (e.g., frameworks as Scrum and Kanban) are also employed, as they prioritise flexibility, iterative development and stakeholder collaboration, thereby enabling rapid adaptation to changing requirements [116];
- The user-centred design (UCD) approach has the objective to engage end-users at every stage of the design process, thereby guaranteeing that the system is aligned with their requirements and possesses an intuitive user interface [117];
- Design Thinking is a creative and user-centric approach that involves the generation of ideas, the construction of prototypes, and the evaluation of solutions in order to address complex problems through the implementation of innovative solutions [118];
- The Soft Systems Methodology (SSM) is a conceptual framework that guides the analysis and design of complex systems. A qualitative approach that addresses complex, ill-structured problems by considering the perspectives of multiple stakeholders to develop a shared understanding and identify potential improvements [119];
- Design Science Research (DSR) is regarded as a foundational and influential methodology within the field of IS. Its distinctive focus is on the creation and evaluation of artifacts, such as models, methods and systems, which are designed to address specific organisational issues while also contributing to the theoretical knowledge base [120].

In comparison to other methodologies, such as Agile or UCD, which focus more on development processes or user involvement, DSRM has a comprehensive approach to the creation and validation of innovative solutions that are both theoretically sound and practically relevant. This makes it a preferred methodology for research projects that aim to produce significant contributions to both practice and theory [120].

2.2.2 Design Science Research Methodology

DSRM was identified as an appropriate methodology for the research project. DSRM originated in the field of IS research and is considered one of the most recognised and robust methodologies for the development of IS [121]. “Design science creates and evaluates IT artifacts intended to solve identified organizational problems” [120]. It is a problem-solving paradigm and focuses on the design of innovative artifacts and, subsequently, their evaluation, with the ultimate aim of tackling complex problems in science [122].

The DSRM consists of a series of steps following a systematic methodology for the design of an IS prototype to solve a relevant organisational problem. Through its structure, this methodology emphasises iterative development and refinement of the artifact through cycles of design, implementation, evaluation and reflection [123]. DSRM is a structured, iterative process comprising six distinct phases shown in the Figure 2.20.

The first phase, Problem Identification and Motivation, involves clearly defining the research problem and its relevance within the real-world setting. The second phase, Design Objectives, establishes the goals and criteria for a successful artifact and outlines the desired outcomes. The third phase, Design and Development, involves creating and refining the artifact iteratively, drawing upon existing knowledge and innovative solutions. The fourth phase, Demonstration, illustrates the artifact's functionality in a relevant environment, showcasing its potential value. The fifth phase, Evaluation, rigorously assesses the artifact's effectiveness in achieving the stated objectives, using appropriate methods and metrics. The final phase, Communication, disseminates the research findings, including the artifact's design, development, and evaluation, to relevant audiences. The dissemination of the research findings, including the artifact's design, development, and evaluation, to relevant audiences is essential for the continuous learning and improvement throughout the research process. This ensures that the final artifact effectively addresses the identified problem.

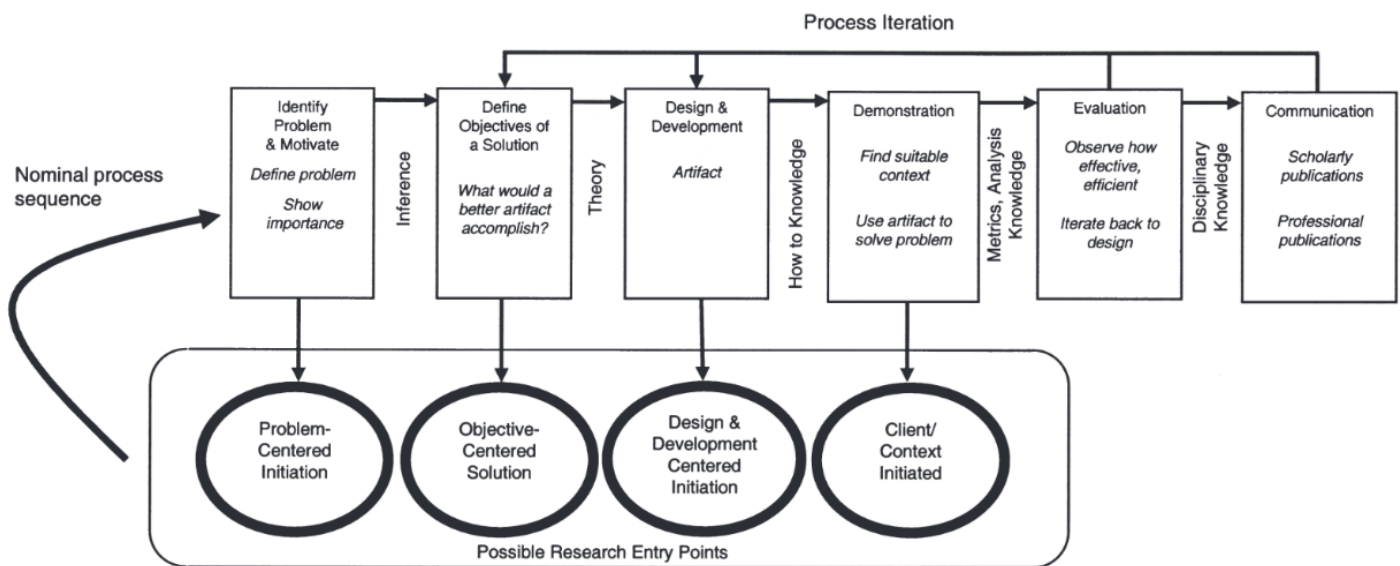


Figure 2.20: DSRM Process Model [121].

In relation to the design phase, the general principles and methods guiding its design

and development are presented below.

The artifact design and development phase is an iterative process, drawing upon a range of methods and sources to create a practical and relevant solution. This process is guided by the previously established objectives, ensuring that the artifact directly addresses the identified challenges and contributes to the overall goal of improving asset management practices.

The following considerations are of particular importance in the design of artifacts:

- *User-centred design:* It is recognised that the success of any system is contingent upon its adoption and effective use. Consequently, the design process prioritises the needs and perspectives of university stakeholders. This involves understanding their current workflows, pain points and desired functionalities through methods such as interviews, surveys and workshops [124].
- *Integration with existing systems:* Italian public universities often rely on legacy systems for various administrative functions. The artifact design considers potential integration points with existing systems to minimise disruption, leverage existing data, and ensure a smooth transition [125].
- *Scalability and flexibility:* The artifact is designed with scalability in mind, acknowledging the diverse needs and sizes of different universities. This involves creating a modular structure that can be adapted and expanded upon to accommodate future growth and changing requirements. The artifact design incorporates mechanisms for tracking asset lifecycles, documenting decisions, and generating reports to ensure responsible and auditable asset management practices [126].
- *Data-Driven Insights:* The artifact leverages data analytics to provide university administrators with actionable insights into asset utilisation, maintenance needs, and potential cost savings. This data-driven approach supports informed decision-making and facilitates proactive asset management strategies. The design process is based on an iterative approach, commencing with low-fidelity prototypes to facilitate the collection of preliminary feedback from users. These prototypes are then subjected to further refinement and iterative improvement in accordance with user input, thereby ensuring that the final artifact is aligned with user needs and expectations [127].
- *Technologies selection:* The selection and integration of appropriate technologies to support the desired functionalities is also a key aspect of the artifact development process. This involves the evaluation of open-source and commercially available solutions, with consideration given to factors such as cost, scalability, security, and ease of integration [128].

Demonstrating the value and effectiveness of a designed artifact is a crucial step within the DSRM process. This demonstration is not merely an exposition of the artifact's features; rather, it is an attempt to exhibit its practical application and potential impact within a real-world context. There are several different approaches to demonstrating an artifact (e.g., using the artifact to solve a problem in a certain context), each of which offers a unique set of advantages depending on the nature of the artifact and the research context:

- *Case Study:* a method of demonstrating the practical application of a designed

artifact within a real-world context. The implementation of the artifact within a real-world case study provides tangible evidence of its efficacy in addressing a specific issue. The data collected during the case study, such as improvements in key metrics or user testimonials, can provide compelling evidence of the impact of the artifact [129].

- *Interactive prototype*: a digital model that allows users to interact with the design in a way that is similar to how it will be used in the final version. A functional prototype enables users to gain direct experience of the artifact's features and functionalities. This interactive demonstration offers a concrete representation of the design, allowing users to explore the user interface, navigate the features, and comprehend the potential applications within their own contexts [130].
- *Scenario-Based Simulations*: Hypothetical scenarios, reflecting common challenges within the target domain, can be used to demonstrate how the artifact can be applied to address these situations. These simulations illustrate the artifact's problem-solving capabilities and highlight its potential benefits across different contexts [131].
- *Data Visualisation and Reporting*: If the artifact involves data analysis or generates data-driven insights, visualisations and reports can effectively communicate its value. These visualisations highlight key performance indicators, track progress towards objectives, and provide insights that support decision-making [132].
- *Expert Evaluations*: In certain instances, expert evaluations can provide invaluable insights into the artifact's design, functionality, and potential impact. Experts in the pertinent domain can assess the artifact's strengths and weaknesses, offering recommendations for improvement and validating its relevance to the field [133].

The evaluation phase is of critical importance in assessing the efficacy of the developed artifact in addressing the identified problem and providing tangible support for the proposed solution. The evaluation phase entails a systematic comparison between the objectives established for the solution and the results obtained during the previous demonstration phase, during which the artifact was implemented and tested.

A variety of methods can be employed for a comprehensive evaluation, including:

- *quantitative performance measurement*: analysis of metrics such as budget adherence, efficiency improvements, or tangible outputs generated through the use of the artifact [134].
- *evaluation questionnaires*: the collection of structured feedback from users and stakeholders is undertaken to assess their satisfaction, perceived usefulness, and the impact of the artifact on their workflows [135].
- *system performance measurement*: the assessment of technical aspects, including the artifact's response speed, information availability, scalability, and security [136].

The DSRM advocates for an iterative approach. Based on the evaluation findings, researchers may choose to reiterate previous phases, refining the artifact based on user feedback and evaluation results. Alternatively, they may proceed to the final phase of

disseminating the research findings and sharing the artifact with the wider community. The last stage of the DSRM concerns the communication and dissemination of the research once it has been completed. It is essential to concentrate on the issue at hand and its significance, to delineate the prototype, its utility and originality, as well as the design phases. The proposed structure, comprising distinct stages, is also recommended as a replicable structure for scientific articles and other publications [121].

2.2.3 Business Intelligence Systems

The term Business Intelligence (BI) encompasses a range of technologies, applications, and practices designed to facilitate the collection, integration, analysis, and presentation of business information. The principal objective of BI is to facilitate more effective decision-making processes by transforming raw data into actionable insights. [137] posit that BI systems are integral to organisations, facilitating the conversion of data into meaningful insights and thereby supporting strategic and tactical business decisions.

A defining feature of BI systems is their capacity to integrate data from a multitude of sources, thereby offering a comprehensive view of the business landscape. Such systems offer robust analytical tools that support data mining, statistical analysis, and predictive modelling. Moreover, these systems are furnished with reporting and visualisation tools that facilitate the interpretation of data. Additionally, numerous BI systems offer real-time data processing capabilities, facilitating immediate insights as elucidated by [138].

The advantages of BI systems are numerous and diverse. As observed by [139], BI systems markedly enhance decision-making processes by furnishing accurate and prompt information. The automation of data analysis processes has the effect of enhancing operational efficiency, while insights into market trends and customer preferences provide a competitive advantage. Furthermore, BI systems can identify inefficiencies and suggesting areas for cost reduction, thereby contributing to overall organisational effectiveness.

Despite the advantages that BI systems offer, they also present several challenges. The assurance of data quality and the seamless integration of data from disparate sources represents a significant challenge, as discussed by [140]. The implementation and maintenance of BI systems can be costly and complex, which presents a barrier to adoption for some organisations. Furthermore, user adoption may be impeded by resistance to change or an inadequate training programme, as observed by [141].

The market offers a plethora of business intelligence software solutions, each with unique features and capabilities. Tableau is celebrated for its robust data visualisation capabilities and intuitive interface, whereas QlikView is lauded for its associative data indexing, which enables users to examine data from diverse perspectives. SAP Business Objects offers a comprehensive suite of reporting and analysis tools, making it an appropriate choice for large enterprises. Microsoft Power BI, conversely, is distinguished by its robust data visualisation capabilities, integration with Microsoft products, and cloud-based services.

In the context of evaluating BI software for integration with other systems in the public sector, Microsoft PowerBI emerges as a leading contender. Its seamless integration

with Microsoft products, including Excel, Azure and SharePoint, is particularly advantageous given their widespread use in public administration. Microsoft PowerBI can achieve the best interoperability through already existing tools, and it is recognized as one of the most suitable software to handle large amounts of data [142]. The user-friendly interface of Power BI is designed to facilitate ease of use for non-technical users, thereby promoting broader adoption across various departments. Moreover, Power BI provides a competitive pricing model, which is particularly advantageous for public sector budgets. Its scalability permits the handling of large datasets and adaptation to the evolving needs of public administration. Furthermore, Power BI offers comprehensive security features, guaranteeing data protection and compliance with government regulations, as emphasised by [143].

In conclusion, the combination of functionality, interoperability, and cost-effectiveness makes Power BI an optimal choice for public administration seeking to leverage BI systems. Its capacity to integrate seamlessly with existing software, coupled with its user-friendly design and robust security measures, substantiates its suitability as a leading BI solution.

2.2.4 Alignment of organisational needs and Information Technology

Digital transformation refers to the integration of digital technology into all areas of an administration, fundamentally changing how organizations operate and deliver value to stakeholders [144]. This often involves adopting innovative tools such as artificial intelligence, machine learning, cloud computing, and big data analytics. These tools can automate routine tasks, improve decision-making, foster collaboration, and deliver superior stakeholder experiences [144]. Nevertheless, the successful implementation of digital technologies is not merely a matter of incorporating new tools; rather, it is fundamentally a process of understanding, redesigning, and optimising existing processes [145].

It is well established in the literature that organisational change is a challenging process to implement successfully [146]. Indeed, empirical studies have demonstrated that up to 70% of large-scale organisational changes fail to achieve their intended outcomes [147]. To harness the full potential of innovative tools, organizations must first deeply understand their existing processes. For instance, Business Process management (BPM) explores current business processes, identifies bottlenecks or inefficiencies, and uncovers opportunities for improvement. By mapping out and analysing processes, organizations can identify which areas would benefit most from digital transformation [148]. Moreover, BPM aids in change management. By providing a clear picture of current processes, it helps stakeholders understand why changes are needed and how they will benefit the organization. This transparency can reduce resistance to change, one of the main obstacles to digital transition [28]. Additionally, BPM ensures that the implementation of innovative tools aligns with the organization's strategic goals. Rather than adopting technology for technology's sake, organizations can make targeted investments that drive their strategic objectives [149]. Nevertheless, business process analysis is an activity that is oriented towards a particular aspect of an organisation's activity and, improving a single business process, local optimisation will occur within individual domains. Thus, from a reductionist perspective, the architectures within this domain may be optimal [150] but not aligned with other domains of the organization. Furthermore, it is frequently asserted that the management of the complexity of any large organisational entity or system is depending upon the

presence of a well-defined architectural framework [151]. In this context, the introduction of Enterprise Architecture (EA) enables the modelling, visualisation and analysis of the organisation in a holistic manner. EA is a complementary tool that does not supersede other modelling standards or approaches; rather, it serves as an umbrella, facilitating the interlinking of disparate techniques and the creation of an integrated set of models representing all aspects of an organization in an holistic way [150].

In an organisational context, EA represents the summary of the topics discussed thus far. In essence, defining an EA entail addressing the following questions: what information is required and from which specific process is it obtained; who the involved actors or stakeholders are (receiving or producing information downstream of a specific process); how the information is processed and in which format; when is the departure or arrival of information [152]–[154].

In conclusion, while innovative tools are catalysts for change, the success of a digital transition lies in a deep understanding of business processes. By conducting thorough process analysis, organizations can ensure that their digital transition is purposeful, strategic, and poised to deliver maximum value.

The following paragraphs will seek to analyse the existing literature on the topics introduced thus far, with a view to identifying the key factors that facilitate alignment between IT and organisational needs. In particular, the focus will be on the role of Enterprise Architecture and Business Process Management in this regard.

2.2.5 Enterprise Architecture

Enterprise Architecture (EA) is a strategic framework that is utilized to oversee and align an organization's Business Processes, Information Systems, and technology infrastructure with its overarching business goals and objectives. It provides a comprehensive blueprint that describes the structure and operation of an organisation, with the objective of determining the most effective means of achieving current and future objectives [155],[156].

[150] defines EA as “a coherent whole of principles, methods, and models that are used in the design and realisation of an enterprise’s organisational structure, business processes, information systems, and infrastructure”.

In the context of change management, EA assumes a pivotal role, offering a systematic methodology for navigating organisational transitions. It guarantees that the IT infrastructure is aligned with business goals, thereby facilitating effective change management by providing a clear understanding of how changes in technology will impact business processes [155]. It facilitates communication providing a common lexicon and structure and ensuring that all parties are aligned regarding changes and their implications [157]. EA facilitates also the simplification of complex systems and processes, thereby enabling the implementation of changes without disrupting existing operations [158].

The implementation of new information systems is a complex undertaking that necessitates meticulous planning and execution. EA provides support for this process in the following ways:

- providing a comprehensive overview of the organisation's processes and systems, thereby facilitating more informed decision-making during the implementation of new Information Systems [156],[159];

- guaranteeing that new systems are aligned with existing systems and processes, thereby facilitating seamless integration and reducing the risk of implementation failures [160];
- enabling organisations to respond rapidly to changes and innovations, thus ensuring the efficient and effective implementation of new systems [161].

Several tools and frameworks are available for modelling and implementing EA, each offering distinctive benefits: The Open Group Architecture Framework (TOGAF) [162] is a standardised approach to EA. TOGAF is one of the most widely utilised EA frameworks. It offers a comprehensive methodology for the development, implementation and management of an EA. The comprehensive approach and capacity to align IT with business goals make TOGAF a beneficial framework [155],[158]; The Zachman Framework is renowned for its emphasis on defining and organising the disparate perspectives inherent to enterprise architecture. It facilitates the alignment of IT infrastructure with business goals and is particularly beneficial for organisations seeking to integrate complex systems [160]; The Federal Enterprise Architecture Framework (FEAF) offers a structured methodology for the organisation and management of Enterprise Architectures. The framework places an emphasis on the integration of business processes and IT infrastructure [155].

In the context of EA, alignment can be defined as the strategic coordination between an organisation's business objectives and its IT infrastructure. This alignment guarantees that information technology resources are efficiently used to facilitate and augment business objectives. The alignment within EA is a multifaceted concept, encompassing the following dimensions: functional alignment is the process of ensuring that the IT systems in place support the specific business functions and processes required to achieve organisational goals. It ensures that IT systems can support business functions and processes, and that technology solutions are adapted to enhance operational effectiveness; structural alignment refers to the integration of IT into the organisational structure, facilitating efficient communication and collaboration between IT and business units. This integration of IT into the organisational structure facilitates efficient communication and collaboration between IT and business units; socio-cultural alignment incorporates an analysis of cultural and social factors into the planning and implementation of IT initiatives, ensuring alignment with organisational values and facilitating acceptance and effective use; infological alignment must guarantee the availability of the correct information for decision-making processes.

[150] described the positioning of enterprise architecture within the context of enterprise management (Figure 2.21). At the apex of this pyramid, we observe the fundamental purpose of the enterprise: its *raison d'être* (i.e., Mission). The vision statement articulates the enterprise's anticipated future state and the values it espouses. Subsequently, the enterprise's strategy is defined, delineating the methodology through which the mission and vision will be accomplished. These are then translated into concrete goals that provide direction and delineate the milestones to be achieved in the execution of the strategy. The translation of these goals into concrete changes to the daily operations of the company represents the domain of EA. It provides a comprehensive view of the present and future operations, as well as the actions necessary to attain the company's objectives. In addition to its architectural framework, which could be regarded as the hard aspect of the company, its culture, shaped by its personnel and leadership, is of equal or greater significance in attaining these objectives.

Ultimately, the enterprise's daily operations are guided by the pyramid (Figure 2.21).

Another important concept in the context of EA, is that of Reference Architecture (RA). It is a standardised template or blueprint that provides a common framework for the design and implementation of architectures across a range of domains. It provides a set of best practices, guidelines, and patterns that can be reused to ensure consistency and alignment with organisational goals. A RA is of value as it provides a model to guide the development of specific architectures within an organisation or across multiple organisations within a sector [163]. The creation of a RA is advantageous as it provides a unified understanding and a common lexicon that can be utilised by both business and IT professionals. The establishment of a shared framework serves to reduce confusion and to guarantee the appropriate utilisation of technologies such as Application Programming Interfaces (APIs) and microservices at the enterprise level [164]. Furthermore, RA play an essential role in enabling the integration of intricate systems and procedures. They provide a structured approach to the management of the diverse and often complex requirements of different organisations or sectors. By offering a standardised framework, RA assist in aligning IT infrastructure with business goals, enhancing communication, and simplifying the implementation of changes without disrupting existing operations [163],[164].

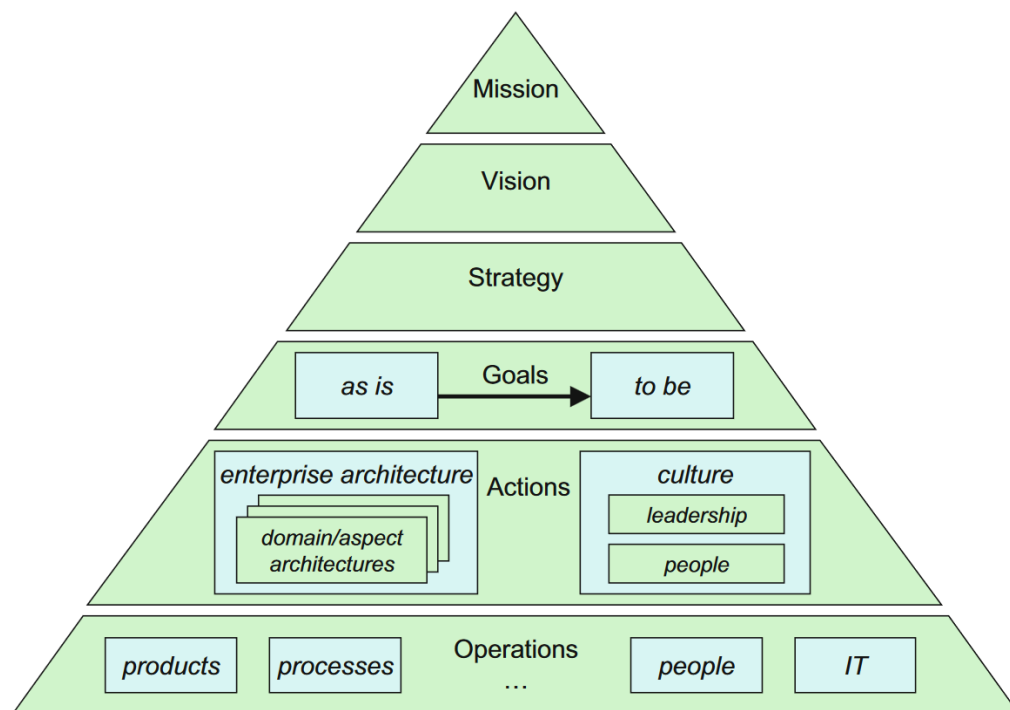


Figure 2.21: Managing an Enterprise [150].

2.2.6 Business Process Management

Business Process Management (BPM) is a systematic approach to the improvement of organisational processes. It entails the analysis, design, execution, monitoring and optimisation of business processes with a view to achieving organisational goals. The roots of BPM can be traced back to the 1970s, when research on office Information Systems first emerged. This subsequently evolved into workflow management in the

1990s, and eventually gave rise to the comprehensive BPM approach that is currently in use [165]. The concept of BPM emerged from earlier management practices, including Business Process Reengineering (BPR) and workflow management. It gained prominence in the 1990s as organisations sought more efficient methods of process management and improvement [165].

BPM is defined as the exploitation of methods, techniques and software to design, enact, control and analyse operational processes that involve humans, organisations, applications and other sources of information [166]. BPM is also defined as “the combination of art and science” that enables organisations to oversee and manage the way in which work is performed. It guarantees the uniformity of results and capitalises on potential for enhancement [167].

The scope of BPM is extensive, encompassing a multitude of activities, including process modelling, automation, control, and optimisation. The principal objective of BPM is to optimise process efficiency and effectiveness, which can result in substantial financial benefits [168]. BPM enables organisations to achieve strategic alignment, improve governance and foster a culture of continuous improvement [169]. By offering a systematic methodology for process management, BPM allows organisations to respond rapidly to changes in the business environment and retain a competitive advantage.

BPM is significant in the context of digital transformation, serving as a vital mechanism for integrating digital technologies into business processes. It enables the automation of routine tasks, thereby allowing organisations to concentrate their efforts on more strategic activities [166]. By leveraging BPM, organisations can streamline their operations, reduce costs, and enhance customer experiences. The deployment of BPM in digitalisation initiatives is particularly discernible in sectors such as e-commerce and e-government, where it serves to facilitate the administration of intricate procedural processes [165].

BPM languages, such as BPMN, facilitate the generation of graphical representations of an organization's critical processes that are readily comprehensible. It is not possible to construct an organisational information system without first utilising process modelling and mapping. BPMN 2.0 [170] is a notation that is straightforward to comprehend. It employs a variety of symbols to delineate the flow of processes. The most significant symbols are as follows (Figure 2.22):

- event (start, end, message and timer);
- tasks (task, send task, receive task and sub-process);
- gateways (the decision point that separates the process flow according to a condition)
- pool and swim lane (it groups business process objects to a lane);
- connecting elements (sequence flow, message flow, and association symbol);
- artifacts (data object, message, data store, group).

In the public sector, BPM is employed with the objective of enhancing the efficiency and transparency of government operations. It facilitates the administration of processes, thereby enabling governments to deliver services in a more efficacious and timely manner, and to respond to the needs of their citizens in a more responsive and expedient manner.

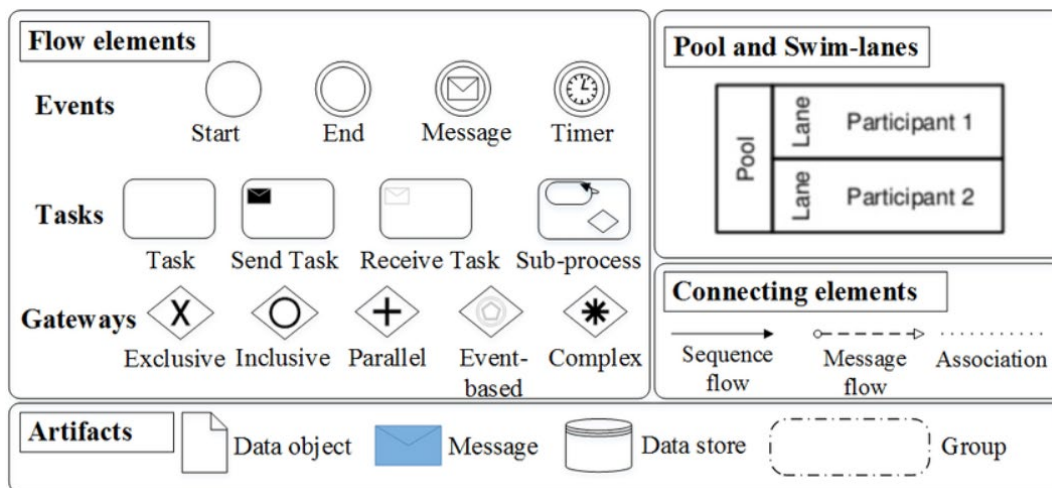


Figure 2.22: BPMN symbols [171].

The implementation of business process management could prove advantageous for public sector organisations seeking to modernise their procedures by enhancing the integration of Information Technology [172],[173]. The adoption of BPM in the public sector is part of a broader trend towards e-government, which seeks to leverage digital technologies to improve public administration [165].

In the contemporary era, business process management (BPM) is acknowledged as a pivotal managerial discipline, assisting organisations in negotiating the intricacies of the modern business environment. A variety of BPM systems (BPMS) are available to facilitate the implementation of BPM initiatives. BPMS provide functionalities such as process modelling, automation and analysis, thereby enabling organisations to manage their processes in a more effective manner. The aforementioned software facilitates and coordinates the execution of business processes and the allocation of tasks [174]. The principal artifact employed for the depiction of a process is a process model. Business modelers typically employ a graphical representation of the process, utilising elements from a predefined language or notation. These may include activities, gateways, events, sub-processes, resources, and data [174]. The position and role of each human resource within the organisational structure is represented in a process model, which also depicts the process itself. To facilitate the execution of business processes and to enable their monitoring (in terms of instances or cases), process models are developed and subsequently refined [175].

As BPM continues to evolve, it is anticipated that it will incorporate emerging technologies such as artificial intelligence and machine learning, thereby further enhancing its capabilities and impact on organisational performance.

2.2.7 Organizational Change Management

Organisational Change Management is a critical field of study that addresses how organisations can effectively implement and manage change within their operations. This discipline is particularly relevant in today's rapidly evolving business environment, where technological advances and market dynamics require constant adaptation. At its core, change management involves preparing, supporting and assisting individuals, teams and organisations to implement organisational change. It

is a structured approach to moving individuals, teams and organisations from a current state to a desired future state, with the aim of maximising the benefits and minimising the risks associated with change.

One of the main areas where change management has become essential is in the implementation of new IS. The integration of IS within an organisation can lead to significant changes in processes, roles and responsibilities. However, failure to manage these changes effectively can result in significant negative impacts, including wasted resources and reduced operational efficiency [176]. The adoption of a robust change management strategy is therefore critical to the successful implementation of IS, as it helps to align technological changes with organisational goals and employee readiness.

Change management models provide a framework to guide organisations through the change process. These models are essential tools to help structure the change process and ensure that all aspects of the transition are considered and managed effectively. These models provide structured methodologies to help organisations anticipate challenges, engage stakeholders and sustain change over time [177].

In the context of the construction industry, change management models are particularly important due to the challenges of digital transformation. These challenges include resistance to change, a lack of understanding of digital benefits, and the need for cultural change within organisations [178],[179]. By applying change management models, construction companies and organisations that manage facilities can better address these challenges, facilitate smoother transitions, and improve the overall efficiency and effectiveness of digital implementations.

In the following paragraphs, the aim is to analyse the existing literature on change management models, and secondly, the experiences that have already been dealt with in the field of construction management, asset management and facility management.

2.2.8 Change Management models

The concept of Change Management is of fundamental importance for the successful completion of digital transition projects [180].

The term "Change Management" encompasses a multitude of potential modifications within an organisational context. These may include alterations to the tools and technologies employed (e.g., the implementation of a novel IS). Alternatively, changes may be enacted at the level of processes, whether pertaining to the delivery of services or the execution of routine activities within an office setting. Despite the potential benefits of such modifications, it is not uncommon for technological and process changes to fail to achieve the desired outcomes. This is evidenced by the fact that approximately 70% of change programmes ultimately fail [181].

A third factor, after tools/technologies and processes, is pivotal to enhance the probability of a fruitful digital transition: human resources. Consequently, it is of paramount importance to evaluate the impact the change might have on people and endeavour to manage it. This aspect is of particular significance in public organisations in Italy, which are typically averse to change and when change is implemented, it tends to be done so in a gradual manner [182].

Over the past few decades, various approaches to change management have emerged, and a substantial body of scientific literature has grown to support them. These approaches are also gaining increasing recognition among professionals, companies,

and administrators who recognize the growing importance of the human factor in organizational change.

To evaluate the potential inclusion of specific change management strategies in the context of a future implementation of the new IS, a comprehensive review was conducted of the most widely used and authoritative frameworks in the fields of scientific research and corporate governance. Following an initial screening process, a detailed assessment was carried out to determine the most suitable framework for application in this context. The frameworks analysed included:

- Lewin's change management model categorises the change process into three distinct phases. The first, “unfreeze”, is concerned with preparing the organisation for change. This involves understanding the necessity for change and dismantling the existing status quo. The second phase, “change”, entails the introduction of new processes and the provision of support to employees as they transition to the new situation. Finally, the “refreeze” phase consolidates the new situation after the change has occurred. This ensures that the change is sustained over time [183];
- The McKinsey 7-S framework is an analytical tool that examines seven interconnected elements of an organisational structure, with the objective of ensuring that they are aligned. These elements are strategy, structure, systems, shared values, skills, style and staff. This method facilitates the comprehension of the issues and the realignment of the organisation for efficacious change [184];
- Kotter's eight-step change model places emphasis on the human aspect of change and comprises the following steps: (1) create a sense of urgency, (2) build a guiding coalition, (3) form a strategic vision and initiatives, (4) make a list of volunteers, (5) enable action by removing barriers, (6) celebrate short-term wins, (7) support acceleration, and (8) institute change [185];
- The ADKAR model focuses on individual change through five stages: awareness of the need for change, desire to participate and support change, knowledge of how to cope with change, ability to implement new skills and behaviours, and reinforcement to support change [186].;
- Nudge theory focuses on subtly guiding individuals towards a desired behaviour through indirect suggestions to positive reinforcement rather than giving direct instructions [187];
- The Bridge's transition model, emphasises the psychological transition of individuals during change by focusing on three steps: “ending” focuses on letting go of old habits and coping with the loss of old habits; “neutral zone” is the middle state where the old is gone but the new is not yet fully operational; “new beginning” focuses on making new behaviours and new ways one's own [188];
- The Kubler-Ross change curve is based on 5 stages of grief: denial, anger, bargaining, depression, acceptance. This model, introduced by Elisabeth Kubler-Ross in 1969 and initially conceived in the context of terminal illness, has been widely used beyond its original framework addressing various forms of change (e.g., organizational change and personal transitions) [189];
- Satir's change model focuses on the impact of change on performance and

confidence, describing 5 phases: late status quo, resistance, chaos, integration, new status quo. This model, originally developed for family therapy, has not been widely used in organizational contexts [190];

- The PDCA cycle consists of four steps for continuous improvement: plan, to identify and analyse the problem; do, to implement the solution; check, to monitor and evaluate results; act, to standardise solutions and plan future improvements [191];
- Appreciative inquiry is an approach that focuses on identifying an organisation's strengths and building on them for positive change rather than focusing on problems [192].

These ten models all offer structured approaches to managing change and each has its strengths, weaknesses and fits better or worse depending on the organisation under consideration.

2.2.9 Organizational Change Management in the AECO Sector

The application of change management models in the construction sector, as well as in real estate asset management and facility management, is crucial for adapting to technological advances and improving operational efficiency.

The construction industry has traditionally been resistant to change due to its complex and fragmented nature. However, the integration of BIM has emerged as a transformative force that requires robust change management strategies. BIM facilitates a collaborative and iterative design process and efficient O&M phase, in contrast to the traditional silo-based approach. The adoption of BIM requires a shift from vertical and hierarchical organisational structures to platform-based and networked organisations that promote collaboration and efficient knowledge management [193].

Challenges in construction:

- *Resistance to change*: There is significant resistance within organisations due to the perceived risks and disruption associated with adopting new technologies such as BIM [112].
- *Skills Gaps*: The transition to BIM requires upskilling of the workforce, which can be a barrier due to the time and resources required for training [112].
- *Interoperability issues*: Integrating BIM into existing systems often presents challenges related to data interoperability and standardisation [194].

Change management strategies:

- *Stakeholder engagement*: Effective change management involves engaging all stakeholders, including clients, contractors and design teams, to foster a collaborative environment [112].
- *Phased implementation*: Phasing in BIM through pilot projects can help organisations manage the transition more effectively [194].
- *Ongoing training*: Regular training is essential to keep staff up to date with the latest BIM advances and to reduce resistance [112].

The application of change management models in the construction sector and related

areas of real estate asset management and facility management is essential for successful digital transformation. The integration of BIM presents both opportunities and challenges, requiring strategic approaches to manage change effectively. Key strategies include stakeholder engagement, phased implementation, ongoing training and strong leadership commitment. By addressing these challenges and realising the benefits of BIM, organisations can improve their operational efficiency and asset performance.

3

CHAPTER

Methodology

The chapter focuses on the proposed methodology while providing an overview of existing systems and methods to address the discussed theme. It presents a reproducible approach for designing and developing an Information System and proposes a Reference Architecture for implementing the tool within an organization.

The proposed methodology is comprised of three principal sections. The first section concerns the conceptualisation and design of an Information System through the Design Science Research Methodology. The second section concerns the analysis of the organisation and the formulation of new Reference Architectures for the implementation of the platform. The third section concerns the proposal of a new organisational unit with the purpose of managing the implementation phase of the Information System and subsequently its maintenance.

3.1 Information System design

3.1.1 Methodology process model

As pointed out in the literature review, the management of large Real Estate (RE) assets presents significant challenges and when the size of the assets is particularly large, the help of digital tools can be of crucial importance to solve a variety of problems.

Considering that the AECO sector is among the least digitised in the world [89] and that the first objective of this thesis work is to design an Information System (IS) to support strategic decisions, the Design Science Research Methodology (DSRM) was chosen to tackle the problem. This methodology is particularly relevant to the present research work as it allows a structured procedure to be followed to investigate a problem that lies at the intersection of the field of Information Technology (IT) and the field of Organisations [121]. Furthermore, to ensure clarity and alignment with the practical aims of this research, a case study approach is employed within the DSRM framework. While DSRM provides the overarching methodology for artifact creation and evaluation, the case study allows for in-depth exploration and demonstration of the

proposed solution within a real-world setting. This approach acknowledges the context-dependent nature of organisational problems and solutions, enabling a more nuanced understanding of the design's feasibility and potential impact.

The DSRM offers four distinct entry points for initiating research (Figure 3.1).

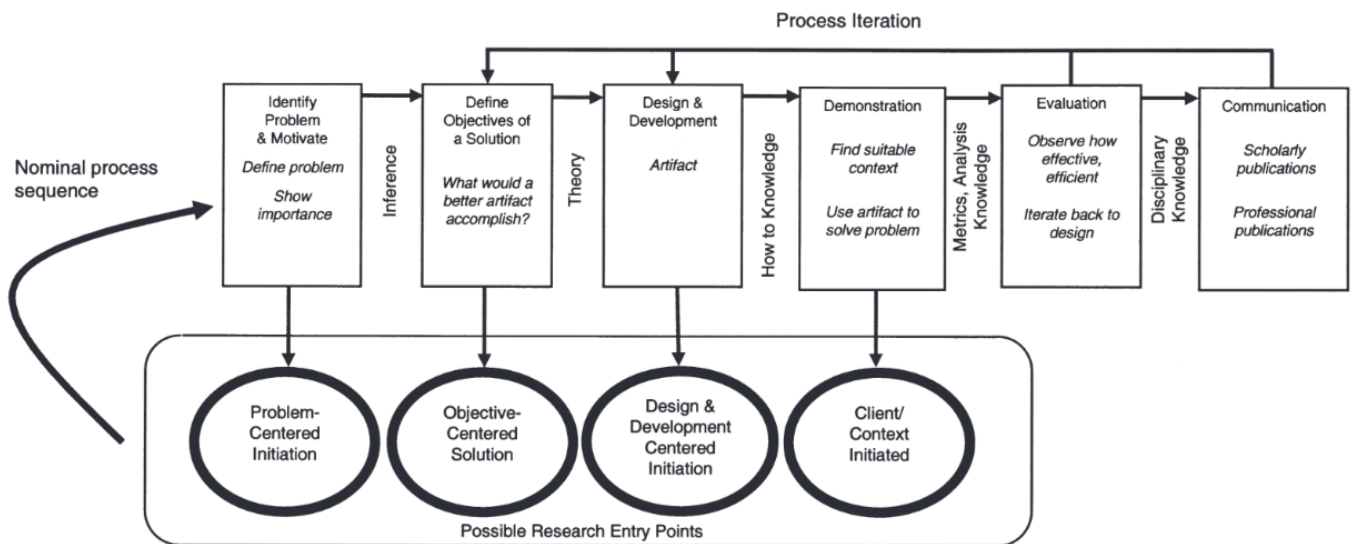


Figure 3.1: DSRM Process Model [121].

This study employs a problem-centred initiation, recognising the urgency and practical significance of the identified Asset Management challenge within Italian public universities. This approach aligns with the core DSRM principle of relevance to practice, ensuring that the research directly addresses a tangible organisational need.

To apply the methodology to the specific problem that this thesis aims to solve, the model of the DSRM process proposed by Peffers [121] was adapted by creating a methodology process which schematically summarises the steps followed and indicates in which chapter the corresponding content can be found. The methodology process is proposed in Figure 3.2 and include an initial problem identification phase in which the issues surrounding the management of particularly large asset portfolios was investigated through literature review, and direct observation of the case study organisation.

This phase is followed by the definition of the objectives that were delineated starting from the highlighted problems and analysing the documentation that the University of Turin produced regarding the strategic objectives (i.e., Strategic Plan). Furthermore, other sources comprised needs emerged from the direct observation of the problems within the organisation as well as from the sources of the literature review regarding Asset Management and Facility Management.

In order to properly develop the first two phases, it was essential to undertake an initial phase of analysis of the organisational structure and management processes within the selected case study, namely the University of Turin (section 4.1). This analysis also serves as the basis for the development of an Enterprise Architecture, a subject that is presented in a dedicated section (section 3.2) as it deserves in-depth analysis.

The third phase, which pertains to the design and development of the artifact, is concerned with the creation of an IS that can respond to the needs that emerged during

the objective definition phase. This system will be named the Asset Information Management System (AIMS). Within this section, all aspects of the AIMS design and development are addressed, with the aim of providing an understanding of the reasons for the choices and the dynamics that subsequently led to iterations of the process.

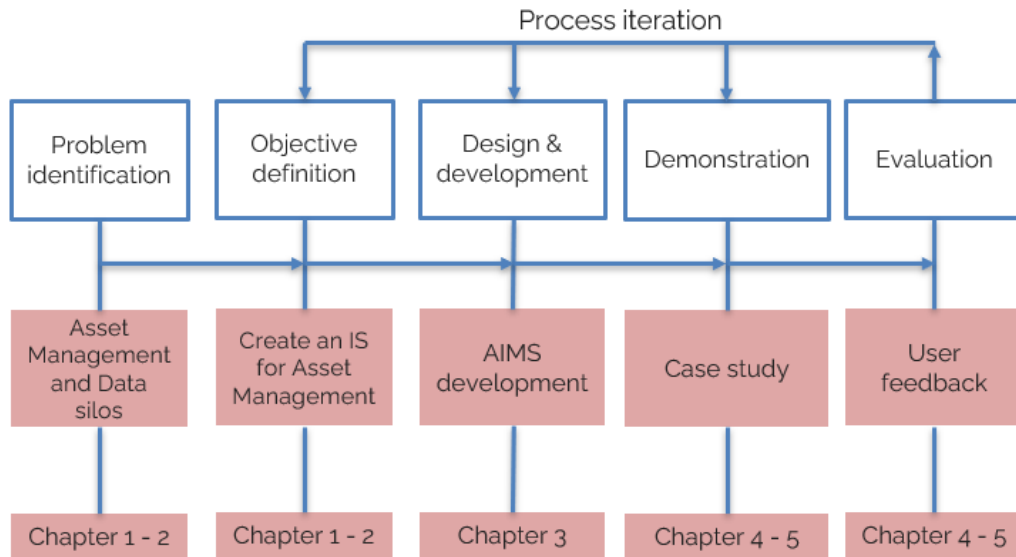


Figure 3.2: Methodology process adapted from [121].

The fourth step, concerning the demonstration of the artifact, is developed within the Chapter 4 and Chapter 5 and offers a demonstration of the result obtained by showing the applications of the artifact on buildings chosen as pilot cases.

Finally, the evaluation step of the created AIMS highlights positive aspects, points out shortcomings, and malfunctions that made it possible to improve the result by repeating the methodological process.

The following sections will then make explicit the specific process used during design and development phase.

3.1.2 Design and development of the first artifact

The primary purpose of the AIMS is to support University of Turin in various decision-making processes related to Asset Management and Facility Management, space occupancy optimization and the administration of staff and educational activities.

The first methodology developed for the AIMS is designed to integrate various types of information related to different management issues at multiple levels of detail. Additionally, the structure of its components is intended to foster collaboration and information sharing between the system's developers and maintainers and the administrative staff responsible for providing and updating data.

The following steps will elaborate upon the outlined methodological framework, which encompasses several essential phases (Figure 3.3):

- analysis of current management processes and existing databases;
- formalization of information requirements;

- structuring data to develop an integrated database;
- Building Information Model (BIM) development and data connection;
- georeferencing the information model within a BIM-GIS web-based platform;
- utilizing Business Intelligence (BI) to design interactive analytics dashboards.

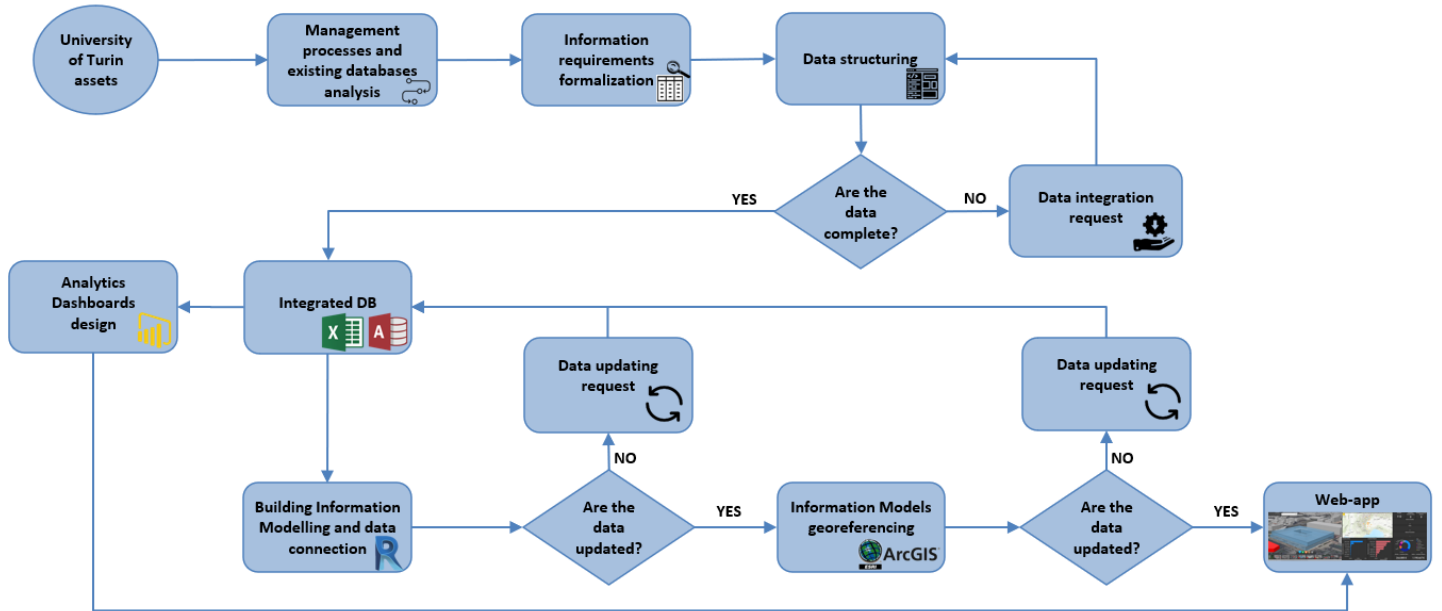


Figure 3.3: Methodological framework for the design of the first artifact.

The research approach began by examining the University of Turin's resources and operational framework. This initial step aimed to identify existing relevant data already in possession of various Directorates or Departments, understand the current methods of data management and sharing and uncover any gaps in the available information. This comprehensive analysis served as the foundation for developing a more efficient and integrated database for the institution.

Initially, the University of Turin's communication channels, including the publicly accessible website section dedicated to core activities and staff official documentation (referred to as the "transparent administration section"), were examined to identify the available data, the administrations involved in Asset Management and Facility Management, and the existing databases and platforms. Table 4 presents the findings of this preliminary analysis. A web platform named OpenSIPI was identified, designed to manage both spatial and functional building attributes (such as dimensions, occupancy, and mechanical assets).

This platform is overseen by the Information Systems, Portal and E-learning Directorate (ICT) and the Building and Sustainability Directorate (BS). Additionally, an external database managed by an Italian consortium of university, namely Cineca, was identified as the management platform for student data, including the course catalogue, enrolment data, and exams.

Table 4: Platforms, databases, data and involved Directorates

Platform or database	Data	Directorate
OpenSIPI	Building stock, Building name, Geometric data, Building location, State of use	Information Systems, Portal and E-learning Directorate, Building and Sustainability Directorate
Excel files	Timetables, Courses	Educational and Student Services Directorate
Cineca	Student, Student career, Course catalogue, Course fees	Educational and Student Services Directorate

A detailed analysis of the existing databases revealed that OpenSIPI is intended to provide a space and an Asset Management tool to explore and visualize the entire university building stock with its spatial attributes, along with interactive digital plans that offer additional information about individual spaces (see Table 5 for spatial attributes available from the OpenSIPI platform).

Table 5: OpenSIPI platform available data.

Data	Format	Data	Format
Building name	Text	Space state of use	Text
Building code	Text	Space height	Number
Area code	Number	Space capacity	Number
Encoding	Number	Area/Capacity	Number
Building type	Text/Number	Space name	Text
Building state of use	Text	Storeys (Building)	Number
City name	Text	Net area (Building)	Number
Address	Text	Perimeter (Building)	Number
Floor code	Text	Net area (Building)	Number
Space code	Number		

However, essential functional attributes for the operations and maintenance (O&M) phase such as occupancy, schedules, furniture, mechanical systems, and evacuation details were completely absent. Additionally, the platform was not regularly updated, resulting in data that did not accurately reflect the current state of the space. Consequently, the Security, Property and Facility Management Directorate (SPFM) needed to compile supplementary documentation to obtain up-to-date data and plans. Furthermore, the identification of ongoing renovation projects was also a key objective, a piece of information that was previously accessible only to the staff directly involved.

Additionally, it was found that Cineca provides the Education and Student Service Directorate (ESS) with two tools, the functionalities of which are detailed in Table 6.

Table 6: *Esse3 and University Planner functionalities.*

Esse3 (for student lifecycle management)		University Planner (for classrooms and resource management)	
Student secretariat	• Admissions • Matriculations • Enrolment renewals • Change of course, suspension, and renunciation • Badge management	Planning	• First draft of timetable (lectures) • Calendar of individual dates (exams)
Didactics	• Courses • Course catalogue	Change management	• Individual timetable changes • Individual calendar changes
Fees and right to study	• Fee payment management • Acquisition and control of income data (ISEE, SPC, and INPS databases)	Monitoring	• Monitoring of the actual progress of scheduled events • Statistical analysis
Student career	• Acquisition of frequencies of teaching activities • Calendar and booking of exams • Calculation of profit and qualification exams, with and without digital signature of minutes • Acquisition of Credits (CFU) for didactic activities • Management of study periods in mobility abroad • Recognition and validation of CFUs • Online thesis (UNITESI module) • Achievement of degree • Traineeships and internships		
Postgraduate studies	• Doctorates • Postgraduate schools • Masters • State examinations		

These include: 1) Esse3, which is used for the management of students' academic careers; and 2) University Planner, which is employed for the publication of timetables. However, it should be noted that this tool does not optimise space occupancy. Interviews with administrative and management staff revealed that Cineca data were not directly queryable and were only accessible through dedicated interfaces. To obtain the required information, it was necessary to submit customised queries to Cineca, which resulted in inefficient management due to the long processing and waiting times. Further analysis conducted in collaboration with ESS revealed that data on academic activities were collected using heterogeneous and customised Excel sheets, which complicated information accessibility and hindered coordinated asset management activities. This phase revealed that the organisation of the University of Turin is structured into technical and administrative areas, with specific commitments and competencies, and is responsible for the production and handling of large amounts of

data. However, it also identified a lack of a shared methodology for the storage, processing, and sharing of data, which has resulted in a fragmented and low-digitalised information management strategy.

Upon completion of the analysis phase, it became evident that the primary challenges were related to the exchange of information between disparate areas. To address these issues, the exchange of information was formalised, resulting in the establishment of a structured information management methodology that is aligned with existing processes. In the context of change management, the implementation of new systems and tools within an organisation is often unsuccessful when current tasks are significantly altered [28],[195]. Therefore, to ensure a smoother transition, the information exchanges were structured in a way that did not disrupt the internal tools used by each area. Instead, their outputs were integrated into a shared Information System, as will be further detailed in chapter 5.

The identification of the Information Requirements (IRs) enabled the definition of the AIMS database structure and formalised the information exchanges between different areas. The IRs were established based on analyses conducted in the preceding phase, with a particular emphasis on the preservation of existing datasets. Subsequently, the IRs were translated into datasets and structured according to the information subjects, considering the receiver and the compiler, while ensuring the separation of any sensitive or confidential data. Table 7 provides a detailed overview of the data required for the mapping of university buildings, as specified in the IR datasets from the Technical and Administrative Area responsible for property acquisition and management. This encompasses data pertaining to the identification, status, and utilisation of the building in question. Furthermore, Table 7 offers guidance on the compilation of datasets, including the data type, number of digits, and available values.

A crucial stage in the process was the identification of the fundamental data sets required for the AIMS of the University of Turin. It was of the maximum importance to create a centralised database that would collect the necessary data from a variety of existing sources, thus ensuring interconnection and integration of the data into a single, accessible database for all stakeholders. The development of this centralised database commenced with the existing data sources, with the primary objective of guaranteeing the flexibility and adaptability required for future evolution throughout the university asset lifecycle.

Table 8 presents the data collected, its formats, and the sources utilized. The optimal method for storing data in a flexible and accessible manner was found to be relational databases (RDBs). These databases represent the most secure and well-established system for organising data with a clear hierarchy [196]. RDBs facilitate the management of various types of relationships between data.

Table 7: Information Requirements example.

Field name	Data source	Type	Feature	Feature Detail	Example
Building code	Technical, and administrative areas	Text	Restricted field in digits	5 Digits	029_B
Building name	Technical, and administrative areas	Text	Free field	-	Campus Luigi Einaudi
Main address	Technical, and administrative areas	Text	Free field	-	Lungo Dora Siena 100
Municipality	Technical, and administrative areas	Text	Free field	Extended name	Turin
Main use	Technical, and administrative areas	Text	Free field	-	Classroom/ educational and research services/Departments/Libraries
Building Type	OpenSIPI, Technical, and administrative areas	Text	Restricted field in values	Available values: Building, Portion of Building, Agglomeration of Buildings, No Type, ND	No Type
Status	OpenSIPI, Technical, and administrative areas	Text	Restricted field in values	Available values: Decommissioned, In use, Under construction, No Status, ND	In use

Table 8: Data collected to structure the database.

Data	Format	Source	Data	Format	Source
Building name	Text	OpenSIPI platform	Space name	Text	OpenSIPI platform
Encoding (Building level)	Number	OpenSIPI platform	Storeys (building)	Number	OpenSIPI platform
Encoding (area level)	Number	OpenSIPI platform	Net Area (building)	Number	OpenSIPI platform
Encoding	Text/number	OpenSIPI platform	Perimeter (building)	Number	OpenSIPI platform
Building type	Text	OpenSIPI platform	Net Area (space)	Number	OpenSIPI platform
Building state of use	Text	OpenSIPI platform	Start time (timetable)	Time	Department office
City name	Text	OpenSIPI platform	End time (timetable)	Time	Department office
Address	Text	OpenSIPI platform	Start-end time (timetable)	Time	Department office
Latitude	Number	Google Maps	Day (timetable)	Text	Department office
Longitude	Number	Google Maps	Day Number (timetable)	Number	Department office
Encoding (Floor Level)	Number	OpenSIPI platform	Subject (timetable)	Text	Department office
Encoding (Space Level)	Number	OpenSIPI platform	Subject code (timetable)	Text/number	Department office
Space typology	Number	New data creation	Title (Building)	Text	University website
Space description	Text	New data creation	Prevalent use	Text	University website
Space state of use	Text	OpenSIPI platform	Annual income	Currency	University website
Equipment	Text	University website	Annual expenses	Currency	University website
Space height	Number	OpenSIPI platform	Course name	Text	Students' registry office
Space capacity	Number	OpenSIPI platform	Course code	Number	Students' registry office
Number of occupants	Number	Department office	Enrolled students	Number	Students' registry office
Area/Capacity	Number	OpenSIPI platform			

At this stage of AIMS development, a considerable quantity of data is managed using Microsoft Excel®, while Microsoft Access® was employed to create the centralised relational database. This approach ensures a high degree of interoperability and minimises data loss, even during the development of analytical dashboards with Microsoft Power BI®, as detailed in the following sections. The database structure, illustrated in Figure 3.4, comprises ten tables populated with the collected data. The organisation is designed based on the forecast data required for future O&M activities. This allows for the determination of how various pieces of information should be interconnected at different levels of detail. The spatial dataset, represented by the "building stock" table in Figure 3.4, was selected as the primary dataset, to which the other datasets are linked. Indeed, spatial data are fundamental to many AM and FM activities and exhibit minimal variation over time. Accordingly, the database structure was developed with the "building stock" dataset as its foundation. From this central dataset, the structure then diverges into data pertaining to floors and individual spaces (including a space typology legend, timetables, and staff). Furthermore, the database structure branches into data concerning titles related to real property, rental incomes, rental expenses, and degree programmes.

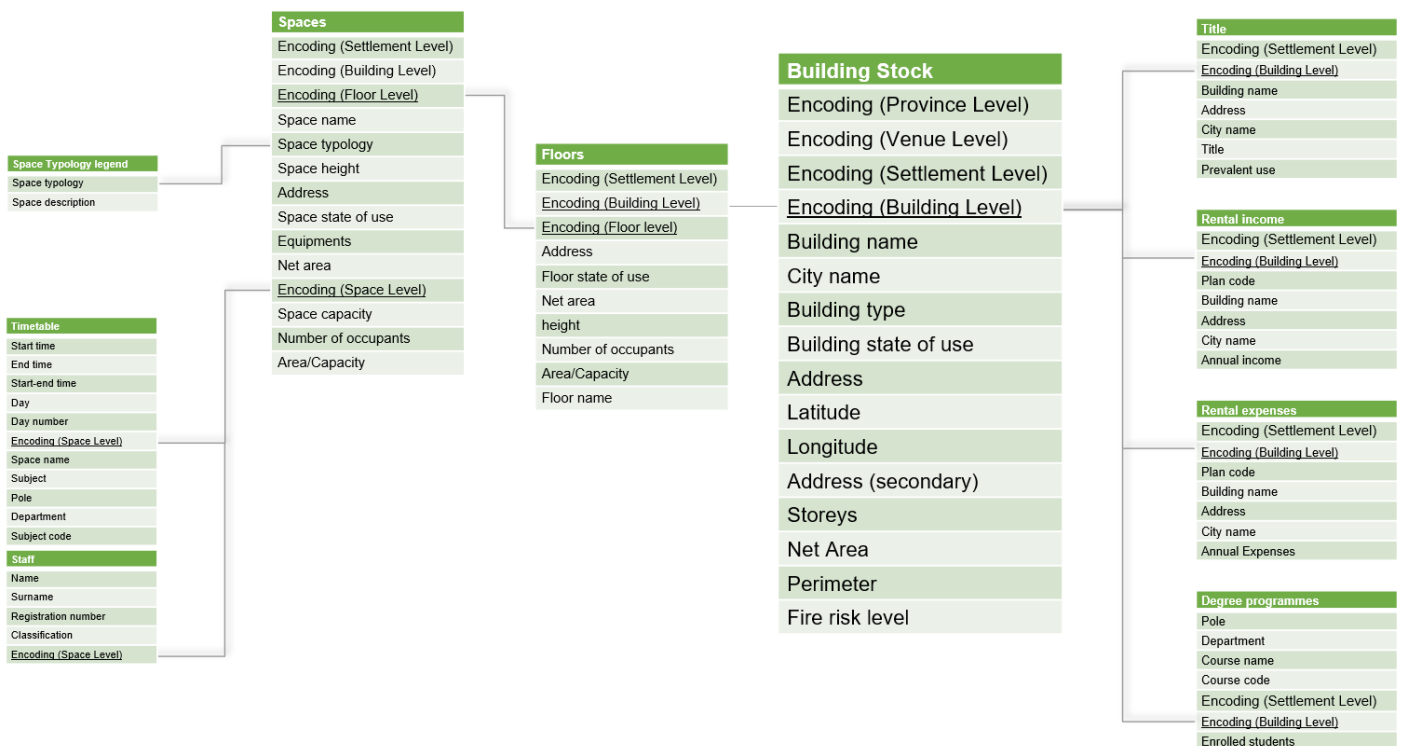


Figure 3.4: Database structure.

A custom encoding system was essential to uniquely identify building spaces and link data across the database. This system addressed current challenges caused by duplicated codes that hinder correct space identification and sometimes result in multiple assignments. To ensure a seamless transition from one management system to another, the encoding system was based on the one used in the OpenSIPI platform, as

follows:

$$TO^1_000^2_000^3_A^4_P00^5_0000^6$$

where:

- TO^1 : Province Code, 2 Digits, Text Type
- 000^2 : Venue Code, 3 Digits, Number Type
- 000^3 : Settlement Code, 3 Digits, Text Type
- A^4 : Building Code, 1 Digit, Text Type
- $P00^5$: Floor Code, 1 Digit, Text Type, 2 Digit, Number Type
- 0000^6 : Space Code, 4 Digits, Number Type.

The encoding system permits the semantic association of datasets, map elements and BIM models. The system can be employed in part, for example, to establish links between maps and territorial datasets, or in its entirety, for instance, to connect the BIM model with individual building entities datasets. Relationships between datasets, BIM models, and GIS-based maps can be managed by linking the various system components in one-to-one (1-1), one-to-many (1-*), and many-to-many (*-*) relationships using the encoding system. In a one-to-one relationship, a record in one table is linked to a single record in another table. In a one-to-many relationship, a record in one table can be linked to one or more records in another table. In a many-to-many relationship, multiple records in one table are linked to multiple records in another table.

The fourth point of the design and development phase concerned the actual modelling of the BIM models and the subsequent input of both semantic and spatial data previously collected into the centralised database. It is worthy of mention that the University of Turin possesses one of the most extensive real estate portfolios among Italian academic institutions. It was therefore neither feasible nor advantageous to create comprehensive BIM models for the entire building stock in an initial phase. Instead, following a different approach, the dispersed campus was modelled as a series of masses and georeferenced using the AIMS. Two buildings were selected for demonstration purposes, with the objective of showcasing the potential of the AIMS. These were developed into detailed BIM models, with information provided at the room level.

On-site inspections enabled the incorporation of supplementary data into the models, which had been identified as lacking following an analysis of the technical drawings (plans, sections, elevations) provided by the BS Directorate. The objective was to create BIM models with an appropriate level of detail to accurately depict the university's diverse real estate portfolio. However, it was crucial to avoid overwhelming the models and, consequently, the platform with an excessive amount of data. Accordingly, the buildings were represented using masses, floors, and rooms. Furthermore, it was essential to ensure the digitalisation and georeferencing of the entire building stock, thereby enabling the display of summarised information that was suitable for routine management activities (e.g. rental costs, property titles, and the number of classrooms and seats) through interaction with the app.

During the modelling phase, it was decided to use Autodesk Revit software®, primarily for three reasons:

- The software permits the representation of the primary volumes of the university building stock, including masses, floors, and rooms, which can be further detailed in the future.
- The Dynamo for Revit® plugin enables the automation of both modelling and parameter assignment processes.
- There is a satisfactory level of interoperability between Revit and Esri's ArcGIS Pro, enabling the direct import of BIM files (e.g., .rvt and .ifc format) into the GIS environment with minimal information loss [58].

Subsequently, the individual categories of elements, namely masses, floors and rooms, were linked to the related spatial and functional data that had been previously acquired and stored in the centralised digital database. This was achieved through the utilisation of a visual programming language (VPL). In particular, the advanced visual programming software Dynamo for Revit® [58] was utilised to integrate the semantic data illustrated in Table 9 within the parametric models of the building stock of the University. Dynamo functions as an open-source Revit interface between its API and VPL [197], enabling the linking of elements to define relationships and action sequences, which are useful for setting up tailored algorithms in accordance with highly customised requirements. The spatial and functional data were individually structured within the database and then linked to the information models. Figure 3 illustrates the steps implemented within Dynamo to import alphanumeric databases and assign them to three categories of parametric elements (e.g., masses, floors, and rooms). The input of the necessary data into the BIM models was done via shared parameters in .txt format. In fact, through customised nodes, it was possible to extract data from the database spreadsheets and make them available in the shared parameters of the BIM models.

Table 9: Spatial and functional attributes of the centralized database information layer.

Layer	Functional attribute	Spatial attribute
Building (Mass)	Building name, building code, address, building state of use, pole, department, space capacity and accessibility Degree programme	Building floors [n°], building net area [m ²], building spaces [n°], building classrooms [n°], building offices [n°], building restrooms [n°], building technical rooms [n°] and dashboard link Enrolled students [n°], professors [n°] researchers [n°], PhD students [n°] and employees [n°]
Plans (Floors)	Floor name, Floor code; Title, Accessibility	Floor capacity [n°], Floor net area [m ²], Floor height [m], Floor technical rooms [n°], Floor classrooms [n°], Floor offices [n°], Floor restrooms [n°], Floor spaces [n°]
Spaces (Rooms)	Space name, Space code, Address, Building name, Floor, space state of use, Space typology, Accessibility	Space capacity [n°], space net area [m ²], Space height [m], space equipment, Space users [n°], and dashboard link

The fifth step of the design and development phase entailed the actual implementation of the information models into the web-based BIM-GIS platform, thereby enabling real-time visualisation of University of Turin assets and their attributes within an interactive 3D digital environment (i.e., the AIMS). The system enabled the simultaneous connection of information models, spatial data, and functional data. Testing the interoperability of BIM-GIS was essential and was achieved through the "BIM to GIS" approach, which employed Autodesk Revit® and ESRI ArcGIS Pro®.

This approach is indicated in the literature [56] as the most appropriate when a BIM model is to be placed within a GIS environment. Moreover, the University of Turin has already adopted ArcGIS Pro for geotechnical research and holds a campus licence, which provides further justification for this choice.

A pivotal phase of the process entails the verification of the BIM models within the GIS environment. This is done to guarantee the accurate importation of linked data, as well as its accessibility and usability. A custom-made workflow was conceived for the purpose of verifying geographical coordinates and attributes, extracting the geometrical coordinates of vertices (X, Y, and Z) using the "Feature Vertices to Points" tool after importing the model to the GIS environment (i.e., ArcGIS Pro). Subsequently, a vertex with known coordinates was identified and employed for the purpose of verifying its geographical coordinates and correcting the georeferencing in space.

Figure 3.5 depicts the BIM-GIS integration workflow employed to model and georeference the entire building stock of the university, which ultimately provides the AIMS application.

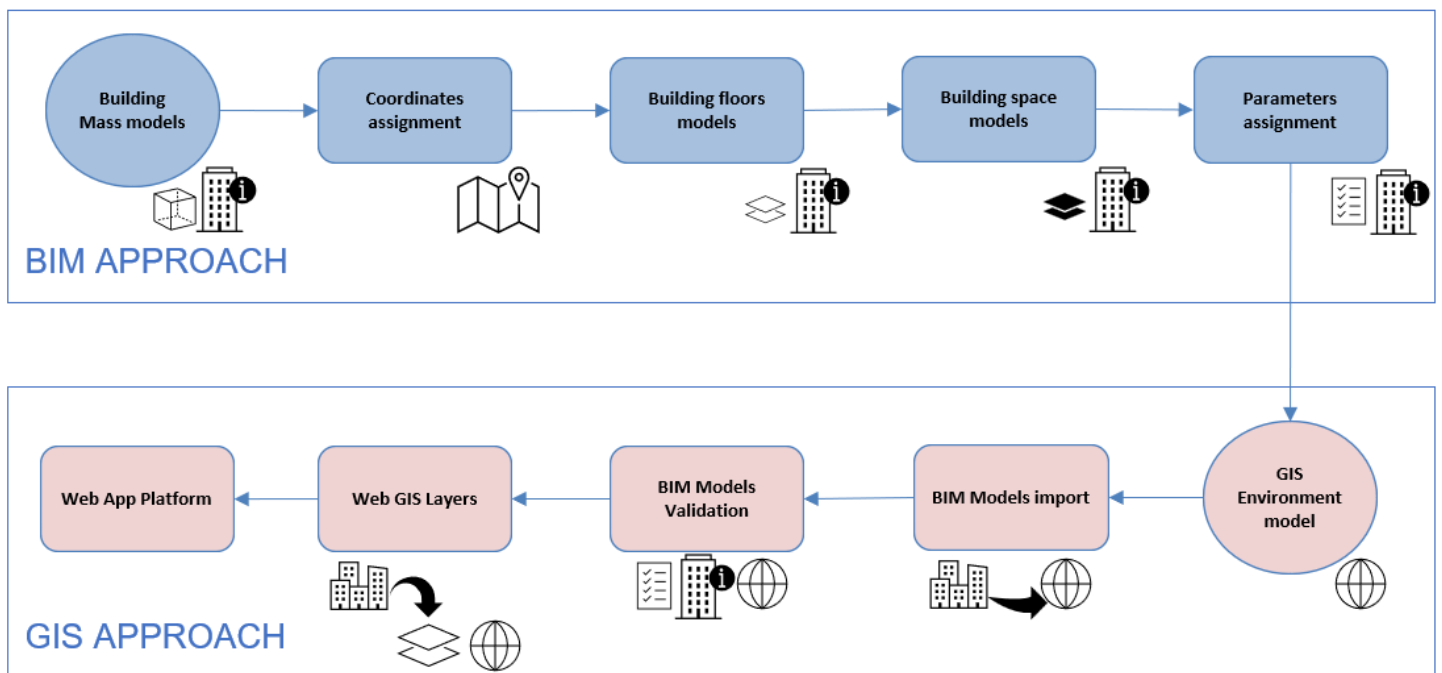


Figure 3.5: AIMS development workflow.

The BIM models of the entire asset were imported into the GIS platform as

georeferenced building masses, complete with geometric and semantic attributes (referred to as the "Building layer" in Table 9). The BIM models of the two demonstrators were fully imported, with detailed geometric and semantic information from the floors down to the individual rooms (referred to as the "Plans layer" and "Spaces layer" in Table 9).

Following the importation of all the buildings into the GIS platform, an interactive map was generated via the web environment. The ArcGIS Web AppBuilder application [198] was employed to import the building models as layers, which were configured to allow specific queries. Customised slides were then created to facilitate user navigation throughout the entire Real Estate portfolio.

The last step of the design and development phase entailed the creation of valuable instruments to assist with strategic decision-making processes. The potential of business intelligence (BI) technology was investigated due to its capacity to analyse extensive datasets and generate interactive dashboards that facilitate the visualisation and comprehension of information, which is vital for future building management.

The preliminary research indicated that the directorates predominantly utilised Microsoft Excel® and the Office® suite. It was therefore decided that Microsoft Power BI® should be selected to guarantee optimal interoperability with the existing tools and to provide a plugin that enables ArcGIS map visualisation, thus maintaining compatibility with the ESRI® suite. Furthermore, Power BI is internationally acknowledged as one of the most appropriate software solutions for the management of extensive datasets [142]. It enables users to work on datasets without modifying the source data, thus preventing data loss. The data were analysed at various levels of detail to develop several dashboards, which provide information visualisation at different scales. These range from the macro level, which concerns individual buildings or groups of buildings, to the micro level, which concerns individual rooms. This is demonstrated in chapter 5.

Two principal types of dashboards have been developed:

- Overall dashboards: These provide a comprehensive overview of the entire University of Turin assets, incorporating analytical and interactive components.
- Single Building Dashboards: These are designed to display information about individual educational centres or departments, including details of their respective spaces and attributes, which are filtered from the overall asset visualisation.

3.1.3 Evaluation and first process iteration

As outlined in Section 3.1.1, within the context of DSRM, the subsequent phase pertains to the demonstration of the functionality of the designed artifact in an application context. As illustrated in Figure 3.2, this phase, within the structure of the thesis, coincides with Chapters 4 and 5.

Subsequently, the DSRM framework encourages the researcher to undertake a further iteration of the design and development phase, with a view to implementing enhancements. This section then considers the rationale for the initial repetition of the methodological process and the subsequent return to the design and development phase, which constitutes the focus of this section (Figure 3.6).

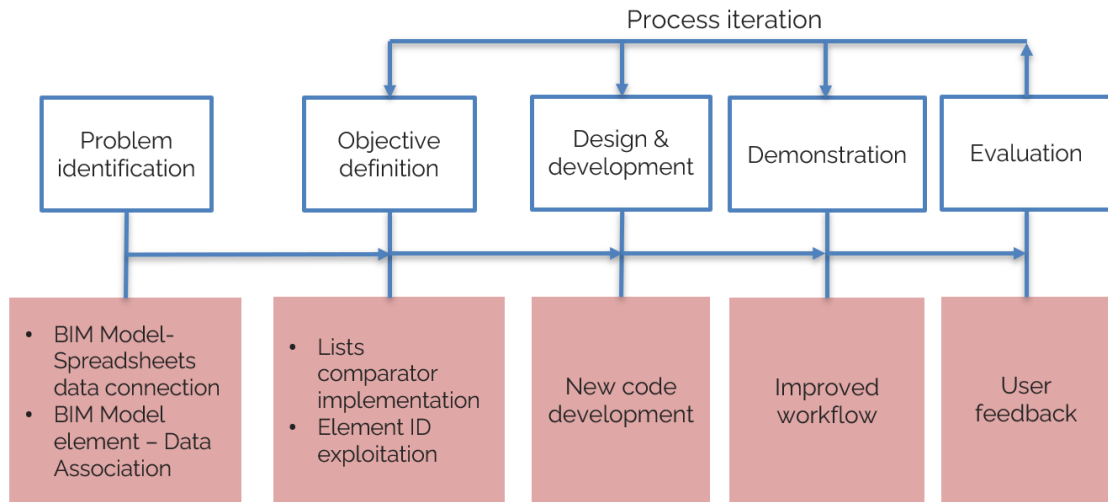


Figure 3.6: Methodology process iteration.

Firstly, issues were identified that had arisen during the utilisation of AIMS, and subsequent modifications were made to the methodology employed in the design and development phase. The primary issues identified, derived from both the writer's utilisation and assessment of the system, as well as from the observations of other experienced users in the field, was related to the data connection between spreadsheets and BIM models. Indeed, there was the potential to introduce errors due to the methodology employed. The formation of connections between data was made possible through the utilisation of semantic association, which entailed the interlinking of data based on their shared values. Accordingly, the fourth step of the design and development phase (section 3.1.2), namely “Building Information Model (BIM) development and data connection”, required particular attention.

With regard to the data connection between the database and the BIM model, as outlined in section 3.1.2 , a Dynamo script was employed which utilised customised nodes for the importation of data to three parametric element categories (i.e., masses, floors, rooms) through the establishment of shared parameters. In the initial workflow, parameters with identical features were generated individually for each element category (one for the mass, one for the floor and one for the room), resulting in the creation of redundant parameters that were common across multiple categories (Figure 3.7).

In this context, it seems useful to recall that the initial step in the process of creating parameters is to define their name, parameter type, group name, group type and reference category element. Moreover, when a parameter (instance) is created, the intention is to create a container that will subsequently be populated with the associated value (content).

To address the issue, the dynamo script was modified to include a node for comparing the parameter lists of each category and subsequently associating the parameters with multiple categories concurrently. The node enabled the automatic identification of parameters that were common to two or three categories, as well as those that were exclusively associated with a single category. For instance (Figure 3.7), Parameter A need to be associated with all the categories (e.g., Building Encoded Name), Parameter

C is common to floors and rooms (e.g., Floor Encoded Name), Parameter B is exclusive for masses (e.g., Building Name), while Parameter D is exclusive to rooms (e.g., Room Encoded Name). The newly created node requires several automated processes to identify parameters, given the considerable number of lists involved.

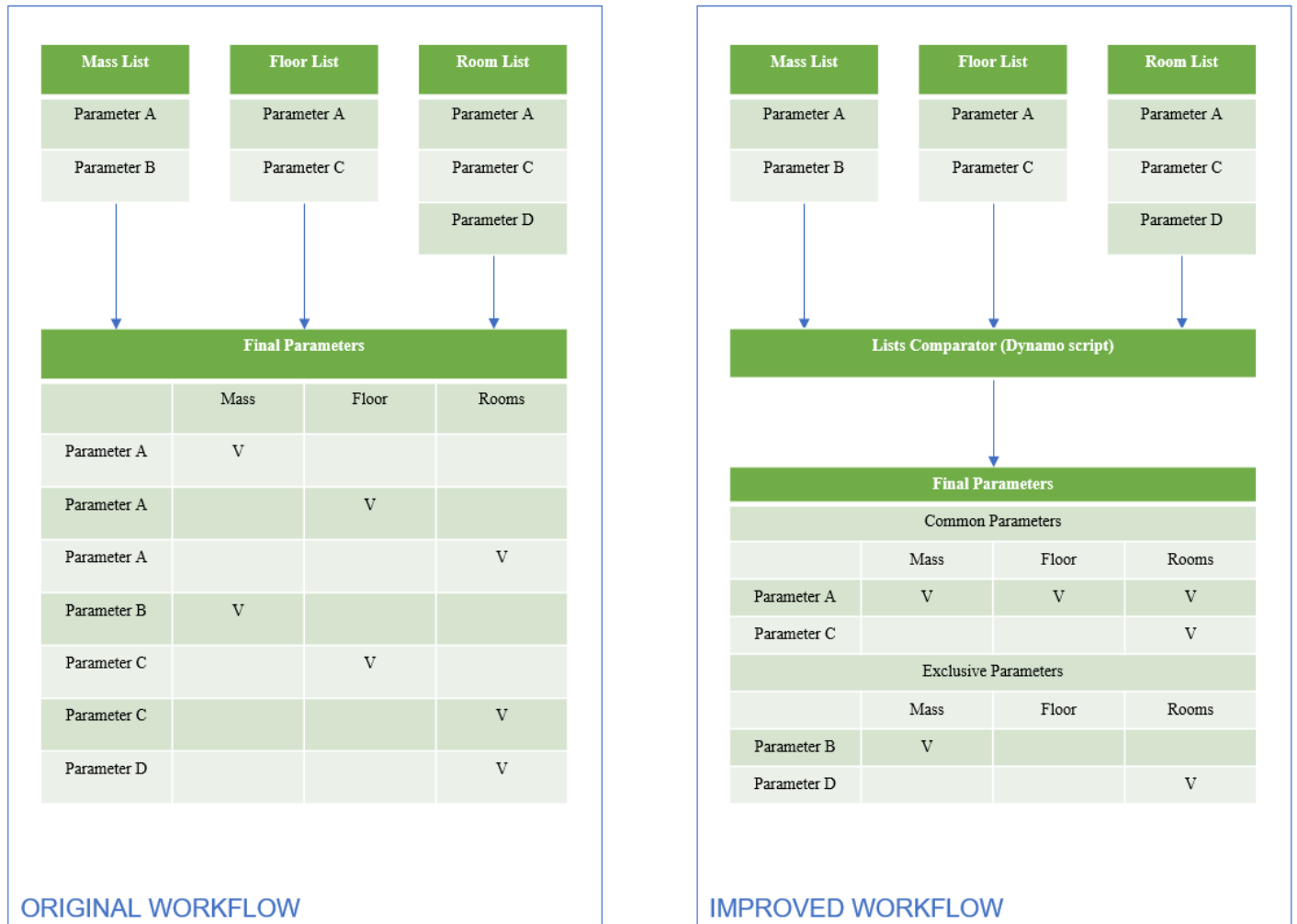


Figure 3.7: Parameter creation without and with list comparator.

A second issue was identified in the data association phase, specifically in instances where alterations had been made to the BIM models. Such modifications may include, for instance, a change in the description of a room or the removal of a room due to the union of two distinct rooms. In the initial scenario, a modification to the data set may result in the absence of a data bridge when a semantic association is employed. Conversely, in the latter case, the lack of data may lead to an erroneous outcome.

To address the issue, the linkage between the data and the BIM model was revised. Initially, this association was established using encoded names. To ensure a unique and unambiguous association, the element ID was leveraged, which is generated by the Autodesk Revit software upon the creation of a new element within the model and remains constant even after the model is shared.

In this manner, in the event of a name change for a room, the associated data would be retained, as it could not be linked to another element ID. Conversely, in the event of

alterations to the building's geometry, a new element would be created within the model, resulting in the generation of a new element ID. In the absence of associated data, this would prompt the user to take note of the missing data on the corresponding table row.

This first iteration of the methodological process thus led to a second version of the AIMS that can rely on a more automatic and robust data connection. This solution greatly lowers the probability of errors in the association between data and elements of the BIM information model.

3.1.4 Evaluation and second process iteration

As previously stated in the literature review, the continuous evaluation and subsequent improvement of the created instrument is the foundation of the DSRM's approach. Considering these assumptions, the research proceeded to investigate whether the proposed methodology could be deemed optimal or whether enhancements might be necessary.

Moreover, research was conducted concurrently to address the second research question explicitly stated in section 1.3. The topics addressed, which will be discussed in greater detail in section 3.2 below and which can be considered as complementary within the field of IS research, broadened the perspective to encompass the organisational context in which the platform is embedded. Considering the aforementioned considerations, several issues have been identified, some pertaining to technical matters and others to organisational concerns:

- the consultation and display of data in 3D maps was unintuitive, with the sole presentation format being in table format;
- the analytical dashboards, accessible via a link in the viewable building data, were not readily noticeable;
- the analytical dashboards opened another web page when consulted, which had the effect of dispersing the user's experience, as they were no longer confined to a single window;
- it was necessary to reload the BIM model in the ArcGIS environment each time it was updated;
- the proposed methodology would have required a great deal of effort from the various departments involved (in terms of data and model management and manipulation).

For this reason, a second iteration of the methodological process was made and the methodology for the design and development phase was changed again.

As illustrated in Figure 3.8, the methodology has undergone certain modifications, and in certain instances, the tools and software employed have also been altered.

In addition to the issues previously identified, two further factors were pivotal in prompting the modification. Firstly, the previous methodology involved the loading of a substantial amount of data into the BIM model, which was subsequently imported into a GIS environment. This was necessary for the purpose of visualising the information within the model. However, this resulted in a BIM model with an excessive amount of data, additional workload for the technical office tasked with loading the

data into the model, and a model update phase within the ArcGIS environment that was particularly time-consuming.

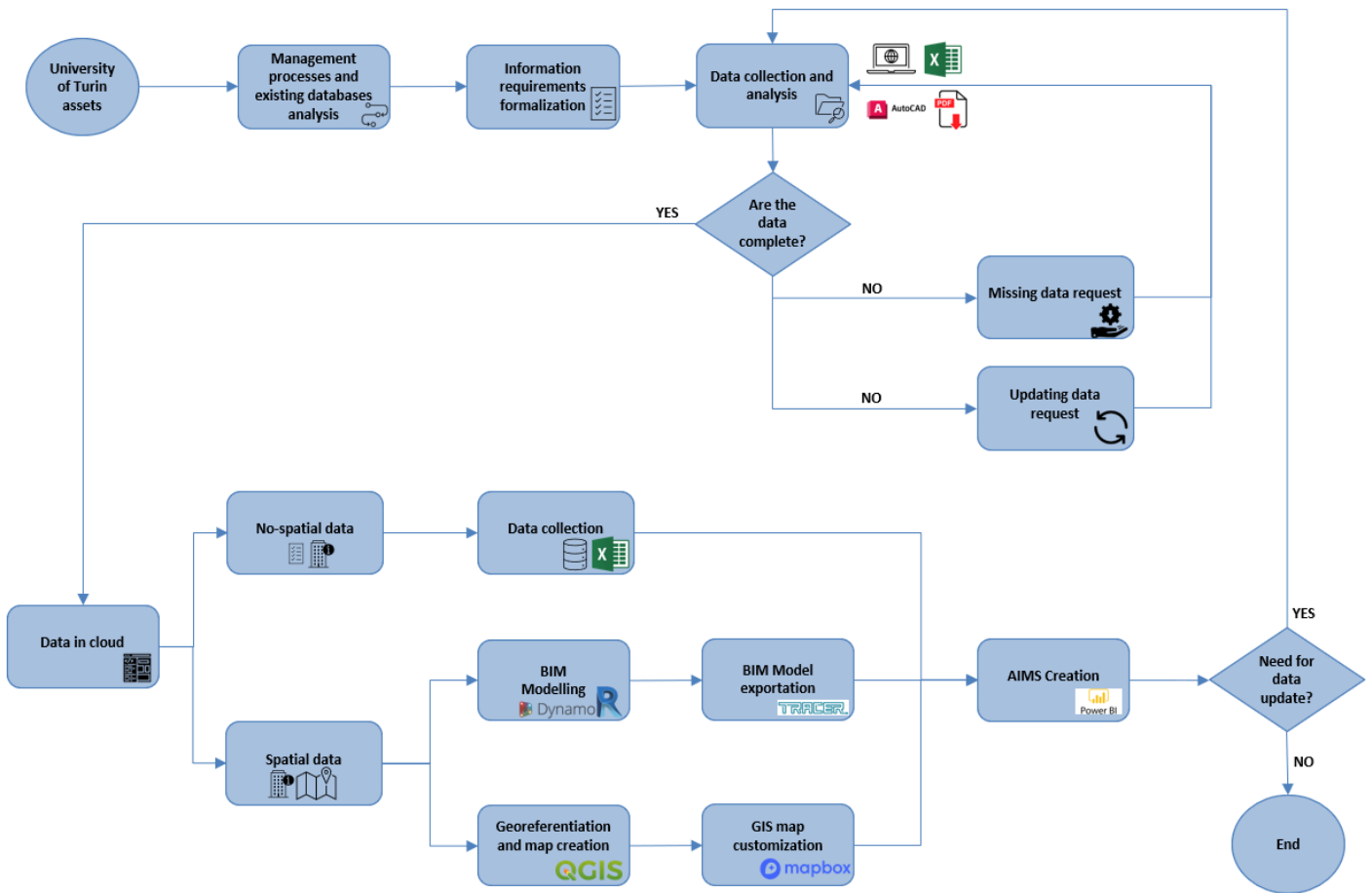


Figure 3.8: Modified methodological framework for the design of the artifact.

Given that AIMS was designed to assist stakeholders in decision-making, it was essential that it retain the capacity to visualise the real estate in question within its contextual framework, thereby facilitating the provision of analytical dashboards that were both useful and responsive. It was also desirable to be able to update AIMS in an agile manner without placing an undue burden on the work already being carried out in the various directorates.

Considering these concerns, the software that formed the basis for the web application (namely, Esri ArcGIS Web AppBuilder) was deemed unsuitable and alternative solutions were sought to integrate all the requisite data into PowerBI. The second iteration of the methodological process yielded a novel methodology, which is elucidated in the following paragraphs.

After the data collection phase, an initial change pertained to the storage and structuring of data. Indeed, the data were stored in a cloud database, in which the various datasets were reorganised with a view to grouping together spatial data, which will then form the basis for the visualisation of maps and models, and non-spatial data, which will be associated according to the need to create analytics. Data have been stored in a cloud repository according to their specific classification, which is based on whether they pertain to building spaces, users and services, or the entire university's assets.

Furthermore, the data were classified according to their static or dynamic nature. Static data, such as geometric information, cartographic data, encoded names, and primary uses of spaces, tend to remain unchanged over long periods and require minimal maintenance and updating. In contrast, dynamic data, including such items as lecture schedules, student numbers, office assignments and sensor measurements, require regular updates. Consequently, GIS-based maps and BIM models are designed to host only the static data directly, while dynamic data are indirectly associated with them through an encoding system's semantic association. This approach facilitates the management and updating of models and maps while enabling greater flexibility in the manipulation of other data for analytical purposes.

Following the methodology in Figure 3.8, once the data were structured, it was necessary to understand how to bring together visualisable BIM models, heterogeneous data from various directorates, spatial maps and exploit them within a Business Intelligence software. Recalling the literature review, it must indeed be remembered that Asset Management and the O&M phase can benefit a lot from the exploitation of BIM and GIS integrated within BI tools [199]. It is undeniable that GIS-based maps facilitate an overview and identification of assets at a territorial level, whereas BIM enables a detailed visualisation and analysis of individual buildings. Based on this rationale, the methodology employs a range of IT tools and systems, utilising the following instruments:

- the utilisation of QGIS-based maps facilitates the identification of assets and the undertaking of territorial analysis;
- the investigation of buildings in depth through BIM Models is facilitated by the utilisation of Autodesk Revit 2023;
- Microsoft PowerBI software is employed for the creation of the AIMS, which integrates all the aforementioned components into a unified application.

The AIMS has been developed with the objective of integrating diverse data types from multiple sources, thereby serving to specific analyses and various stakeholders. To ensure seamless integration and visualisation of components, additional tools have been employed, including Proving Ground Tracer for visualising BIM models within Microsoft PowerBI and Mapbox for map visualisation, publishing, and customisation. The selection of these software solutions was based on the criteria of enhancing interoperability and data management, thereby avoiding disruptive changes to existing procedures.

The following paragraph provides a detailed overview of the new methodology, including explanations of the georeferencing, map creation, customisation and visualisation processes.

The QGIS software facilitated the creation of maps on a variety of topics, including the identification of University of Turin's building stock. The initial identification of buildings was conducted within the City of Turin, and subsequently across the Piedmont Region and the Aosta Valley, utilising related datasets. This process made use of open-source Web Map Services (WMS), Web Feature Services (WFS), and download services to extract information regarding the geometry and height of the buildings in question. The buildings utilized by the university during the years 2020-2022 were identified and geolocated in separate shapefiles, which included details such as the building name, building code, address, municipality, primary use, and administrative reference hub. A separate dataset and shapefile are produced for each

year, thus enabling the analysis of changes in the building stock over time. Furthermore, maps were created using the same methodology to indicate which buildings were used for educational services or administrative functions. It should be noted that the GIS-based maps produced as part of this project contain only static data. However, thanks to the encoding system employed, further datasets can be integrated during the BI phase. The maps were customised using Mapbox tools to enable 3D visualisation and sharing via URL links, which were then imported into Microsoft PowerBI. The 3D view offers a more comprehensive understanding of building distribution and consistency, providing a detailed perspective of their locations within cities and enabling interactive querying of the displayed buildings.

Regarding the matter of BIM modelling, once the BIM model has been populated, it can be exported and integrated into Microsoft PowerBI. This process employs Proving Ground's Tracer plugin, which enables the export of the BIM model into an SQL database. The database contains both two-dimensional (2D) and three-dimensional (3D) geometric information, as well as the dataset values associated with the elements. The importation of a limited amount of information from a BIM model and corresponding SQL database into Microsoft PowerBI, coupled with the linking of these datasets with additional data, enables the undertaking of comprehensive analyses on a range of subjects. Moreover, the importation of only the essential data ensures that the files remain lightweight, thereby enhancing system functioning and facilitating file management.

As we approach the final stage of the methodology, we come to the step where models, maps and data converge and are linked to provide valuable information: the exploitation of BI software.

The extant literature highlights the considerable potential of Business Intelligence (BI) tools in the processing, analysis and visualisation of data. Furthermore, the capacity to integrate disparate data types and facilitate comprehensive information sharing has rendered these tools the optimal choice for the construction of the AIMS. A pivotal stage of the methodology entailed the structuring of the AIMS using a variety of Microsoft PowerBI interactive dashboards, which were subsequently grouped into reports and made accessible through the university website. As illustrated in Figure 3.9, the reports are organized based on distinctive characteristics depending on the associated datasets. The five topics, distinguished by different colours in Figure 3.9, provide information on the following areas: spaces, personnel, organisations, economics, and buildings. Further sections address matters of health and safety, energy, and sustainability. Although each report on a given topic is autonomous, they are linked in a tree structure, enabling navigation to a single point of departure from the homepage.

The subject of the report is the focus of the analysis, which may be conducted at the building level or the territorial level. Building-level reports furnish information on a particular building and its inhabitants, whereas territorial-level reports encompass the entirety of the university's assets. Access to building-level dashboards is available from the main territorial level. The level at which the dashboards are accessed determines which types of models can be visualised: at the level of the building, this may be a BIM model; at the territorial level, it may be a GIS-based map, or both may be available. BIM models exported via the Proving Ground Tracer software are incorporated into the building dashboards, offering both 3D and 2D visualisations for more straightforward consultation by non-expert users. Furthermore, the encoding system

facilitates the integration of previously excluded data, such as dynamic datasets (e.g., environmental sensor measurements, timetables, personnel information), with the model elements. It is possible to incorporate GIS-based maps into territorial reports and to establish connections with datasets by utilising the building encoding name. In general, the relationships between datasets, BIM models, and GIS-based maps are managed using Microsoft PowerBI, which allows for the establishment of one-to-one, one-to-many, and many-to-many relationships through the encoding system.

Information accessibility is a key consideration in the context of dashboards, particularly given the vast amounts of data that universities are required to manage. While some data may be shared with the entire community, there are instances where sensitive information must be controlled and limited. This is in line with the safety-oriented approach recommended by ISO 19650:2018, part 5 [200]. As a result, specific reports, such as "Employee Information" and "Economic Evaluation," are accessible only to authorised personnel following an authentication procedure.

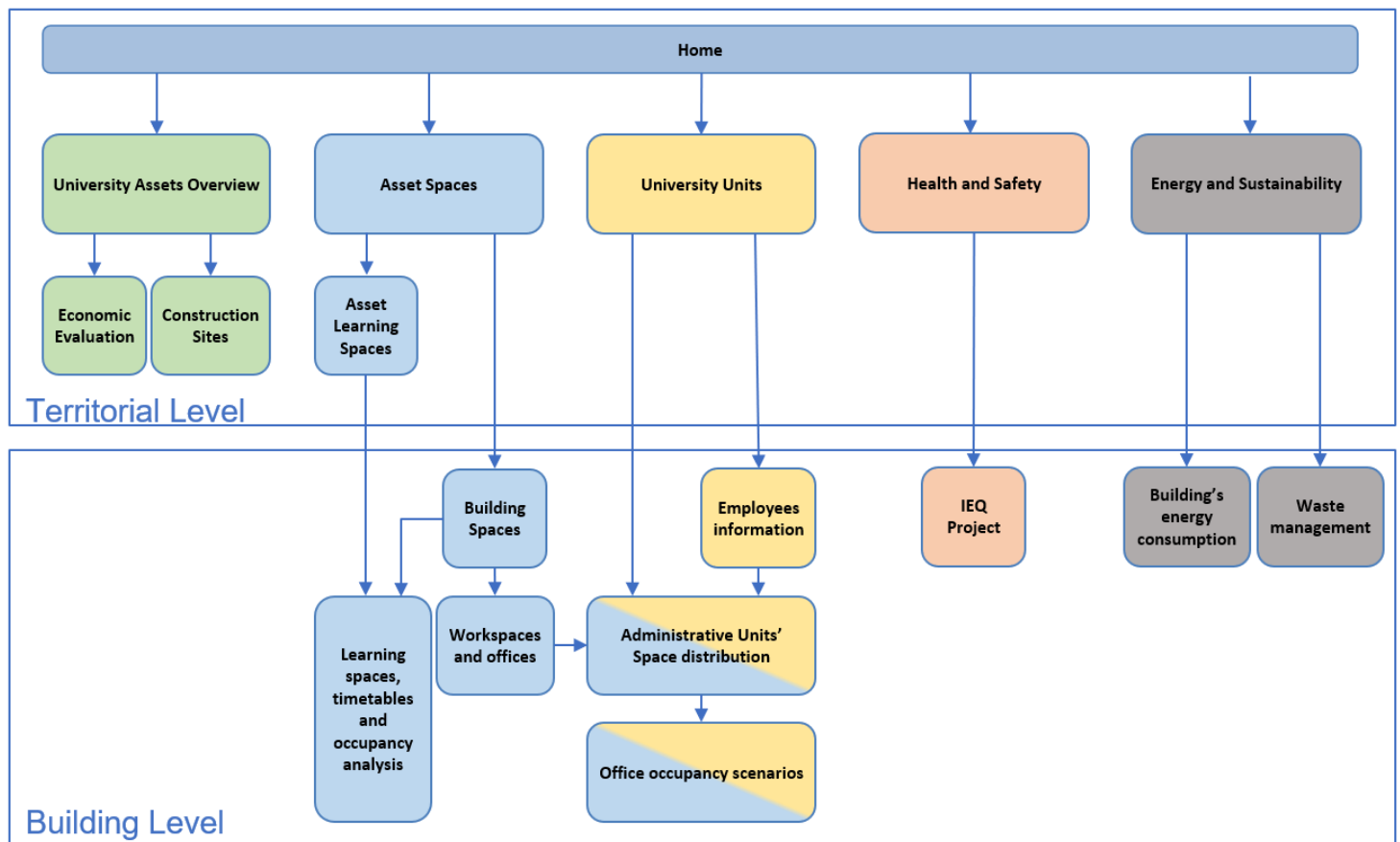


Figure 3.9: AIMS Structure.

The final phase of the developed methodology is concerned with the maintenance and updating of the AIMS. Despite its robust and comprehensive structure, there is always scope for further development through the addition of new topics or the updating of existing reports. The introduction of new topics can be achieved by following the previously outlined methodology steps, with the necessary adjustments to the platform's overall structure and connections. Conversely, the complexity of the updating process may vary depending on the significance of the updates in question. As the datasets employed in the dashboard analysis are linked rather than imported,

any alterations to their values will be reflected automatically in the dashboard. Connections between maps and the dashboard are established via a link, thereby ensuring that updates made on the Mapbox publishing server are reflected in real time on the dashboard. However, any amendments to the BIM models require a new export. Updating the AIMS can be either scheduled or requested by the relevant departments or Directorates as required, facilitating collaborative information exchanges between the university structures. It is recommended that the University Structures promptly communicate any changes to their datasets. To ensure continuous updating, it may be useful to organise an annual audit involving directorates and departments.

3.2 Enterprise Architecture

In the context of a digital transformation and during the design phase of an Information System it is crucial to identify the key requirements from the stakeholders and to develop a Reference Architecture (RA) that can guide the implementation process [201],[202]. The adoption of a RA is particularly relevant when multiple organizations or departments are involved, as it can help avoid duplication of efforts and promote synergies between the different systems.

To answer to the second research question and understand how the Information System could be implemented within the organisation efficiently, the field of Enterprise Architecture (EA) was investigated. EA is a discipline that aims at providing a holistic view of an organization's IS, including the relationships between its various components. This holistic view is essential to understand the complexity of the problem and develop a comprehensive solution.

The present paragraph proposes a methodology for an analysis of the as-is situation of the university EA and subsequently the design of a to-be version aiming at describing the future state of the organisation once the AIMS is fully operational.

The proposed architecture serves as a RA and it is a tool to facilitate the implementation of the AIMS and the alignment of business-side and IT-side requirements in the context of an approach that allows for a holistic analysis. Furthermore, the methodology fits into the context of an established framework widely used by both industry experts and researchers, the Architecture Development Method (ADM) developed by The Open Group Architecture Framework (TOGAF) and to date the de-facto standard for EA [162].

3.2.1 Analysis of the Organizational structure

The development of a robust RA using EA principles necessitates a profound comprehension of the organisational structure it is designed to support. This analysis is not merely a preliminary step; rather, it is an ongoing and iterative process that runs in parallel with and complements the design of the IS itself. Failure to consider the intricacies of the organisational structure can result in misaligned architectures, which in turn impede the effectiveness of the IS and ultimately prevent the achievement of the desired business outcomes.

Regarding the present research, an in-depth analysis of the case study organisation was carried out with a view to informing the design of the IS. Consequently, it serves as the foundation also for the EA considerations. Results regarding organisational analysis will be discussed in section 4.1 .

At the methodological level, the analysis was conducted through direct observation of the organisation and its dynamics, through the analysis of internal documentation concerning roles, responsibilities and organisational charts, and finally through targeted interviews with some key figures of the organisation (Figure 3.10).

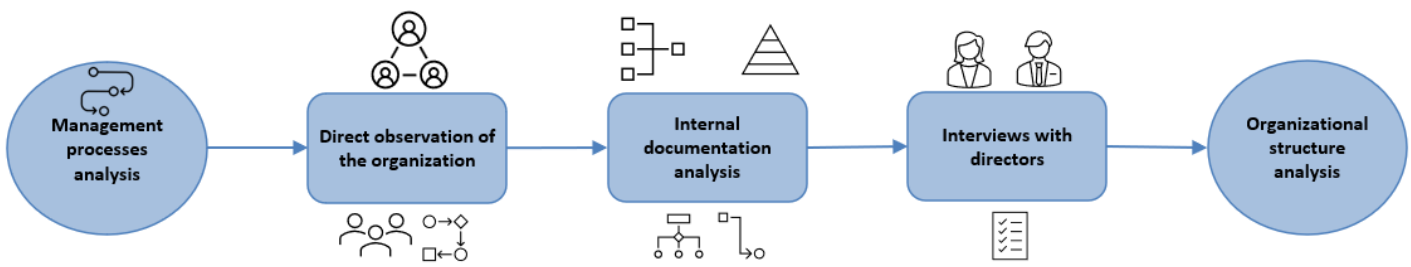


Figure 3.10: Steps of the organizational analysis.

3.2.2 Modelling the Enterprise Architecture

As previously stated in the literature review, EA represents an approach for effectively managing complexity. In particular, it provides a means of efficiently managing the complexities inherent in organisational structure, the business environment and Information Systems, as well as integrating the various elements of strategy, people, business, data and IT [203],[204]. EA comprises a number of architectural models, including Business Architecture, Application Architecture and Technology Architecture [150].

Typically, an EA is developed to address alignment issues between business processes and IT systems within an organisation [205]. The architect's role is therefore to identify business needs and strategies of all stakeholders and to develop an architecture by creating views that demonstrate how to address and balance the needs of all stakeholders. In the absence of an Enterprise Architecture, it is unlikely that all concerns and requirements will be considered and addressed in a systematic manner.

To represent the various Architectural models, this research project employed the ArchiMate modelling language [205], which is managed by TOGAF [162].

In selecting the most appropriate language for the project, an initial comparison was conducted between various visual modelling languages to identify the most suitable option. In view of the necessity to represent both business processes and diagrams and schematics pertaining to software applications and technological infrastructures, the Unified Modelling Language (UML), Business Process Modelling and Notation (BPMN) and ArchiMate were subjected to evaluation.

The primary objective of UML is to facilitate visual modelling in the domains of software engineering, system design and, on occasion, business process modelling and data modelling. BPMN is a language primarily utilized for the visual representation of business processes and workflows within an organizational context, with a particular emphasis on the delineation of stakeholder roles, events, and decisions. Ultimately, ArchiMate is employed to delineate and illustrate the architectural configuration of an organisational entity, encompassing business elements, information, software applications and technological infrastructures.

ArchiMate is particularly well-suited to the intended purpose as it is a language that can describe the organisation at a high level and encompass various aspects, whereas the UML and BPMN languages are highly detailed and granular and are not scalable to the level of EA.

To provide an explanation of the way the architectural diagrams were modelled for the case study that forms the subject of this research, it is considered useful to provide some background on the ArchiMate language. This will facilitate an understanding of its logic, potential and limitations.

The fundamental structure of ArchiMate is constituted by elements and their relationships, which may be specific according to the different layers that have been defined. In the context of the ArchiMate core language, the following layers are defined:

- *business layer*: it is concerned with the visualisation of the products or services produced by business actors through business processes in the context of the organisation;
- *Application layer*: it permits the visualisation of the application services that support the business, as well as the applications that realise them;
- *Technology layer*: this layer encompasses elements of both information technology and operational technology, including processing, storage, communication technology, physical equipment, facilities, and distribution networks.

It is important to note that the general structure of the individual layer models is extremely similar, with the same type of elements and relationships being utilised. This may result in a representation that initially appears superfluous but is, in fact, distinguished by differences in granularity and nature.

The most meaningful relationship between different layers is that of “serving”, which demonstrates how an element of one layer is “served” by the service of another layer. As illustrated in Figure 3.11, a second type of interlayer connection may be that of “realisation”. This indicates that elements of one layer may realise comparable elements in other layers (e.g., a “data object” of the application layer may realise a “business object” of the business layer).

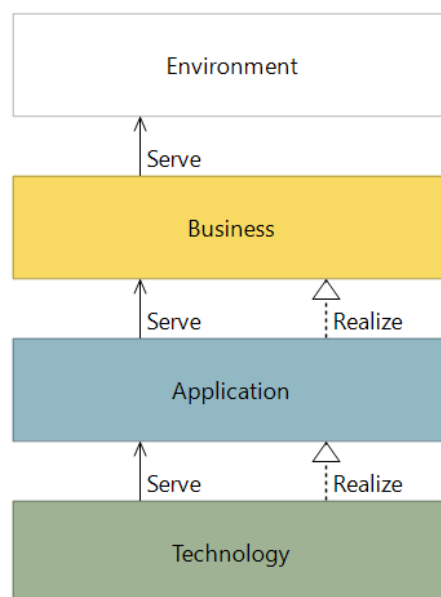


Figure 3.11: Relations between layers.

To facilitate comprehension of the language and the visualisations derived from it, it is also deemed beneficial to present the so-called “aspects” of the ArchiMate core language and to illustrate how they intersect with the layers. As can be observed in Figure 3.12, the framework, represented by nine cells, known as the ArchiMate Core Framework, permits the elements of the language to be classified through three aspects and three layers.

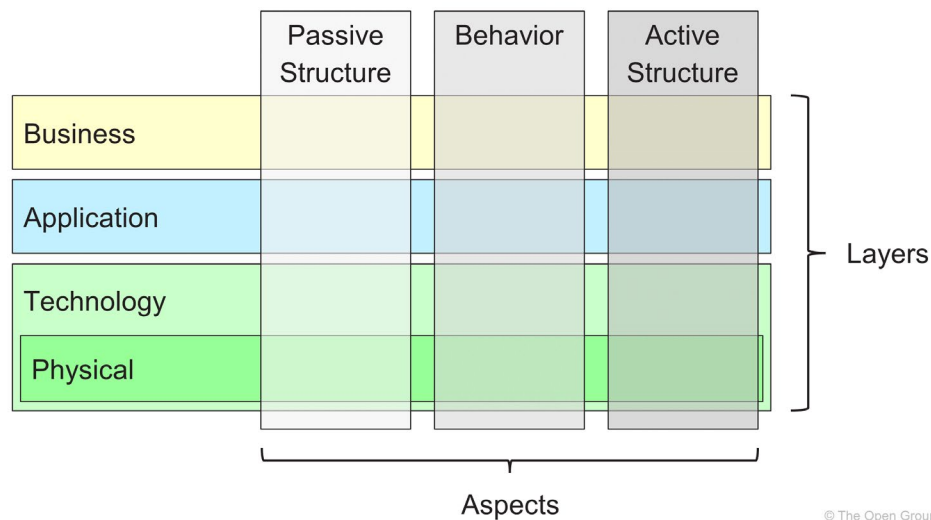


Figure 3.12: ArchiMate Core Framework [205].

It is crucial to highlight that this pattern may not always be adhered to in practical applications involving real-world case architectures. In certain instances, the connecting elements (i.e., relations) assume a pivotal role, and thus, warrant special consideration.

The dimensions of the framework are as follows:

- *layers*: these are the three levels (Business, Application, Technology) at which an organisation can be modelled in ArchiMate and will be discussed in more detail in the following paragraphs;
- *active structure aspect*: represents the structural elements (the subject of the activity);
- *behaviour*: represents the behaviour of the subjects of the activity;
- *passive structure*: represents the objects on which the behaviour is performed (typically information objects in the business layer and data objects in the application layer or physical objects).

These aspects are inspired by natural language (subject-verb-object), but it is important to emphasise that this order is not found in the spatial organisation of the elements within the architecture visualisation.

Specific conventions have been established regarding the colouring of the elements and their geometric form. In particular, the business layer is associated with the colour yellow, the application layer with the colour blue and the technology layer with the colour green. Those elements that possess edges are classified as structural; those with rounded edges are regarded as behavioural; and those with diagonal edges are identified as motivational.

The elements of the ArchiMate Core framework were employed for the modelling of the enterprise architecture undertaken for this research project, and the colour and shape conventions were maintained.

The following paragraphs delineate the ArchiMate elements employed during the modelling phases in the context of this research and provide illustrative examples of their functionality.

The objective of the business layer is to represent the organisation's operations in a manner that is technology independent. As previously stated, the structure is comprised of multiple elements that can be classified as passive, active, or behavioural. A process architecture depicts the most significant business processes and their interconnections, as well as, when feasible, the principal phases within the processes. In general, the process is not represented in detail in ArchiMate; rather, this is the task of other business process design languages (e.g., BPMN).

To illustrate the functioning of this layer, Figure 3.13 presents the representation of two processes from the example case study included in the ArchiMate 3.2 standard documentation.

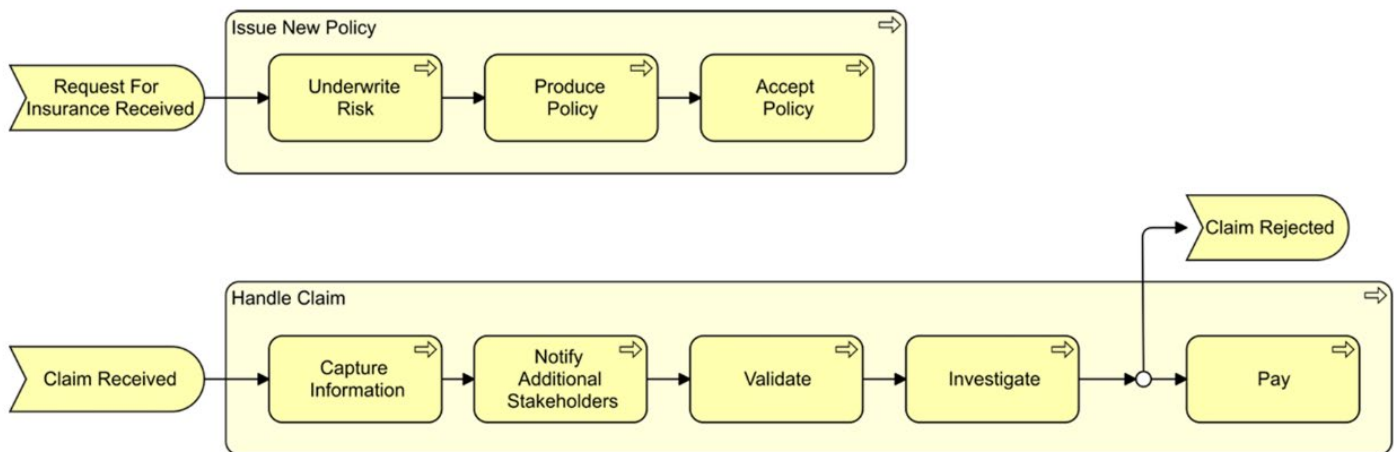


Figure 3.13: Business Process view [206].

The two processes, designated "Issue New Policy" and "Handle Claim," are described at a high level and comprise only the fundamental steps of the process. It should be noted that while the specifics of the process may vary depending on the product being processed, the fundamental steps remain consistent.

The principal objective of this research project was to identify and represent the organisational processes that were most representative and impactful in terms of the use and management of space and associated data. In addition, the processes that used data and information systems in the existing situation were examined, as well as how these processes might change in the future.

The active structure elements employed for this purpose are as follows:

- *Business Actor*: in this context, the term "business actor" is used to describe a business entity that can perform a given behaviour. It may represent business entities at varying levels of detail (e.g., it may be an actor or an organisational unit) and may be representative of a human, a department, or a business unit. A

business actor may be assigned to one or more business roles, thereby enabling the performance of the associated behaviours;

- *Business Role*: represents the responsibility to perform a specific behaviour within the organisation and may be assigned to a business actor. Business roles with specific responsibilities or skills are assigned to business processes, thereby assuming responsibility for the actual performance of a given behaviour. This may entail either undertaking the task oneself or delegating and managing performance.

The behavioural elements employed are as follows:

- *Business Process*: it represents a sequence of business behaviours that achieve a specific result. It describes the internal organisational behaviour that a business role implements to produce a series of products and/or services. A business process may be initiated or function as a catalyst for the commencement of another business process. It is important to emphasise that this tool is not suitable for representing processes with high levels of detail, which must instead be modelled using business process design languages (typically through the BPMN standard) [170];
- *Business Event*: it represents a change of state related to the business. It may either trigger or interrupt business processes or other business behaviour. A business event is an instantaneous occurrence with no defined duration. Nevertheless, a business event may be assigned a temporal designation, which can be employed to construct temporal schedules.

The tools were found to be of fundamental importance in the modelling methodology of the EA. In particular, the tools enabled the modelling of the business layer architecture in both its current (as-is) and future (to-be) states, thereby facilitating the identification of processes, roles, actors and responsibilities pertaining to the activities of interest within the research context.

The next stage in the modelling of the EA is the modelling of the application architecture. The Application layer is a fundamental part of the EA because it is intended to align business objectives and Application capabilities. The application layer is employed for the purpose of modelling the application architecture, encompassing the structure, behaviour and interaction of the organisation's applications. The term application is understood as the architecture of the IS and is intended to represent both the applications present within the organisation and how they cooperate (e.g., it represents what information flows between one application and another).

The modelling of this layer is of particular importance in the design and evaluation of an IS, as it allows for the visualisation of the management of information and its transfer between applications in a concise manner. As illustrated in the ArchiMate 3.2 standard documentation (Figure 3.14), the as-is representation on the left enables the situation to be analysed and changes to be made, resulting in the to-be situation on the right.

It is similarly crucial to consider the alignment between the business application and the methodology employed in modelling the application architecture. It is therefore critical to bear in mind that applications are responsible for supporting various elements of the business layer, particularly in the context of one or more business processes.

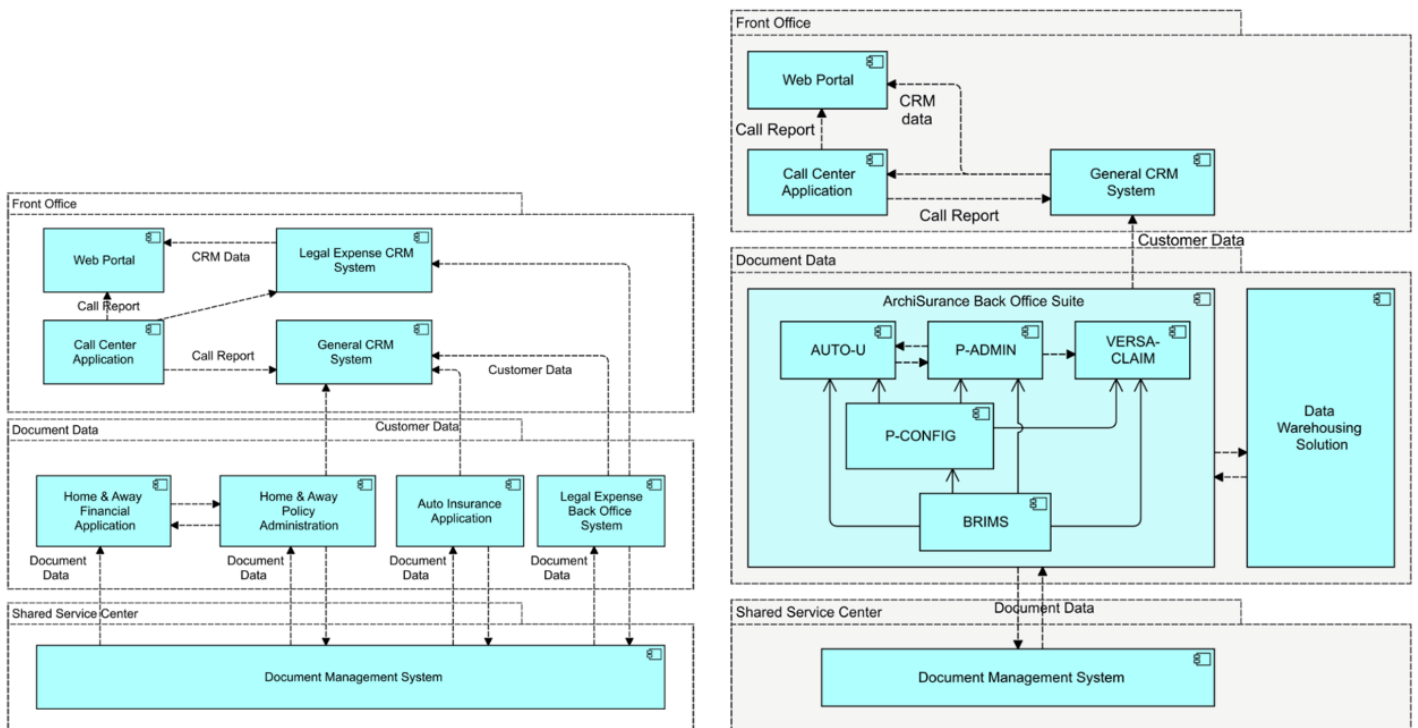


Figure 3.14: Application cooperation as-is and to-be [206].

The representation of the application's utilisation by the business processes is a valuable tool in the design phase of an application, as it enables the identification of the services the application must provide to the business process. Furthermore, it can facilitate the analysis of the business processes and the implementation of changes to optimise the use of existing applications.

Figure 3.15 illustrates the alignment of the business application within the ArchiMate 3.2 standard, as exemplified by the ArchiSurance case study.

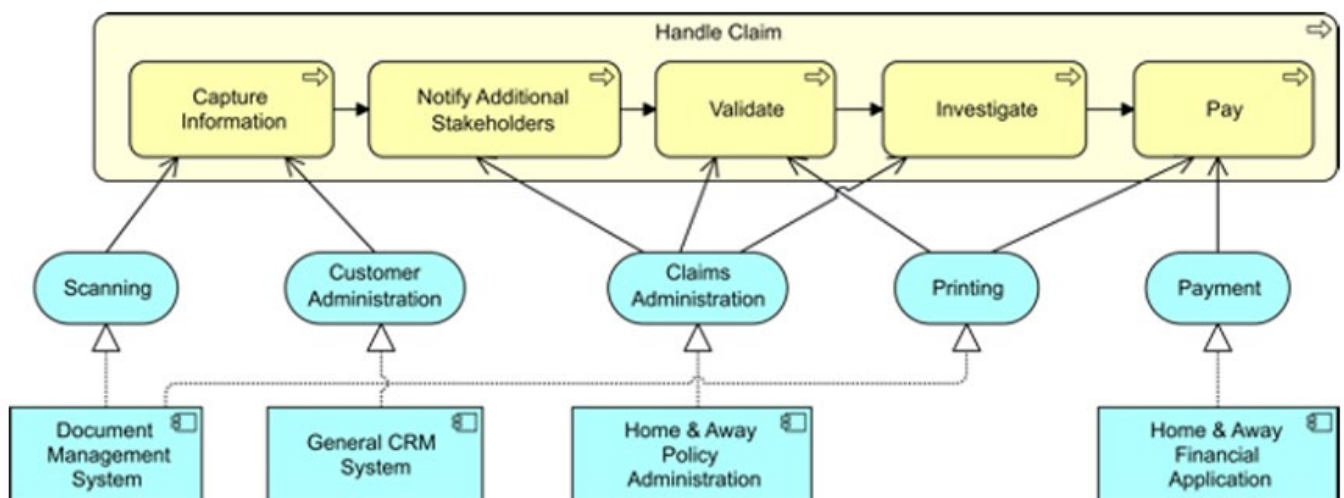


Figure 3.15: Business-Application alignment [206].

In this view, the service concept of the application is central, showing how different services (scanning, customer Administration, claims Administration, printing, payment) serve one or more sub-processes of the general “Handle claims” process.

For the purposes of this research project, it was essential to identify and map the applications that exist within the organisation and how the associated data is used. The representation obtained is, in fact, the basis for understanding whether certain existing applications can still be used or integrated to minimise the problems caused by major changes in an organisation's application architecture. The same language is then used to represent, through the application architecture, the future scenario within the organisation and the expected changes.

The active structure elements employed are as follows:

- *Application component*: it represents the encapsulation of the functionality of an application, aligned to the implementation structure. It is modular and replaceable. It is a standalone unit and is therefore independently reusable, replaceable and distributable. A component of an application performs one or more functions of the application. It encapsulates its behaviour and data and offers services by making them available via interfaces;
- *Application interface*: it represents the access point where application services are made available to a user, another application component or a node.

The following behavioural elements are employed:

- *Application function*: it is used to describe an automated behaviour that can be performed by a component of an application;
- *Application service*: an application service represents and defines the visible behaviour of an application. It makes the functionality of a component accessible to the surrounding environment. An application service may be used via one or more application interfaces, with one or more application functions responsible for its realisation. The application service must have value within the environment of an organisation. This means that if there are business processes in the environment, then the application service must offer a relevant service to it.

The passive structure elements employed are as follows:

- *Data object*: this represents structured data that is prepared for automatic processing. In particular, the data object represents a standalone piece of information that has a clear meaning for the organisation and is not only relevant to the application itself.

The elements were instrumental also in the evaluation phase of the IS, facilitating the acquisition of a comprehensive representation that encompassed all the aspects considered during the study of the IS and the analysis of the organisational context of the Turin University case study. This representation was achieved through a process of continuous improvement and adaptation, characterised by cycles of change and iterations.

The final stage of the process is the modelling of the organisation-related technology architecture, which encompasses the elements of the technology layer and describes the structure and behaviour of the organisation's technology infrastructure. The technology layer also comprises the physical elements that represent the tangible

world. These include only active and passive structural elements, excluding behavioural elements. In other words, the technology-related visualisation encompasses the elements of the hardware and software infrastructure that facilitate the functioning of the application layer, including physical devices, system software, operating systems, databases, and networks.

As was the case with the application architecture, it is also beneficial to model this architecture, as it enables assessments to be made regarding both the existing infrastructure and the desired future state of infrastructure. It is similarly crucial to consider the interconnections between the various layers when conceptualising a prospective future state. The technology architecture directly serves the application architecture, thereby providing a fundamental basis for supporting business processes.

Similarly to the other layers, the methodology followed was to first model the as-is state of the organisation to be able to make preliminary assessments and evaluate connections with the applications layer. At a later stage, the future to-be state of the technological infrastructure was designed, always keeping two fundamental aspects in mind:

- where possible, one can opt for the preservation of hardware and software that already exist in order to preserve the tools and skills already acquired by employees;
- the overall design of the architecture must keep in mind a holistic view of what the EA is to provide the right tools to serve the applications that in turn serve the business processes.

In consideration of the aforementioned factors, the following elements were employed in the modelling phase of the technology architecture:

- *Node*: the node represents the principal element within the technology layer. It is employed to depict structural entities and serves to denote a physical or computational resource that hosts, manipulates or interacts with other computational or physical resources;
- *Technology collaboration*: it represents an aggregation of two or more elements belonging to the internal active structure that work together to perform a collective technology behaviour;
- *Technology interface*: it represents an access point through which technology services offered by an element of the active structure can be accessed;
- *Communication network*: a series of interconnected infrastructures that facilitate the transmission, routing, and reception of data between devices or system software. Indeed, it represents a tangible communication infrastructure.

Regarding the physical active structure elements, a single element was utilized:

- *Facility*: it represents a physical structure or environment. It is typically employed to represent factories, buildings, or other structures that are pertinent to the organisation's operational processes.

Once the business, application and technology architectures have been modelled, the methodology follows to obtain a Reference Architecture that can serve as a basic model for other universities facing organisational problems like those identified in the case study of the University of Turin. It seems reasonable to posit that the organisational

structure of other Italian universities is similar to that of the case study under investigation. Consequently, the RA obtained can be readily generalised and adapted to other cases within the Italian context.

To gain an overall understanding, the potential interconnections between the various layers were investigated with a view to developing a comprehensive EA, which could serve as a reference model for the implementation of an IS for the management of spaces, real estate and services at a major Italian public university.

Similarly, the architectural models pertaining to the individual layers can be employed as a point of reference and a foundation for analogous cases, with the potential for tailoring the architectural models to align with specific requirements that emerge in the context of the individual cases under consideration.

3.2.3 Business Processes and Business Process Management

As previously emphasised in the literature review and as evidenced in the section on EA, processes play a fundamental role within organisations, as well as in the design and implementation phases of a digital transformation. It is evident that a successful and sustainable digital transformation cannot be achieved solely by introducing new tools and technologies to all stakeholders. The analysis of processes and their management must be integrated with the introduction of digital tools if effective results and a true digital transformation are to be achieved.

Accordingly, the most significant and impactful processes pertaining to the utilisation of space were subjected to analysis and modelling in accordance with the BPMN language, with the objective of conducting an in-depth examination of the existing situation. When undertaking a detailed analysis of business processes, it is no longer appropriate to use the ArchiMate language. Instead, the BPMN language should be employed to identify specific actors and processes with greater precision and at a more granular level.

The present situation was examined regarding the procedures pertaining to the establishment and revision of the teaching schedule and the distribution of office space. The current state was represented based on official internal university documentation, personal experience within the institution, interviews with those involved, and reports on the activities of the offices involved.

To facilitate the management of spaces in an Italian university, the Business Process Model and Notation (BPMN) was employed to create transparent and standardised process models. The processes that have been modelled include:

- *Classroom Management*: this encompasses processes pertaining to the allocation and scheduling of classrooms, with the objective of ensuring optimal utilisation of space and time;
- *Office Space Assignment*: this process pertains to the allocation of office spaces to university personnel, with the objective of ensuring the optimal utilisation of available resources.

Following the analysis of the initial situation, changes to workflows were postulated based on the introduction of new applications with the implementation of the platform. In general, there was a shift from processes based almost solely on the human factor to processes in which technology acts as a support and guide for the choices of the actors

involved.

To guarantee the accuracy of the modelled flows, software tools were employed that can evaluate the modelling result and validating it in the event of a positive outcome. Furthermore, this approach allows for the evaluation of the potential integration of these BPMN workflows within process management software, ensuring that the file is machine-readable and validated.

The Bizagi Modeler software was employed for the purpose of modelling the aforementioned processes. Bizagi is a robust tool that offers support for BPMN and provides a range of features for the design, analysis and optimisation of business processes. The software enables the creation of comprehensive process diagrams, thereby facilitating the identification of inefficiencies and bottlenecks.

The modelling process comprises the following steps:

- *as-is process modelling*: The initial stage of the process involved the creation of diagrams representing the current state of the processes. This entailed the mapping of the extant workflows and the identification of areas in need of improvement;
- *analysis and validation*: the as-is models were subjected to analysis with a view to identifying inefficiencies, redundancies and areas requiring improvement. Bizagi's simulation capabilities were employed to validate the process flows and confirm their fidelity to the actual operational procedures;
- *to-be process design*: modifications were subsequently implemented based on the findings of the analysis, resulting in the creation of the to-be models. The diagrams illustrate the optimised processes, which have been modified with a view to enhancing efficiency and effectiveness and implement the new IS.

3.3 Organizational Change Management

When a decision is taken within an organisation to implement new tools and new working methodologies, it is also necessary to assess the presence of the necessary skills within the organisation. Moreover, to initiate the project and commence the innovation, it is essential to allocate the time of specific resources, who will typically collaborate in either temporary or permanent teams. Considering the aforementioned considerations, this section aims to delineate the process undertaken in formulating the proposal for a novel organisational unit tasked with facilitating the inception and implementation phase of the proposed IS, along with the subsequent management and maintenance of the AIMS.

The advent of a digital transformation process inevitably entails a transformation in the manner of working of the individuals involved, necessitating the acquisition of new skills. Those responsible for initiating the change must therefore ensure that the requisite training is provided or that the necessary human resources are acquired. To propose the introduction of a new organisational unit, the various possibilities of intervention within organisations were subjected to analysis.

This analysis is based on the examination of the organisational structure of the case study of the University of Turin. This provided a general understanding of the structure of the organisation. Considering the public nature of the organisation and the roles of management defined by law, analyses were conducted to assess potential interventions and modifications to the existing structure. Considering the unfeasibility and unsuitability of disrupting the extant structure, the analysis concentrated on specific instruments that facilitate horizontal coordination within organisations, namely task forces and teams:

- *Task forces*: these are temporary, project-oriented units assembled to respond to a specific problem or achieve a particular objective within a set time. They are usually multidisciplinary teams and members are drawn from various departments of the organisation to bring different skills and points of view. Another distinguishing feature must be agility and efficiency and for this reason they are usually composed with as few staff as possible with the aim of achieving quick decisions and actions [207];
- *Team*: is a group of individuals working together to achieve a common goal. The main characteristics include a long-term existence, having no set end time. They also usually have a certain autonomy and authority over the decisions they make, being the experts in a particular field related to their tasks [207].

Given the objective of implementing and maintaining an IS within the university and managing data in a single university database, the proposed new organisational unit has the characteristics of a team. The characteristics match the nature of a long-term project and, in addition, the formation of the team can facilitate horizontal coordination between Directorates. In view of the need to concentrate skills from very different fields in a single team, profiles from different backgrounds were chosen and are presented in the section 3.3.2 .

3.3.1 Choice of the change management model

Considering the context of the case study of this research work, an Italian public university, it was assessed that the implementation of a new IS requires a broad effort at the organisational level and embraces most of the present Directions. For this reason, the chosen framework must be able to plan actions that can be effective in the public sector with a coordinated and accepted effort. With this in mind, three models most appropriate for the context and already used for other projects in the public sector [208]–[210] were chosen and a comparative analysis was carried out to decide which one to use.

The three frameworks selected for comparison are the AKDAR model, the Kotter's 8-step model and the Lewin's change model. It is emphasised that, even when making an in-depth comparison, it is not possible to state with certainty which model is the most appropriate. However, it is possible to attempt to identify the model that seems to be the most suitable for one's own needs or to create a new one. This could be achieved, for example, by applying only those elements of each methodology that are most appropriate for one's own situation.

Table 10 presents a comparative analysis that considers a range of factors, including the model's focal point, the proposed methodology, and the potential benefits and drawbacks, as extrapolated from the existing literature on the subject matter.

Table 10: Change Management Frameworks comparison.

	Kotter's 8-Step Model	ADKAR Model	Lewin's Model
Focus	Comprehensive organizational change	Individual change	Psychological and systemic change
Phases	8 steps: Create urgency, build a guiding coalition, form strategic vision, enlist volunteer army, enable action by removing barriers, generate short terms wins, sustain acceleration, institute change.	Five steps: Awareness, Desire, Knowledge, Ability, Reinforcement.	Three phases: Unfreeze (prepare for change), Change (implement change). Refreeze (solidify change).
Strengths	Clear steps, emphasizes leadership and communication, strong focus on managing resistance and maintaining momentum.	Focus on individual readiness, address personal barrier to change	Simple and easy, emphasizes psychological aspects of change.
Weaknesses	Rigid sequence of steps	Resource intensive for individual training, may overlook organizational context.	Lack of detailed steps can lead to oversight of important organizational aspects.

Considering the objective of this paragraph, which is to propose an initial indication of the possibility of drawing up a change management plan, it is important to note that, in the context of the present research project, the future EA and IS have already been determined, and the processes have consequently already been designed. The selection of the framework is also contingent upon the following factors: the prospective scope of implementation will be a public institution, which presents critical issues pertaining to organisational structure and resistance to change; the necessity for change in asset management primarily emanates from management (although it frequently also reflects

the requirements of staff); certain modifications are necessitated by the advent of new technologies.

In light of the considerations, the required model should possess the following characteristics: a structured approach, broad management consensus, the possibility of involving staff at all levels, alignment with the organisational culture and promotion of horizontal coordination between directorates.

The model selected as a result of these considerations is Kotter's 8-step change model, which is considered to be the most suitable given its comprehensive approach, focus on vision and leadership, and successful application in the context of higher education [211],[212]. Furthermore, the model emphasises the formation of a team to spearhead the change process, which aligns well with the objective of establishing a novel organisational entity within the existing organisational structure.

3.3.2 Constitution of the working group

A new unit, designated the Data Analysis Team (DAT), will be constituted within the staff of the ICT Directorate. Its concern will encompass the management and maintenance of the recently implemented AIMS, in addition to the coordination of activities pertaining to the digital management of assets. This will be achieved in collaboration with the relevant Directorates and Departments. The DAT is responsible for the design and creation of new information dashboards, which may be requested by any of the Departments involved or by the Rector and Director General. In the temporary period preceding the implementation of the AIMS, the unit is tasked with helping the Security, Property and Facility Management Directorate (SPFM) in the digitisation of the University's existing buildings and structures, as well as defining the information requirements for the as-built models of both existing and new buildings. Furthermore, the DAT defines the information requirements for the centralised university database (CUD), thus establishing the data and metadata necessary for the correct functioning of the AIMS. Additionally, the DAT establishes the naming conventions for the files stored in the Database.

To provide an indication of the figures that should be within the new team, professional figures were identified who are generally already present within companies and are involved in various tasks in the fields of Asset Management, Facility Management, data management and analysis, implementation and use of BIM methodology and GIS systems.

About certain figures, particularly those associated with data analysis and management, their integration into corporate environments is relatively recent. Consequently, their competencies are frequently the subject of debate and their descriptions are in a state of constant evolution. The methodology pursued thus entailed a meticulous examination of the tools and methodologies employed for the design, creation and utilisation of AIMS, with the objective of identifying professional profiles that would be optimal for the formation of the team tasked with the implementation and management of the IS. A multitude of skills and professional profiles have been identified among the personnel already present within the organisation. In this case, particular attention must be paid to integrating new staff and employees already in the organisation into the team.

4

CHAPTER

Case study

The objective of this chapter is to present the case study selected for analysis, namely the University of Turin. The objective is twofold: firstly, to provide an in-depth analysis of the organisational structure, and secondly, to describe the assets owned by the public institution. In addition, the existing Enterprise Architecture and business processes are presented in their as-is state.

4.1 The University of Turin

4.1.1 Organisational analysis

The first research phase involving the case study required the analysis of the organisational structure through field research within the organisation and the analysis of official documentation. This forms the basis for both the design of the AIMS and the investigation of the organisation's architecture.

In the case under study, the University of Turin, the focus is on the management of the university spaces and buildings. Thus, following a comprehensive examination, the focus of the investigation was directed towards aspects of space management and the underlying processes. Furthermore, while trying to understand the needs, the aim was also not to lose sight of the context. Indeed, it must be considered that some of the analysed university Structures (i.e., Directorates and Departments) will cooperate in the design, implementation and management phase of the future AIMS.

Prior to undertaking an initial analysis of the stakeholders in the context of the case study, it seems beneficial to recall the asset management standards, particularly the ISO 55000 series [6]. This will ensure a clear understanding of which assets can bring value to an organisation and how these assets are classified. Indeed, the standard introduces the concept of tangible and intangible assets and, moreover, defines critical assets as those that have the potential to exert a significant influence on the realisation of the organisation's objectives. In the context of Italian public universities, where the primary objectives relate to teaching, research and the third mission, the critical assets

that facilitate the achievement of these objectives can be classified into two main categories: tangible assets, including buildings, technological equipment and movable assets, and intangible assets, such as leases, patents, trademarks, intellectual property and so forth.

To gain a comprehensive understanding of the organisational structure of the University of Turin and the constituent parts within it, official documents pertaining to the university's strategic planning and internal organisation were subjected to detailed examination. In particular, the following documents were subjected to investigation:

- University of Turin Statute [213];
- University Regulations [214]:
 - University Regulations for the temporary use of University of Turin spaces and classrooms (R.D. no. 3615 of 02/09/2021);
 - Regulations for the handing over of the University of Turin's real estate assets to the heads of the University Structures (R.D. no. 1394 of 07/05/2021),
 - Regulations for the management of the University of Turin's movable property inventories (R.D. no. 3857 of 27/09/2018);
 - General Organisation Regulations (R.D. no. 4712 of 30/12/2016);
- Strategic Plan 2021 – 2026 [215];
- Three-year MUR Programme 2021 – 2023;
- Departments' Three-Year Plans 2022 – 2024;
- Three-Year Public Works Plan 2024 – 2026;
- Integrated Activity and Organisation Plan (PIAO) 2024 – 2026;
- University Organisation Charts;
- Board of Directors' meeting reports;
- Academic Senate meeting reports;
- Palazzo Nuovo student services office report;
- Luigi Einaudi Campus student services office report;
- Director interviews.

Considering the potential of an AIMS and the support it must provide for the achievement of objectives, it can be argued that the stakeholders concerned by the introduction of such a system in the context of an Italian public university are the university management team, the technical administrative staff, the teaching and research staff and the students. The guidelines, strategic indications and objectives are defined by the management team, which therefore has a fundamental role in the initial phase of gathering requirements.

In accordance with the provisions set forth by Italian law, an examination is conducted of the individuals comprising the university's management team and the functions currently assigned. The organisation of universities in Italy and the bodies provided for their functioning are defined by Law 240 of 2010 [216]. In particular, the following bodies are required: Rector, Academic Senate, board of Directors, board of auditors,

evaluation board, Director general.

- The Rector is the legal representative of the University and is responsible for formulating and implementing policies related to scientific and teaching activities. Additionally, he is tasked with pursuing the University's objectives in accordance with quality standards and in alignment with the principles of effectiveness, efficiency, transparency, and meritocracy.
- The Academic Senate is responsible for formulating proposals and mandatory opinions on matters pertaining to teaching, research, and student services. Furthermore, it has the authority to activate, modify or suppress courses, venues, departments and structures; approve the University Regulations; approve (with the favourable opinion of the Board of Directors) regulations pertaining to departments and structures, regulations on teaching and research, and the University Code of Ethics.
- The Board of Directors is responsible for approving the annual and three-year financial planning and human resources planning, ensuring the financial sustainability of activities, and providing strategic guidance. The Board is empowered to decide on the activation or suppression of courses and university venues, provided that the favourable opinion of the Academic Senate is obtained. Moreover, it bears responsibility for the enactment of regulations pertaining to administration and accounting, as well as for the approval of the annual and three-year budget, subject to the favourable opinion of the Academic Senate for matters within its purview and to the Rector's proposal.
- The function of the board of auditors is to audit the university's accounts. It consists of three full members (at least one of whom acts as chairman, chosen from among administrative and accounting magistrates and state lawyers) and two alternates, with a maximum term of office of four years.
- The Evaluation Board is a self-contained entity, endowed with the autonomy to define its own organisational arrangements. Its objective is to ascertain the quality and efficacy of a range of activities, including research conducted by departments, teaching provision, activities undertaken by Structures and staff.
- The Director General bears responsibility for the comprehensive management and organisation of services, instrumental resources and technical-administrative personnel. His actions are informed by the directives set forth by the Management Board.

Italian law, in addition to the presence of these figures and bodies whose task is to run the university while respecting the principles of effectiveness, efficiency, transparency, promotion of merit, and to decide on guidelines at the strategic level, provides that the university is organised internally with a series of Directorates whose task is to manage teaching-related activities, administrative activities, and all activities that ensure the proper functioning of the university. In accordance with the stipulations set forth in Law 240 of 2010, the University of Turin has established an organisational structure that delineates a clear distinction between academic structures devoted to teaching and service structures tasked with ensuring the institution's optimal functioning:

- Academic structures;
 - Departments;

- Schools;
- Research and Services Centres;
- Special Educational Structures;
- Service Structures;
 - Directorate General;
 - Directorates.

As illustrated in Figure 4.1, the Directorates are positioned within the organisational structure and report to the Directorate General. They are entrusted with the provision of management, technical and administrative services. The Directorates are as follows:

- General Affairs and Cultural Heritage Directorate;
- Budget and Contracts Directorate;
- Medicine Directorate;
- Humanities Directorate;
- Education and student service Directorate (ESS);
- Building and Sustainability Directorate (BS);
- Human Resources Directorate (HR);
- Research, Innovation and Internationalisation Directorate;
- Security, Property and Facility Management Directorate (SPFM);
- Information Systems, Portal, E-learning Directorate (ICT);
- Organisational and Human Resources Development and Institutional Support for Departments Directorate.

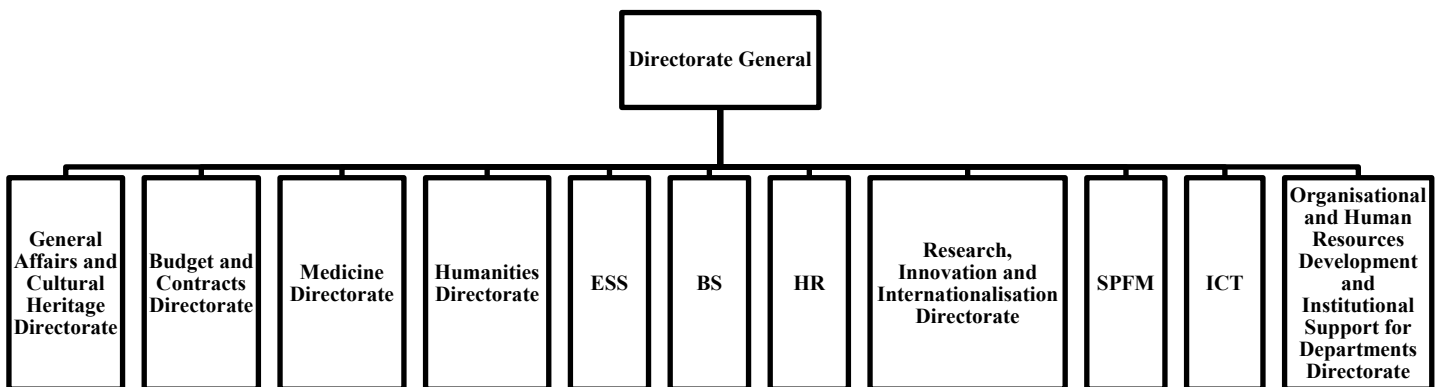


Figure 4.1: Organisational chart.

In order to provide the appropriate management, technical and administrative services to all the University's venues, seven “Territorial Poles” were also established. These are premises in which the operational areas detached from the Directorates belonging to the central administration are located.

In view of the extensive and complex structure of the University of Turin, a preliminary

assessment was deemed necessary to ascertain which departments were directly involved in the management of assets and, consequently, in the phases of creation, implementation, management and use of the AIMS. It is essential that the AIMS can provide stakeholders with the necessary support to make informed decisions regarding the management of spaces, encompassing both occupancy and maintenance. Furthermore, it must facilitate decision-making with regard to the management of the University's personnel and the provision of services within the University, such as lectures, seminars, examination sessions, and so forth.

In order to ensure the involvement of all relevant stakeholders from the outset, five Directorates were identified as being directly involved in one or more phases of the creation, implementation, management and use of the AIMS. This was on the basis of an assessment of the activities they perform and the skills of their staff. The involved Directorates are indicated in the organisational chart in Figure 4.2.

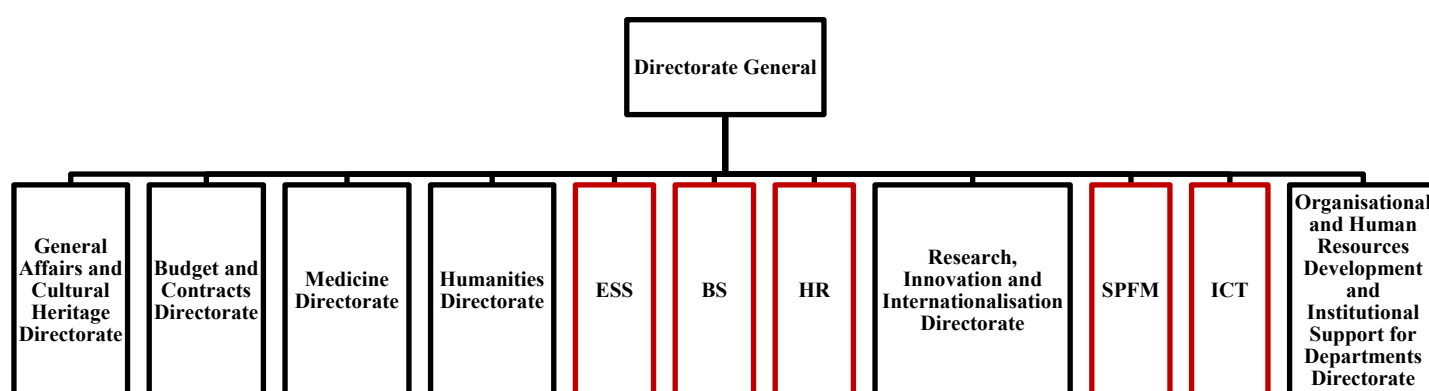


Figure 4.2: Organisational chart.

The following section presents the Directorates, accompanied by a description of their current responsibilities.

The ESS is responsible for the provision of didactic services, the establishment of didactic regulations, the management of agreements pertaining to didactic matters, the administration of postgraduate training programmes and the operation of specialisation schools. Furthermore, the Directorate is responsible for the provision of student services, including the administrative management of careers, the processing of applications for the right to education, the administration of student contributions, and the provision of services for students with disabilities or DSA. Furthermore, the Directorate is responsible for the management of data, procedures and indicators pertaining to the field of education.

The BS is responsible for the construction, renovation and adaptation of the university's building stock. Additionally, it oversees the coordination of the implementation of the University Building Plan. Furthermore, the BS is responsible for the design and implementation of building works outlined in the three-year public works programme, with a budget of €150,000 or above (excluding contracts and framework agreements for the maintenance of buildings and facilities). Furthermore, the BS Directorate is responsible for the management of building and plant maintenance activities that require design, energy management and sustainability aspects, as well as projects related to reducing the university's environmental impact. These include green public

procurement, food quality and sustainability, energy and climate, sustainable mobility and waste cycle management.

The HR is responsible for the management of labour relations, salaries, pensions, research grants, staff agreements and welfare initiatives. Furthermore, it fulfils a support function in the field of labour relations and is responsible for the recruitment and scheduling of personnel.

The SPFM is responsible for ensuring the fulfilment of all current safety obligations. It may take any initiative or action provided for in coordination with the RSPP, the competent doctors and the other functions provided for by the regulations. The responsibility for undertaking building and plant maintenance work that does not require design activities lies with the SPFM Directorate. In addition, it is the role of the SPFM to oversee and regulate the planned preventive and corrective maintenance activities for the university buildings, including plant equipment. Furthermore, the department is responsible for providing general services and facilities assistance and surveillance, as well as maintenance requests, on-call and emergency services. Furthermore, it is responsible for the provision of logistics services through the territorial poles.

The ICT is responsible for the provision and management of ICT services pertaining to the planning and development of information services, dematerialisation, digital identity, e-learning systems, the University Portal System and IT security. Furthermore, the ICT Directorate furnishes information services via the territorial poles.

The analysis provided an understanding of the organisational structure of the University of Turin and the main stakeholders operating within the institution. Furthermore, it was possible to determine which Directorates could be most involved in the current management of buildings, spaces and related activities. This information will allow this aspect to be considered in the future alignment of business, IT and technology needs. It is crucial to acknowledge that the university is subject to legal obligations that delineate the entities that must be constituted within the organisational structure. Furthermore, as a public entity, it is bound by several legal obligations pertaining to public administration, including the utilisation of management, budgeting and monitoring tools as prescribed by law.

A further step was to attempt to contextualise the organisational structure of the university within existing literature on the subject, with a view to identifying similarities and differences between the two.

In order to analyse an organisation at a general level, it seems useful to adopt Mintzberg's definition [217], which identifies five main components: the strategic Apex, the middle line, the Operating core, the support staff and the Techno structure Figure 4.3.

The strategic top management comprises those individuals who bear responsibility for the direction and co-ordination of the organisation (e.g., chief executive officer, general manager, top management). Their role is typically to formulate the organisation's strategy, objectives and policies, to supervise the organisation and to manage relations with the external environment. The operational core comprises the personnel engaged in the direct production of goods and services.

The operational core comprises those engaged in the direct production of goods and services. The middle line, situated between the two components, comprises mid-level

managers whose responsibilities include transforming strategy into operational policies, coordinating and controlling activities conducted at the operational level, and periodically reporting to the strategic leadership. The support staff are responsible for ensuring the orderly conduct of activities and the maintenance of the organisation's physical and human components. This includes, for example, the management of human resources, the maintenance of facilities, the management of the canteen, the management of information systems and the supervision of housekeeping. The technostructure comprises those responsible for adapting and modifying the organisation to enable it to cope with or anticipate environmental changes that control, regulate and stabilise the organisation's activities, including marketing and research and development activities. Examples of such roles include engineers, technicians and researchers. The Mintzberg model comprises components that appear to be distinct entities, but in practice, they often overlap. In small organisations, individuals often engage with activities pertaining to multiple components simultaneously.

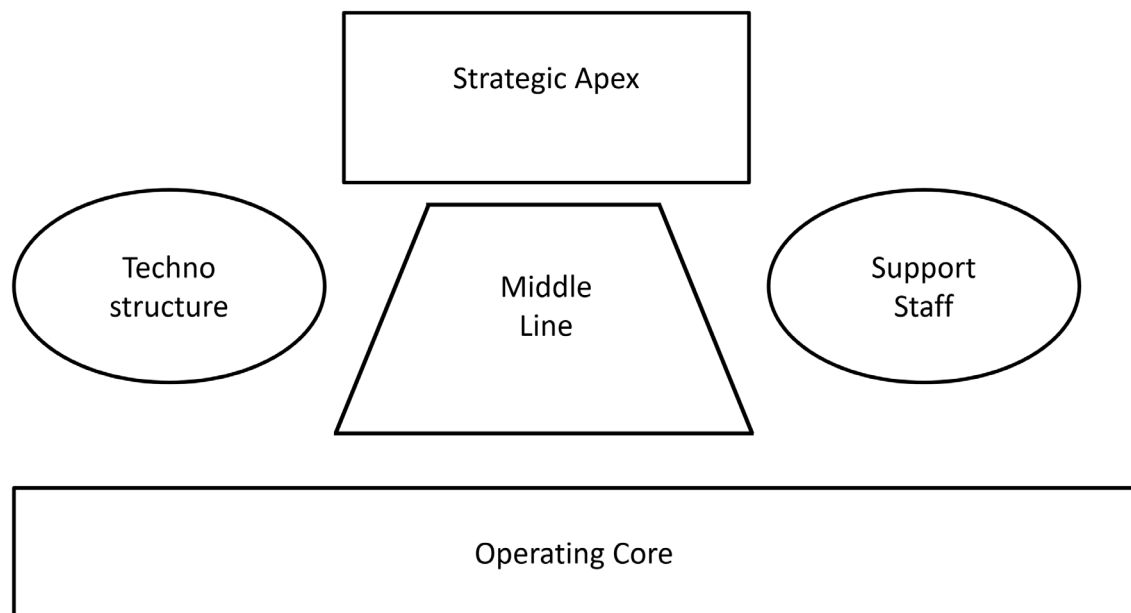


Figure 4.3: Mintzberg Model [218].

To contextualise the Mintzberg model within the background of universities, it is possible to describe the components in the following manner (see Figure 4.4). The strategic apex of a university is constituted by the Rector, the academic senate and the board of Directors. The Rector is responsible for presiding over both bodies. The Operating core comprises Professors, the teaching staff and technical and administrative personnel (e.g. student secretariat, research office) who, with differing roles, contribute to the realisation of the outcomes pertaining to the three missions of each university (teaching, research and third mission). The middle line is constituted by the technical and administrative staff, who direct the offices and units that contribute to the achievement of the results concerning the three missions, as well as the Department Directors and School Directors. The techno-structure is constituted by Professors who are delegated ad hoc on specific issues (e.g., the Didactics Delegate, in collaboration with the Didactics Commission, is responsible for innovating the University's didactic offer). The support staff is formed by technical and administrative personnel that are responsible for a range of tasks, including personnel management, salary payments and the management of information systems.

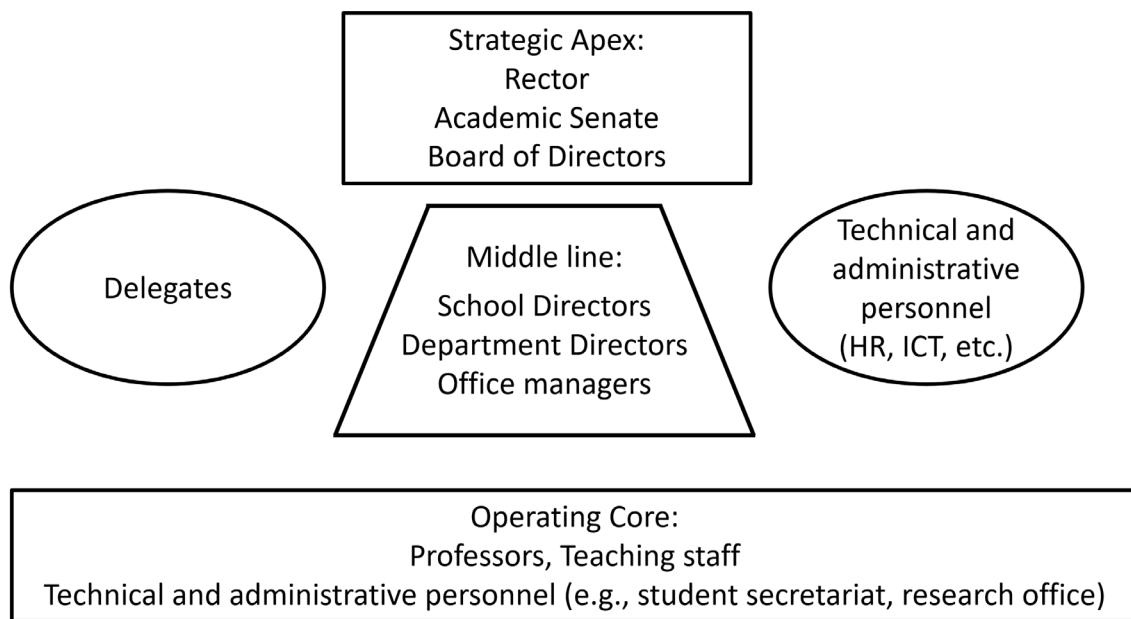


Figure 4.4: Mintzberg Model for Universities; adapted from [218].

To gain further insight into the nature of organisational structures and their underlying principles, it is helpful to provide a clear definition. An organisational structure can be defined as the set of authority and communication channels that are established between different roles and organisational units. Consequently, in order to describe an organisational structure, it is essential to delineate the criteria for the division of labour, hierarchical relationships and formal channels of communication, utilising organisation charts and job descriptions as the principal instruments [218].

Regarding the organisational structure of the University of Turin's service structures, it can be stated that the Italian public university, and the University of Turin in particular, exhibits a hierarchical-functional structure, as evidenced by traditional models found in the literature. Indeed, in a hierarchical-functional structure, the primary organisational units are the functions, with the criterion used to group roles within a function being linked to the knowledge system and the tools used to perform the role. Consequently, there is a tendency to cluster individuals who possess analogous training, knowledge bases, and engage in analogous pursuits. A similar division is evident in the organisational structure of the University of Turin's directorates, as illustrated in Figure 4.1. The most significant benefit of this organisational structure is the specialisation of personnel, which subsequently enhances the overall efficiency of the organisation. The disadvantages, however, are primarily associated with the potential loss of an overarching perspective. Indeed, each function tends to concentrate on its own outputs, operating in a siloed manner with minimal coordination between the various functions. This results in a rigid organisational structure that is resistant to change.

It is important to emphasise that, given the university of Turin's large size, it was necessary to set up territorial poles that in turn offer the same services managed by the central directorates. In this regard, the University of Turin also exhibits a divisional organisational structure, wherein the extensive organisation is fragmented into numerous sub-organisations that are, in turn, hierarchical-functional. This enables the university to operate effectively and efficiently in accordance with the requirements of

each territorial pole. The most significant drawback of this configuration is the elevated cost of management, which is a consequence of the inability to realise economies of scale in the functional units that are replicated across the various poles and cannot share resources.

It is thus imperative that these factors be considered when designing the organisation's information system and architecture. It must be borne in mind that the objective of a digital transition is also to facilitate horizontal coordination of the various Directorates and a sharing of data that can facilitate the work of many divisions.

4.1.2 The assets of the University of Turin

To contextualise the case study that forms the subject of this research, it is also necessary to analyse the assets that the organisation has at its disposal for the purposes of management and maintenance. In particular, the buildings that form the focus of this study will be considered to gain an understanding of the problems and opportunities that arise in the context of space management. The University of Turin campus was therefore selected as a case study to evaluate the AIMS through buildings that served as a pilot case.

The buildings, which are managed directly by the university, are situated in a dispersed manner throughout the province of Turin. In certain instances, there are also facilities located outside the region. The University of Turin represents the fourth largest university among those in Italy classified as "mega-universities" and has approximately 81,000 students enrolled for the 2023-2024 academic year. The real estate heritage comprises approximately 120 elements, including buildings and land, primarily situated within the city of Turin. However, it also encompasses several other buildings dispersed across two regions, six provinces, and ninety municipalities. In addition to the numerical and geographical aspects, it is essential to consider the considerable heterogeneity of the buildings that comprise the heritage, in terms of both construction techniques and age of construction. Indeed, a substantial number of the buildings that constitute the heritage are historic and constructed using a variety of techniques, which are occasionally obsolete but nevertheless possess significant value and are subject to historical and cultural constraints. These constraints often result in severe limitations or excessive costs associated with modifying the buildings to adapt them for current use. Conversely, other edifices are markedly contemporary, erected in response to the considerable expansion of the University of Turin that has occurred in recent decades.

It is also of fundamental importance to consider the activities that take place within the buildings and the people who use them to gain an understanding of the size of University of Turin's assets. It is notable that the buildings under examination frequently serve as venues for non-academic pursuits, with facilities accessible to the public for the purpose of hosting events or functioning as museums. Furthermore, in addition to academic activities, there are all administrative activities and the offices that house them. In conclusion, University of Turin's campus is home to approximately eighty thousand students and a large catchment area, including academics, researchers, citizens, managers, technical and administrative staff, as well as a range of services, such as courses, lectures, seminars, and master's degrees. Furthermore, the extensive range of undergraduate and postgraduate degree programmes (68 undergraduate and 83 postgraduate degree programmes, 100 postgraduate master's degree programmes and 54 doctoral programmes in the 2023-2024 academic year) necessitates the

provision of diverse facilities and resources, tailored to the specific subject area of study (e.g., chemistry or anatomy laboratories, language laboratories, botanical research facilities, virtual reality laboratories). In addition to the considerable student population and assets, the administrative staff at the University of Turin comprises approximately 2,000 users, in addition to some 2,100 professors and researchers. In total, the asset management department is responsible for approximately 90,000 internal users. A comparison with municipalities in Italy reveals that the University of Turin would represent the 50th largest Italian municipality in terms of inhabitants. It is intertwined in the urban fabric of the city of Turin, which has approximately 860,000 inhabitants. These individuals are often involved in the activities offered by the university, including museums, exhibitions, events, and so forth.

The described characteristics and the large number of variables to be considered when dealing with the O&M phase of University of Turin and its asset management describe a complex system due to the highly dynamic and variable environment. For this reason, to demonstrate the potential of an IS at the territorial level, the University of Turin campus was used, while for the analysis at the building level, a series of demonstrators were chosen as the iteration phases of the design and development phase of certain parts of the IS progressed.

The first building selected as a pilot case was that of the Computer Science Department (CSD), the Piero della Francesca Centre, located in the north-west of Turin. The University of Turin bought part of a multi-purpose centre (2,850 m² out of 170,000 m²), which houses several offices and shops (Figure 4.5), to accommodate the teaching, administrative and research activities of the CSD.

Compared to other buildings, the available square footage is not high, yet in the last five years the department has experienced the highest rate of increase in university population (50 %), with a constant demand for new space. In particular, the university has space on the ground, first and third floors of the building. The ground floor is mainly used for teaching purposes, while the first and third floors are used for research and administrative purposes.



Figure 4.5: Piero della Francesca Centre.

The 12 classrooms on the ground floor can accommodate up to 1,318 students, while the 93 offices on the first and third floors can accommodate 153 people. This demonstrator was found to be suitable for testing the planned methodology for the development of the IS, as its small size and the presence of only one department made it easy to define the required data and test the functionality of the platform.

Another building analysed during the design phases of the IS is the Palazzo Nuovo, chosen for its architectural and managerial complexity and for its size, as opposed to the simpler case of the previous building housing the CSD. Moreover, the departments it houses are characterised by a high degree of congestion, making it an important case study for the refinement of the proposed methodology.

Palazzo Nuovo is home to the School of Humanities, with five departments, 33 degree programmes and around 965 courses. In the 2021-2022 academic year there were 22641 students, or 27.7% of the total University population, with a positive enrolment trend over the last four years, with a growth rate of 14.8%. The structure consists of seven floors above ground and three underground floors, as well as three large classrooms separate from the main building (Figure 4.6).



Figure 4.6: Palazzo Nuovo.

It can accommodate up to 3,975 students in the lecture theatres and 1,000 in the study rooms, for a total of 5,006 seats, including those allocated for graduation ceremonies; in addition, there are external seats in other buildings, for a total of 7,475 seats. This shows that the current number of seats is not sufficient to meet the needs of the Palazzo Nuovo and the complexity of its management.

During the development of the IS and the design iterations, different buildings with quite different characteristics were considered at the same time. This was also done to understand whether the general approach, which was modified from time to time, could be universal for any type of building, or at least easily adaptable.

The Campus Luigi Einaudi (CLE) was chosen as the third building (Figure 4.7). The CLE is an important case study because it is one of the largest assets of the University of Turin, located in the urban context of the city of Turin and built in 2012 to a design by architect Norman Foster [219]. CLE's main facility is located in the north-east of Turin and has a total net area of over 36,000 square metres. It has a large catchment area and is involved in many activities, including a wide range of teaching programmes. In fact, the facility houses the Faculty of Law, the Faculty of Political and Social Sciences and the Faculty of Economics and Statistics “Cognetti de Martiis”, which hosts more than 500 research fellows. In addition, several administrative areas employ approximately 100 administrative staff to manage space, personnel, contracts and related administrative matters. In addition, the CLE has 47 classrooms and accommodates approximately 16,700 university users, making it a significant case study with a wide range of activities. In fact, considering the students and staff who work in the CLE on a daily basis, it can be calculated that they represent about a quarter of the total population of the University of Turin. This building has also been the subject of an environmental quality monitoring experiment, with the installation of 37 sensors in 33 lecture rooms.



Figure 4.7: Campus Luigi Einaudi.

Its characteristics, size, number of users, location and availability of data from the IoT devices installed to measure the indoor environmental quality of the classrooms make it an ideal demonstrator. The Luigi Einaudi Campus was the pilot building used for the latest iteration of the design to date and is therefore the most complete in terms of all the aspects that can be managed by the latest version of the IS.

4.2 Enterprise Architecture and Processes

It has been demonstrated that the design of an IS can present significant issues and challenges throughout the development process. By attempting to satisfy the requirements of managers and accomplish the desired outcomes, a specialized application can be developed and it can be replicated in other contexts. Furthermore, hardware and software tools could be used in conjunction with existing applications within the organisation, ensuring maximum compatibility. However, it is important to note that a technical solution does not necessarily address the organisational issues identified during the analysis phase. It is essential to ensure optimal alignment between the IT tools, the developed applications and the business processes (i.e., workflows) within the organisation.

It is of particular importance to ensure that all relevant stakeholders are informed about the planned change and how they can contribute to the success of the new vision in terms of organisation architecture, especially when a change is to be undertaken. An analysis is thus conducted in the context of the case study, employing the tools of the EA field. The reasons why EA may be instrumental in facilitating the digital transition process include, but are not limited to:

- *The alignment of new applications with the strategic objectives of the organisation is a key consideration in the EA process:* the EA function ensures that new applications are aligned with the strategic objectives of the organisation [220].
- *Integration and Interoperability:* EA ensures that new applications integrate with existing systems and processes. This is achieved using a visual language to map the interactions between the various components of the IT infrastructure, thereby facilitating the identification and resolution of potential integration issues. This consequently mitigates the risk of incompatibility at the system level and ensures an optimal data flow within the organisation [221].
- *Optimisation of resources and cost reduction:* the availability of a comprehensive inventory of the organisation's IT assets facilitates more informed decision-making with respect to the development of new hardware or software and training for human resources, thereby ensuring the efficient implementation of the new application. The implementation of EA may result in cost savings through the identification of redundancies in IT systems, which can then be addressed through process streamlining and the optimisation of resources [222].
- *Improved collaboration and communication:* By providing a shared view of the IT landscape for all stakeholders, EA can foster better communication and collaboration between different directorates or departments within the organisation. By visualising the EA, all stakeholders are on the same page regarding new applications and the reasons for their inclusion [223].
- *Flexibility:* Having a clear roadmap through the EA allows the organisation to adapt faster to changes [224].

For these reasons, the use of EA is of great importance in the assessment of the impact of change and the assurance of alignment with the organisation's objectives. Furthermore, it facilitates communication with stakeholders, who, through the

utilisation of visual language, can gain a deeper comprehension of forthcoming developments and the rationale behind them. This, in turn, encourages their active participation in the change process.

4.2.1 Organisational analysis through Enterprise Architecture

The initial stage in the implementation of EA principles and the exploitation of their advantages is the establishment of a precise understanding of the prevailing circumstances within the organisational context. This is achieved through the analysis of the organisational structure (section 4.1.1 the examination of the hardware and software utilised within the various Directorates, and the investigation of the information exchange flows between Directorates, Departments and external entities.

To create a model and visual representation of the current situation, it was beneficial to have already conducted an analysis of the data present within the organisation, its processing and storage, its usage in the various directorates, as well as the software used and the file storage format during the IS design phases. The analyses, in conjunction with the examination of the organisational structure and a comprehensive examination of the processes within the organisation, permitted the modelling of the general architecture of the University of Turin using the ArchiMate language. This enabled the identification of both positive aspects and shortcomings, as well as potential bottlenecks and critical issues within the organisation architecture.

As illustrated in Figure 4.8, the modelling of the Business Architecture (depicted in yellow) was conducted at a high level of abstraction. The business processes and the business actors assigned to those processes are illustrated. Among the processes that can be assigned to the various directorates, those most pertinent to AM, and in particular FM and space management, were identified.

As illustrated in the organisational charts presented in section 4.1.1 there are five Directorates that are directly involved in the operation, direct use, maintenance of buildings, or in the use, operation, and maintenance of the AIMS.

In Figure 4.8, the ESS Directorate is responsible for the creation and updating of the teaching timetable, while the BS Directorate oversees the creation, management and updating of CAD drawings and BIM information models. The HR Directorate is then responsible for the creation and management of the dataset concerning human resources information. The SPFM Directorate is responsible for two key processes: the creation and management of a dataset for real estate asset management and the management of security, logistics and building maintenance. The ICT Directorate, on the other hand, oversees the creation and management of a dataset concerning technological assets (e.g., computers, printers, etc.) and, in addition, the management of Information Systems, the University website and the e-learning service is also within the remit of this Directorate.

The Light Blue section depicts the Application Architecture, which, as illustrated in the accompanying legend, comprises an application component representing the specific type of software application in use. The application component realizes an application service (i.e., it defines the visible application behaviour and exposes the functionalities of a component to the environment) and therefore it makes explicit the service that is offered to support a business process. Then, data flows from application service to the application interface, which represents the point at which the various

stakeholders can utilise a specific service.

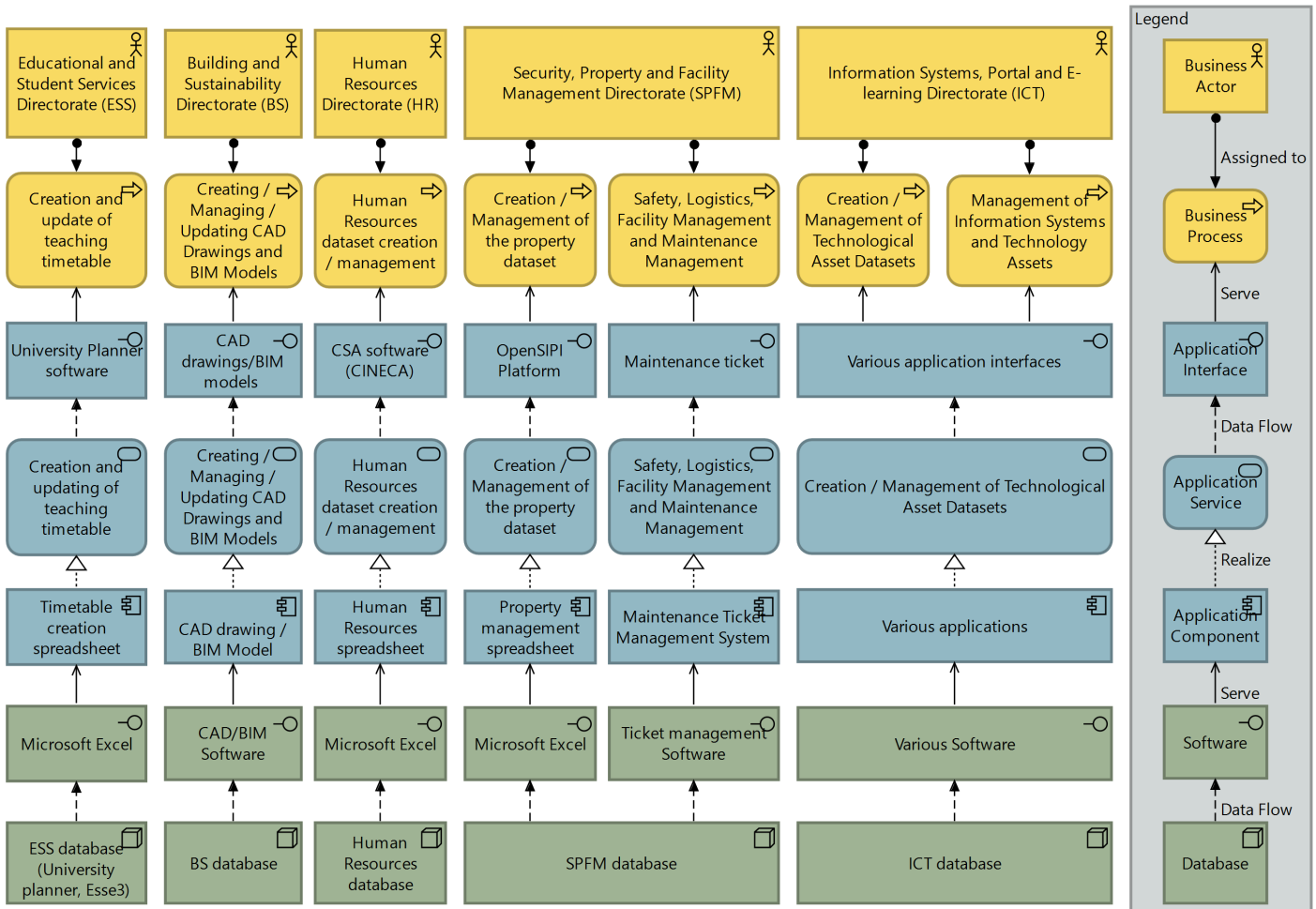


Figure 4.8: University of Turin Enterprise Architecture As-is

A detailed examination of the various Directorates reveals that the services supporting each directorate are designed to facilitate a specific business process. However, as illustrated in the accompanying diagram, each Directorate employs different application components and the service flows into distinct interfaces for each Directorate. A comprehensive inspection of the interfaces reveals that the ESS Directorate utilises University Planner, the BS directorate employs CAD drawings or BIM models, the HR Directorate relies on CSA, the SPFM Directorate incorporates OpenSIPI for real estate visualisation and a dedicated portal, with the possibility of receiving tickets, to manage maintenance activity. The ICT Directorate has a diverse range of interfaces linked to the specific services it offers.

Finally, the green colouring represents the architectural aspects of the technology, which in this case have been illustrated with two elements. The first node element is used to symbolise the various databases employed by the Directorates, whereas the interface element represents the software utilised for the visualization and modification of database data, as well as its storage in the pertinent file format. It is evident that each directorate maintains its own database, operates independently, and there are no plans to achieve interoperability between the various software utilized by the Directorates.

The overview presented in Figure 4.8 offers a traditional representation of the

organisation as comprising distinct, autonomous units. This visual representation also highlights the vertical structure of the organisation and the existence of information silos, which impede the sharing of crucial data and the creation of valuable information for all stakeholders.

4.2.2 Business Processes and Business Process Management

This section presents a detailed examination of specific processes related to space management and previously presented in the EA. To conduct a more detailed analysis of the processes, we transition to the BPMN language, which enables analysis at a different level than ArchiMate.

A fundamental and indispensable technique in the context of business process improvement and management is the analysis of current processes (as-is) and comparison with future processes (to-be). The principal aim of this technique is to conduct a comprehensive examination, evaluation and improvement of existing business processes, with the objective of enhancing efficiency and operational productivity. The analytical framework is comprised of two principal phases, namely the as-is and to-be phases. It plays a pivotal role in the systematic implementation of business process improvement initiatives. The implementation of these distinct phases enables organisations to embark on a journey of self-examination and transformation, with the overarching objective of identifying areas in need of improvement and designing future, leaner and more effective process states.

This chapter presents an analysis of the selected case study, accompanied by diagrams illustrating the current situation. The as-is phase encompasses the documentation and comprehensive examination of the existing state of a business process. The objective of this phase is to provide a clear and comprehensive understanding of the current functioning of the process.

The principal activities undertaken during this phase are as follows:

- The process mapping stage involves the creation of a visual representation of the business process in question. This representation is created to facilitate comprehension of the process and to identify potential areas for improvement. The creation of flow charts or detailed diagrams, which illustrate the step-by-step sequence of activities in the current process, is also a key activity within this phase;
- Stakeholder interviews are conducted to gain insight into the perspectives and experiences of individuals or groups who are directly or indirectly involved in the process under study. The objective of the interviews is to obtain information and identify critical points from the perspective of individuals involved in the process;
- The identification of bottlenecks and inefficiencies is a crucial aspect of process analysis and it aims at identifying areas where the process may be characterised by slow performance, a propensity for errors or the utilisation of significant resources.

The case study of the University of Turin encompassed two key processes: the creation of a new teaching timetable and the allocation of an office for a recruit. The following aspects are highlighted: stakeholders and activities, data resources and their format,

salient events and expected scenarios.

The diagram of the creation of a new teaching timetable by the administrative offices of the university can be seen in Figure 4.9. The diagram was modelled using Bizagi modelling software and BPMN notation was used.

As illustrated in the diagram, the process commences with a request for a new teaching timetable, which is typically directed to the educational and student services office of the pertinent cluster. The subsequent activity is conducted directly by the office staff and entails the transmission of an electronic message to each of the course representatives, based on the number of contact persons within the cluster, the schools associated with the cluster, and the academic departments associated with the schools. Subsequently, upon receipt of the electronic communication, each designated contact person is responsible for aggregating the expressed preferences of the participating lecturers about the specific course of study in question. Thereafter, the lecturers are afforded the opportunity to indicate their respective preferences with respect to the optimal days of the week and times for lecturing via a shared Excel file.

Once the course referees have received the lecturers' preferences, they send a communication by email to the teaching office to inform them that the data compiled on the excel spreadsheet are the final ones. It is emphasised that at these stages the process is heavily based on exchanges of information between people and that there is no automatism to help staff in their work.

Once the data concerning lecturers' timetable preferences have been received, the teaching office proceeds to create the teaching timetable. In order to be able to do this, it is necessary to cross-reference a series of data from different sources: the characteristics of the individual teaching schedule (lecturer, credits, teaching hours, space required, equipment needed and students enrolled), lecturers' preferences (e.g., there are part-time lecturers who can only lecture on Thursdays and Fridays) and finally the space available in the centre of interest (classrooms with different capacities and facilities). When creating the timetable, staff must obviously bear in mind that several lectures must take place at the same time during the semester and the available classrooms do not always meet the space requirements. Another critical point is the fact that the final number of enrolled students is often communicated to the teaching office once the courses have started, as it is possible for students to change their study plans once they have start (within certain limits).

Therefore, the creation of the timetable is done using tools such as excel spreadsheets in which systems have been set up to consider the cross-referencing of the various data needed and using the knowledge of the employees themselves who after years of experience know how much the attendance of the various courses could be. It is evident that this approach has inherent limitations. Firstly, it is not grounded in empirical evidence. Secondly, it is an ineffective means of estimating the number of students required for the development of new courses.

Following the creation of the timetable then, the teaching office staff, as depicted on the diagram, can proceed to compile the data on the UP university database dedicated to teaching timetables and subsequently publish it for student consultation.

Additionally, the diagram illustrates a lane designated for ICT, which oversees the maintenance and interfacing with the Cineca consortium for databases containing data on teaching and enrolled students, as well as the UP service for publishing teaching timetables. It is important to note that the UP service provided to the University of

Turin does not include a module for the automatic or facilitated creation of timetables. Rather, it is used solely as a database and viewer.

Following the same methodology and using the same tools, the as-is process concerning the allocation of office space following a new hire was modelled (Figure 4.10).

In this case, the pool lanes considered are:

- HR: represents the Human Resources Directorate lane;
- University structure/Administration: represents the university structure at which the new hire will assume employment;
- Recruitment contact person: represents the person to whom the recruit will report during his/her work experience;
- Hired Personnel: represents the person hired;
- SPFM: represents the Security, Property and Facility Management Directorate;
- ICT: represents the Information Systems, Portal and E-learning Directorate.

The diagram therefore describes the process that usually takes place following a new recruitment and starts with the event of hiring a new staff member: this may be a full professor (PO), an associate professor (PA), a type a or b fixed-term researcher (RTDa, RTDb), a research technician (TdR), technical administrative staff (PTA), a research grant holder, a research fellow or a doctoral student (PhD). At this point, the HR Directorate, having acquired the contract and completed the bureaucratic procedures, notifies the structure in which the recruit will work.

Upon receipt of the communication, the university will prepare a formal notice of recruitment with an induction date and a request to provide any office space and equipment requirements. Depending on the presence of a contact person, this communication will either be sent to the contact person (e.g., area manager) or directly to the recruit if the person is independent (e.g., full professor). At this point, therefore, the flow takes different paths depending on the requests received: only a workspace may be requested and therefore the university structure will only interface with SPFM; specific equipment may also be requested (e.g., laptops, printers, etc.) requiring simultaneous communication with SPFM and ICT.

About the request for spaces, three different situations may arise, resulting in distinct solutions:

Space available: the requested space is available and is allocated to the newly recruited resource;

Space available because of reorganisation: a temporary space is allocated to the resource and office space is subsequently reorganised in order to meet requests and subsequently allocated;

Space available following maintenance work: a temporary space is assigned to the resource and the procedure for extraordinary maintenance work is started. The requested space is then allocated to the resource.

As can be seen in the ICT lane, it can happen that specific requests are made for equipment in the IT area. In this case a request is initiated in parallel to check the availability of the material and in this case, there may be either immediate availability,

with consequent assignment of the material to the resource, or the need to order the equipment and wait for it to arrive. Following the assignment of the equipment to the resource by association with the serial number, the ICT department interfaces with SPFM to find out the code of the room where the requested material is to be supplied. The process, as far as ICT is concerned, ends with the delivery of the requested equipment to the premises indicated by SPFM.

The formal closure by SPFM takes place by notifying the interested parties (hired personnel, possible contact person, university structure) of the final allocation of the space to the resource.

Thanks to the description of the processes by means of BPMN notation, it was therefore possible to describe the as-is situation for two processes related to the university's space management and then to assess which inefficiencies and bottlenecks were present and to propose solutions by reorganising the processes and inserting automatisms also thanks to the introduction of new digital tools.

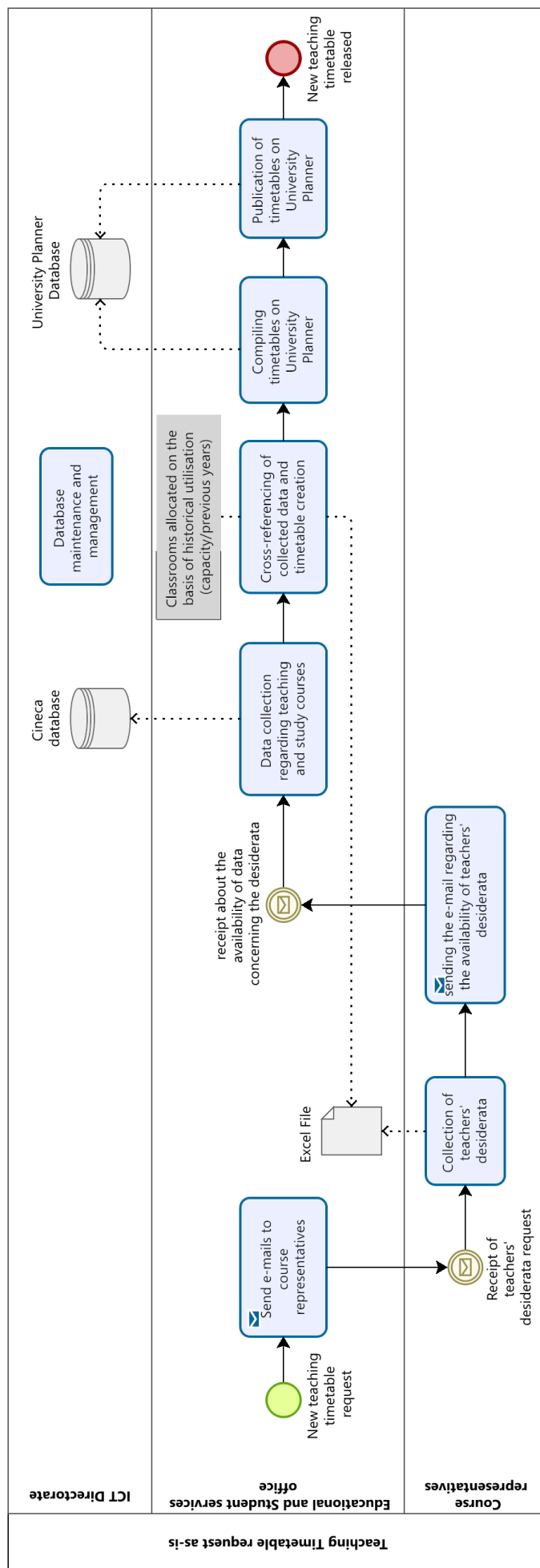


Figure 4.9: Creation of a new teaching timetable as-is.

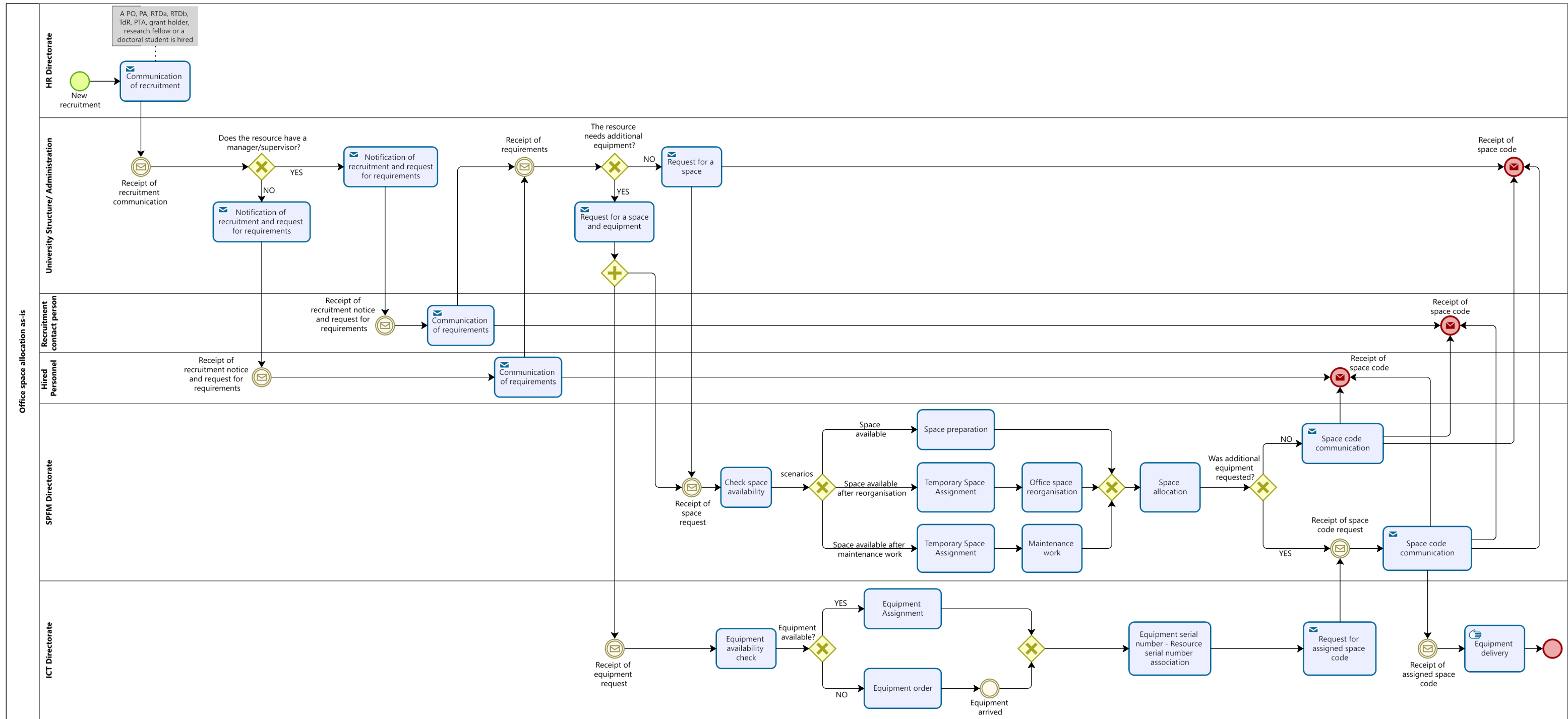


Figure 4.10: Office space management as-is.

5

CHAPTER

Results and findings

The objective of this section is to present and discuss the results obtained at the conclusion of the design phases of the Information System for the management of the University's Real Estate assets. The information dashboards, which have been created using Business Intelligence tools, are presented in terms of the analytical data that has been entered, the types of visual objects that have been used and the potential uses of the dashboards.

From an organisational point of view, the results obtained in modelling new EA and business processes concerning the future state of the organisation are presented. The EA also serve as Reference Architecture to replicate the work done for the university of Turin in other universities.

5.1 An Asset Information Management System

The result of the design phases and iterations of the DSRM is an information system for the management of assets and related information. The aim of the system was to link heterogeneous data coming from different departments and areas of the University of Turin, to support those who have to make strategic decisions. However, the system has also proved useful in supporting certain activities carried out within the University's administrative offices during day-to-day operations.

In the following paragraphs, the main features of the information system and the data processed are presented in detail. The results achieved and the potential of the solution in supporting stakeholders are highlighted, as well as the critical issues encountered.

5.1.1 Territorial level dashboards

The management of real estate on a territorial scale necessitates the gathering and organisation of data pertaining to the geographical location of buildings, the status of

ownership (including direct ownership, rental income from other institutions or private entities, partial ownership or lease), the overall occupancy rate, the presence of historical buildings and other pertinent information for the effective management of facilities. Presently, data pertaining to facilities are frequently stored in disparate documents or Excel files, thereby impeding the ability to conduct integrated analyses for the purpose of informed decision-making. To address this challenge, comprehensive dashboards have been developed to provide an integrated overview of real estate portfolio. The dashboards permit the simultaneous examination of disparate data sets, thereby affording a visual representation of the geographical distribution of the buildings. The elements displayed in the dashboards, including maps, charts, diagrams and tabs, are dynamic and interactive. The selections made in one view function as filters for all other views on the page or in the entire dashboard report, contingent on the specific requirements of the user. It is imperative that spatial dashboards be employed to facilitate strategic decision-making concerning university facilities. Figure 5.1 illustrates a territorial dashboard that presents an overview of the general data pertaining to University of Turin real estate assets. Additional information may be displayed in other spatial dashboards, such as data on facilities undergoing renovation, with specific information on interventions or buildings. This integrated approach to spatial data analysis enables the administrative areas of the University of Turin to monitor the building stock, identify buildings and relevant information, and ascertain the status of any renovations.

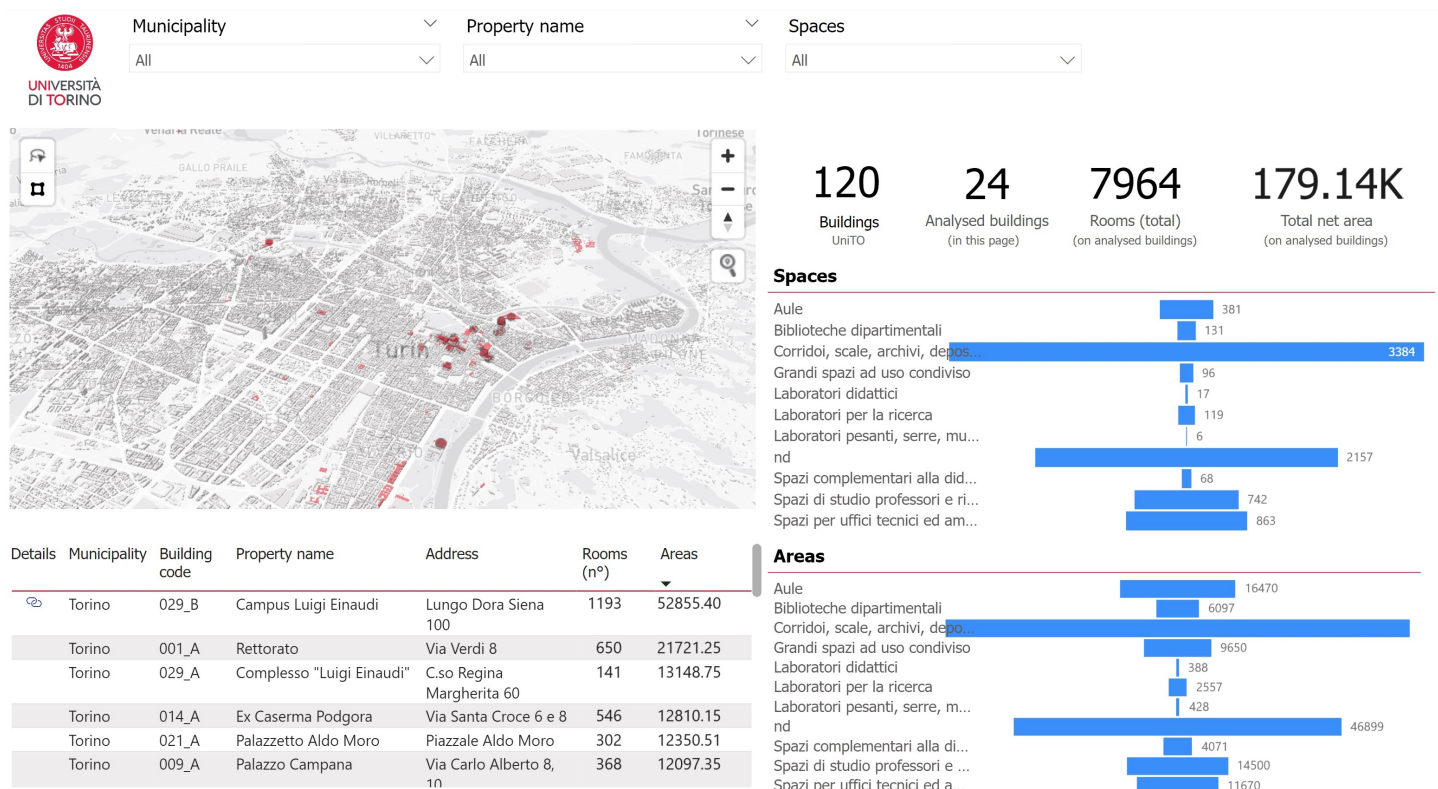


Figure 5.1: AIMS territorial level dashboard - General data about University of Turin properties.

In terms of accessibility, the majority of these dashboards are designed to be accessible only to individuals involved in strategic decision-making processes (e.g., rectors, deputy rectors, general managers, area managers, members of the academic senate,

etc.). This facilitates informed choices and broader assessments at the territorial level by enabling the consultation of different information in a glance, thereby providing unquestionable value.

A spatial analysis has been conducted to determine the distances and proximity between university buildings. The results of these analyses can be visualised through informative dashboards that are aligned with the logic adopted in the development of the AIMS. The dashboard presents an analysis of the proximity between the various buildings, taking into account their respective distances. This type of analysis is beneficial for both the organisation of teaching timetables and the management of emergency situations that require the unplanned relocation of lessons (e.g., in the event of the collapse of a suspended ceiling or other emergencies). It enables students and staff to promptly reach the new location and furthermore, it is possible to filter the display of selected routes by distance range (including: up to five minutes, five to ten minutes, and over fifteen minutes).

Figure 5.2 demonstrates how the dashboard can be used to show the routes that can be navigated in a travel time of up to five minutes, commencing from Palazzo Nuovo. This can be achieved by setting such a query through filters. This application is particularly beneficial in the context of Palazzo Nuovo building, given its high student and staff attendance (approximately a quarter of the University of Turin total). It is also advantageous in instances where full accessibility is impeded by social events or demonstrations.

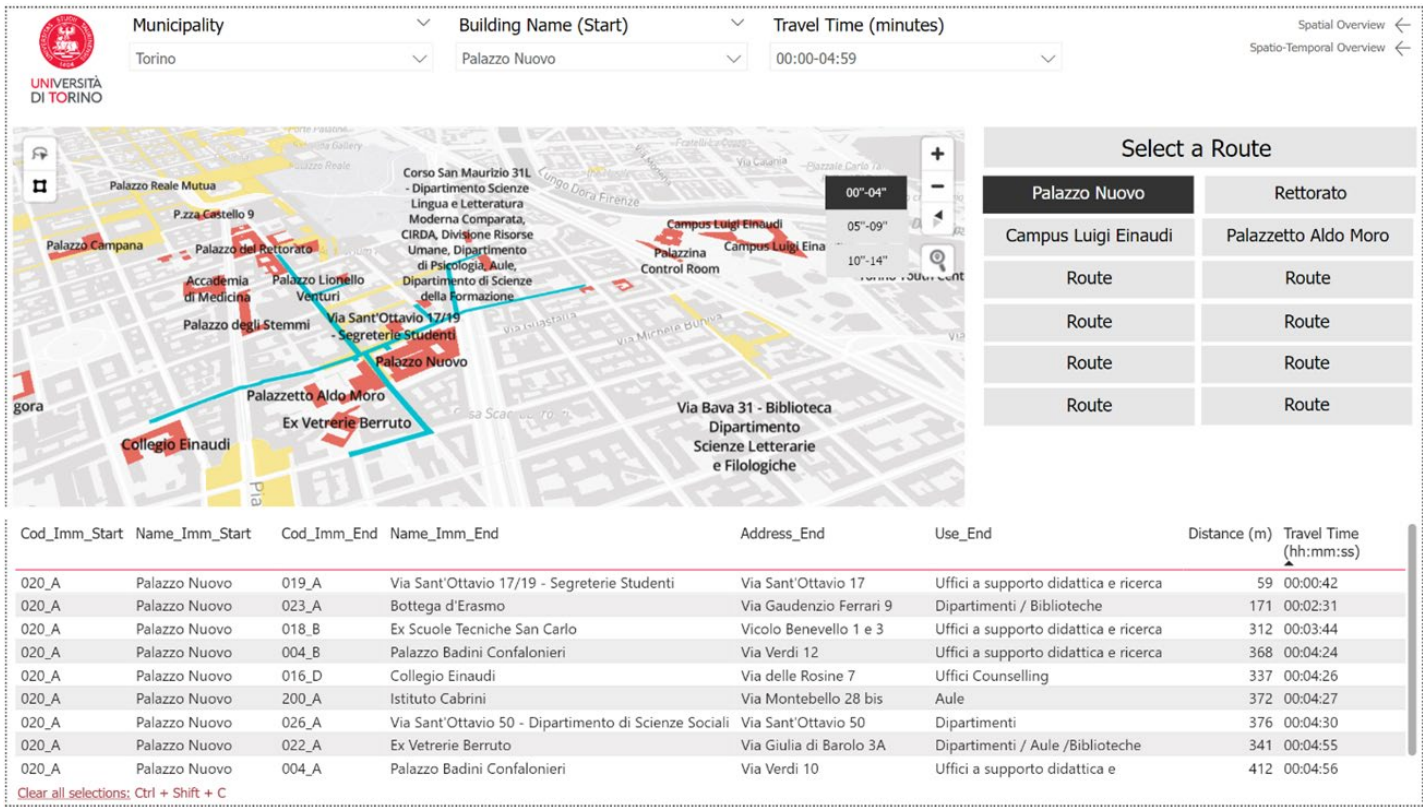


Figure 5.2: AIMS territorial level dashboard - Pedestrian walkways

Furthermore, this type of dashboard can be of significant benefit during maintenance or renovation projects that result in alterations to space usage and availability. In such instances, the dashboard enables the optimal reallocation of resources. The system can facilitate both short-term reorganization, which may be completed within hours, and

long-term planning. Furthermore, it can accommodate the teaching obligations of University of Turin personnel across disparate locations in Turin, thereby decrease prolonged commutes, mitigating holdups and stress, and reducing the overall environmental impact.

A further potential application of AIMS is the provision of data regarding the physical classroom environment and the scheduled commencement and conclusion times of classes. Indeed, the management of teaching spaces and the organisation of class schedules represent a significant challenge, especially in the context of certain buildings in the historic centre. For example, in the case of the Campus Luigi Einaudi (CLE), given the many variables to be contemplated such as the presence of several departments, each with its own approach to timetabling, adds to the complexity of the situation. Furthermore, the wide range of teaching hours in the different subject areas and the multitude of activities require a flexible approach to scheduling, even within the same building.

The current process for the planning of classes and the allocation of spaces is organised through three distinct directorates/offices. Firstly, the ESS provides details pertaining to course enrolments, course codes and academic credits for each course. Subsequently, this information is conveyed to the Degree Programmes Office, which, under the direction of the school, collaborates with academic departments to develop the teaching timetable. Ultimately, a local branch of the SPFM is responsible for space allocation, based on the finalised teaching schedules. The process is characterised by a lack of integration and coherence in the management of data, with reliance placed on manual procedures that are susceptible to inaccuracies and inconsistencies.

The principal objective has been to consolidate data into a unified analytical platform, thereby ensuring secure management while facilitating the assessment of teaching space utilisation. To achieve this objective, a dashboard was developed which provides a comprehensive view of data that would typically need to be gathered from three separate offices. The dashboard permits users to access information pertaining to teaching spaces, including the names of classrooms, room codes, capacity, equipment availability, and net area. Figure 5.3 and Figure 5.4 show two dashboards that provide insights into space utilisation and teaching hours, thus enabling the estimation of the percentage of time classrooms are booked, reserved, or available. This approach facilitates more efficient and accurate data access and analysis, thereby enhancing the efficiency and accuracy of teaching space management through the identification of optimisation opportunities through analytics. It is crucial to emphasise that data access must be regulated in accordance with varying levels of privacy. The data pertinent to the creation of the timetable are accessible to the administrative staff of the three offices. Furthermore, the finalised timetables and information regarding the allocation of space are also available to professors and students.

Another noteworthy feature is the capacity to view rooms in both three-dimensional and two-dimensional formats. Irrespective of the selected view, users are able to select specific rooms and access detailed information (Figure 5.3 and Figure 5.4). An interactive line graph permits direct interaction with the data, while users are also able to filter the results by building floor. As illustrated in Figure 5.11 the scheduled usage of each space can be displayed for various time frames, such as a week, a month, or a year. In the future, a significant challenge will be to align teaching schedules with actual classroom usage. Future developments of this system will include the automation of attendance monitoring, enabling the allocation of the most appropriate spaces based on actual student attendance, as well as the incorporation of other tailored requirements such as equipment and location.

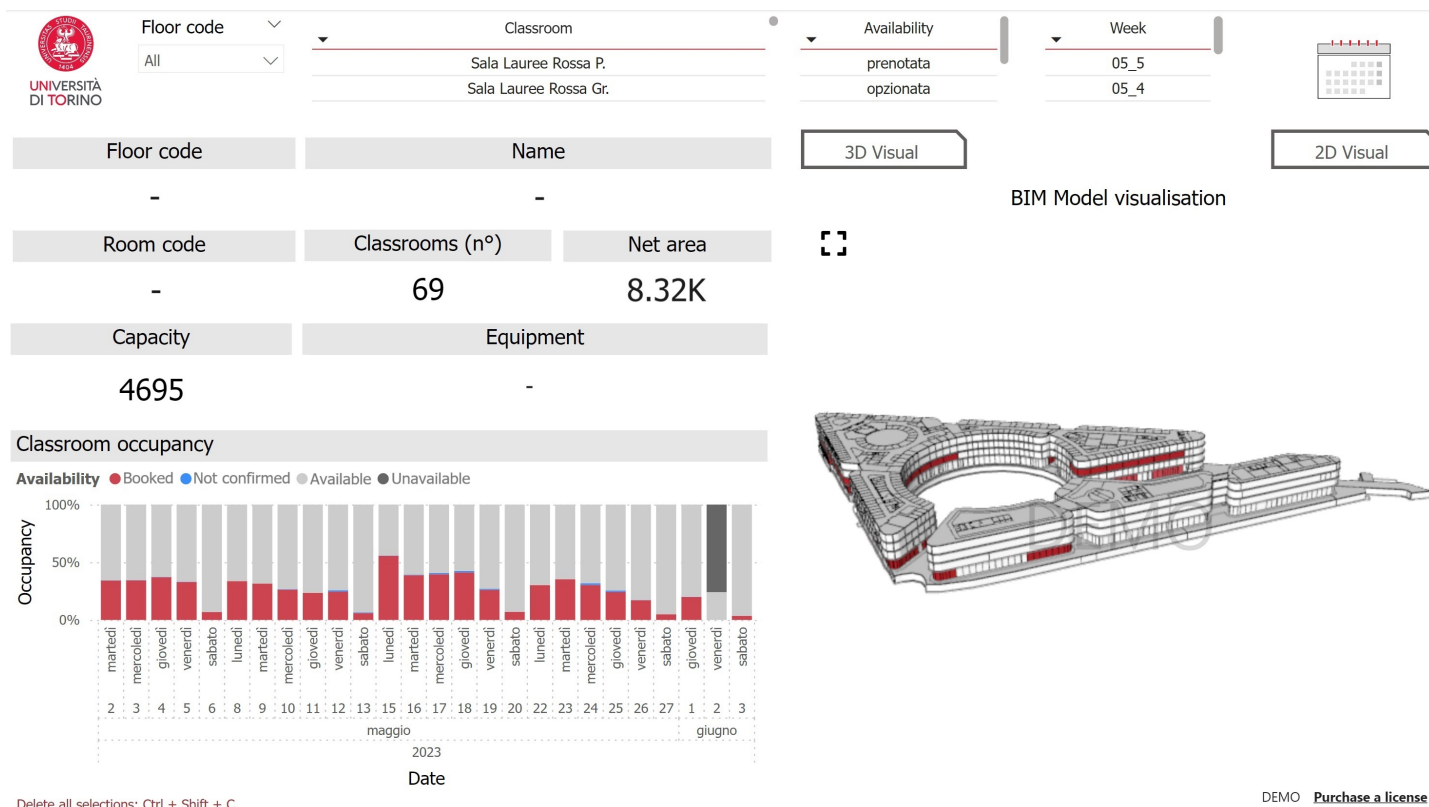


Figure 5.3: AIMS dashboard – Availability and occupancy of lecture hall spaces with the use of three-dimensional visualisation.

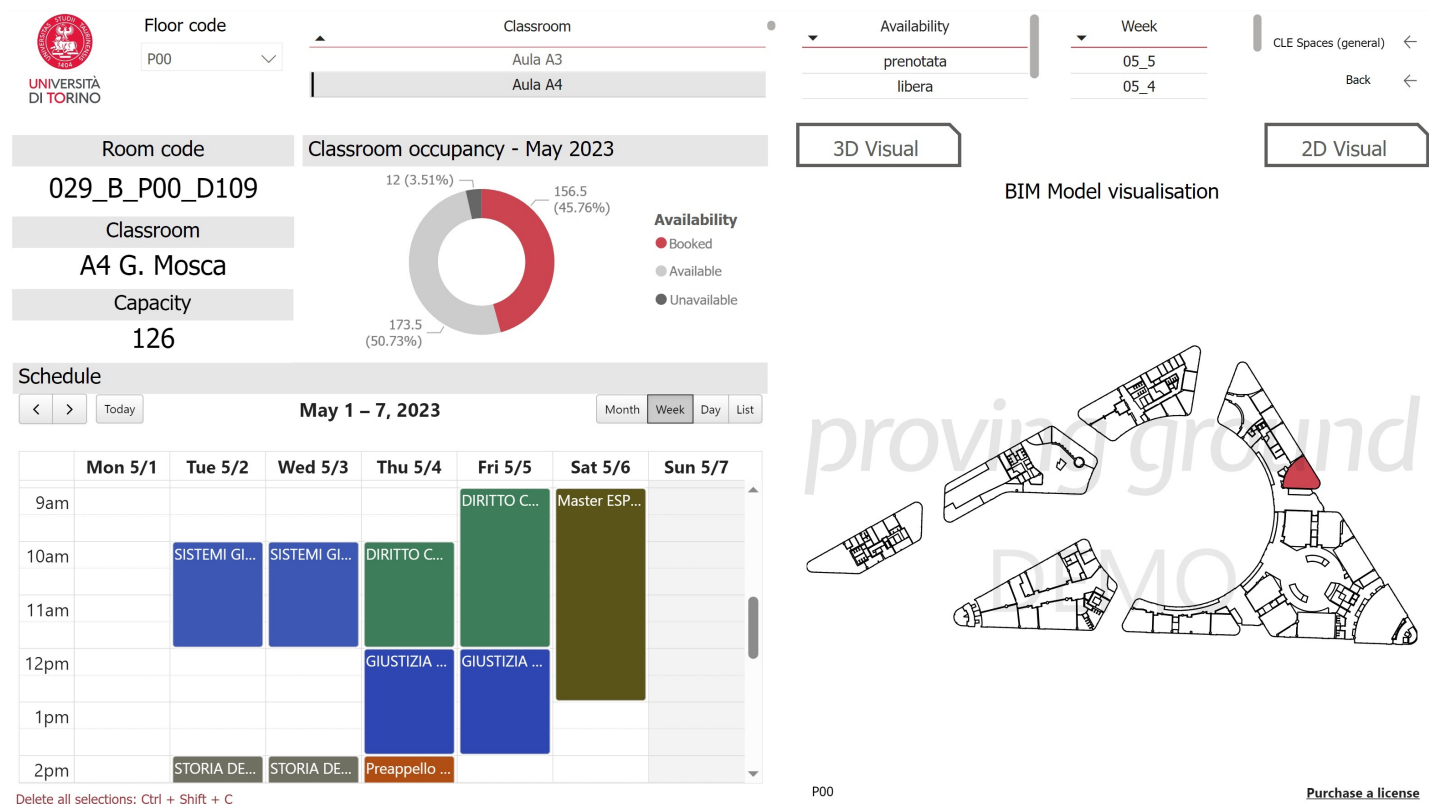


Figure 5.4: AIMS dashboard - Availability and occupancy of lecture hall spaces with the use of two-dimensional visualisation.

5.1.2 Building level Dashboards

The management of real estate assets at the building level encompasses a range of activities that are pivotal to an effective and efficient O&M phase. Such responsibilities include the management of personnel, encompassing the administration of contracts and the allocation of space and equipment. Additionally, there is the task of overseeing the distribution of space to departments and areas within each building. At present, the operational management of buildings at University of Turin is the responsibility of the departments or administrative staff with jurisdiction over each facility. In addition to space codes, which are standardised across the entire administration, all other information is managed at the local level by the space management staff in each building. A centralized structure for the oversight of space management across all facilities is currently lacking. Accordingly, the principal aim of this application is to facilitate decision-making processes pertaining to University of Turin facilities by consolidating all pertinent information and generating comprehensive building-level dashboards. The dashboards will analyse a variety of factors pertaining to the utilisation of space, occupancy, and personnel management. This will be achieved through the integration of BIM, GIS and other data sources, facilitated by the utilisation of BI technology. The data processed for this purpose comprises the following:

- Location within the building, area size, and type of space;
- Allocation of spaces to departments or administrative units;
- Assignment of spaces to University of Turin personnel, including their role, contract type, and affiliation with a department or administrative unit.

The AIMS dashboard at the building level provides a comprehensive overview of all spaces. Figure 5.5 and Figure 5.6 illustrate the graphical user interface and at-a-glance view offered in one of the buildings used as a pilot case, the CLE. The dashboard incorporates dynamic maps and charts that present detailed information on space types, room counts, and the allocation of spaces to various departments or administrative areas. Furthermore, the dashboard includes specific data points, such as space net area and room counts, which facilitate a comprehensive analysis of occupancy and staff allocation within offices. This enables users to access general space data, visualise the distribution of space types across building floors, and review summaries of the total building net area and room count.

A comprehensive analysis of the offices within the CLE case study, offering insights into the distribution of spaces and staff percentages across various departments and administrative areas are presented in Figure 5.6. The graphical representation enables a comparison between the number of employees and research fellows assigned to spaces and the maximum capacity of each room based on its net area. This facilitates the formulation of well-informed decisions regarding the allocation of new staff members to departmental spaces, while ensuring an impartial distribution of spaces among departments and areas. The dashboard is of great importance, as it provides a comprehensive overview of the building and the utilisation of each floor. Furthermore, the data may be filtered by department or area, thus enabling users to view information on allocated staff, vacancies, the number of workstations per department or area, the average space per user, and the potential for accommodating additional staff by selecting individual rooms.

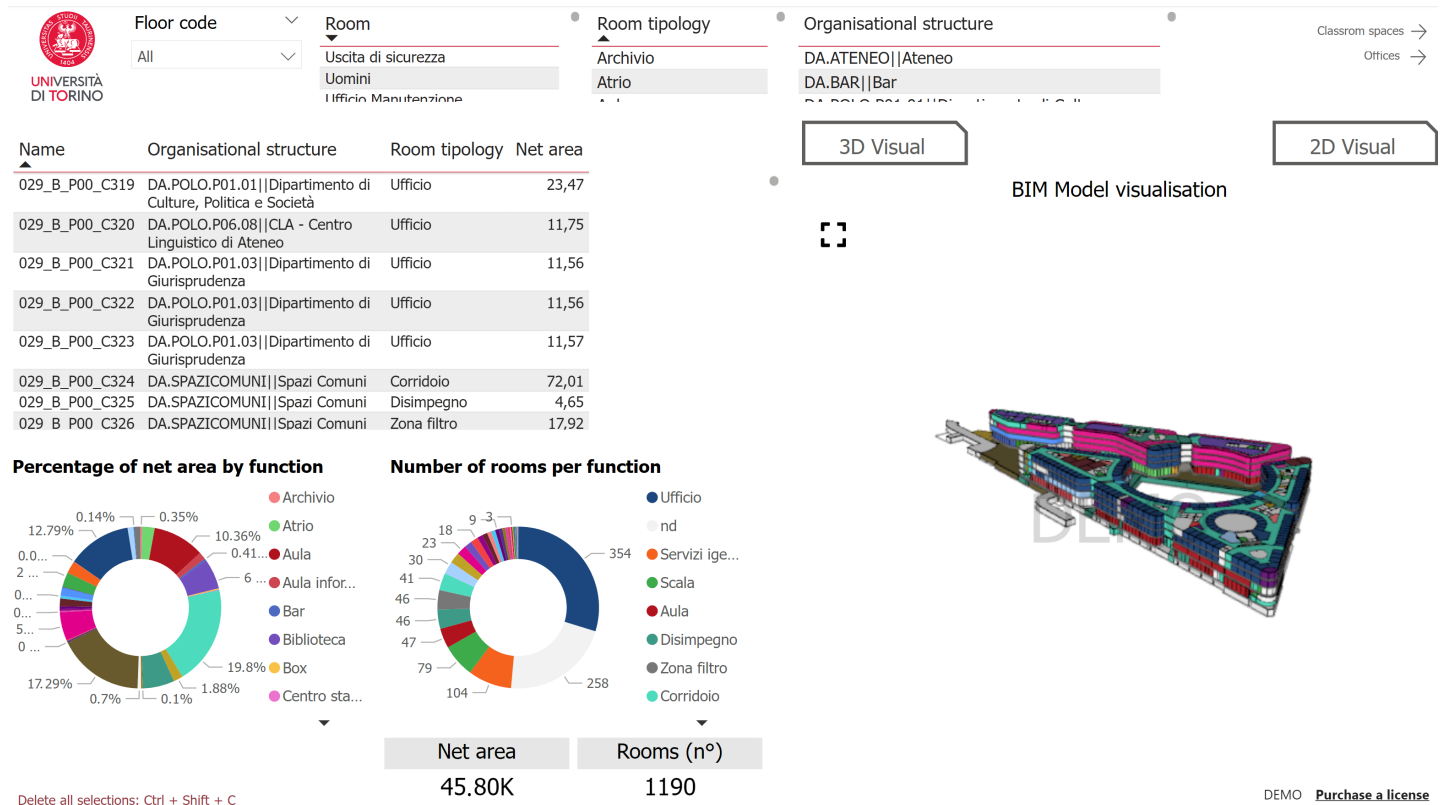


Figure 5.5: AIMS building level dashboard – characteristics and allocation of spaces.

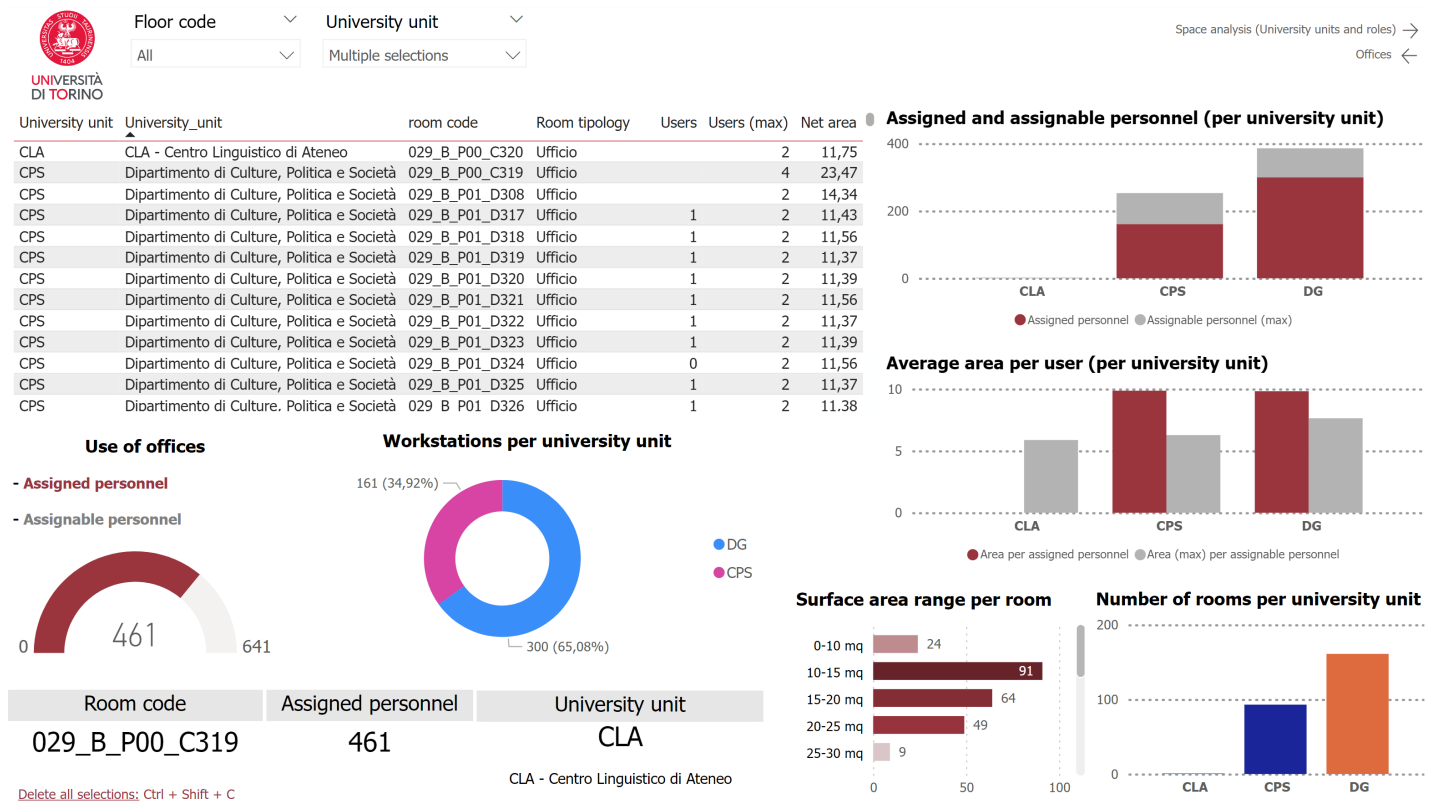


Figure 5.6: AIMS building level dashboard – office spaces and staff allocation analyses.

The dashboards are accessible to individuals with responsibility for space management, including school directors, departmental directors, and logistics and maintenance managers. Once the management of the AIMS will be fully integrated into University of Turin administrative offices, data access will require different privacy levels. Thus, relevant staff members will be required to log in using a designated username and password in order to access the specific reports of interest.

The objective of enhancing space management in the designated demonstrators prompted an investigation into methodologies to optimise occupancy, space allocation and utilisation by integrating work-from-home practices. At present, the contracts of professors, research fellows and PhD students afford flexibility in both working hours and locations, thus facilitating the organisation of work-from-home schedules. For administrative employees, however, work-from-home practices were initially introduced during the period of the global pandemic caused by the novel coronavirus (SARS-CoV-2) and have since been maintained for two days per week. Notwithstanding this transition, there has been no discernible enhancement in the management of workspace resources in relation to flexible work scheduling. Thus, the AIMS has been developed with the additional objective of addressing this issue by proposing an uniform distribution of work-from-home days among employees and researchers sharing the same office throughout the workweek. This approach optimises the utilisation of the office space, as not all occupants are present simultaneously. The scheduling of work-from-home days is designed to ensure that a portion of the office occupants are engaged in remote work on a daily basis, thereby increasing the overall occupancy of the building. If each employee were to work remotely for two days in a five-day workweek, the total building occupancy could increase by approximately 60% (Figure 5.7).

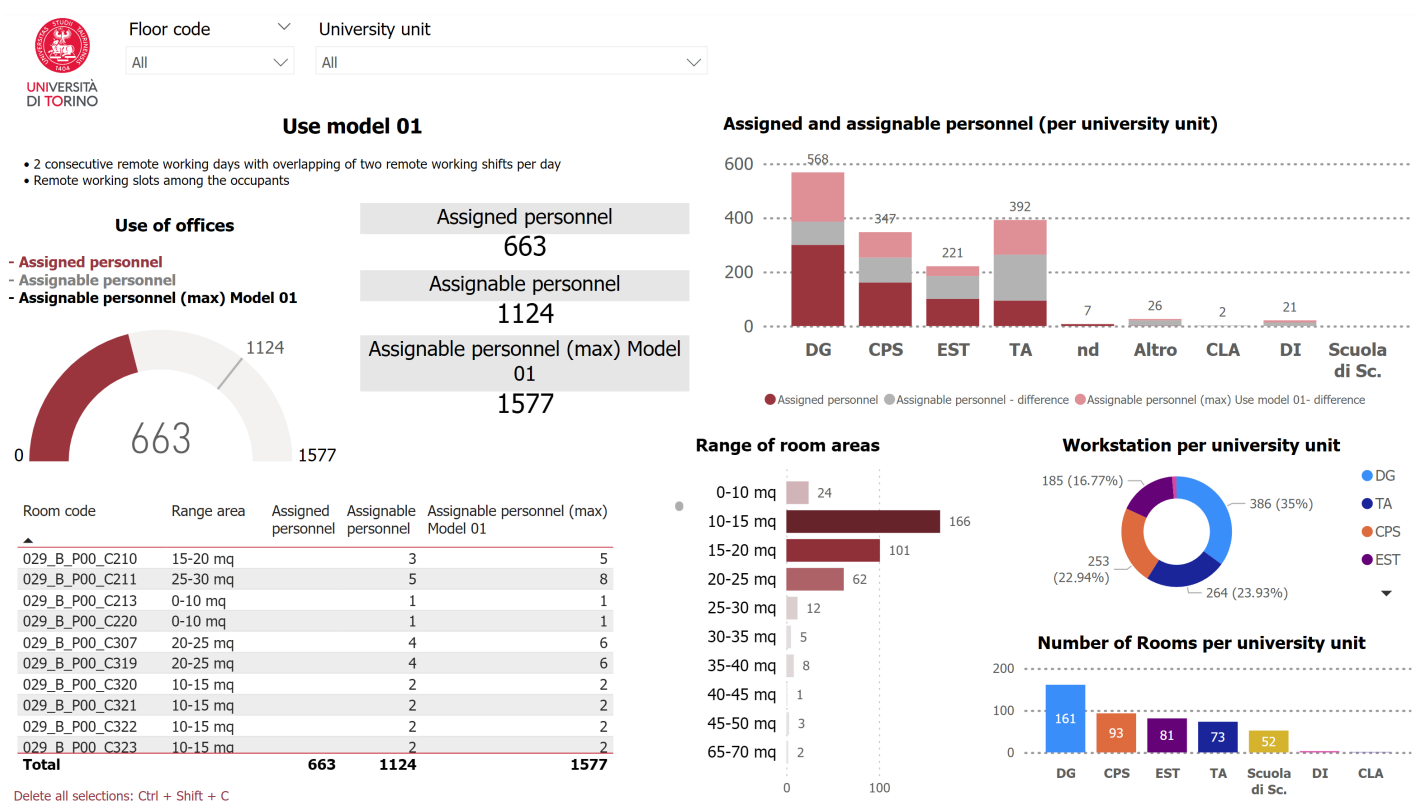


Figure 5.7: AIMS building level dashboard – space analysis in terms of maximum capacity, space allocation, occupancy, maximum occupancy with work-from-home scenario.

This strategy ensures that, in the event of new hires, the requisite workstations within existing facilities can be made available, thus obviating the need to procure or lease additional space.

Another topic developed within the information dashboards is that of the environmental quality of the spaces used by students, professors, researchers and technical administrative staff. The monitoring of environmental quality data in educational spaces and offices is of paramount importance for two principal reasons. Primarily, it ensures the maintenance of a healthy environment that enhances productivity and learning performance. Secondly, it facilitates the detection of faults that may necessitate system adjustments or remodelling. Additionally, this practice has the additional benefit of promoting energy savings and reducing emissions from heating and cooling systems. Over the past two years, University of Turin has deployed Internet of Things (IoT) devices for the monitoring of indoor environmental quality (IEQ) in its buildings. The CLE building provide an optimal setting for testing, given the extensive array of sensors and the diversity of classrooms, which encompass varying capacities and orientations. University of Turin has selected AirCare® IoT devices, which can capture fifteen distinct types of measurements, including those pertaining to air quality, environmental comfort, and electro smog indicators. It is noteworthy that the accuracy and reliability of these devices for measuring PM_{2.5} and CO₂ have been scientifically validated by the Italian Society of Environmental Medicine (SIMA). A total of 39 Internet of Things (IoT) devices were strategically installed across thirty-seven classrooms within the demonstrator, with a focus on the ground and first floors, which are primarily used for teaching. The data collected by these devices are transmitted directly to a cloud platform, thereby facilitating the efficient collection of data. At present, the data is accessible via reports on an experimental platform managed by the ICT directorate, but it is not publicly available or shared with other departments.

The objective of creating a dedicated dashboard was to take advantage of the capabilities of the AIMS by associating the data with specific locations and generating interactive charts that display real-time information from the IoT devices. In order to fully utilise the benefits of measuring multiple data types with a single IoT device, the dashboard was designed to associate viewable spaces with data on CO₂, CO_{2e}, VOC, PM₁₀, and PM_{2.5}. Furthermore, the dashboard incorporates the data with floor plans, thus providing unambiguous visual indications of sensor locations within classrooms. As illustrated in Figure 5.8 it is straightforward for users to access and visualise recorded values over the course of the week by selecting a specific classroom.

In order to serve as alert indicators, given threshold values were established for the key parameters. In accordance with the standards set forth in UNI 11300, temperature thresholds were established between 20 and 22 degrees Celsius for the heating season and between 22 and 24 degrees Celsius for the cooling season. The threshold for CO₂ concentration was set at 1000 parts per million (ppm). In regard to particulate matter, the limits recommended by the World Health Organization were adopted: a concentration of under 25 µg/m³ for PM₁₀ and a concentration of under 50 µg/m³ for PM_{2.5}. Furthermore, a limit of 550 parts per billion (ppb) was selected for volatile organic compounds (VOCs), in accordance with guidelines set forth by the US Environmental Protection Agency (EPA). This approach offers several advantages. Firstly, it enables the immediate visualisation of data collected by IoT devices and their correlation with specific spaces, thus facilitating the identification of patterns and trends. Secondly, it permits the examination of recorded irregularities in occupancy and class schedules for the aforementioned spaces. In conclusion, this comprehensive

strategy offers valuable insights for maintaining a healthy and optimised learning environment.

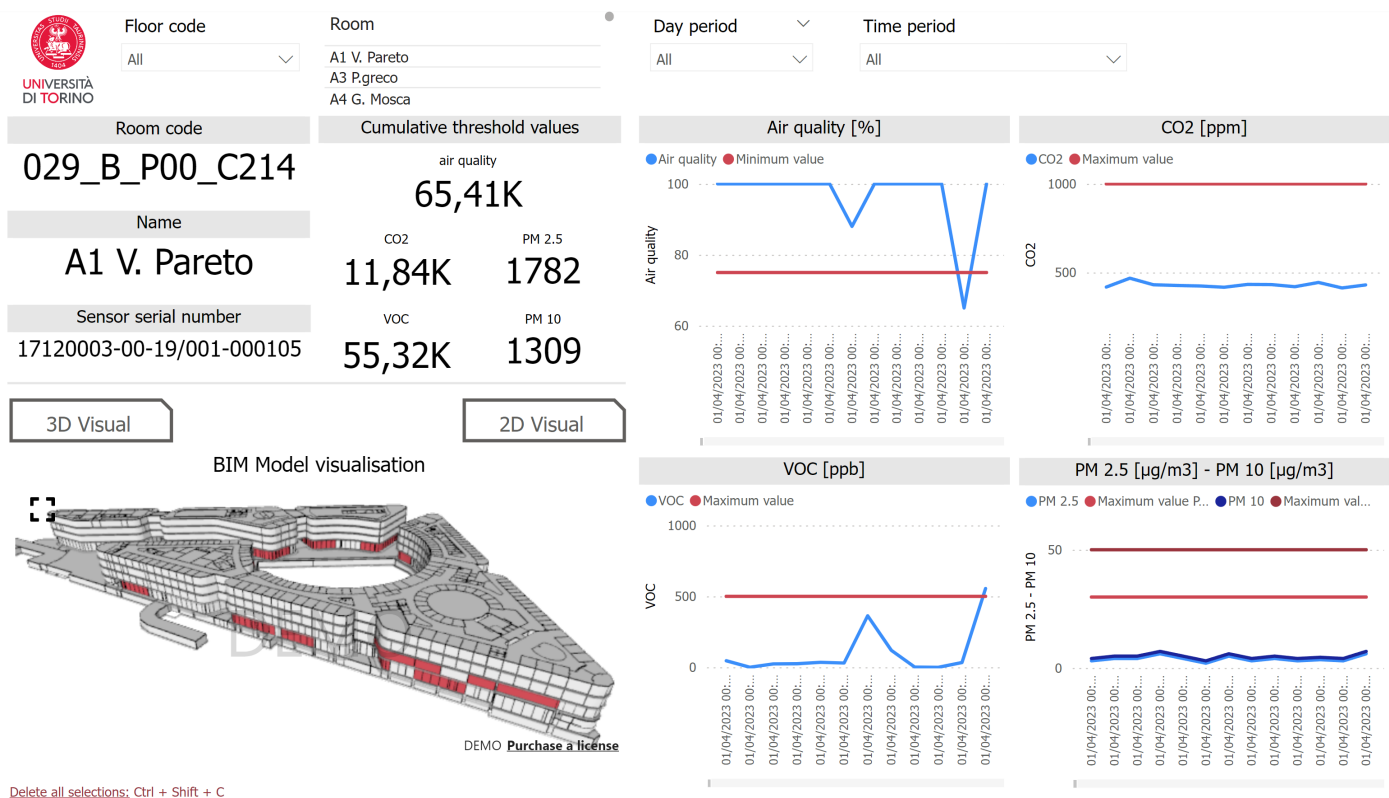


Figure 5.8: AIMS building level dashboard – IoT devices data visualisation.

The indoor environmental quality dashboard offers a multitude of valuable information, catering to a diverse range of users. By way of illustration, the university energy manager is able to monitor trends in parameters in order to guarantee optimal system performance. Furthermore, the data can be of benefit to students, professors, researchers and administrative staff, who may monitor their work and study environment, gain awareness and potentially contribute to a healthier atmosphere for all.

Further applications of this dashboard may include the integration of environmental data with building system operations. It is conceivable that IoT devices could serve not only as monitors but also as actuators, adjusting environmental conditions when specific thresholds are reached. Initially, this could entail straightforward threshold-based adjustments; however, prospective developments may encompass more sophisticated triggers and for instance, exploiting machine learning, the system could facilitate predictive solutions, enabling preventive adjustments before thresholds are surpassed.

5.2 Reference Architecture model

This section presents the results of the Enterprise Architecture modelling process. The model elucidates the congruence between the business objectives and the applications offered with the support of technological tools. Potential benefits of such an analysis within the organisational context are discussed. It is emphasised that the tool discussed in this chapter enables a comprehensive analysis of the Enterprise Architecture.

5.2.1 Enterprise Architecture future state

To comprehend and convey the prospective state of the organisation subsequent to the implementation of the AIMS, the business, application and technology architectures were modelled and their alignment was then evaluated, thus facilitating an overall view of the EA.

The business architecture for the future state describes the main processes related to the new digital management of the University's assets and makes it possible to visualise how a new organisational unit can facilitate horizontal coordination between directorates. The processes included relate to the digital asset management phases by highlighting the processes that are carried out within a new organisational unit and the processes that are carried out by the various directorates depending on the trigger event that occurs. Each process then concludes with either a collaboration with the Data Analysis Team (DAT) that receives the data necessary for the update or with a collaboration between different directorates, facilitating horizontal coordination and collaboration.

As shown in the legend in Figure 5.9, the elements used are the Business Event, symbolising a business event that, when it occurs, triggers the start of a business process, and each process can be associated with a Business Actor, symbolising the person or university structure responsible for that process. The process managed by DAT, which is related to digital heritage management, comprises sub-processes that may occur in a chain or may originate from an intermediate point in the process, contingent on the occurrence of an event. The process symbolises the phases of the management of the IS by the DAT with all the cases that may occur. It usually begins with the acquisition of an updated Building Information Model (BIM) model (for new construction or renovation), then data is acquired and dedicated datasets are created that will then be associated with the BIM models. Subsequently, dashboards can be created or existing dashboards can be updated with new data. The final phase is publication, whereby the information dashboards are made available to the intended users.

Common to all processes is the data update process, which ensures that data, models and dashboards are constantly updated and is triggered by event-driven processes. Specifically, when a new timetable is requested, the process of creating or updating timetables and the consequent updating of the university centralised database is activated. The same dynamic occurs with the request for a new office workstation, the event of a new construction, renovation, building or space modification, the termination of a work contract, the request for maintenance work or the start of scheduled maintenance, the acquisition of a new space or its decommissioning. Each process is assigned a business actor, which can be an individual or, more generally, a Directorate. In this way, for each process, the Directorates collaborate with at least one other Directorate or organisational unit, and everyone must play their part in order to always have up-to-date data and to exploit the potential of the centralised university database.

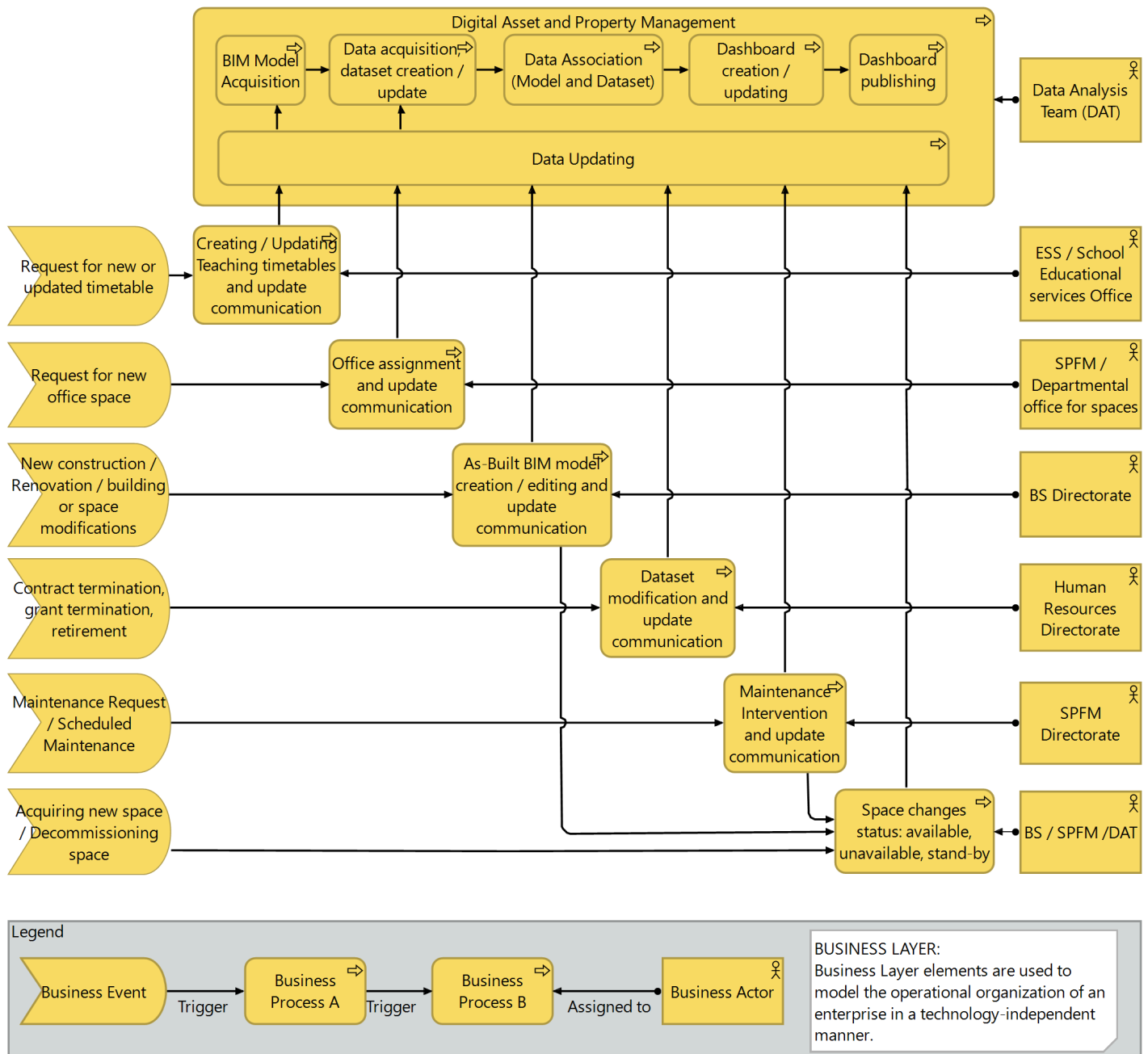


Figure 5.9: University of Turin Business Architecture to-be.

Following the modelling and description of the prospective business architecture, the modelling proceeded to the application aspects of the organisation. The application architecture represents a fundamental element of the organisation's architecture, serving as a conduit between business processes and the IT infrastructure. In other words, it enables stakeholders to leverage the hardware and software infrastructure through applications that can also interact with each other and support business processes.

Regarding the University of Turin, an application architecture was created (Figure 5.10) based on existing systems and on the IS designed ad hoc to meet the university's specific requirements. As illustrated in the accompanying legend, the architectural design comprises several distinct elements, exhibiting a high degree of complexity.

The central element to start the description is the data object, which represents the various datasets from which data is extracted for use within the IS. From the data object, certain application components may be drawn (in reading and in modification) which symbolise the various components used to operate the IS. In contemplating the existence of these application components, with the objective of preserving certain practices that are already in place within the organisation, they were allocated to the Directorates that are responsible for operating those applications.

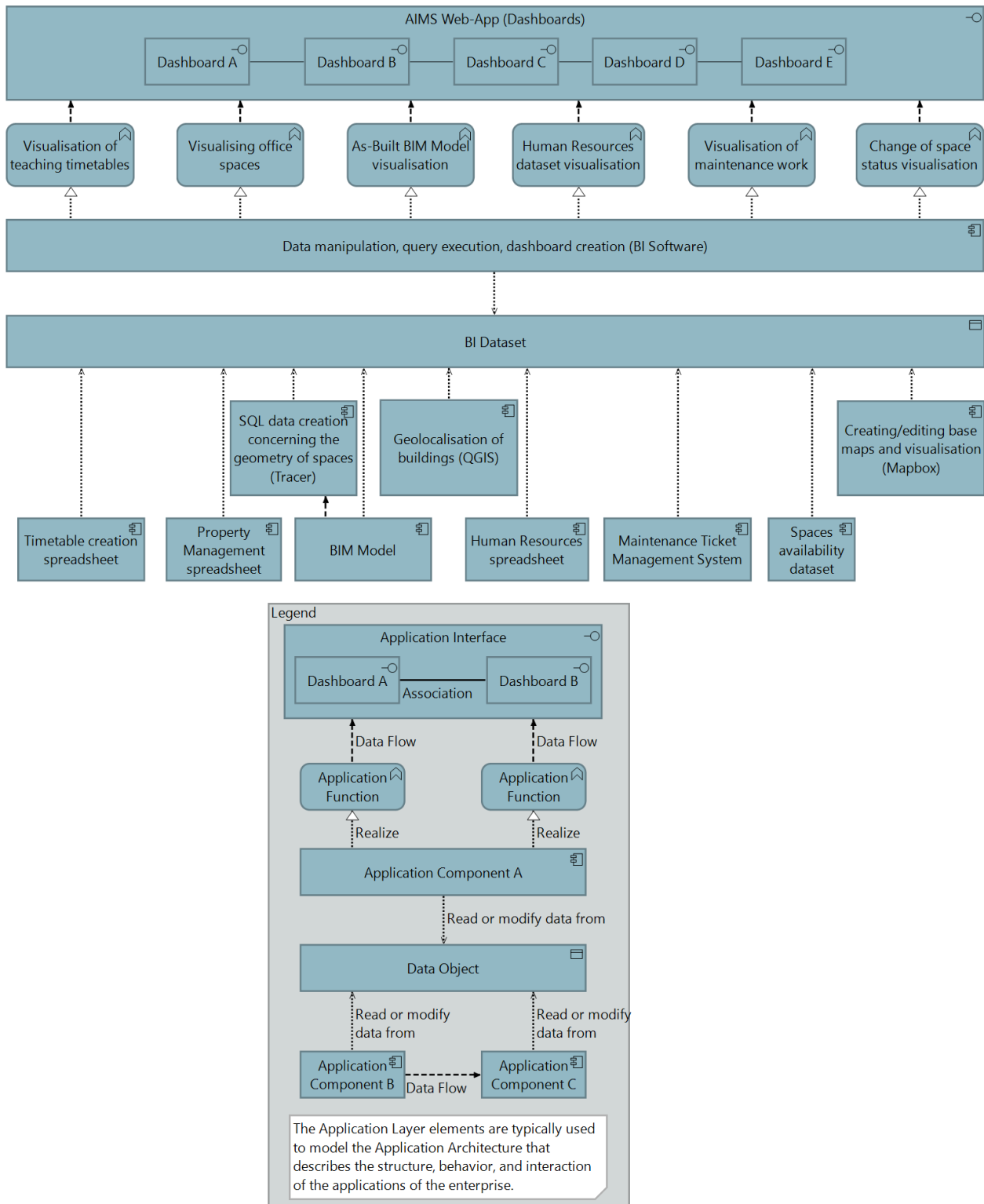


Figure 5.10: University of Turin Application Architecture to-be.

In envisaging the presence of these application components, with the intention of also maintaining certain practices already present in the organisation, they were ideally assigned to the directorates that should operate those applications. As can be seen in the image starting from the bottom left, we find a spreadsheet for the creation of the teaching timetable (Educational and Student Services Directorate), a spreadsheet for real estate (Security, Property and Facility Management Directorate) a BIM information model (Building and Sustainability Directorate), a spreadsheet for human resources (Human Resources Directorate), a spreadsheet for maintenance (Security, Property and Facility Management Directorate), a spreadsheet for space availability (Building and Sustainability Directorate, Security, Property and Facility Management Directorate, Data Analysis Team).

Further up, three additional components are visible. These include an application for transforming the geometric data of Building Information Modelling (BIM) models into data suitable for visualisation on a business intelligence platform; an application for georeferencing buildings; and an application for map management and visualisation. The three applications are assigned to the recently established organisational unit (DAT), which oversees the operation of the IS and performs a horizontal coordination function within the organisation.

Eventually, the application component, which serves as a basic application to integrate the functionalities and data of the other applications (Business Intelligence application) and is also able to read data from the datasets, then realises application functions of various types that are distributed and visualised by the stakeholders through interfaces (dashboards). In particular, the functions are: the visualisation of teaching schedules associated with spaces and analytical data, the visualisation of data concerning office locations, the visualisation of the BIM model, the visualisation of data concerning human resources, the visualisation of maintenance operations, and the visualisation of the change of status of spaces. This application and the management and maintenance of the dashboards is also entrusted to the new organisational unit.

Lastly, the modelling of the technology architecture concerns the description of the structure and behaviour of the organisation's technology infrastructure. As noted in Section 4.2.1 in the initial situation, the organisation worked in watertight compartments and this also entailed a division in terms of databases. Each directorate, in fact, had its own database and in some cases the work was based on files prepared by the staff of the various offices on their own initiative. Therefore, there was no standard format or guidelines for creating interoperable files and data between different structures.

In modelling the future state of the technology architecture, the new configuration with regard to data storage, the formats used and the software used with a focus on interoperability between software and between data formats can thus be visualised.

As can be seen in the legend in Figure 5.11 a centralised university database (CUD) has been assumed as the basis from which all stakeholders can draw secure and always up-to-date data. The collaborative technology element therefore symbolises a database server or a cloud database (depending on the choice made by the organisation) within which the node elements represent the various datasets that are used to manage, modify and store the data necessary for the management and Information System. One of these datasets (i.e., IoT dataset) is fed directly from a communication network through which data is transmitted from buildings that are equipped with IoT sensors.

Subsequently, the data flow can be directed to a variety of interfaces, which represent the software utilised for the manipulation and modification of the data in instances

where updates or new data are required.

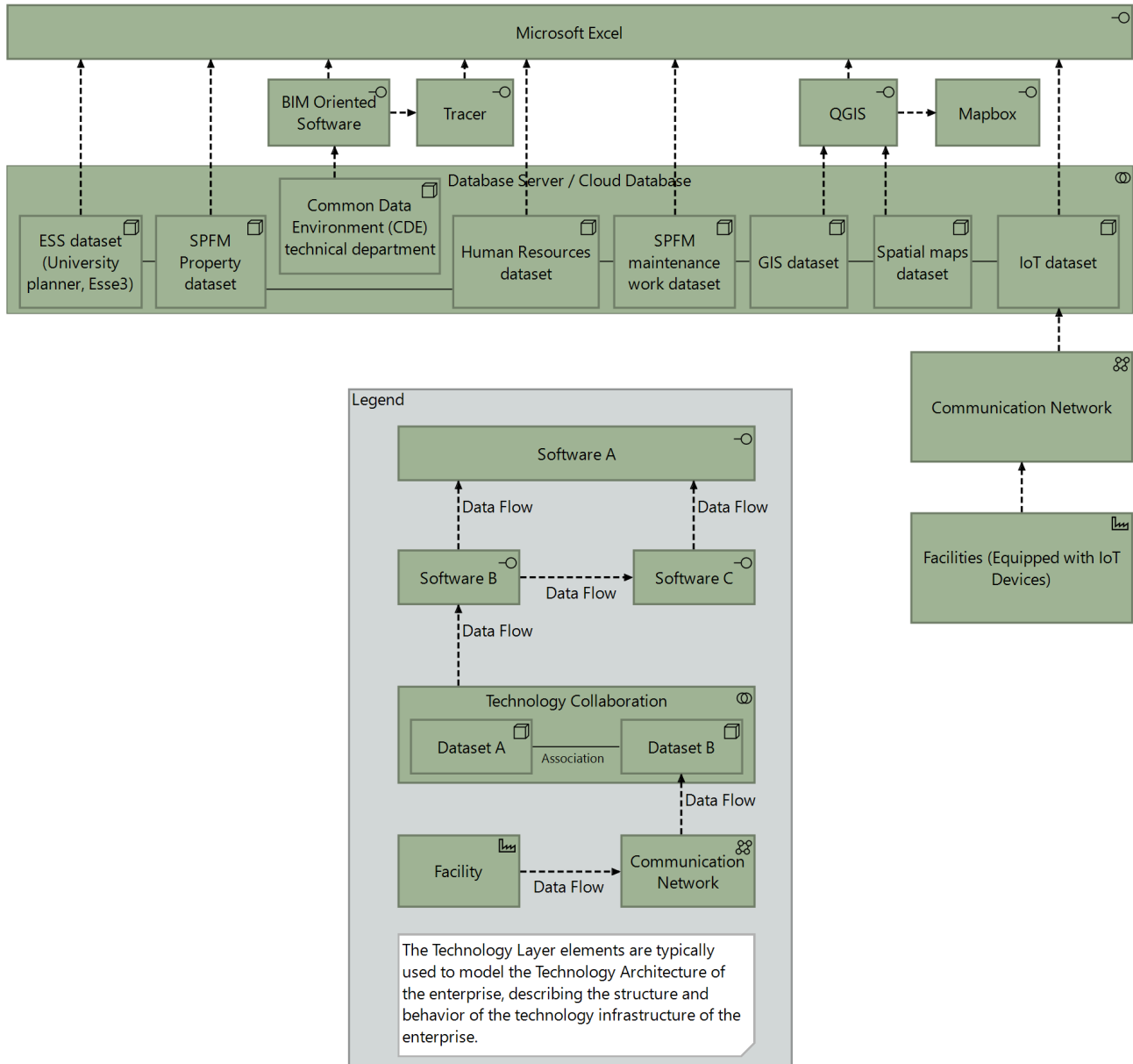


Figure 5.11: University of Turin Technology Architecture to-be.

As can be seen, the Microsoft Excel interface has been provided for data editing by the dedicated offices, as it is the most widely used application by offices for data management and spreadsheet use. Furthermore, the Microsoft Excel software is part of a software package (i.e., Microsoft Office) that is the most widely used worldwide in the administrative sphere and is regarded as very reliable by organisations. This allows for excellent compatibility both within the organisation and with the external environment and, furthermore, it is compatible with the business intelligence software (i.e., Microsoft PowerBI) used as the basis of the latest version of the Information System. In any case, given the widespread use of Microsoft Excel spreadsheets and their proven interoperability with other software, the System can also be set up in the same way in other organisations that use different Business Intelligence tools.

5.2.2 Reference Architecture and alignment

Following the modelling of the architectures for the three core layers of the ArchiMate language in isolation, an assessment of the alignment between the business, application and technology architectures can be conducted. Indeed, from the perspective of the entire organisation, the objective is to guarantee alignment between the three architectures, thereby ensuring that the devised solution genuinely aligns with the organisation's requirements. Furthermore, the tool can be employed to monitor the organisational architecture over time, thereby enabling the identification of any misalignments or shortcomings resulting from changes in the scenario that may occur over time.

Figure 5.12 provides an opportunity to analyse the alignment between the business layer and the application layer. At this juncture, it is possible to comprehend the way applications can facilitate business processes and, if required, implement modifications. The application, designed to facilitate AM and FM activities within the University of Turin, offers the possibility of consulting information dashboards via an interface. The various processes of the business layer are thus connected with the application layer via a “serving” connection, which represents the fact that the various application interfaces provide their functionality to the specific processes. In particular, the following points should be noted:

- the process of creating and updating teaching timetables is facilitated by the dashboard pertaining to teaching;
- the process of assigning office spaces is supported by the dashboard concerning offices;
- the process regarding the creation and editing of the as-built BIM model is enabled by the dashboards pertaining to individual buildings;
- the staff management process is facilitated by the office dashboards;
- The maintenance-related processes are served by the dashboards that display the status of scheduled maintenance work or ticket management;
- The process of changing the status of a space is served by dashboards that allow the visualisation of the status of the space, which may be available, unavailable, or on standby due to maintenance or renovation.

Monitoring the alignment between the business and application architectures is crucial even after the implementation of the platform because it allows the situation to be monitored and problems to be noted, or it allows changes to be planned according to new business needs or the availability of new technologies that may change the application architecture.

About the alignment between the application layer and the technology layer, on the other hand, it is important to align both hardware and software tools and the technology infrastructure in general with the applications offered within the organisation.

In Figure 5.13, it is possible to appreciate the alignment between the two architectures, which ensures that the right tools are always at the service of the applications dedicated to the organisation.

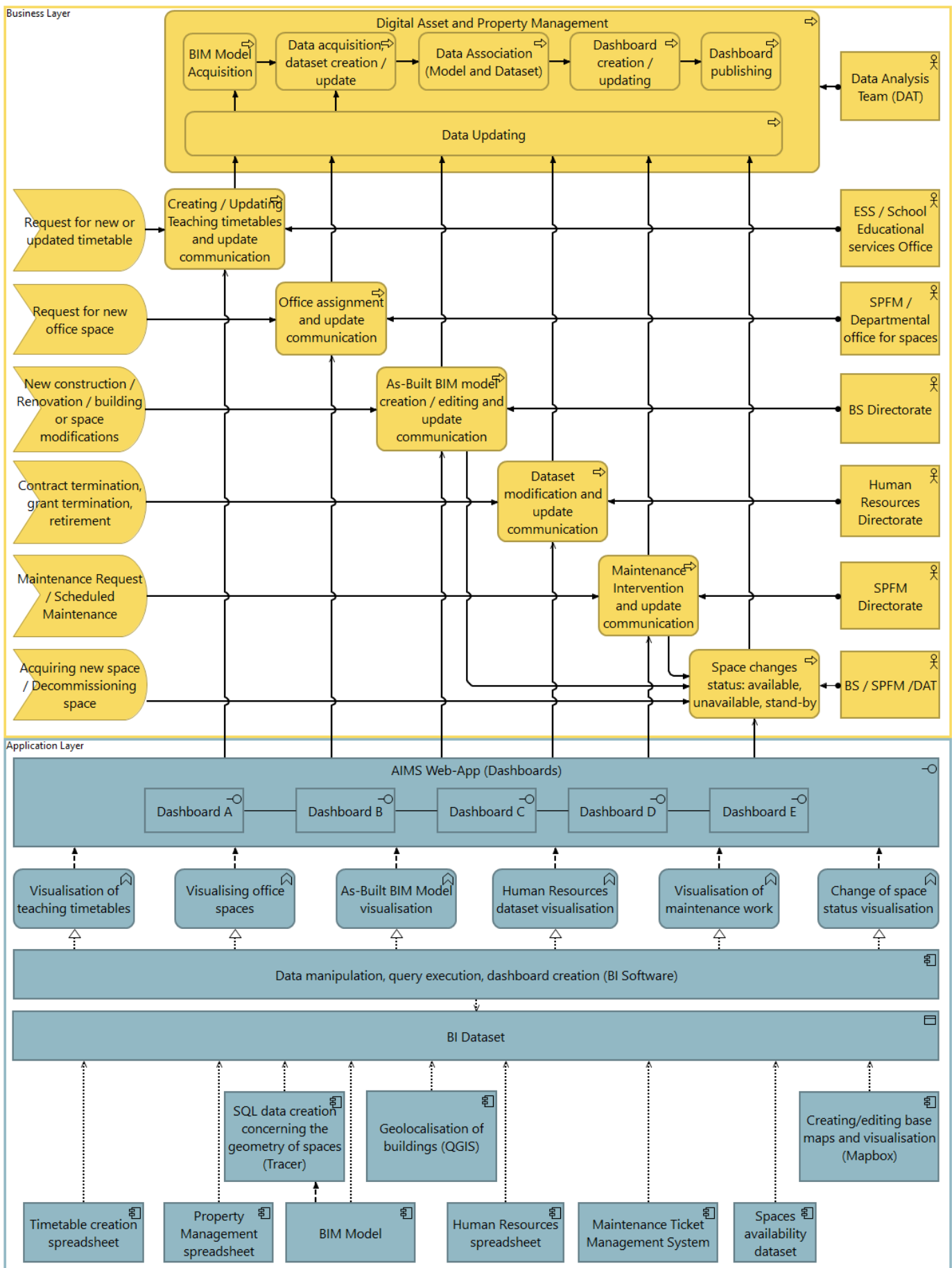


Figure 5.12: Business – Application alignment To-be.

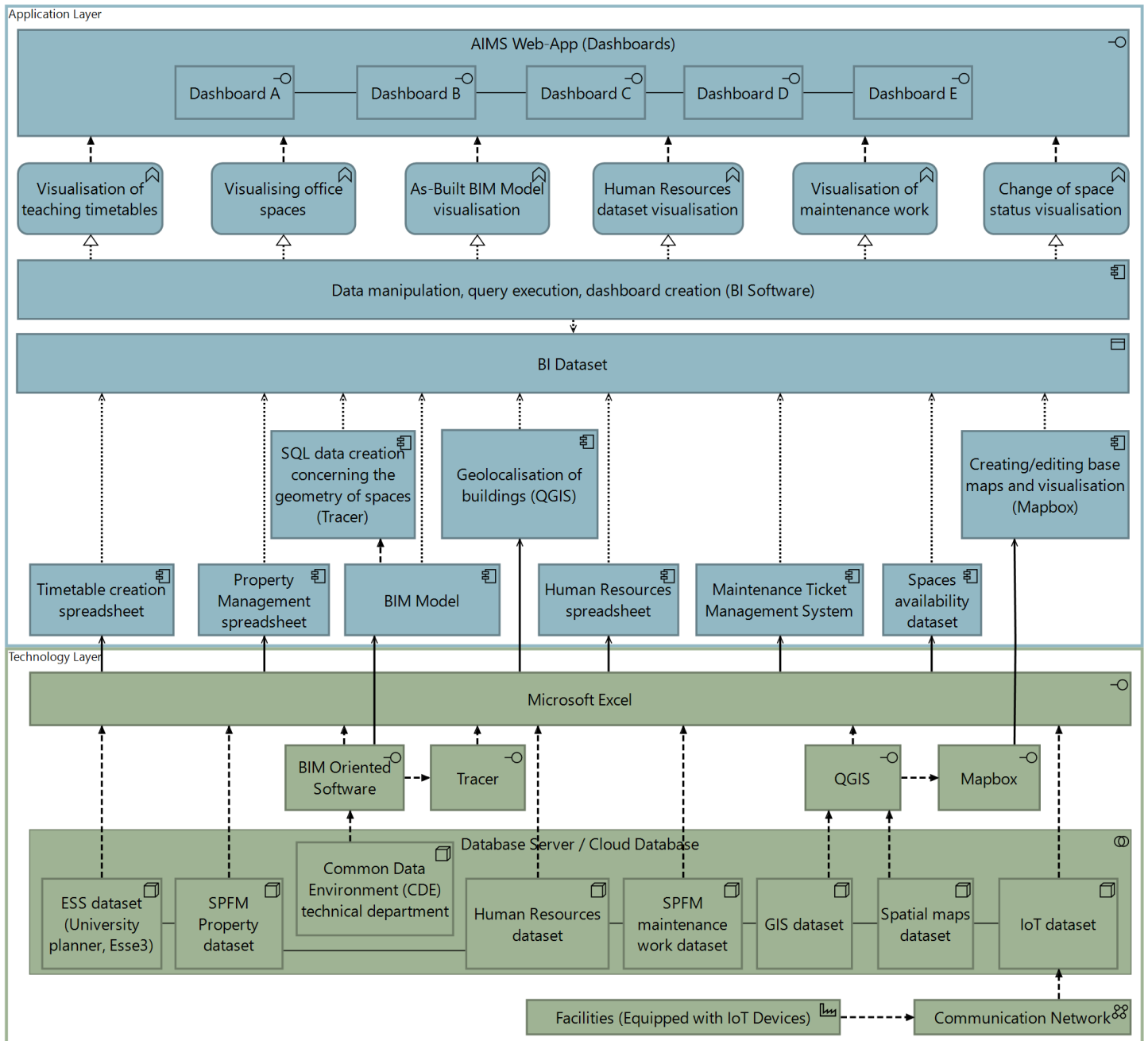


Figure 5.13: Application – Technology alignment To-be.

It should be noted that the interface connections are of the “serving” type. Furthermore, it is possible for many applications to use Microsoft Excel software (or alternatively other software capable of managing spreadsheets) as an interface, thus allowing almost all university employees to take part in the work of creating and modifying datasets. Indeed, at the time of the transition, it is reasonable to assume that many staff are already familiar with this type of software. Once the change has been fully implemented, it will be possible to consider introducing automated processes that will reduce the need for manual intervention in data management. Should the need arise to modify or update data, some datasets are already editable by university staff (i.e. Teaching Dataset, Heritage Dataset, Human Resources Dataset, Maintenance Dataset), while others will require the introduction of new skills:

- The implementation of a Common Data Environment (CDE) within the technical office will be mandatory by law from January 2025. Using BIM authoring software, it will be possible to manage BIM models and enter the necessary information and extract (using dynamo software) a spreadsheet with the necessary data for each building. Still using the BIM model and the tracer plugin as a software interface, it is possible to extract a data file in SQL format that allows the visualisation of the model and the connection of the data within the business intelligence software.
- The management of GIS data is not usually among the skills present among the administrative technical staff of Italian universities. Therefore, the management of spatial maps and GIS-related datasets will be handled by personnel recruited with the new organisational unit planned with the IS implementation phase. In particular, the GIS data can be managed through the open software Qgis, while for the visualisation of the spatial maps within the business intelligence platform the use of the software Mapbox has been envisaged.
- For the management of sensor data, there is currently a platform designed and offered by the sensor suppliers themselves. It is monitored by the ICT Directorate and no other interface software is needed at the moment. The data can be downloaded and fed into the university database where it can be associated with each individual space via the space code.

The alignment between the application layer and the technology layer may change in the implementation phase at other Italian universities depending on the software and services present but, in general, the general scheme can certainly function as a Reference Architecture since the type of data processed and the associated software are similar when not identical.

The general EA (Figure 5.14) can be seen as a template (i.e., Reference Architecture) to be used for the design of an IS for the management of large real estate assets by an organisation. The template allows for many requirements such as communication, evaluation, design or redesign of the system. The architecture serves as a basis and suggests an optimal solution for the management of large real estate assets, especially in the context of universities. However, it is not a definitive architecture but more an abstraction of the general structure for potential generalisations of similar solutions.

To better understand how the implementation of the Asset Information Management System can affect the directorates in a public university, it seems useful to specify in what way each Directorate can collaborate, according to its competences, for the proper functioning of the information system. It is also important to assess how the different directorates can use the information system to extract useful information for decision support.

The Educational and Student Services Directorate (ESS) participates in Asset Information Management by providing data on the scheduling of teaching and classroom space utilisation, the number of students enrolled in teaching and study courses. As a user of the University's Asset Information Management System, the ESS has access to business intelligence tools through information dashboards on the use of classroom space and trends in space utilisation over the academic years under review.

The Building and Sustainability Directorate (BS) implements and applies the BIM methodology and tools to ensure the correct production and delivery of the BIM as-built model at the end of each contract. In addition, the BS handles and manages

relations with external economic operators (designers and construction companies) to ensure the correct application of the University's Asset Information Management System standards.

The Human Resources Directorate (HR) contributes to the information management of assets by providing data on staff in the University's structures and updating its records when contracts, grants and scholarships are suspended or terminated, or when retirements occur.

In order to digitally manage aspects related to safety, AM and FM, the Security, Property and Facility Management Directorate (SPFM) is implementing the BIM methodology and using BIM tools in the management and monitoring of service contracts, the management of tenders and purchases of services and supplies, the management and relations with external operators (maintenance companies) to ensure the correct application of the standards of the University's Asset Information Management System. In addition, the management ensures the correct production and delivery of the BIM as-built model for existing buildings following survey campaigns and updates the models whenever there is a change in geometry or data following maintenance work. SPFM shares data through the University's Asset Information Management System and can use analytical dashboards to make informed decisions about safety and the planning of routine maintenance of the building and facilities, including preventive and remedial work.

As part of the AIMS project, the Information Systems, Portal and E-learning Directorate (ICT) provides support to all participating departments, the Rector and his staff about the supply and management of hardware and software, the availability of network and telecommunications systems, and the proper management of data and IT security. ICT provides support for the management of the Common Data Environment (CDE), the centralised university database and is responsible for managing relationships with suppliers of IT solutions (BIM authoring software, data sharing platforms, business intelligence software, etc.).

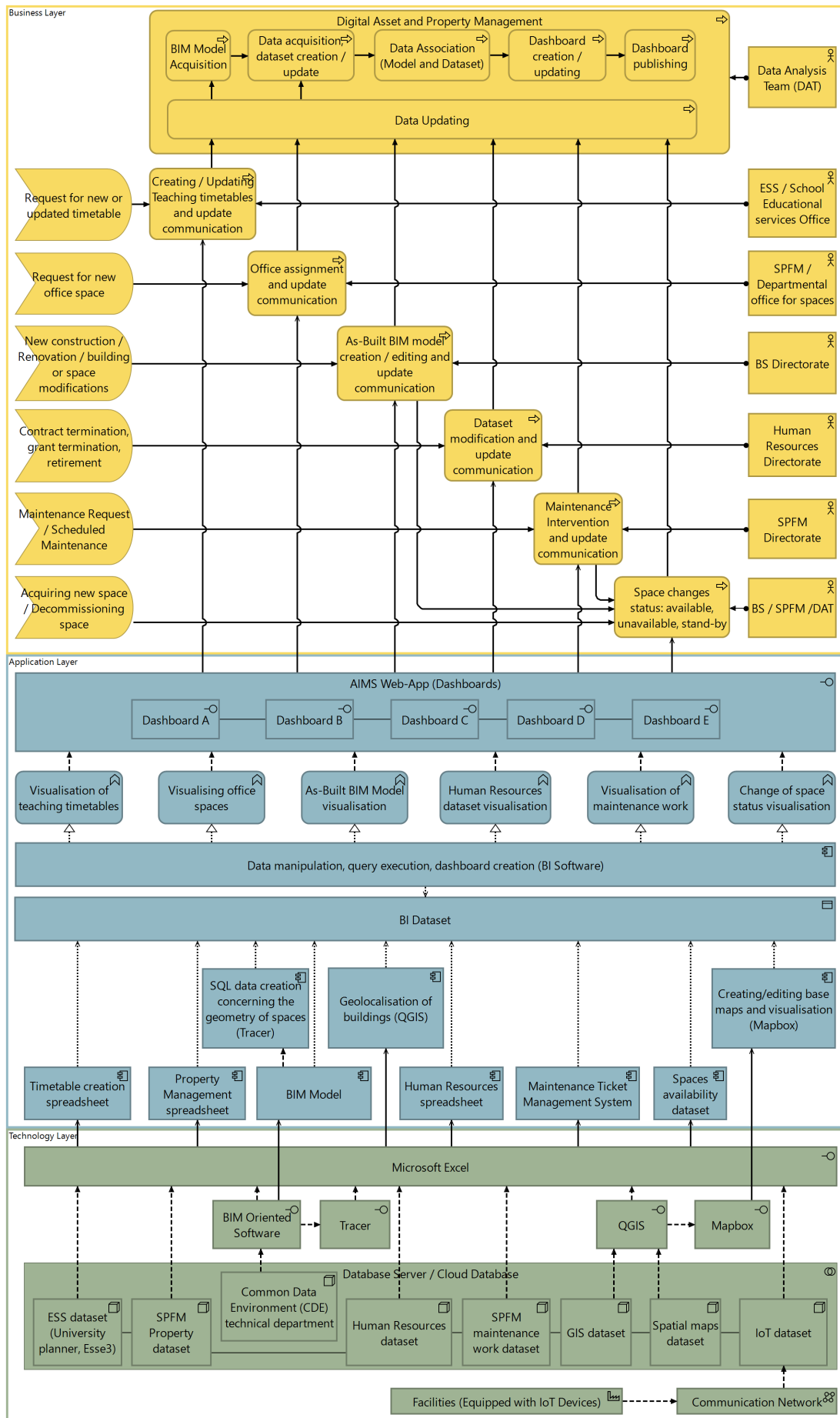


Figure 5.14: General Enterprise Architecture alignment to-be.

5.2.3 To-be scenario Processes

As seen in Chapter 4, the description of the two processes chosen, using the BPMN language, highlighted critical issues and the processes consolidated to date within the university of Turin have ample room for improvement. In fact, the followed procedures do not take advantage of digital tools that are already available and widely used in companies or other public bodies.

The main criticalities encountered are therefore as follows:

- Communication is based almost exclusively on e-mail correspondence, making the process slower and subject to the direct interaction of people. This can cause considerable delays due to the waiting time between the various email exchanges;
- Course contact persons represent an intermediate interface that adds complexity to the communication between the teaching office and lecturers;
- Exchanges and shared excel files are prone to errors due to manual data compilation;
- The experience of the teaching office staff proves invaluable for the creation of the timetable of the most established courses, however, it may be subject to bias or may not function in the best way in cases of emergencies or any substantial changes to the courses of study.

Therefore, with the aim of improving the processes and helping the involved stakeholders with a smoother process, the to-be version of the process related to the creation of the teaching timetable was modelled (Figure 5.15). Also imagining the future set-up of the organisation, as modelled in the reference architectures, the process stakeholders included a lane dedicated to DAT and a lane representing AIMS.

Retracing the process from the beginning, one then encounters the request for a new teaching timetable. This time, the teaching office, instead of starting to send out e-mails to the various course contact persons, can make use of a form to be filled out by selecting the courses or individual subjects whose timetable has been requested. The structure of the form is not based on manual compilation but on the selection of data within predefined options, thus minimising the possibility of error.

In the next step, a mailing list already pre-set in the system starts to send e-mail requests to interested teachers, inviting them to fill in a form with their wishes. Here again, the steps appear much more streamlined as the teacher can use an interface to choose days and times within the form from those available. When the preference form is closed, notification is automatically sent to the teaching office about the availability of the data.

The next step involves the use of some dashboards produced for the AIMS Information System. In fact, the teaching office staff can consult the dashboards relating to the historical use of classrooms and teachers' wishes in parallel. Consequently, it is possible for the teaching office to make an informed assessment and create timetables using the views offered by the dashboards.

Finally, the publication of timetables is still entrusted to the teaching office, which communicates the update of data to the DAT for subsequent verification that the dashboards are correctly updated. It is worth noting that the DAT - ICT lane hosts a repeatable task concerning the management and maintenance of the AIMS and the

centralised university database. There is also a representation of the database showing the read and write data flows related to the specific tasks in the various lanes.

The result is therefore a to-be process that clearly outlines how in a future state procedures could be streamlined, who the main stakeholders are and what responsibilities and tasks they perform. It also highlights how the information dashboards created can be used.

Analysing, on the other hand, the case of the process concerning the management of office space, and particularly the allocation of a space to a new employee, similar problems to the previous case can be discerned. In particular, the massive use of e-mails (with associated waiting times), the presence of many stakeholders involved, the lack of data sharing between different departments and the possibility of errors in communication and data compilation.

Therefore, a to-be scenario was modelled to allow for continuous process improvement and at the same time visualise the impact of the digital transformation imagined in the future scenario.

In Figure 5.16, it can be seen that the sending of e-mails by PTA staff has been reduced to a minimum. In the to-be scenario, only automatic e-mails will be received, which will communicate the possibility of advancing in the procedure and provide the link to access the various dedicated services. Thanks to this system, it is also possible to visualise more immediately at what point the various processes may have reached and it is possible to view the activity history without having to go back to specific e-mails to try to understand how each process reiteration developed.

This is a paradigm shift related to digital transformation: the development of predefined and digitised processes allows staff to be helped in daily activities that may even be repetitive. Furthermore, the progress of a process is no longer linked to a single figure within the organisational unit and the related exchange of emails but can be managed by everyone in a more agile manner.

Analysing the new to-be process related to the management and allocation of office space for personnel, it can be seen that two more lanes have been inserted related to the presence of the new organisational unit called DAT and the presence of AIMS representing the new services related to digital transformation.

Therefore, after the recruitment of new staff, the personnel department will directly fill in the necessary data via forms on a new user interface and this will start the proposed new process. Afterwards, a communication will be automatically sent by e-mail to the competent university structure, which in turn will enter more detailed data about the new resource into the system. At this point, depending on the data entered, communications will automatically be sent to the person recruited and his/her manager or only to the person recruited and, for information, to the interested parties.

At this point, thanks to access managed by specific credentials, the portal can be accessed by the manager and/or hired staff to communicate space and equipment requirements. This entry then triggers the start of the space and equipment request. Also in this case, based on the data filled in by those concerned, the system will be able to distinguish between two scenarios: the resource needs additional equipment or not.

At this point the process handles two main tasks: the request for a space for the new recruit and the possible request for specific equipment.

In the first case, the System will send automatic communication to SPFM, which will then have to access the portal to continue the process. The verification of space

availability can be done directly on the AIMS without the immediate need to visit the building concerned. Through the information dashboards it is in fact possible to have a complete overview of the status of the building.

The scenarios that arise for SPFM are the same as those described in the as-is process, but this time the verification of space availability and evaluations in the case of maintenance or reorganisation work can certainly be facilitated by the presence of up-to-date and readily available data.

Once the space has been allocated, SPFM can associate the person with the relevant space code and update this data directly on the System. By entering the data on the centralised university database, this will be available for profiles that have access to this type of data, speeding up any subsequent operations.

As far as ICT is concerned, if they receive a request for the supply of IT material, they can directly consult the centralised university database instead of sending an e-mail communication to SPFM. In this case the database becomes a fundamental tool for horizontal alignment between directorates and makes the daily operations of technical administrative staff more agile. The process in this case ends with the delivery of the equipment to the person concerned.

As for the processes started in the other lanes of the diagram, they end with the communication of the assigned space to the assigned subjects. This is always done automatically by the platform, which, once it has received the process termination input, already has the necessary data and mailing list to start the communications.

Finally, in the lane called DAT - ICT, one can see the presence of a process with the possibility of continuous reiteration linked to the management and maintenance of the AIMS and the centralised university database.

The flow diagrams presented therefore give an idea of what the processes will look like once the AIMS information platform has been implemented and how daily practices could be further streamlined using additional digital tools with the aim of making the most of the centralised university database.

With a view to continuous improvement and in adherence to the principles of business process management, the process tool modelled in BPMN language serves as a basis for continuous process improvement. The mapping of processes and their subsequent modification is therefore an important management tool that, once introduced, allows for timely monitoring and intervention in the event of further future changes that may be linked to a variety of reasons (e.g. strategic changes, external changes, emergencies, etc.).

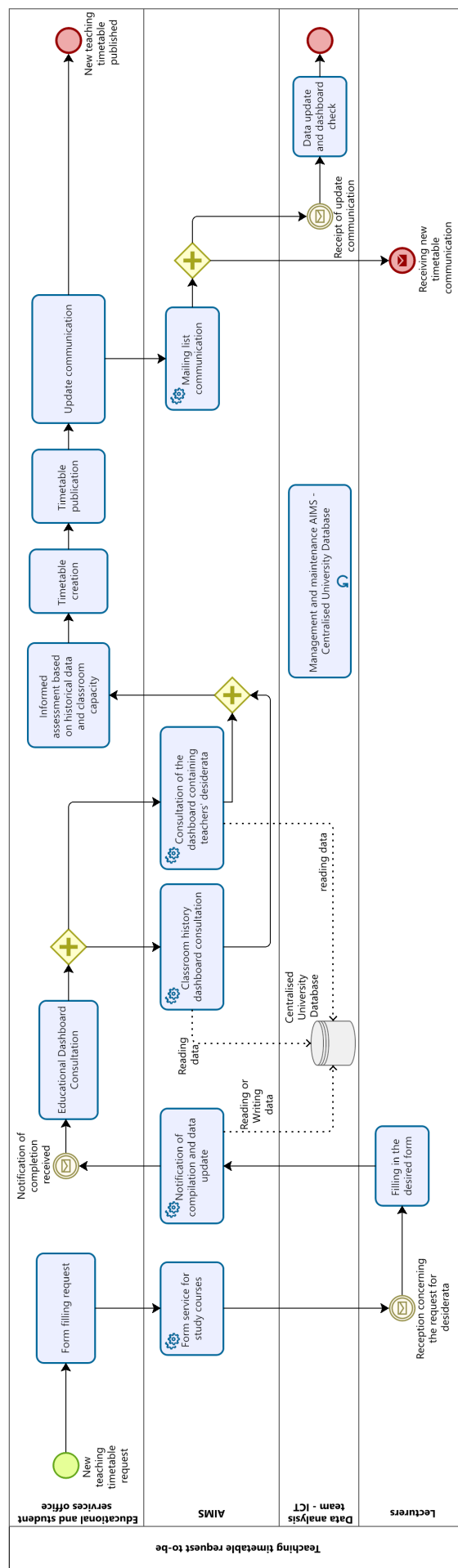


Figure 5.15: Creation of a new teaching timetable to-be.

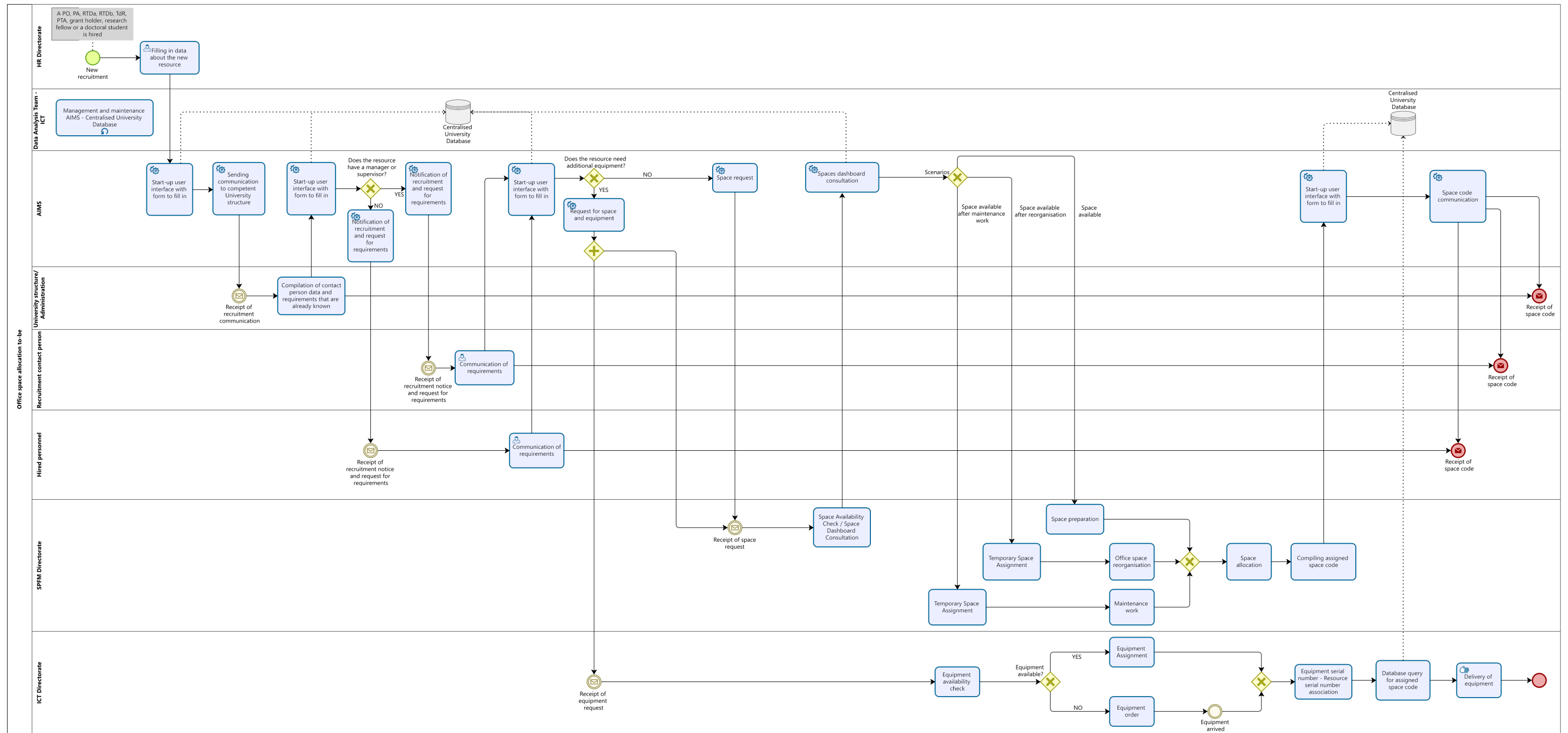


Figure 5.16: Office space management to-be.

5.3 University of Turin and Change Management

This section presents the results obtained in the context of proposing a plan for organisational Change Management. Focusing on the human aspect of change, the aim was to provide an initial version of a change plan to guide the university's management team through a consolidated framework. In addition to the planned steps, the figures involved and their expected characteristics and results will be described.

5.3.1 Proposed Change Management plan

In the context of the University of Turin case study, Change Management solutions are proposed based on the framework selected in the methodology section. The objective set by this section is the future drafting of a plan for Change Management and digital transition.

The proposed change management roadmap comprises eight steps and is adapted from Kotter's conventional change management model:

In the change management model, the first step to be taken and planned is to create a sense of urgency towards the change that management group would like to see happen within the organisation. In fact, according to Kotter, in established organisations there is much more likely to be complacency than a desire for change [225].

This step, declined to the case study of the present research, led to the indication of the following actions to be implemented within the organisation: emphasise the benefits of digital transformation such as the improvement of administrative efficiency; exploit external pressures such as national policies that promote digital innovation (e.g., National Recovery and Resilience Plan) or laws imposing methodological changes as in the case of the introduction of BIM methodology (e.g., L.D. No. 36/2023); involve stakeholders early on in order to identify those most prone to change and incite them to support the change within their Directorates and Departments.

The second step, derived from the aforementioned model, entails the formation of a leading coalition. It is essential that this group of individuals possesses sufficient influence to facilitate change. In the case of the University of Turin, it would be beneficial to establish a guiding coalition comprising representatives from a range of departments and directorates, people who have credibility and authority to make decisions for their field of expertise.

The third step concerns the creation of a vision and strategy and in this context the already modelled Reference Architecture and the proposed processes can be of great help. In fact, the main actions that should be pursued are as follows: create a clear and convincing vision outlining the future state of the university after the transformation by showing that the initiative is in line with the university's mission and strategic goals; create a roadmap detailing how the vision will be achieved through key milestones and initiatives.

The fourth step concerns the communication of the vision for change, and it is also one of the most important steps that is often overlooked by organisations. To ensure maximum effectiveness in this step, the following actions need to be taken: involve the university community and communicate the vision and strategy through as many channels as possible and to all stakeholders; promote an open dialogue to address any

concerns and encourage feedback.

The fifth step derived from the model concerns the removal of any obstacles to change. To do this, it is essential to change the structures or systems that undermine the proposed vision of change while encouraging the sharing of innovative ideas.

In the context of the specific case study dealt with in this research, the proposed actions are: to identify obstacles that impede progress such as outdated policies or lack of resources; to provide training and support to all stakeholders to adapt to the new digital processes.

The subsequent phase is to generate short-term successes in order to demonstrate the feasibility of change and create momentum. In accordance with Kotter's approach, the successful implementation of change must be clearly discernible and demonstrably linked to the desired direction of change [185].

In creating the change plan for the University of Turin, it will therefore be necessary to set realistic short-term goals and celebrate their achievement to give momentum and demonstrate the benefits brought by the digital transformation. It is also necessary to publicise successes by sharing them with the entire university community to strengthen the change effort.

The seventh step aims to consolidate results and produce further changes. Actions to be envisaged in the change plan will therefore be those related to building on the momentum, building on the credibility of early successes in order to introduce and address greater challenges. It is also crucial to promote continuous improvement by encouraging continuous evaluation and adaptation of strategies to ensure lasting progress.

The last step aims to anchor the newly introduced approaches to the organisation's culture. In this case, it is to ensure that digital practices become part of the university's culture by aligning them with core values and norms. Further action to be envisaged will be to reinforce the changes by recognising and rewarding the behaviours and outcomes that support digital transformation.

By following these steps, the university will be able to effectively manage its digital transformation by embracing and supporting change throughout the organisation. This structured approach will serve as the basis for drafting a more detailed change management plan in the future. It will also help manage the complexities of change and achieve long-term goals.

5.3.2 Working group within the university of Turin

The digital transition and the introduction of new tools necessary for the implementation and management of the Information System give rise to the need for new skills and new professionalism. This makes it necessary to recruit new human resources with specific skills in the field of data and information management as well as in the use of specific technologies. In order to maximise effectiveness in the implementation of the new system and to have coordination for the planned activities, a new organisational unit is also proposed that will work alongside the units already present within the University of Turin's Directorates and Departments.

The unit will therefore operate with functions of connection and coordination between the various Directorates with the intention of implementing the vision described in the

strategic plan in relation to the digital and energy transition of the built environment.

In the future, it is expected that AIMS will be managed and maintained by the university organisation, including the collection and updating of structured data according to appropriate guidelines and protocols. It is envisaged that this task will be performed by the DAT unit.

The objective of this paragraph is to present the professional figures involved in the digital management of the University's heritage and the skills required. The figures involved will be framed both within the organisational unit called the Data Analysis Team and within the Directorates and Departments involved on the basis of the skills required; the roles necessary for the use of the BIM methodology are also reported, which may be framed within the BS Directorate that directly adopt this methodology:

- The Data Analyst is a professional able to analyse and aggregate data in order to study the historical trend of a certain parameter. In addition, he/she is able to design predictive models that make it possible to forecast a future trend of the parameters under examination. Typically, he or she is in charge of retrieving data from various sources, organising and structuring data according to precise rules and aggregation logic, using statistics to interpret data, and communicating through reports;
- The Data Engineer is an IT professional who has the ability to prepare data for subsequent analytical or operational use by ensuring data availability and quality. The Data Engineer's main skills typically include: database design; knowledge of languages to describe data, define access and manipulate databases; knowledge of data access strategies and mechanisms; engineering services and distributed systems;
- The Data Scientist is a complementary or overlapping figure with respect to the Data Analyst, the Data Scientist is able to perform all tasks related to data analysis, methods for navigating databases and interrogating them through specific queries and extracting information. Unlike the analyst, he or she does not deal with a specific niche but has a deeper understanding of the dynamics and functioning of the organisation and is therefore able to identify different challenges and problems than the organisation has already identified. He is able to use data visualisation and communicates through reports;
- The GIS Expert is a professional who specialises in using GIS technology to analyse spatial and non-spatial data, create maps, and provide knowledge based on geographic information. He/she combines technical skills with analytical skills as well as project management knowledge in order to make the best use of geographical information from various sources. His profile is very important in the field of spatial data analysis and visualisation.
- The BIM Manager is defined by Legislative Decree No. 36 of 31 March 2023 and UNI 11337 as a “digital process manager”. His tasks are mainly at the Organisation level and are as follows: ensuring the implementation of the digitisation of the Organisation's BIM processes; coordinating and supervising the assignments relating to the digitisation of processes; drafting (or supporting the BIM Coordinator in drafting) the information specifications; drafting (or supporting the BIM Coordinator in drafting) the information management offer; drafting (or supporting the BIM Coordinator in drafting) the information management plan; guaranteeing, together with the BIM Coordinator, the

consistency and coherence of the information content; designating the BIM Coordinator; drafting and updating the organisation's guidelines on information management; promoting a research and development training programme; preparing reports and collaborating on audit activities; defining contractual aspects relating to information management and CDE environments;

- The BIM Coordinator is defined by Legislative Decree of 31 March 2023 no. 36 and by UNI 11337 and is the “coordinator of information flows”; he operates at the level of the individual assignment, follows the indications of the BIM Manager, and his tasks are as follows guaranteeing the efficiency and effectiveness of the digitised process with reference to the specific assignment: drafting (or supporting the BIM Manager and/or the person in charge of the assignment in drafting) the information specifications; drafting (or supporting the BIM Manager and/or the person in charge of the assignment in drafting) the information management offer; drafting (or supporting the BIM Manager and/or the person in charge of the assignment in drafting) the information management plan; assigning the information requirements to the stakeholders; supporting the BIM Manager's activity; configure or transpose the digital workflows within the data sharing environment, guaranteeing their integrity throughout the entire flow; select the necessary personnel and tools and take care of interpersonal relations; manage the identification of interferences and inconsistencies (of a geometric-dimensional and alpha-numerical nature) in the federated models; define and analyse the control rules (of correspondence and adherence between information specifications, information requirements contained and the information management plan); support the BIM Manager in defining the contractual aspects relating to information management and CDE environments.
- The BIM Specialist is the subject defined by UNI 11337 as “advanced information management and modelling operator”. He/she operates at the level of the individual assignment with the following tasks: modelling objects through specific applications; analysing and supporting the BIM Coordinator and BIM Manager in the drafting of the information management plan; introducing disciplinary knowledge into the modelling and information management operating methods; transferring disciplinary specialist skills in digital terms, actively collaborating with the disciplinary specialists themselves, in support of the BIM Coordinator; preliminarily verifying information models; contributing to validating the information consistency of model objects; supporting the BIM Coordinator and BIM Manager in the choice of instrumental resources useful for the assignment.
- The CDE Manager defined by Legislative Decree of 31 March 2023 no. 36 and by UNI 11337 as “manager of the common data environment” searches for IT solutions for the management of the data environment and has the following tasks: managing the CDE and supporting the actors involved; connecting the contents of the information models with other digital data; controlling and guaranteeing unambiguousness, traceability and consistency of information; controlling and guaranteeing the interoperability of information contained in different applications; guaranteeing correctness and timeliness of information flows within the CDE; supporting the BIM Manager in identifying and applying data defence and protection techniques, in accordance with the Organisation's security protocols; using data analytics techniques.

Further figures are presented below, whose general activities it is considered useful to outline, as they are involved in the management of buildings and spaces within the university and may have contact with the Data Analysis Team or be users of the information system each for their own competence:

- The Asset Manager manages the activities related to Asset Management and is therefore responsible for the methods and the planning by which the organisation creates value through its assets. Together with his team, this figure is responsible for defining the information requirements of the assets.
- The Facility Manager is responsible for managing facility management activities, which include maintenance, documentation and updating information. He also works with the BIM Manager to update models and databases.
- The project manager is in charge of project management activities and is therefore responsible for directing and controlling the operations necessary to achieve the set objectives.
- External designers develop and create BIM models following the specifications for information modelling (such as Guidelines, Operational Documents, etc.) provided by the BIM Manager and/or BIM Coordinator.
- The construction companies conduct the works and update the As-Built model developed by the designers, following the specifications for information modelling (such as Guidelines, Operational Documents, ICs, etc.) provided by the BIM Manager and/or BIM Coordinator.
- The maintenance companies take care of the ordinary and extraordinary maintenance operations, referring to the Facility Manager and filling in the sheets related to the interventions carried out. They also update the building management model (AIM) created by the planners, following the specifications for information modelling (such as Guidelines, Operational Documents, ICs, etc.) provided by the BIM Manager and/or BIM Coordinator.

6

CHAPTER

Conclusions

This section provides a comprehensive presentation of the research project, outlining the problem to be addressed, the methodology used to address the problem and achieve the research objectives, the main findings from the case study conducted at the University of Turin, the strengths and weaknesses of the proposed methodology, and possible avenues for future development.

6.1 Contributions to Knowledge

This research project aimed to address the issue of the management of large real estate assets in the public sector. It sought to identify how digital transformation could be used to develop innovative methods and tools to address this problem.

The research is positioned within the context of the ongoing digital transformation in the AECO industry, which is reshaping management practices through the integration of data-driven and digital tools to enhance efficiency and productivity. The integration of digital methods alongside information management strategies enables organisations to facilitate enhanced collaboration, more structured information exchanges and access to up-to-date shared data, all of which effectively support decision-making throughout the asset's lifecycle. This approach can have a significant impact, particularly during the operational and maintenance phase, which is often the costliest and challenging to manage due to the absence of up-to-date and comprehensive information, as well as the lack of formalised management processes with clearly defined information requirements.

The issue of organisational change, particularly in the context of the introduction of new tools and working methods, was also considered.

In order to evaluate the efficacy of the proposed solutions, the University of Turin was selected as a case study. This institution possesses one of the most extensive real estate portfolios among Italian universities, and it also exhibits a considerable degree of organisational complexity.

The research questions that guided the work are:

- How to create a decision support system for the management of the university of Turin's real estate assets?
- What are the organisational and process changes following the implementation of a new decision support system for real estate management at the University of Turin?

This research found that the digital tools available today and the proper management, storage and use of data are of paramount importance in supporting the decisions of all stakeholders within an organisation. In particular, the Information System developed showed how the sharing of tools and data can bring benefits to the entire organisation as opposed to today's compartmentalised system. In particular, it exploits the potential of the combined use of BIM, GIS and BI tools in providing integrated data and analysis to support decision-making processes and optimise the management of one of Italy's largest university assets, proposing a replicable and scalable approach.

A closer examination of the contributions to knowledge made by this work reveals that, in addressing this type of problem, it is not only a technological issue that must be considered, but also organisational and change management factors. This is particularly evident in large and complex organisations, such as the one under study. The findings indicate that the system tested in a complex context can also function effectively in smaller, less complex contexts.

The critical success factors are associated with both the selection of appropriate information requirements and the management of change within the organisation. Indeed, from a technological standpoint, the most reliable and advanced technologies currently available were identified. However, during the course of the study, it became evident that the acceptance of these technologies by the organisation's personnel is a crucial factor in ensuring a successful digital transformation.

The methodology has yielded the development of models that are adaptable and replicable in other contexts. In this sense, the contribution to theoretical knowledge is that of an established and tested methodology for the design of a new information system and for the organisational analysis and consequent modelling of a Reference Architecture. The methodology for the development of the information system is undoubtedly beneficial for technicians tasked with designing similar systems. Furthermore, Enterprise Architecture serves as a crucial instrument for both ICT technicians and those occupying strategic roles, as it pertains to matters relating to strategy and management. Indeed, the tool provides a foundation for more effective and proactive communication during the design and development phase of the system. Furthermore, it facilitates the monitoring and agile implementation of changes within the organisational structure, as well as the communication of these changes to all stakeholders, regardless of their technical or managerial expertise.

In terms of practical contribution, the presented research provides a functional system comprising information dashboards that facilitate the visualisation of all essential information for strategic decision-making in asset and facility management. Moreover, the centralised university database, which has been structured, represents another concrete outcome of the experimentation that has been conducted. At the organisational level, two practical tools are immediately available for use by university administrators and IT professionals. These comprise the Reference Architecture and the steps involved in drawing up an extensive change management plan.

Nevertheless, it is essential to contextualise the results obtained within the specific context of Italian universities. Indeed, given the generally valid methodology employed in the design of the information system, it is necessary to consider the implications of the resulting organisational outcomes. It is important to note that organisational analysis focuses on specific aspects of the Italian university system that may vary significantly in other contexts, such as other European or extra-European countries. The organisational analysis and the consequent Reference Architecture are the result of an analysis carried out in the Italian context and therefore informed by Law 240 of 2010, which clearly indicates the organisational methods and the figures that must be present. It is, however, important to emphasise that, with regard to facility management, the issues and methods of intervention are likely to be similar to those encountered in other European countries. This makes the research highly relevant to both Italian and European contexts. Moreover, the methodology employed in this study represents a significant contribution to the field of real estate research, offering insights that can be applied to other academic institutions and contexts, including schools and hospitals. Indeed, the method's replicability and scalability facilitate its adaptation to other contexts and different organisational settings.

Eventually, the significance of government actions is underscored as essential for the successful and efficient implementation of BIM and digital technologies within organisations, particularly in the public sector, which can set an example and influence the private sector. The adoption of change management strategies is also highlighted as crucial for ensuring a smooth transition. Disruptive and ineffective changes should be avoided by promoting the development of modelling guidelines and protocols that are aligned with information management strategies and created in collaboration with both technical and administrative staff within organisations. This approach allows for a more seamless and effective digital transition, facilitated by the formalisation of information requirements and exchanges among stakeholders.

6.2 Impact and implications

Impacts on the university's real estate management, decision-making processes and resource allocation were assessed. The results demonstrate how the AIMS facilitates the integration of data that is currently siloed and managed by both the technical and administrative departments at the University of Turin, enabling its visualisation through BIM models and GIS maps. This data is combined with other sources and presented in analytic, queryable dashboards that generate reports tailored to specific management needs. Certain dashboards are designed for managing assets at a territorial level, while others focus on building-level information. Additionally, the reports and dashboards are accessible with varying levels of detail and privacy, depending on the end-user and the sensitivity of the information. To ensure a smooth introduction of the AIMS into the University of Turin management processes, the system has been developed using software and tools that are compatible with those already utilised by the technical and administrative staff.

The implementation of this information system has a significant impact on the management of the university. In particular, it enables the acquisition and display of up-to-date data. In certain cases, such as those involving IoT sensors, it facilitates the collection and display of real-time data on the quality of the university's environments. Furthermore, the availability of business intelligence systems has facilitated more effective maintenance planning. This is due to the comprehensive overview they provide, which enables the assessment of priorities within an estate comprising approximately 120 buildings. Furthermore, the information system has a beneficial impact on space management, as it enables the creation of teaching schedules based on historical data and space analysis. Moreover, the management of office space is facilitated, as it is always possible to have an overview of the current situation and to make more agile decisions in the event of departmental moves or mergers. Indeed, the filter for analysing buildings at the departmental level allows for the precise and analytical calculation of both the percentage of occupied space and the percentage of allocated personnel.

The entire campus was used as a case study to showcase the potential for supporting decision-making at the territorial level. Additionally, demonstrators were used to explore the capabilities of the information system in improving management processes at the building level. The AIMS addresses several key areas, including: space management and utilisation for multi-level data analysis and enhanced facility operations; optimising teaching schedules based on real-time classroom availability and capacity; improving workplace management through the introduction of remote working strategies; IoT monitoring for analysing and enhancing indoor environmental quality and user comfort.

In conclusion, the introduction of the AIMS helps overcome many of the challenges associated with traditional asset management practices and siloed information systems, providing structured information and access to comprehensive, up-to-date data. By leveraging BIM models, GIS maps, and other analytics, it enables a better understanding of space usage and exploitation patterns, facilitating the identification of optimization opportunities and effectively supporting decision-making processes.

Considering the impact on organisations, there are some organisational changes that have been identified as essential for the successful implementation of the System. For the case of the University of Turin, this involves establishing a new organisational unit

across various Directorates and Departments, tasked with collecting, integrating, and updating data. Another important factor to consider is the frequency of data updates, which should be determined by the nature and variability of the data—whether it is static, dynamic, or gathered from the field.

Considering the change management theories studied, it can be said that resistance to change within public organisations is one of the main obstacles to be overcome. A fundamental organisational change within Italian universities can be assessed on two different levels. Firstly, from the public administration's point of view, it is necessary to ensure that staff have the necessary skills to use and manage the new tools and, secondly, it is necessary to ensure that the managers of the various Directorates are aligned with the strategic objectives of the university and act as leaders in the start-up and subsequent implementation phases of the system.

In the context of Italian public universities, they can prepare themselves to manage change and deal with resistance by informing all stakeholders at all levels of the organisation, publicising the various change initiatives and highlighting the benefits both at an organisational and individual level for human resources.

This research therefore contributes to the digital transformation in the context of Italian universities by firstly offering technological and methodological solutions to design, implement and manage an information system for overseeing the information and assets of Italian universities. Secondly, it contributes by offering a Reference Architecture for the reorganisation of universities at the level of IT infrastructure and applications, which are designed ad-hoc for various identified business processes. Lastly, it proposes an outline for the subsequent drafting of a Change Management plan that will aim to increase the chances of success of the desired digital transformation. This last aspect focuses on people management and how to involve people, who are a fundamental resource for realising the strategic vision of any university and, in general, any organisation.

6.3 Limitations and future research

In this research, a prototype Information System was designed, demonstrated and subsequently empirically evaluated through interviews and usage simulations. However, this evaluation was based on the typical single-case design principle [220] and although the chosen case study represents a complex case, further studies are certainly needed to generalise the results.

From the point of view of information system design, one limitation is certainly the software used. In fact, some of the software proposed in the methodological section concerning the design of the Information System require a licence or are proprietary software. Although the AIMS was initially developed using certain proprietary authoring software, minor adjustments can allow for the replacement of these tools with other solutions, particularly open-source alternatives. For example, the IFC standard (ISO 16739, 2013) can replace Autodesk Revit's .rvt format, enhancing interoperability in line with current regulations (L.D. 36/2023; ISO 19650:2018). Therefore, as information requirements (IRs) are being identified and datasets defined, they are also being mapped to the IFC standard. In the future, open-source software may be tested and adopted for both BIM modelling and BI applications. The introduction of such software is being carefully evaluated, taking into account its stability and the necessary staff competencies, in order to avoid disruptive changes that could hinder the success of the digital transition and the implementation of AIMS within the organization.

Another potential limitation concerns the flow of data between the different applications that make up the AIMS Information System. At the moment, they still require the intervention of a person and a periodic update whenever, for example, the status of a space changes, a new maintenance operation is initiated, or spaces are assigned to new users. Therefore, in future developments, more in-depth analysis is needed to understand how automated data flow and analysis can be implemented through Artificial Intelligence (AI) and Machine Learning (ML). Specifically, (AI) and (ML) can automatically identify and correct errors, inconsistencies, and anomalies in data, thereby improving accuracy and completeness while reducing the need for manual intervention. These technologies enhance efficiency and scalability by streamlining data processing tasks such as cleaning, integration, and transformation, allowing for faster and more efficient handling of large datasets.

The formalisation of IRs and datasheets to collect data from the various areas makes it possible to provide a single centralised repository, defining standardised queries to automatically extract the necessary data, feed and update the system, ensuring consistency over time. When AIMS is fully integrated into the University of Turin management system, thanks to structured and formalised processes with associated IRs, it will also be possible to automate activities. For example, the assignment of a space to a new resource will not need a request from the resource, area or department managers. Likewise, when a resource leaves due to retirement or change of job, the assigned space will be automatically available and viewable through the application, without the need for time-consuming inspections and updates. Of course, protocols for the periodic management and updating of data are being defined to ensure maximum effectiveness throughout the entire life cycle of the resource.

In the case of the routes between the various buildings of the university and the function to calculate which is the shortest possible route, it is possible to think about

improvements and the inclusion of additional functions. The use of optimal path analysis between buildings can serve as a foundation for implementing real-time guided evacuation systems during emergencies, creating true Digital Twins (DTs) of buildings. With this structured and comprehensive knowledge base, combined with the integration of BIM and GIS, it becomes possible to develop functional DTs that enable buildings to respond dynamically to events both inside and outside, whether under normal or emergency conditions. To achieve this, challenges include the correct installation of suitable IoT networks, the collection of near real-time data, the integration of predictive tools and artificial intelligence, and the connection to the AIMS. However, the system already provides a structured, integrated, and continuously updated knowledge base that is essential for DT development. The current capability of displaying BIM models on GIS maps, along with analytical dashboards that present insights from sensors monitoring indoor environmental quality (IEQ), establishes an excellent foundation for developing and managing DTs. These DTs can drive actuators to optimize a building's environmental conditions by leveraging real-time sensor data and analysing historical data, enabling predictions and corrections for deviations from expected behaviour.

Considering the proposed Reference Architecture, one limitation is certainly the specific context for which the RA was developed. In fact, there is no doubt that the university of Turin has its own specificities and peculiarities, both in terms of property assets and organisational structure. For example, the phases of data retrieval could differ greatly depending on the internal organisation in other public institutions. For this reason, a future development certainly concerns the validation of the proposed RA in other geographical and institutional contexts.

Finally, with regard to the proposed steps, which are preparatory to the development of a change management plan, the limitations are related both to the specific context in which the research was carried out, which may have led to some research bias, and to the chosen framework which, although judged to be better than the others, presents some critical issues related to its rigidity in the sequence of steps. Future developments in this field certainly concern further experiments that have the possibility of following a real implementation phase of an information system in a real case and the consequent mapping of what are the expected and unexpected results through monitoring during the phases. In this way, knowledge in this field of research, which has often been neglected within public organisations, could be increasingly refined.

The work carried out represents a solid basis from which to propose a unified methodology for the management of the real estate of Italian universities. These properties often represent an important part of the historical and cultural heritage of Italian cities and an Asset Information Management System is a necessary tool for the management and valorisation of this heritage. A homogeneous management within the Italian territory could also be of great value as a tool to preserve the historical real estate heritage of the whole country and manage it in the best possible way.

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Annex – Selection of published papers

D. Accardo, S. Meschini, L. C. Tagliabue, and G. M. Di Giuda, ‘Digitization and Energy Transition of the Built Environment – Towards a Redefinition of Models of Use in Energy Management of Real Estate Assets’, in *Towards Radical Regeneration*, Cham, 2023, pp. 163–174. doi: 10.1007/978-3-031-13249-0_14.

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Digitization and Energy Transition of the Built Environment – Towards a Redefinition of Models of Use in Energy Management of Real Estate Assets

Daniele Accardo¹ , Silvia Meschini² , Lavinia Chiara Tagliabue³ ,
and Giuseppe Martino Di Giuda¹ 

¹ Department of Management, University of Turin, 10134 Turin, Italy
daniele.accardo@unito.it

² Department of Architecture, Built Environment and Construction Engineering,
Politecnico di Milano, 20133 Milan, Italy

³ Department of Computer Science, University of Turin, 10149 Turin, Italy

Abstract. Thousands of years of progress in urban development led to complex urban environments that can be considered as complex systems. The management of complex systems must account for uncertainty, unpredictable future states and nonlinear behaviour. In this context, digitalisation can play a key role in the development of innovative tools to support strategic decisions and emergency management. In particular, the management of university building stocks can be facilitated with the creation of digital environments.

In the Italian case, university campuses are often complex assets composed of widespread buildings and the management process is still based on fragmented databases handled by different administrative divisions resulting in a lack of information among stakeholders.

The integration between Building Information Modeling (BIM) and Geographic Information System (GIS) is already making some steps towards the creation of a digital model of the city. The combination of BIM-GIS with a platform for the data management is the base to develop an Asset Management System to exploit Business Intelligence (BI) tools for Operation and Maintenance (O&M) in smart campuses.

This research aims to integrate BIM, GIS and BI tools in a digital framework for the development of an AMS and web-based application for the improvement of the experience among users and the optimal use of resources. A real case study is proposed for the development of the research project, namely the University of Turin building stock, in Italy.

Keywords: BIM-GIS · Asset management · Energy transition · Information value · Sustainability

1 Background

University campuses are difficult to maintain since they are made up of many diverse buildings, many of which were erected at various times, especially in Italy. Their administration is frequently structured on fragmented databases that are difficult to access and are still document-based, resulting in insufficient and asymmetrical information that leads to unproductive choices and resource utilization, particularly during the operation and maintenance (O&M) phase. In terms of the total cost of the asset life cycle, this period proved to be the costliest [1]. Building usability and energy consumption are strongly influenced by the effective use of spaces (i.e., space management connected to occupancy flows), users' behaviour, and the demands for supply and services. As a result, if they are not properly managed, they can waste resources and raise management, operating, and maintenance expenses. The digital transformation of process management has become critical in the development of digital Asset Management Systems (AMS) as decision-support tools for managing and optimizing university spaces and activities [2, 3]. To make the transition to full digital management easier, a method for Information Management (IM) and information protocols for tailored data modelling are required. These methods and protocols must ensure the availability of accurate information at the right time and in the required format for the appropriate subject [4]. To construct digital AMS solutions capable of managing all the data required over the whole university asset lifespan, information regarding how and when data exchanges should occur, as well as among which stakeholders, must be established.

The combined use of BIM (Building Information Modelling) and GIS (Geographic Information System) has shown promise in the development of Smart Cities and Digital Twins (DTs) in recent decades [5, 6]. BIM is essential for creating extremely complex architectural models, whereas GIS allows them to be managed and analysed using a worldwide geographic reference system [7–9]. Furthermore, the BIM-GIS merger, also known as GeoBIM received little attention in the field of Asset Management (AM) [10]. The current availability of both new technologies and large data quantities, along with BIM-GIS compatibility, can optimize management operations, particularly during the O&M phase. It can also help to design successful AMS [11]. The capacity to digitally manage the asset from the geographical macroscale to the microscale of the single asset component is one of the major capabilities of BIM-GIS integration [12].

Based on these assumptions, the research project intends to design a digital and repeatable approach for developing an AMS based on BIM and GIS integration via a web platform (i.e., AMS-app) targeted at improving information management and decision-making processes in large and distributed assets. The AMS app should collect all the data that is presently managed independently by multiple administrations, allowing for independent yet collaborative management. As a result, rather than managing each building, the building asset may be managed at the system level. Another significant result of the study is the creation of an information protocol to improve distributed university asset modelling using BIM-GIS platforms. The study focuses on the tremendous effort to aggregate data from multiple separate databases into a consolidated and easily accessible one, and it describes the reproducible methodological approach used to construct the AMS app. It's also shown how the AMS app was created using a centralized

database to enable real-time representation of the whole distributed asset in an interactive 3D map. The product is a “GeoBim” system that allows users to store, examine, and exchange continually updated geometric, spatial, and functional data, which will help the institution manage its assets more efficiently and sustainably. Finally, the paper demonstrates how to put the theory into practice. Furthermore, the study describes how to apply the stated technique using two demonstrators, highlighting preliminary findings, potentials, and limits. The two demonstrators are part of the University of Turin building stock, which is a pilot use case. It is one of Italy’s most dispersed campuses, with a large catchment area and unstructured management. Due to these characteristics, there is a significant information asymmetry, which prevents knowledge of its consistency and usage, resulting in resource waste and efficiency losses. Furthermore, one of the targeted aims in the University’s strategic plan, which stands out as a novelty in the Italian panorama, is the digitalization of building stock and the employment of digital technologies for AM.

2 Methods and Data

Starting with a state-of-the-art examination of methodologies and tools for producing AMS of large building stocks using BIM-GIS integration, the research approach was designed. In the second phase, which focused on the examination of the pilot use case, namely the University of Turin building stock and its present management practices, the real definition of the methodological approach began. Following the analysis, processing, and structuring of the collected data, a centralized relational database was created to collect all the disparate data about the asset’s geographical and functional features. Finally, a unique BIM-GIS online platform was created to allow the university’s building assets and characteristics to be seen in an interactive 3D digital environment. Figure 1 depicts the study methodology, which might be applied to various scenarios.

The examination of the asset’s consistency and the identification of the administrations engaged in its management were the initial phases of the analytical approach. The major goal was to determine which data were required, from which administrations, which were previously available or not, how they were maintained and shared, and where the missing data might be gathered. To achieve this, the institution’s communication channels (i.e., the website and its Transparent Administration section, which contains official documentation related to the institution’s core activities and people working there) were investigated to collect data and identify administrations involved in the management processes (Table 1). Subsequently, it was investigated how a web platform called Opensipi was being used to handle data on the building stock (e.g., dimensions, occupancy, mechanical assets, and so on). The “Information systems and e-learning portal Directorate” was in charge of this platform, which may be updated by the “Building, logistics, and sustainability Directorate”. Academic activity data was also discovered to be held in heterogeneous excel sheet files handled by administrative workers from the “Educational Services Directorate.” Finally, an external database, namely Cineca, was recognized as having students’ data handled through specific interfaces but not available for consultation.

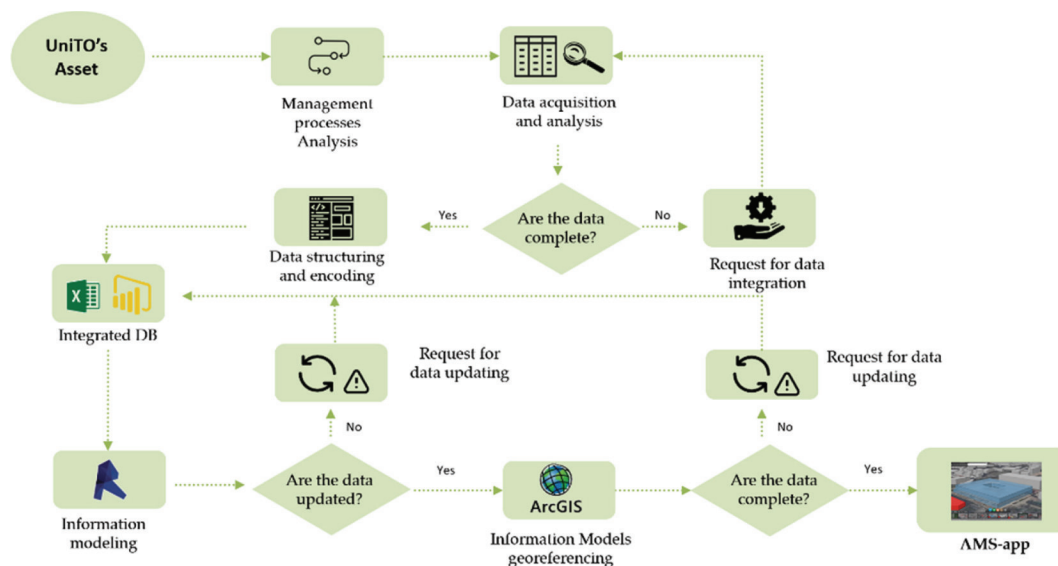


Fig. 1. Methodological approach

The interviews with administrative and managerial professionals from numerous departments verified this fragmentation and underlined the difficulty in acquiring the necessary data because extrapolation must be done on purpose, resulting in extended wait periods. Then, to identify which data should be linked and connected for the effective administration of the University's assets and operations, an in-depth investigation of the databases was done.

The Opensipi platform was created to make a GIS-based solution for space and asset management. Using Google Maps, Opensipi allows to search and see the whole University building stock. The software also displays spatial features and specific premises of each building via digital interactive plans (Table 1). It's worth noting that the functional characteristics of places (such as occupancy, furniture, and mechanical systems) that are important during the O&M phase aren't present. Another issue is that the platform is not updated regularly, therefore its data may not reflect the current state of the spaces. Subsequently, current building stock data and plans were acquired through short interviews and documentation requests to the technical office.

The "Educational Services Directorate" employed heterogeneous excel sheet files to manage schedules and course data, as shown in Table 1. On the other hand, Cineca, which is also responsible for data storage, provides a specific application for managing data linked to students' careers, fees, and course catalogues. Short interviews with workers were also done in this case to better understand which data they manage and how various administrations interact. It was noted that the "Educational Services Directorate's" excel sheet files were not linked to the data given by the database supplier Cineca.

As a result, there was a lack of communication across administrations, resulting in highly fragmented data, which added to staff workload and inhibited job automation. Cineca, as previously stated, is a third-party software and service provider in charge of data administration. The administrative staff cannot directly alter data contained in the database; instead, a specific program is required to see information, and Cineca must be queried using bespoke queries, resulting in high processing times and inefficient administration. Direct access to a centralized database and the necessity for efficient

Table 1. Administrations involved in management processes and dedicated databases

Database	Data	Administrative directorate
OpenSIPI	Building name Geometric data Building location State of use	Information systems and e-learning portal Building, logistics and sustainability
Excel sheet files	Timetables Courses	Educational services
Cineca	Student career Course catalogue Fees	Not directly accessible

functionality is critical for developing AMS for scattered and heterogeneous building stock [13]. Therefore, an integrated database was required, in which data from Cineca and other databases converged, resulting in a data source that was easily accessible and queryable. Such an AMS may be a game-changer for the “Educational Services Directorate,” which would be able to rely on a single source of data on the number of students, available spaces, and courses.

The structure of the centralized database was established considering the existing situation while keeping in mind the possibility of future deployments. Following the acquisition of the data, a state-of-the-art study was undertaken to determine the optimum approach to preserve them to give flexibility, easy updating, and user accessibility. Relational databases (RDBs), which enable data to be structured according to a specific hierarchy, resulted to be a well-established method of storing data [14]. RDBs allow numerous sorts of connections between data to be established, allowing for customised queries as well as the ability to filter and aggregate data based on the intended purpose. The database structure was separated into 9 tables that were supplied with the acquired data and were also based on future database usage and queries related to asset management operations (Fig. 2).

This allowed us to see how the various levels and types of data should be linked. The initial stage was to select the primary data to which additional data would be linked. Because spatial data are required for most management operations, it was chosen to start there. As a result, the database structure was built on spatial data in a core table called “Building Stock”. Then, on the left side, there were connections to more information regarding “Spaces”, “Occupancy” and “Timetables”. Data regarding “Real property titles”, “Rental revenues”, “Rental costs,” and “Degree programs” were branched out on the right side.

One of the most important steps in identifying the building’s areas was to create a custom encoding system that could also connect data through the database. It is arranged as follows, according to the various building stock levels of definition:

$$PR^1_000^2_000^3_A^4_P00^5_0000^6$$

Province 1; venue 2; settlement 3; building code 4; floor 5; rooms 6.



Fig. 2. Database structure

This technology allowed data to be connected following the building's level of detail. Both the encoding strategy and the centralized database structure were important in the AMS app since they allowed users to filter shown information using the single data set described above. The assignment of the semantic data recorded in the centralized database to the building stock was the fourth phase. The initial step was to create BIM models that were to be enhanced with building characteristics, beginning with two pilot cases: the Faculty of Computer Science's headquarters and the Faculty of Humanities' headquarters. The major goal of this early phase was to get a level of data that was appropriate for representing the entire university asset without being burdened by an excessive volume of data. As a result, a significant decision was to model the building stock using masses, floors, and rooms rather than a high level of detail. The Autodesk Revit® authoring tool was chosen, which is one of the most widely used BIM tools in the AEC sector. This decision was based on three factors: the ability to represent only the main volumes of the university building stock as masses, floors, and rooms (which will be implemented in the future); the availability of the Dynamo plugin for Revit®, which automates both modelling and parameter assignment processes; the high level of interoperability between Revit® and GIS platforms (such as Esri's ArcGIS Pro), which allows for the import of BIM Models [15].

The individual categories of created elements (i.e., masses, plans, rooms) were assigned to the spatial and functional attributes previously stored in the centralized digital database using VPL (Visual Programming Language) [16], which is widely used in the AEC industry with significant improvements both in modelling and data management [17]. VPL is a programming language that substitutes ordinary computer programming with special objects (i.e., nodes) that have unique functions. Dynamo is an open-source

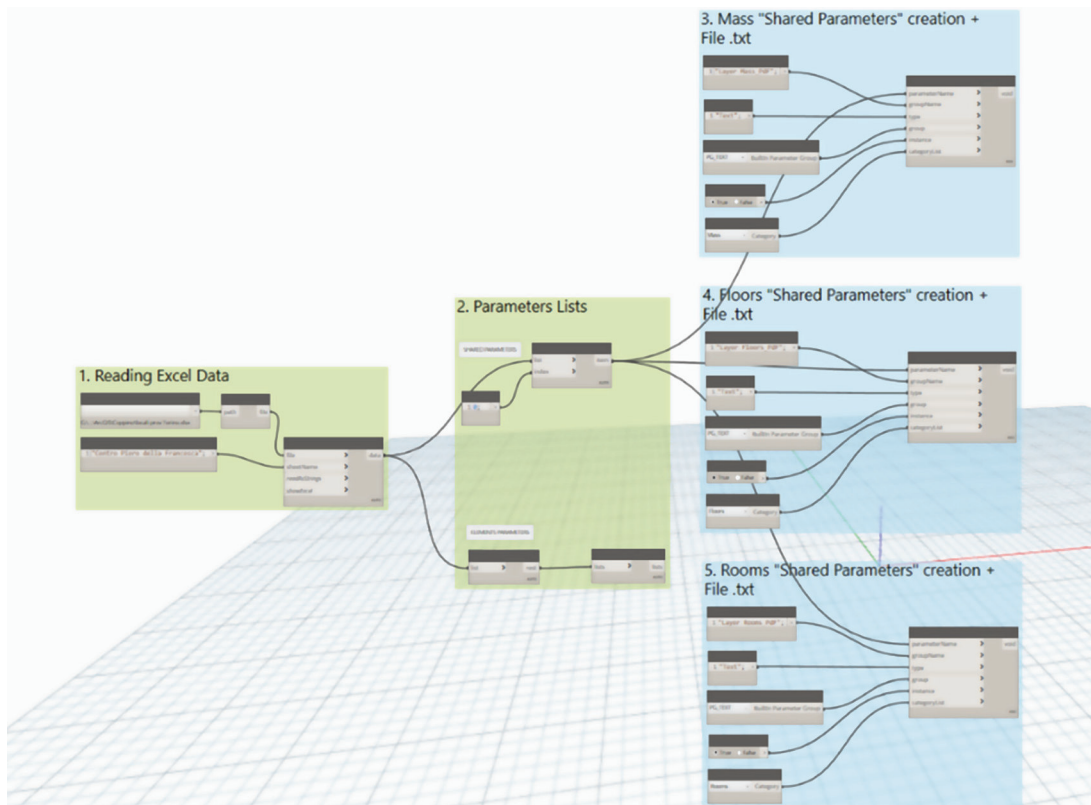


Fig. 3. Dynamo nodes

interface that connects VPL and Revit API nodes to construct highly customizable algorithms [18]. The geographical and functional data were first organised separately before being coupled to the parametric models. Extrapolating data from spreadsheets, creating new-shared parameters in.txt format, and assigning them to three kinds of parametric components (masses, planes, and rooms) in BIM models were all done with customized nodes (Fig. 3).

The fifth phase of this research project focused on the creation of a web-based BIM-GIS platform (i.e., AMS-app) that allows for real-time display of assets and their properties in a 3D digital map (Fig. 4). This platform may be thought of as a GeoBIM system since it allows users to link information models, geographical data, and functional data all at once. Therefore, georeferenced masses with geometric and semantic information were imported into the GIS platform. The building stock may be explored and filtered at several information levels (asset, single building, floor, and local), allowing for asset analysis and strategic decision-making by gathering and visualizing only the information required.

Finally, through business intelligence (BI) technology, it was feasible to turn data into meaningful information and give important instruments to assist strategic choices. Microsoft Power BI® was chosen to provide the best interoperability with excel sheet files used by administrations and minimize data loss. It is often regarded as one of the best ideal applications for managing massive amounts of data [19], and it supports the presentation of Arcgis maps via a custom plugin.

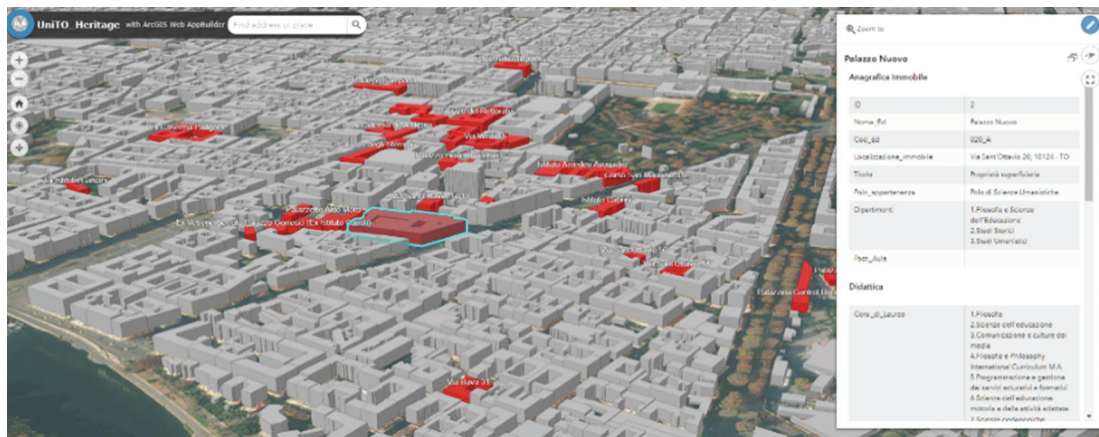


Fig. 4. University of Turin's asset in the AMS-app with an example of a summary table

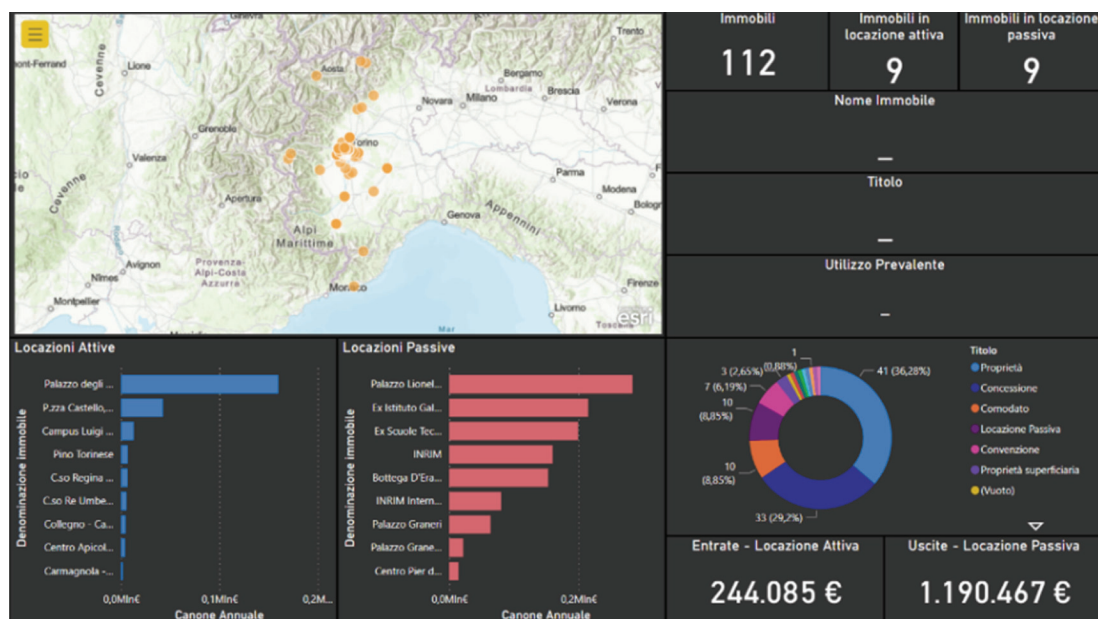


Fig. 5. Building stock dashboard 1

The capacity to work on datasets without altering the data source is an important advantage. Using this functionality and the previously mentioned centralized database, various interactive and detailed dashboards are offered to let university building users visualize and interpret relevant information (Figs. 5, 6, 7 and 8).

A first dashboard was constructed containing the asset's general analytic features (Fig. 5). It shows an interactive map with connected data (e.g., number of buildings, building name, building title, prevalent usage, rental revenue, rental expenditures) and certain user-interactive components. Data may be filtered or aggregated by clicking them, and key performance indicators (KPI) can be changed interactively via maps, bar graphs, and ring graphs. As a result, without having to wait for reports, the online application provides a comprehensive picture of the building stock consistency, allowing administrators to better allocate resources.

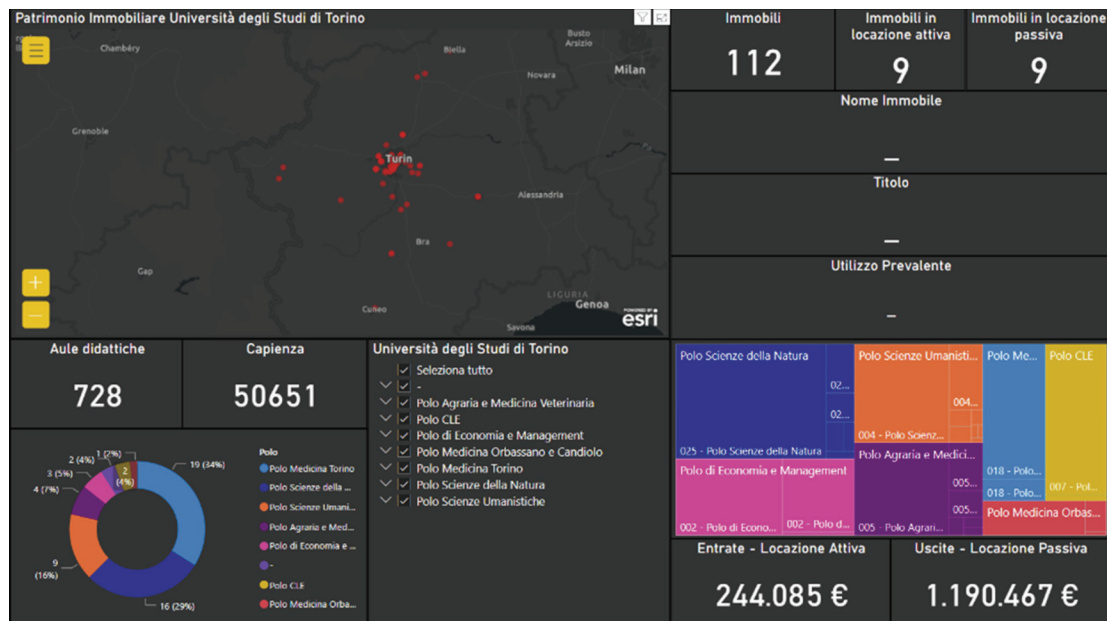


Fig. 6. Building stock dashboard 2

In a second dashboard (Fig. 6) assets and associated information might be sorted by educational pole or department for the depiction of the whole building stock. These data, when combined with information on classroom occupancy and course schedules, allow for better course allocation, facility use, and user mobility around the campus, resulting in a more sustainable campus. Then, for the examination of the first demonstrator, two further types of dashboards were created (Fig. 7 and 8).

The first dashboard provides for a more detailed study of the various activities at the building space level (Fig. 7). Some classes were underutilized, while others were

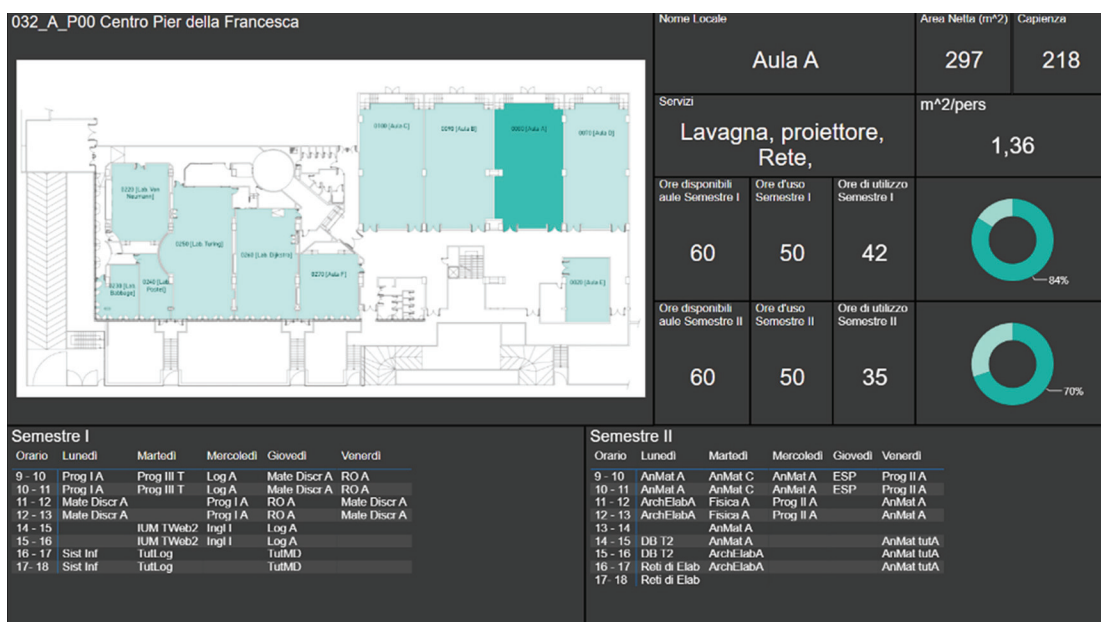


Fig. 7. Piero della Francesca centre's dashboard 1

overutilized, resulting in user discomfort and leasing costs for exterior areas. The Educational Services Directorate and other authorities may now readily examine and reference this data to allocate study courses optimally based on real space availability.

The last dashboard (Fig. 8) was dedicated to the offices' floor in which a detailed analysis regarding the utilization of the space could be done, visualising briefly the distribution of persons and the percentage of spaces used by role.

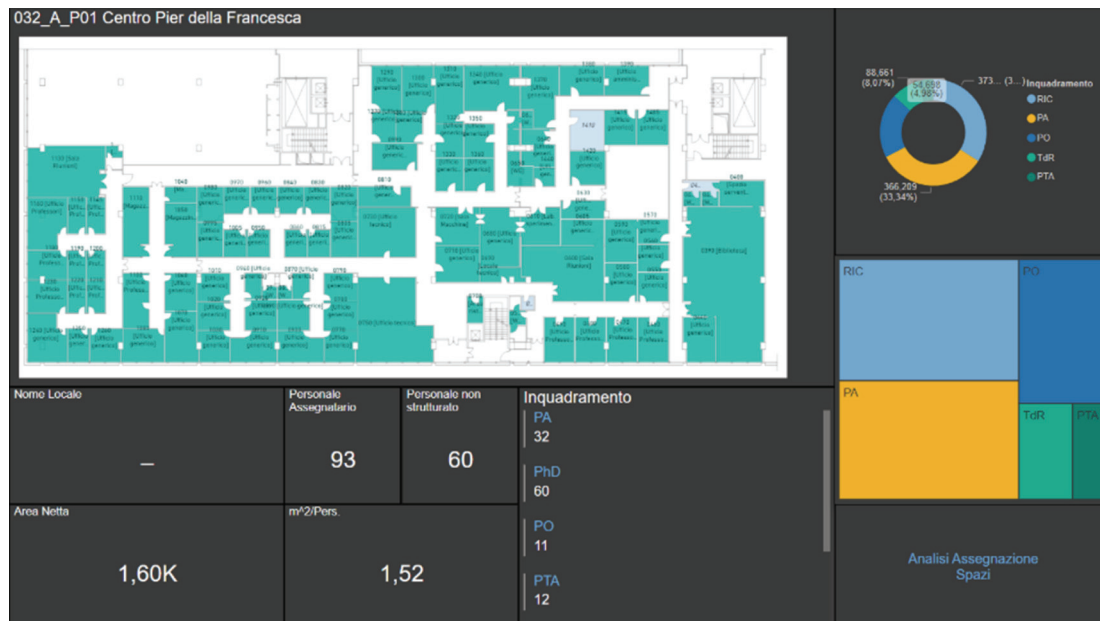


Fig. 8. Piero della Francesca centre's dashboard 2

3 Results and Conclusions

The main output of this research is the AMS app that allows users to view the whole University of Turin building stock and its properties in a 3D interactive map. It is now confined to authoring formats, but open standards may be used in the future to enable more compatibility between BIM and GIS (e.g., IFC, CityGML). The established AMS allowed for the resolution of present fragmented and document-based management challenges. It enabled effective decision-making and management operations by storing comprehensive and up-to-date data in a centralized and easily implementable database. Useful strategic data and graphs might be shown using synthetic dashboards and BI tools linked to the AMS app. These characteristics allowed for improved financial and geographical resource management at the institution, as well as waste reduction and cost reductions. It is possible to: rationalize space use based on actual availability, course schedules, and occupancy; optimize real estate investments by visualizing over or under exploitation of both buildings and spaces; manage maintenance and cleaning operations optimally about actual space use. Furthermore, thanks to the unified database, energy bills are also linked to each building, making it possible to highlight anomalies in energy consumption compared to the average per square metre. The AMS-App allows users

to access information through a webapp without any installation requirement. With different levels of permissions every stakeholder can access to valuable information and participate in its improvement through dedicated text boxes. Sensor networks to detect thermal comfort, energy consumption, people presence, and any other valuable data for effective management of the O&M phase are scheduled to be installed in most major buildings in terms of dimension, occupancy and complexity. These data will be collected using the database that has been created and displayed using custom dashboards. As a result, BIM models might be used to create important DTs that allow for real-time optimization of internal comfort conditions, energy consumption, emergency evacuation, supported maintenance operations, and optimal occupancy using VR/AR tools. As a result, real-time or predictive building management might be given, along with improved user experience and lower administration costs and resource usage.

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Smart digital campus UniTO: data gathering and visualisation to support sustainability and indoor comfort

D Accardo^{1*}, S Meschini², P Gasbarri¹, L C Tagliabue³, G M Di Giuda¹

¹ Department of Management, Università degli Studi di Torino, Turin, Italy

² Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy

³ Department of Computer Science, Università degli Studi di Torino, Turin, Italy

*Corresponding author: daniele.accardo@unito.it

Abstract

This research aims to identify and investigate the best digital tools to improve indoor comfort conditions and sustainability through energy efficiency enhancement in educational buildings, integrating data gathered from sensors. By leveraging an existing asset management platform that integrates Building Information Modelling (BIM) and Geographic Information Systems (GIS), data from Internet of Things devices were linked to the BIM model of a test case building creating a digital shadow in order to gather real-time data on indoor conditions, including temperature, humidity, and CO₂ levels. The methodology enables continuous evaluation of the building's state of usage and calls for automatic and frequent updates of data. The digital shadow can display current usage conditions and alarms when conditions exceed what is comfortable, and it allows for immediate feedback through colours based on the internal detected conditions. The platform can be used with business intelligence tools to support strategic choices and enable future innovations, including machine learning techniques to estimate building occupancy and identify any deviations from expected usage patterns. This study presents a promising workflow for creating sustainable and comfortable educational buildings, which could be replicable and scalable in the future.

1. Introduction

The European Green Deal aims to decrease greenhouse gas emissions by 2050, emphasizing buildings' emissions reduction (at least 40% of emissions) [1]. In Italy, public buildings represent a significant portion of the built environment and constructions are often older and hard to maintain.

In recent decades, the Architecture, Engineering, Construction, and Operation (AECO) sector has seen the introduction of various digital tools and new working methods due to technological advancements. Among others, Building Information Modelling (BIM), Geographic Information Systems (GIS), and Internet of Things (IoT) devices are technologies that are rapidly changing the AECO sector.

Among public buildings, the case of university building management can be particularly challenging, especially in older institutions where there is a need to balance preservation with modernization and upgrades. This can drain resources and increase the university's carbon footprint and, in addition, the comfort within the rooms can be unsatisfactory.

In this context, the built environment's digital and energy transition is paramount to avoid wasting resources and lead to more informed decisions.



The literature shows that the mismanagement of buildings is commonly known to lead to resource wastage and increased operation and maintenance costs, as well as negative environmental impacts. This is largely due to the significant impact of human presence on space management, which is affected by a range of factors such as behaviours, needs, and habits of occupants [2].

According to Botín-Sanabria [3], with regard to the digitalization of buildings and the possibility of linking data to them, three different stages of development are defined:

- Digital Model: it's a virtual model which replicates an object of the real world with no direct information connection with its physical counterpart (BIM model).
- Digital Shadow: the connection with the physical object exists but, the integration of information flow is unidirectional, from the real object to the digital one.
- Digital Twin: information flows bidirectionally and automatically between the virtual and physical worlds.

Furthermore, the literature recognizes the value of integrating spatial information with live data from sensors to assess a workspace's performance [4]. Indoor and outdoor sensors can provide data on energy usage and comfort patterns, allowing for real-time monitoring of buildings and quicker decision-making by facility managers regarding maintenance activities [5,6]. Additionally, the system can detect any malfunctions or failures. Occupancy-related visualizations can also be produced to highlight changes in building performance throughout the day, week, or month [7]. This approach allows for the identification of efficiency opportunities during both occupied and unoccupied states, which may be missed by a building's overall benchmark, thereby providing more specific and accurate measures of building efficiency.

The present study utilizes a platform under development at the University of Turin (UniTO), which proposes an Asset Management System (AMS) for the management of university buildings integrating BIM and GIS technologies and Business Intelligence Tools.

While GIS allows the georeferencing of the campus' assets (over 100 buildings) and spatial analysis, BIM enables the 3D view of the single buildings carrying basic information about space geometries and main uses. The platform aims to store multiple datasets that once connected to the GIS and the BIM, can be analysed and visualized with dashboards.

So, the platform enables multiple stakeholders to interact with the BIM models and the stored data, supported by information visualization on dashboards.

In this context, the paper aims to show how the IoT devices incorporation and the leveraging of digital tools, data collected from sensors, including temporal series of physical measurements, can be integrated and visualized within the AMS platform, providing a practical solution for monitoring and improving a building's indoor comfort and energy efficiency.

2. Methodology

In order to investigate the potential of digitalization on a university campus, and the usage of IoT devices for environmental comfort and energy performance improvement, this study selected one building of the UniTO's assets as a pilot case, the Campus Luigi Einaudi. The building has several IoT devices installed for real-time data gathering. The methodology was designed with replicability in mind, to enable the future expansion of the IoT network. This study presents a workflow for gathering, updating, and visualizing indoor comfort information, including temperature, humidity, and CO₂ levels. To facilitate the ongoing evaluation of the building's usage, the methodology requires automatic and frequent updates of data.

2.1. The pilot case

The Luigi Einaudi Campus (Figure 1) was chosen as pilot case for sensor analysis. The campus, which opened in 2012, can accommodate approximately 10000 users, representing over 12% of the UniTO population. The building has glass facades, which stretch for about one kilometre on each floor, strike an optimal balance between natural and artificial light. However, during the initial years of operation, the building's energy consumption had a significant impact on the university's costs and the campus

underwent several interventions aimed at improving energy efficiency and management, as well as enhancing internal comfort (e.g., installation of transparent solar shielding films, installation of presence and illuminance sensors and educational activities for the involvement of campus users).



Figure 1. Luigi Einaudi Campus (Unito.it).

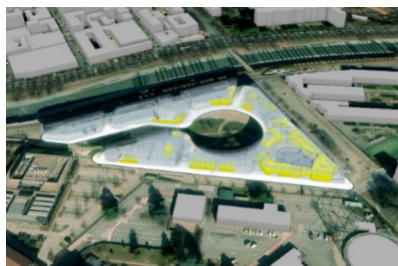


Figure 2. Digital model of Luigi Einaudi Campus in the AMS Platform.

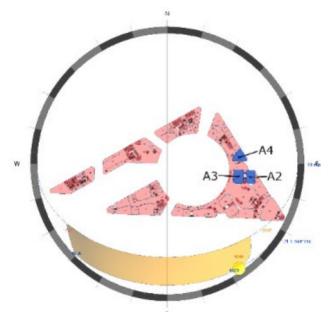


Figure 3. Rooms with active sensors at Luigi Einaudi Campus.

2.2. Data gathering through IoT devices

Among the various interventions, the University of Turin installed IoT devices in selected rooms to track environmental information and to optimize the setting of heating and cooling systems. This presented an opportunity to enhance the AMS platform with up-to-the-minute data. The University of Turin opted for the AirCare® pro+ device [9] that can capture 15 different data types regarding air quality, environmental comfort and electro-smog. SIMA (Italian Society of Environmental Medicine) has endorsed the device's PM2.5 and CO₂ measurements scientifically. This data can enhance the health and comfort of users within a university building, as air quality and environmental comfort are critical components of a healthy environment. Acquiring this sort of information within a university building can be instrumental in mitigating indoor air quality issues and boosting the quality of life for users. Furthermore, by cross-referencing classroom occupancy data with IoT sensor data, it is possible to gain a more comprehensive understanding of the air quality in relation with room's occupancy. For instance, if an IoT device detects a high concentration of particles during a lecture, cross-referencing the data with classroom occupancy data can help establish whether the presence of many individuals is responsible for the elevated particle concentration. This knowledge can aid in identifying factors that impact the air quality inside a classroom, including inadequate ventilation or the use of chemicals. Consequently, informed decisions can be taken to improve air quality and enhance the health of individuals within the university building.

At the Luigi Einaudi Campus, a total of 39 IoT devices were positioned, primarily on the ground floor and first floor of the building, which are frequently used for teaching activities. The areas where the sensors were positioned (marked in yellow in figure 2) were pinpointed in the model on the AMS Platform. By leveraging the encoding formulated for platform management, it was feasible to establish links between the pre-existing data and the data gathered from the sensors.

To leverage the real-time data associated with the BIM model, the plan was to focus on monitoring key parameters, including temperature, CO₂, CO₂ e, VOC, PM10, and PM2.5. The experiment involved three classrooms located on the ground floor of the main building of the Luigi Einaudi Campus: Classroom A3 (154 seats), Classroom A2 (134 seats), and Classroom A4 (126 seats) (as depicted in Figure 3).

2.3. Data connection

In the pre-existing UniTO's AMS platform data connections are possible thanks to semantic association between datasets. Data relations are the key to the different connections for all the technologies involved. The BIM model is fed with visual programming language nodes that recognize the element ID and match the correct values. Then, once georeferenced in GIS, it brings the information previously added and

acquires spatial data connection. Moreover, both in GIS and in Business Intelligence tools it is possible to relate datasets tables through the association of the encoded name of spaces.

The encoded name of spaces is also the bridge for sensors' data connection to the platform. In fact, the serial numbers of all environmental sensors are associated with the coded name of the space in which they are installed, allowing the association of the product data with the BIM model and the other datasets. The subsequent approach was implemented to create a direct correlation between the data collected from the IoT devices and the AMS platform database, and subsequently, the BI solution employed (i.e.: Microsoft PowerBI®). To retrieve the data, a "http" request was established employing the python language, with specific use of the "requests" library, enabling access to the website. Following this, a "post" request containing the username and password was dispatched. Subsequently, a "get" request was initiated to access the URL of the page where the ".csv" file is available for download. Then a second "get" request was made to download the content of the ".csv" file from the URL. Utilizing the "pandas" library, the ".csv" file was parsed, and data was extracted. Finally, the data was saved in the database in ".csv" format, facilitating its rapid use in PowerBI® and therefore, to load the data into PowerBI®, the "pandas" library was leveraged to read data from the file. Subsequently, utilizing the "pyodbc" library, SQL queries were executed, enabling data insertion into the PowerBI® dataset. To automate all the steps, configuring a "task scheduler" and setting up automatic data updates via PowerBI® was essential. To resolve the issue, the "schedule" library was employed, executing functions at predetermined intervals and the "refresh service" was configured in the PowerBI® software. This service also provides access to the "refresh history" report.

2.4. Business Intelligence tools

Once the data stream was connected to the BIM model the digital object can be considered as a digital shadow. At this stage it became crucial to establish relationships between the data to generate useful information and enable quick and efficient visualization. To enable the visualization of the real-time data linked to the digital shadow, an initial dashboard was created, linking floor plans and highlighting classrooms where sensors are present. By selecting a classroom of interest, the values over the course of a week can be viewed instantly (as shown in Figure 4).

The dashboard's development involved overlapping data of different types to create information otherwise challenging to find. For instance, data on air quality and thermal comfort were cross-referenced with university schedule and classroom use data. The analysis was performed for the week from November 28, 2022, to December 4, 2022, a period when teaching activities are in full swing. The graphs also include a threshold indicating the optimal levels for each parameter measured.

By means of the quick and contextual visualization offered by the dashboard, it is feasible to gain insight into the condition of the rooms and identify connections between indoor comfort conditions, air quality, and occupancy levels within the classrooms.

3. Data analysis and Results

The connection of IoT devices data to the digital shadow and the overall database, achieved important automation, allowing for quick and easy access to information to support strategic decision-making in a well-timed manner.

Observing the data monitoring during the studied week, some correlations can be identified. For instance, regarding temperature, it was found that Classroom A2 remained within the optimal temperature range during the class hours throughout the week, not exceeding 22 °C. However, classrooms A3 and A4 constantly surpassed the 23/24 °C limit. It is worth noting that Classroom A4 has windows on one side facing northeast, providing an option to open them. On the other hand, Classroom A3 is situated in an interior area of the building without direct outward-facing, and Classroom A2 has a limited eastward-facing. Furthermore, there is a clear correlation between the temperature peaks and the presence of classes inside the classrooms.

The human body's metabolism leads to an elevation in temperature and CO₂ levels. When people exhale, they release CO₂ and generate heat, which can cause the temperature in a room to rise. As the

number of people in a classroom increases, so does the temperature and CO₂ levels. Inadequate ventilation can result in excessively high CO₂ levels, which may cause lethargy, headaches, and reduced cognitive function.

Classroom A2 performed the best in terms of CO₂ levels, managing to stay below the 1000 ppm threshold during classes throughout the studied week. However, classrooms A3 and A4 had peaks of around 1300/1400 ppm during scheduled class hours. As for PM_{2.5} and PM₁₀ values, they generally remained below the average of 25 µg/m³ for PM_{2.5} and below the average of 50 µg/m³ for PM₁₀. Notably, when PM_{2.5} and PM₁₀ levels inside the classrooms peaked, there was also a corresponding drop in temperatures and CO₂, suggesting that users intervened by opening windows. It's worth noting that high levels of outdoor air pollution can enter the classroom through open windows or doors, especially if pollution caused by traffic or industrial activities nearby is high, as in the city of Turin.

The VOC monitoring reveals that the weekly average is acceptable, remaining below 500 ppb, thus there is no cause for alarm regarding the levels recorded in the three classrooms. The main benefit of connecting the data flow to the model is the ability to immediately link the data collected by the IoT devices to the correct location within the building and quickly identify any potential issues caused by the surpassing of key indicators of environmental quality and thermal comfort. The primary challenges faced during the data connection stage relate to managing large data streams, given that the IoT devices record the situation every 5 minutes. To address this issue, automated data storage could be delegated to a cloud service, which could also serve as a database for the sensor component.

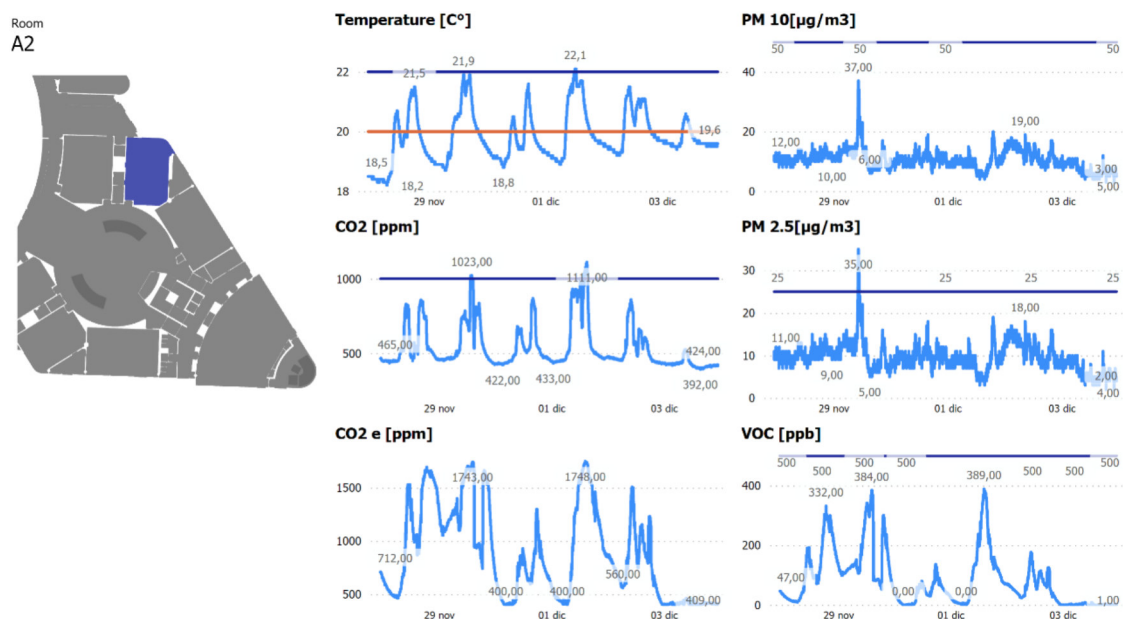


Figure 4. A2 Room dashboard with real-time data monitoring.

4. Conclusion

The study focused on the procedures involved in connecting IoT devices data to an AMS platform that caters to real estate asset management, in accordance with the principles of Digital Shadow. This constitutes a crucial step in the creation of a smart and interconnected campus.

The capability to integrate diverse types of data presents opportunities in the realm of real estate management, especially if the building stock is vast and involves intricate dynamics.

At present, IoT devices are regarded as one of the most compelling solutions owing to their capacity for transmitting data directly to a cloud-based environment, eliminating the need for multiple data handovers between various platforms. By linking data obtained through IoT devices data to BIM models and subsequently correlating it with AMS data, it is possible to gain prompt and effortless access to information that may aid in making timely strategic decisions. The primary benefit of this integration is the capacity to match data with the appropriate space in the structure, which facilitates the identification

of potential issues resulting from the surpassing of critical parameters. Nevertheless, the handling of extensive data streams remains a crucial challenge that requires resolution. In general, the utilization of IoT devices in building automation has the potential to boost indoor environmental quality, encourage energy efficiency, and elevate occupant comfort and productivity. Indeed, current occupancy levels and activities significantly impact IAQ, deviating from the original design assumptions and underscoring the importance of monitoring building spaces. By monitoring IAQ parameters, a clear association emerges between the presence of individuals and a rise in temperature, carbon dioxide (CO₂), and volatile organic compounds (VOCs) in university classrooms, underscoring the impact of external factors and human presence on indoor air quality and thermal comfort.

Possible future developments of the ongoing research process could follow the guidelines proposed in Level 3 of the EU Commission's user manual on IAQ [10], which aligns with a shared EU framework of fundamental indicators for evaluating the sustainability of buildings throughout their life cycle, not solely in terms of environmental performance, but also concerning health and comfort, life cycle cost, and potential future performance risks. The primary aim of such a project is to enable building-level actions that contribute substantially to the broader European environmental policy objectives. Specifically, Level 3 [10] proposes a "two-pronged approach" to objectively assessing IAQ, which comprises air sampling and monitoring using a quantitative and objective approach and collecting occupants' feedback through surveys administered online during occupancy.

The two kinds of collected data can be cross-checked with occupancy rates and usage patterns, thereby providing useful insights for potential corrective measures on the HVAC system. Furthermore, in the future, there may be scope for exploring the creation and integration of machine learning systems, which can learn from user behaviour and the data gathered from the building, taking advantage of increasingly automated and precise systems.

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BIM-GIS AND BI INTEGRATION FOR FACILITY AND OCCUPANCY MANAGEMENT OF UNIVERSITY ASSETS: THE UNITO PILOT CASE

Giuseppe Martino Di Giuda, Daniele Accardo & Paola Gasbarri

Department of Management, University of Turin, Turin, Italy

Silvia Meschini

Department of Architecture, Built environment and Construction engineering, Politecnico di Milano, Milan, Italy

Lavinia Chiara Tagliabue

Computer Science Department, University of Turin, Turin, Italy

Laura Scomparin

Department of Law, University of Turin, Turin, Italy

ABSTRACT: *The integration of Building Information Modelling (BIM) and Geographic Information System (GIS) with Business Intelligence (BI) is promising for managing vast and diffused assets. It enables valuable insights into asset performance and resource uses, supporting savings, improved efficiency, and sustainability. The research proposes a web-based Asset Management System application (AMS-app) via BIM-GIS-BI integration, providing an updated digital representation of university assets by combining spatial, performance, and operation data with related analytics. The AMS-app was developed in the context of the University of Turin's strategic plan as a pilot case to improve asset management procedures through a data-driven approach. Indeed, campuses are complex assets managed by multiple actors through still document-based and fragmented databases, often leading to ineffective and untimely decision-making processes. The AMS-app represents a valuable decision support system for facility managers aimed at asset monitoring and user experience improving through better and more sustainable decisions concerning space, occupancy, and indoor environmental quality (IEQ). To demonstrate the effectiveness of the BIM-GIS-BI integration through the AMS-app, several case studies were implemented with the following objectives: (i) the digitalization of university building data, (ii) the optimization of courses timetables according to space availability, (iii) the optimal workstations management, and (iv) the analysis, monitoring and optimizing of IEQ and comfort via IoT networks. The paper illustrates the advantages and applicability of the developed methodology through the case studies, and further developments in university asset management.*

KEYWORDS: *Asset Management System, BIM-GIS integration, Business Intelligence, Information management*

1. BACKGROUND AND MOTIVATION

University assets, especially Italian ones, are characterized by strong management complexity due to their diffused buildings, often built in different eras with various construction technologies and high heterogeneity. The management is often based on fragmented, incomplete, and hardly accessible databases, preventing the correct definition and optimization of usage patterns, as well as the normalization of management processes (Qian and Papadonikolaki, 2020). This results in inefficiencies in services and maintenance activities, leading to wasted resources and inefficient decisions concerning the expected performance, user comfort, and economic and environmental sustainability. Thus, university assets represent a crucial opportunity to propose a solution to the information gaps currently found in managing large assets. There is an increasing need for the adoption of information management strategies aimed at shifting from highly document-based and fragmented approaches to digital and collaborative ones (Chen et al., 2015). Digital tools and effective information management strategies enable data integration, ensuring the availability of accurate information with various granularity levels, at the right time, in the required formats, and throughout the asset lifecycle. Despite its application in asset management is still rare (Moretti et al., 2021), BIM-GIS integration provides high potential (Liu et al., 2017; Beck et al., 2020), especially in borrowing the Smart City concept at the Campus scale, improving the management of such complex assets for a better user experience and optimal resource utilization (Lu et al., 2020; Ward et al., 2021; Wang et al., 2019). BIM enables the development of highly detailed building information models, while GIS allows their management and analysis through a global spatial reference system (Zhu et al., 2021). BIM-GIS integration combined with BI tools can be exploited to optimize the management of large assets and to foster the development of AMS tools as concrete decision support systems (Pärn et al., 2017). The further integration of IoT and digital devices can facilitate data collecting, providing a better maintenance and asset management through the monitoring and analysis of real-time data about asset performance and condition, enabling timely interventions (Wong et al., 2018).

The research project exploits BIM-GIS integration with BI tools to develop an interactive, web-based 3D map (AMS-app) for the management of large and diffused university assets. The main objective consists in facilitating information management and decision-making processes by improving information accessibility and sharing among stakeholders, and normalize management processes. The paper illustrates the replicable methodology developed to define and implement the AMS-app within the management system of the University of Turin (i.e. UniTO), an emblematic case for testing and demonstrating the potential offered by such a decision support system. Then it describes how data are collected from various siloed databases and integrated, providing an easily accessible and implementable knowledge base. Indeed, the AMS-app collects all the data currently handled separately by different administrative offices, providing a still independent but collaborative management system. Thus, the asset can be managed at the system level, rather than at the level of individual isolated buildings. The potential that such an AMS-app can provide to asset and facility managers of large university assets is described through the illustration of several case studies implemented so far, selected based on the management needs encountered within UniTO. Finally, the results are discussed, and the potential future developments and implementations are reported. Further objectives concern the development of information modelling protocols and guidelines to facilitate the adoption and transition to such a digitalized and shared management approach. In this way, the data can be modeled and structured ensuring the availability of accurate information at the right time, in the required format, throughout the asset lifecycle, and the method can be easily replicated.

2. METHODOLOGY

The main steps of the methodology adopted to develop and implement the AMS-app in the university organizational structure are illustrated in the following paragraphs.

2.1.1 Main objectives and needs definition

The first step concerns the definition of the main objectives and needs that the organization intends to handle via the AMS-app. The organizational structure was analyzed to understand the management issues faced by UniTO and to define the relevant case studies to be implemented and tested through the AMS-app. Consequently, meetings and interviews with the managers of the technical areas in charge of the university asset management, its maintenance, information systems management, as well as teaching and educational services were conducted.

2.1.2 Current database structure and dataflow management strategies investigation

An investigation of the procedure currently adopted by the university to manage the information flow has been conducted to identify which information and data are handled by the different technical areas, as well as the methodology used to produce, store, and exchange them. One of the main aims of the analysis concerned the identification of the tools and formats currently exploited by the areas so that the AMS-app could be developed without disruptively changing current workflows, facilitating its adoption.

2.1.3 Organization information exchange and information requirements formalization

Once identified the organization's current database structure and dataflow management strategies, the analysis and formalization of the information exchange among the technical areas have been performed. The main aim was to ensure the easy integration of modifications occurring over time, providing a constantly updated digital representation of the building asset. The information exchanges were formalized to ensure that the technical areas can continue to rely on current tools and procedures with minor changes in data production and management. Then, the Information Requirements (IRs) have been defined to foster communication and support the creation of a coherent database to feed the AMS-app. Table 1 provides an example of an exchange information requirement schedule.

Table 1: Example of an exchange information requirement in the standardized form for data collection.

Field	Data source	Note	Type
Building code	OpenSIPI, Technical Areas: EDISOS, SILOM, SIPE, Asset Management	Building coding (Settlement_Building: e.g. 029_B)	Text
Building name	OpenSIPI, Technical Areas: EDISOS, SILOM, SIPE, Asset Management	Free field	Text
Main address	OpenSIPI, Technical Areas: EDISOS,	Free field	Text

SILOM, SIPE, Asset Management			
Municipality	OpenSIPI, Technical Areas: EDISOS, SILOM, SIPE, Asset Management	Extended name, es. Turin	Text
Main use	OpenSIPI, Technical Areas: EDISOS, SILOM, SIPE, Asset Management	Free field	Text
Building Type	OpenSIPI, Technical Areas: EDISOS, SILOM, SIPE, Asset Management	Bound field: Building, Portion of Building, Agglomeration of Buildings, No Type, ND	Text
Status	OpenSIPI, Technical Areas: EDISOS, SILOM, SIPE, Asset Management	Restricted field: Decommissioned, In use, Under construction, No Status, NDo	Text

Furthermore, a possible change in the university's organizational structure was investigated for better supporting the AMS-app adoption.

2.1.4 AMS-app development: approaches, technologies, and tools selection

As stated before, the scientific literature has widely discussed how BIM and GIS integration can bring significant benefits in the field of asset management. BIM enables an overview of a single building and GIS allows the contextualization of each building, enabling analysis at a territorial level. Thus, the two resources optimally lend themselves to the university campus management, which, given its complex infrastructure, the amount of heterogeneous data, and spaces spread over a vast territory, needs systems that can facilitate the management, use, and maintenance of their assets at different levels. The proposed system integrates these resources providing the necessary tools for understanding, visualizing, and analyzing information related to the university building stock, its services, and infrastructure, thanks also to the support of BI tools. Data are core to the system, populating it and being the key to the different components' connections. The platform integrates data of various nature and from multiple sources: geographic data, geometric and functional data, as well as data concerning IEQ derived from sensors (Table 2).

Table 2: Data sources, information and types.

Source	Information	Type
Piedmont Territorial Geoportal	Building location, heights, geometries, restrictions	Text, numbers, coordinates, shape files. Static data.
OpenSIPI	Name, encoding, address, floor numbers, state of use, geometries, area, department assignment	Text, numbers, drawing. Static data.
Department offices	Courses schedule, personnel employed information, buildings construction site	Mainly text. Sheet-form organization. Dynamic data (on long term)
University website	Timetables, organizational units, building property state and expenses	Mainly text. Sheet-form organization. Dynamic data (on long term)
IAQ Platform	Environmental sensors measurement (CO ₂ , humidity, temperature, VOC, PM _{2.5} , etc.)	Numbers. Dynamic data (on brief term)

The different datasets are then collected from various sources, processed, and stored in a cloud repository so that data can be queried by any operator without duplicates, errors, or information loss. Aiming at the optimal integration between the different data, information sheets have been prepared and provided to the technical areas, asking for their fulfillment. Nonetheless, their compilation is not always possible such as in the case of geometric data derived from drawings or models, or geographical data from cartographic services such as the Geoportal of the Piedmont Region. In these cases, the sheets have been compiled manually by the authors.

Once the needed data have been collected, they are interlinked thanks to the semantic association of encoded names. An encoding system was defined for each city, building, and space, which is part of the university asset, starting from the one currently used by the university's administration to promote a smooth integration process. The encoding system was also key for data association in GIS. The entire campus buildings were identified, geolocated, and associated with their encoded names. The map was developed in a 3D view, aiming at offering a better perception of urban space, asset consistency, and distribution. Thanks to the geolocation of the encoded buildings through a 3D environment, and to the association with functional data, various analyses were developed

at the territorial level, providing the depth knowledge of the university asset with information on its use and consistency, useful to support decision-making processes.

QGIS was selected for the shape files creation and first population, while Mapbox was exploited for the 3D map development and visualization. It was chosen for its easy integration with Microsoft Power BI, thanks to the opportunity to generate a customized web map based on the created shape files, shareable through URL and carrier of selected information. In addition to the GIS representation of the university asset, BIM was exploited for the analysis and visualization of each single building at different levels. The modeling phase succeeded in exploiting the Autodesk Revit Software for geometrical construction and the Visual Programming Language Application Dynamo for information population. The BIM modeling and the Dynamo nodes were developed with the aim of generating a replicable workflow, adaptable at each building of the asset. So, each BIM model presents three different levels of consistency: the building volume, the building levels, and the building spaces, modeled as mass, floors and rooms, respectively. Each element is firstly associated with the corresponding code, then the encoded name and the Revit Element ID are exported for each geometry modeled. The encoded name association ensures the association between the different datasets, but the connection between the BIM geometries and the information occurs via the Revit Element ID association. It is needed for various reasons, for example, some rooms may temporarily present the same encoded name during a space renovation, or their geometry can change throughout the building lifecycle, as well as their name. Despite the mutability of information such as the name, the Revit Element ID remains unchanged over time.

The BIM model is then associated with information related to the standard use of the building and its characteristics. During parameters' creation, a parameters comparator enables to individuate the shared parameter between masses floors and rooms, avoiding repetition that could lead to association errors or can compromise the final model quality. Both the Revit parameters and the associated values are extrapolated by the same dataset, stored in the cloud repository, and in the future, each building of the university asset will have its own datasets for better management. At this stage, the association of the most dynamic information, such as the real-time collected data, has been avoided. In this way, the model can represent the basis for multiple analyses related not only to environmental quality but also to space occupancy or educational and working spaces management. This choice provided also lighter models, with smaller file sizes and greater smoothness. Finally, with the aim of facilitating BIM and Microsoft Power BI integration, the BIM model was exported with Proving Ground Tracer. This software allows the exportation of both 2D and 3D geometries with related information, all preserved in an SQL database generated by the software itself. At the end of the process, the BIM is then ready to be imported and visualized in Microsoft Power BI. It demonstrated great capacity in data analysis and visualization, allowing information sharing between different stakeholders through analytic dashboards which can involve data, BIM models, and GIS maps. So, it represents the preferential software for web-app structure development.

2.1.5 Data visualization, analytics, and dashboard structure definition

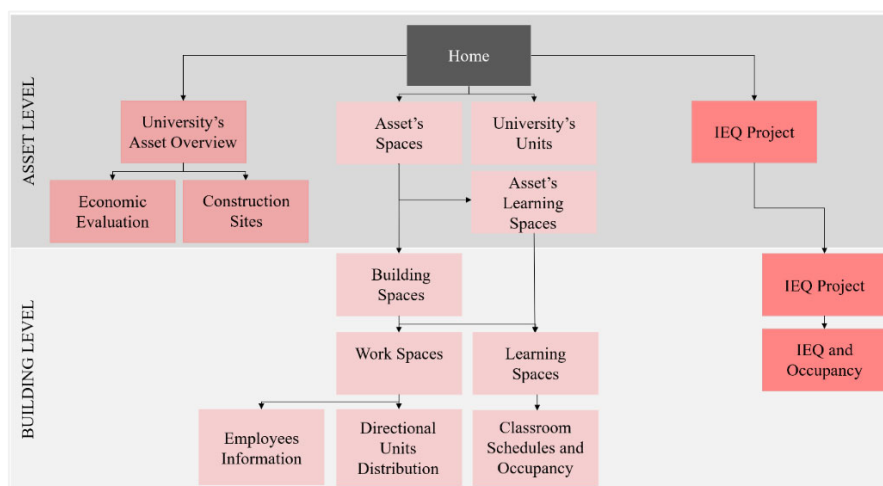


Fig. 1: UniTO's asset management system platform based on BIM-GIS-PBI integration

Power BI was chosen not only for data analysis and visualization but also as the software to generate the AMS-app main structure. The dashboards created are directly connected to datasets stored in the cloud repository and can be integrated with BIM and GIS maps. Thanks to these connections, based on the relationship of the encoded

names, it's possible to associate the resources, the data previously excluded, such as the dynamic data related to real-time environmental quality measurement, the course timetables, the occupancy rates, etc. The platform is structured so that the dashboards are gathered in thematic reports (asset consistency, economic evaluation, construction sites, IEQ, spaces' occupancy, etc.), classifiable also into territorial and building reports, depending on the level of information visualizable. Each report is correlated to the others based on a predefined structure (Fig. 1), but still independent, allowing to introduce different accessibility levels according to the requesting user.

3. RESULTS AND DISCUSSION

The proposed methodology and AMS-app are being applied as a pilot study to the UniTO asset management, as described in the following sections.

3.1 UniTO pilot case

3.1.1 Main objectives and needs definition

UniTO aims to create an integrated AMS-app that enables updated data visualization to optimize the management of its diffused asset, providing information about performance and resource utilization, to promote cost reduction and improve efficiency. The main goal consists in improving the management of spaces and resources. The AMS-app enables to identify and monitor the asset over time, leading to better decision-making concerning space, occupancy, and IEQ management. It was applied to digitalize the whole UniTO building stock, providing an overall view with data about its consistence and usage (i.e., geolocation, building asset consistency, geometrical and financial data, building performances, rooms capacity, equipment, and performances, occupancy level, and usage, etc.). The updated visualization of the building portfolio through a 3D map with data and information handled through GIS, BIM, and BI systems aims to support the:

- Management of university facilities at the territorial and building levels allowing to produce data analytics at different layers for improved facility operation;
- Optimization of university teaching timetables based on the actual teaching space availability and capacity;
- Optimization of workstations management by introducing remote working strategies;
- Analysis and optimization of IEQ to improve users' comfort and safety through IoT monitoring.

3.1.2 Current database structure and dataflow management strategies investigation

Currently, the university technical areas handling data and documentation about facilities, spaces and related equipment, performance, capacity, workstations' number, and concerning the teaching timetables' definition, rely on a document-based system characterized by siloed information. Data about spaces and related usage are stored and exchanged via semi-structured formats such as .xls or .csv. Information exchanges take place mainly via traditional communication systems (printed reports, e-mails, calls, in-person or remote meetings, etc.), and data are not shared between stakeholders or administrative offices, resulting in struggling or absent analysis of integrated aspects and information to support the decision-making processes. Thus, a data integration system is proposed with the aim of creating an updated tool collecting data from several sources, shared among the whole UniTO staff. The different data silos are integrated by exploiting BI tools and methods, enabling to collect and integrate data from the various Excel sheets produced by the technical areas. In this way, it is possible to maintain the current processes adopted to manage space, staff, and usage data, avoiding disrupting the management procedures. Furthermore, it is possible to avoid the effort of creating a structured DB (e.g., a relational SQL database) that would have been more disruptive and difficult to integrate within the UniTO management system. This allows for the gradual and low-impact integration of the AMS-app and the system, with a greater likelihood that it will be concretely used by UniTO staff.

3.1.3 Organization information exchange and information requirements formalization

The data integration system has been set up by a cross area within the UniTO organization represented by a research group of seven people which acts as a data analysis area. The authors are part of this research area that collects the different data from UniTO areas integrating them through the proposed system (AMS-app) according to the schema illustrated in Figure 2.

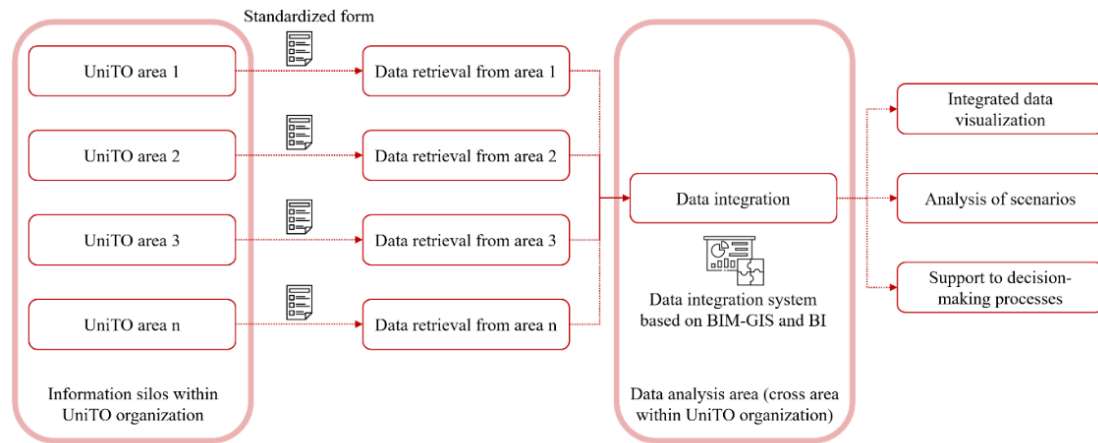


Fig. 2: Information exchanges and data processing schema within UniTO organization.

Data are retrieved from UniTO technical areas via standardized forms (Table 3), and the data analysis area receives information concerning buildings, spaces, capacity, occupancy, people occupying the spaces, etc. through similar forms. This enables quick data management via structured data sheets and avoids the cleaning and processing of data first. The integrated data, the resulting information, and knowledge are made available and displayable via the platform, enabling scenario-based analysis to support the decision-making processes of the UniTO's asset management staff.

Table 3: Example of standardized form for collecting data about some of UniTO facilities, collected in the.

Building code	Building name	Main address	Municipality	Main use	Building type	Status
001_A	Palazzo del Rettorato	Via Verdi 8	Torino	"Uffici a supporto didattica e ricerca	Fabbricato	In uso
020_A	Palazzo Nuovo	Via Sant'Ottavio 20	Torino	Dipartimenti / Biblioteche / Aule / Uffici a supporto didattica e ricerca	Fabbricato	In uso
021_A	Palazzetto Aldo Moro	Piazzale Aldo Moro	Torino	Uffici a supporto didattica e ricerca / Aule / Dipartimenti	Fabbricato	In uso
029_B	Campus Luigi Einaudi	Lungo Dora Siena 100	Torino	Dipartimenti / Biblioteche / Aule / Uffici a supporto didattica e ricerca	Fabbricato	In uso
032_A-B-C	Centro Pier della Francesca	C.so Svizzera 185/Via Pessinetto 12	Torino	Dipartimenti / Aule / Magazzino / Rimessa / Uffici a supporto	Porzione di fabbricato	In uso
064_A	Torino SUISM	Piazza Lorenzo Bernini, 12	Torino	Aule/Uffici a supporto didattica e ricerca	Fabbricato	Dismesso

Specific applications of the proposed data integration system and AMS-app are described in the following subsections, including advantages and limitations. The case study selected as a demonstrator for such applications at the building level is the Campus Luigi Einaudi (CLE). The main facility of CLE is located in the northeast area of Turin, with a total net area of more than 36,000 square meters. The facility hosts the Department of Law, the Department of Political and Social Sciences, and the Department of Economics and Statistics "Cognetti de Martiis", hosting more than 500 research fellows. In addition, there are numerous administrative areas with around 100 administrative employees dealing with the management of spaces, people, contracts, and related bureaucratic matters. Furthermore, the CLE has 47 lecture halls and hosts around 16700 university users, so it represents a significant case study with a large catchment area and many activities within it.

3.2 Real estate asset management at territorial level

Real estate asset management at the territorial level deals with the storing and managing of data concerning the location, the type of building property (e.g. owned, rented from another institution or a private subject, partially owned or partially rented, etc.), the overall occupancy, the presence of listed buildings, and other facility

management data. This kind of data regarding UniTO facilities currently are stored in siloed documents or .xls files, preventing the integrated analysis needed to support decision-making processes. Thus, overall dashboards regarding the whole UniTO's real estate property are produced to investigate multiple data at once. The dashboard maps provide an overview of the entire territory over which UniTO buildings are distributed, useful to investigate data at a territorial level. All the views provided on the dashboard pages (e.g., maps, charts, graphs, and cards) are dynamic and interactive. A selection in one view, acts as a filter for all other views of the page or of the entire dashboard report, according to the specific requirements. The dashboards at the territorial level support the decision-making processes regarding the strategies to be pursued at a high level on the whole university facilities.

Figure 3 shows the dashboards at the territorial level with general data regarding UniTO real estate propriety. Other information, such as UniTO facilities under refurbishment and data concerning specific interventions or the listed buildings are visualized in other tailored dynamic dashboards, allowing an integrated analysis of the data and supporting complex decisions of the UniTO's administrative areas.

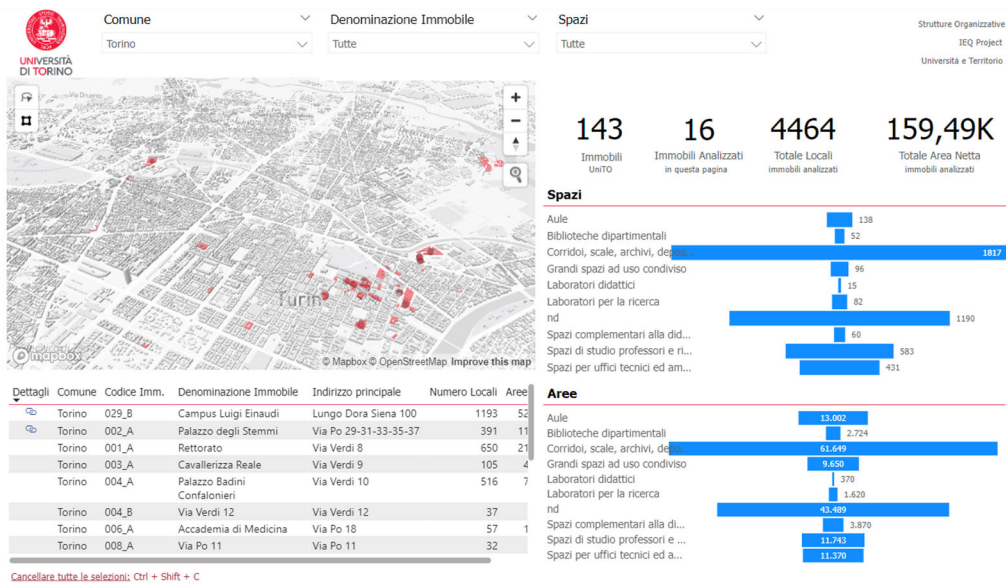


Fig. 3: AMS-app dashboard at territorial level regarding general data of UniTO real estate propriety.

3.3 Lecture hall spaces and teaching timetable management

Managing teaching spaces and, specifically, organizing lesson timetables, poses a multifaceted challenge. The problem is intricate due to the numerous and diverse variables involved, especially concerning CLE. Notably, the presence of various departments and their distinct methods of allocating the timetable adds to the complexity. Additionally, the extensive range of teaching hours dedicated to different subjects and the diverse nature of activities carried out further necessitate a highly varied schedule even within the same building.

The current process for creating class schedules and allocating spaces seems to be structured in stages, with three distinct directorates/offices involved. Firstly, the “*Educational Services Directorate*” supplies information regarding course enrolments, course codes, and academic credits assigned to each course. This data is then passed on to the “*Degree programs office*” which operates under the school's guidance, serving the departments and is tasked with creating the teaching timetable. Finally, a local branch of the “*Building Logistics and Sustainability Directorate*” is responsible for space allocation based on the received teaching timetables.

The entire process is characterized by fragmented data handling and manual switching between different software, which could increase the risk of errors. Thus, the primary objective was to consolidate the data into a single data analysis platform, ensuring more secure management and facilitating the analysis of teaching space utilization. To achieve this goal, a dashboard was developed, providing a comprehensive view of various data that would otherwise require gathering from three different offices. This single dashboard allows users to access information about the teaching spaces, including classroom names, room codes, capacity, classroom equipment, and net area. Moreover, the dashboard also offers insights into space utilization and teaching hours, enabling the estimation of the percentage of hours during which classrooms are booked, optioned, or available for use. This centralized and user-friendly approach streamlines data access and analysis, enhancing overall efficiency and accuracy in managing teaching spaces. Figure 4 illustrates the flexibility of viewing rooms in both 3-dimensional and 2-dimensional formats. Regardless of the chosen view, users have the option to select specific rooms and access detailed data. The interactive line graph enables direct interaction with the data, and users can also apply filters based on the building's floors. At the room level, the scheduled time for each room throughout the week, month, or year can be displayed, as depicted in Figure 5.

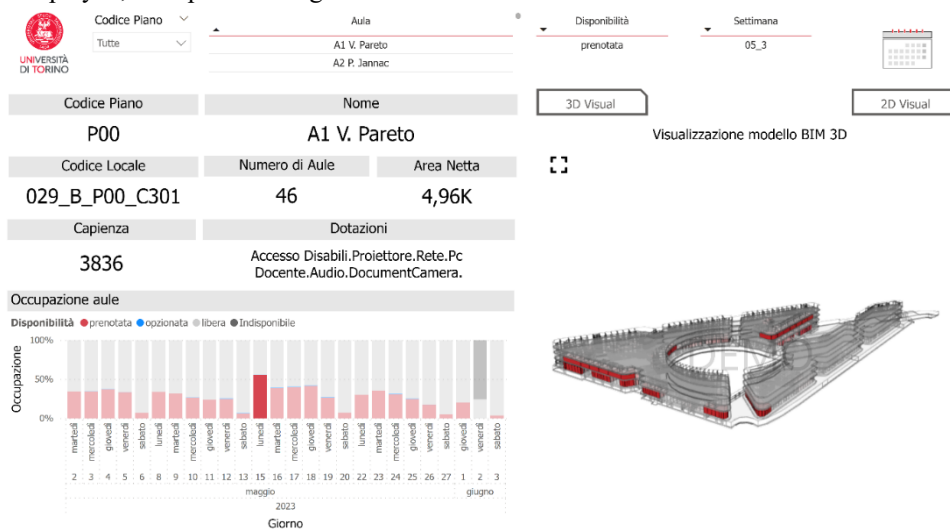


Fig. 4: AMS-app dashboard at building level with the analysis of lecture hall spaces and occupancy.

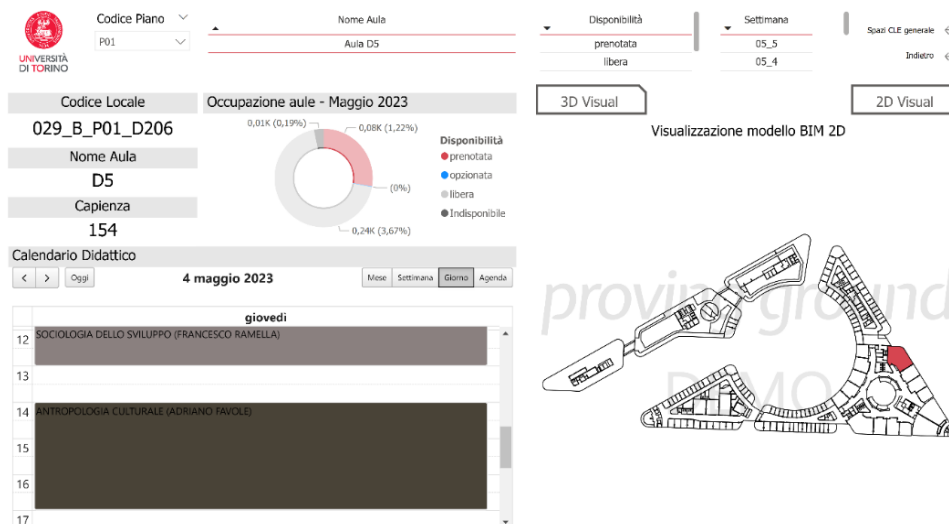


Fig. 5: AMS-app dashboard at room level allowing the analysis of lecture hall spaces, occupancy and timetable.

3.4 Real estate asset management at building level

Real estate asset management at the building level refers to multiple activities necessary to operate a facility and can include the following: people management including contract management, space and equipment allocation; space management including space allocation to the departments and areas hosted in each building. As of now building operation at UniTO is performed by the same departments or administrative staff hosted in each facility.

Except for space codes, the structure of which is common to all UniTO administration, all other space management information is managed locally by each building's space management staff. There is no central structure that manages all UniTO facilities at the space level.

The main objectives of this application are to support the decision-making processes regarding UniTO facilities, collect all the necessary information, and produce dashboards at the building level to investigate space, occupancy, and people management via BIM-GIS integration and BI technology. The data that are treated are the following:

- Space data regarding the location inside the building, area, and space typology;
- Allocation of spaces to the departments or administrative areas;
- Allocation of spaces to specific people and their role inside UniTO, contract typology, affiliation to a department or administrative area.

Figure 6 and Figure 7 show the AMS-app dashboard at the building level regarding all the spaces of CLE and the specific analysis of occupancy and staff allocation in the offices respectively.

Figure 6 allows the analysis via dynamic maps and charts of the spaces in terms of space typology and number of rooms, the allocation of the spaces to the departments or administrative areas, and single data points concerning the space net area and the number of rooms. The page allows the overall analysis of the building and the consultation of the general data regarding spaces, as well as the distribution of the space typologies on each building floor and the summary of the total building net area and number of rooms.

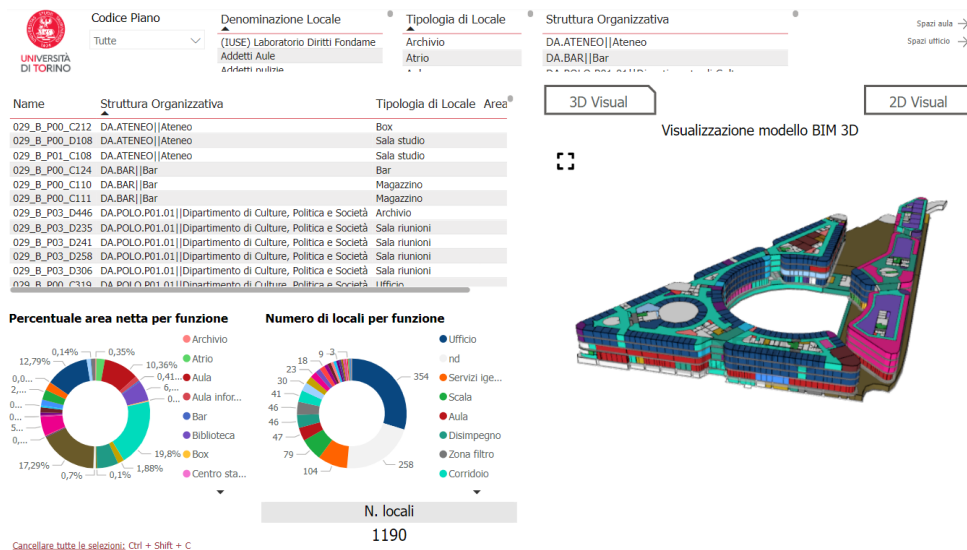


Fig. 6: AMS-app dashboard at building level allowing the analysis of space features and allocation of CLE.

Figure 7 enables a more specific analysis of the offices at CLE, including the percentages of area and staff assigned to each department and administrative area. A graph allows the comparison among the employee and research fellows allocated to the spaces and the maximum number of people that can be hosted according to the net area of each room, supporting the decisions related to the new staff that can or cannot be allocated in a space. In addition, an equal distribution of the spaces among departments and areas can be ensured based on the analyses

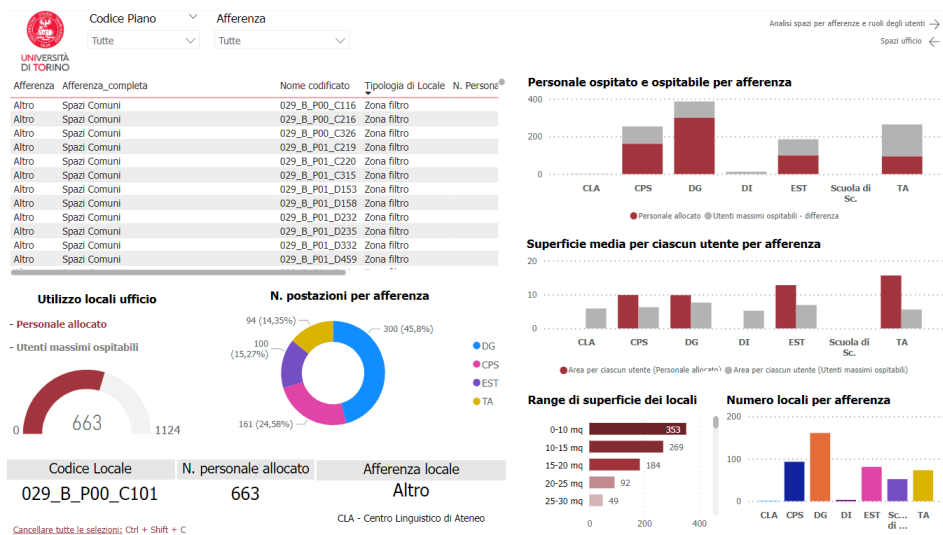


Fig. 7: AMS-app dashboard at building level with the detailed analysis of office and staff allocation at CLE

3.5 Space management improvement

Space management improvement in UniTO pilot case refers to the study of strategies to improve space occupancy, allocation, and usage with the introduction of work from home (WFH) practices. The contracts of professors, research fellows and PhD students already include flexibility as regards working hours and location, consequently, WFH is already allowed. On the other hand, concerning administrative employees, WFH practices have been introduced due to the recent COVID-19 pandemic events and then maintained for a total of two days a week. However, as of now, no improvement in space management has been introduced related to flexible work scheduling.

This application of the UniTO AMS-app aims at improving space management by hypothesizing a homogenous distribution of WFH days of the employees/researchers of the same office over the working week. As a consequence, the maximum occupancy of a single office can be increased. All the occupants are never present in the office at the same time, while WFH days are planned so that in each day of the week a certain number of office occupants work at home. As a results, the overall occupancy in a building can be increased. Considering two days a week of WFH for each worker in a five-day working week, the overall occupancy of the building increases by around 60% (Figure 8). This ensures that in the case of recruitment, workstations are already available in the existing facilities, without the need of acquiring or renting new spaces.

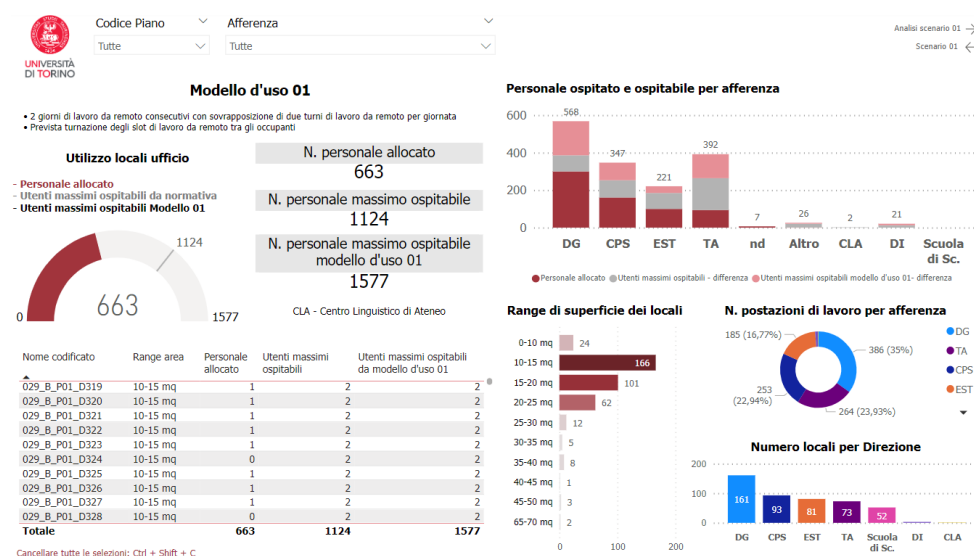


Fig. 8: AMS-app dashboard analyzing space allocation and current number of occupants, the maximum capacity of each space, and the maximum one with WFH and strategies to improve CLE space usage.

3.6 Indoor environmental quality monitoring and optimization

Monitoring data related to environmental quality data monitoring within educational spaces is of utmost importance. It serves two primary purposes: ensuring a healthy learning environment for conducting lessons and detecting any anomalies that may indicate system faults or the need for system remodeling. This approach also contributes to energy conservation and the reduction of heating and cooling systems' emissions. Over the past two years, several UniTO's buildings have been equipped with IEQ sensors. Among these, the CLE buildings serve as an excellent testing ground for evaluating the effectiveness of these systems due to the high number of sensors and the presence of classrooms with different capacities and orientations. UniTO has chosen IoT devices from Aircare® that can capture 15 types of measurements, including air quality, environmental comfort, and electro-smog indicators. Notably, the devices' accuracy and reliability have been scientifically validated by the Italian Society of Environmental Medicine (SIMA) for PM_{2.5} and CO₂ measurements. A total of 39 IoT devices were strategically installed across 37 classrooms within the CLE, focusing on the ground and first floors, dedicated to teaching activities. Once installed, the data generated by these devices was directly streamed to a cloud platform, facilitating data collection. The collected data are accessible through reports, providing valuable information via an experimental platform managed by the ICT directorate, and at this stage data aren't shared publicly or with other directorates.

The objective was to optimize the AMS-app potential by linking the data to specific spaces and creating interactive dashboards to display real-time data from the continuously flowing information from the IoT devices. To maximize the advantages of measuring multiple types of data with a single IoT device, it was decided to associate viewable spaces with data related to CO₂, CO₂e, VOC, PM₁₀, and PM_{2.5}. A dashboard was developed to integrate the data with floor plans, clearly indicating the locations of installed sensors in the respective classrooms. By selecting a specific classroom, users can readily access and visualize the recorded values throughout the week (Figure 9).

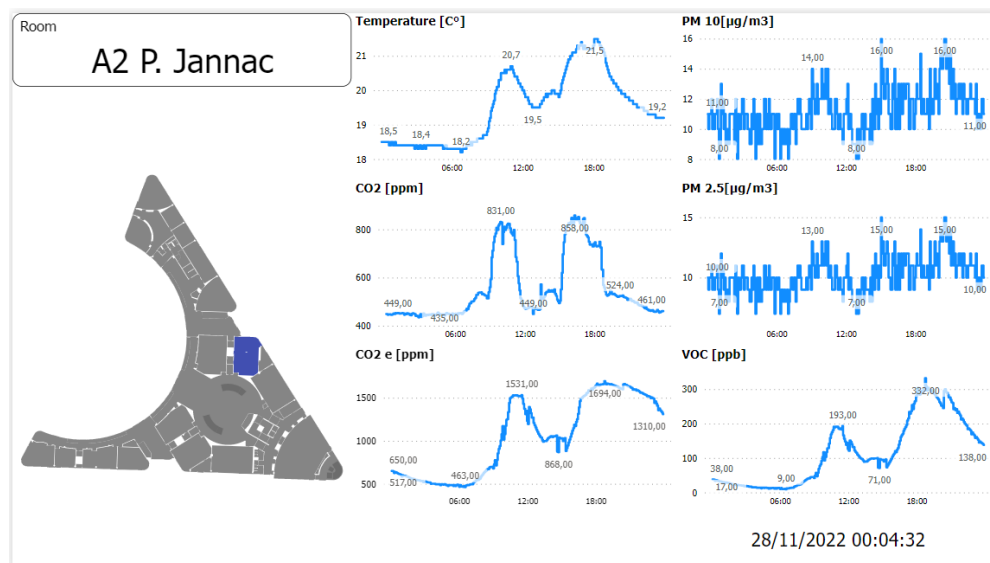


Fig. 9: AMS-app dashboard at room level allowing the visualization of spaces and data acquired from sensors.

To serve as alert indicators, specific limit values were established for the main parameters. During the heating season, temperature values between 20 and 22 degrees Celsius were selected, while for the cooling season, the range was set between 22 and 24 degrees Celsius. The CO₂ concentration threshold was defined at 1000 parts per million (ppm). As for particulate matter, the limit values suggested by the World Health Organization were adopted: below 25 µg/m³ for PM₁₀ and below 50 µg/m³ for PM_{2.5}. Furthermore, for volatile organic compounds (VOCs), the limit of 550 parts per billion (ppb) was chosen, following the guidelines of the US Environmental Protection Agency (EPA). This solution offers various advantages: firstly, it allows immediate visualization of the data collected by IoT devices and their correlation with specific spaces; secondly, it facilitates the analysis of recorded anomalies in relation to occupancy and class schedules of those spaces. This comprehensive approach provides valuable insights for maintaining a healthy and optimized teaching environment.

4. CONCLUSIONS AND FURTHER DEVELOPMENTS

The paper illustrated the research conducted under the umbrella of the UniTO's strategic plan, aimed at developing an AMS-app to optimize the management of one of the largest university assets in Italy. The replicable methodology developed for the definition of the app and its implementation in the organizational system was illustrated. The BIM-GIS-BI integration enabled to systemize the various information currently siloed managed, providing an integrated decision-support tool accessible starting from the territorial level to the single building and component. Through the illustration of several case studies implemented so far on selected buildings, the potential of this management system was illustrated, also highlighting the difficulties encountered and the margins for improvement. Such a system is easily replicable and showed true potential in being able to manage the available resources optimally and consciously. Both in terms of space and economics, it also allows for the optimized management of facility services and improved IEQ performance for the end-user experience, leading to effective and sustainable management. In the future, information protocols and guidelines will be developed for the proper adoption of such an AMS and the correct definition of the IRs. Furthermore, it is envisaged that the management processes currently underway will be reviewed in consultation with the heads of the technical-administrative areas aiming at the optimal adoption of the system, as well as the implementation of a data-sharing system exploiting a data lake from which to extrapolate the targeted information, identified based on the management processes and the defined IRs.

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