ANNEX 81

EBC
Energy in Building and Communities Programme

International Energy Agency

A Guide on Data Platforms for Data-Driven Smart Buildings

Energy in Buildings and Communities Technology Collaboration Programme

November 2023

Technology Collaboration Programme
by iea

ANNEX **81**

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A Guide on Data Platforms for Data-Driven Smart Buildings

Energy in Buildings and Communities Technology Collaboration Programme

November 2023

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 30 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes (TCPs). The mission of the IEA Energy in Buildings and Communities (IEA EBC) TCP is to support the acceleration of the transformation of the built environment towards more energy efficient and sustainable buildings and communities, by the development and dissemination of knowledge, technologies and processes and other solutions through international collaborative research and open innovation. (Until 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.)

The high priority research themes in the EBC Strategic Plan 2019-2024 are based on research drivers, national programmes within the EBC participating countries, the Future Buildings Forum (FBF) Think Tank Workshop held in Singapore in October 2017 and a Strategy Planning Workshop held at the EBC Executive Committee Meeting in November 2017. The research themes represent a collective input of the Executive Committee members and Operating Agents to exploit technological and other opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy technologies, systems and processes. Future EBC collaborative research and innovation work should have its focus on these themes.

At the Strategy Planning Workshop in 2017, some 40 research themes were developed. From those 40 themes, 10 themes of special high priority have been extracted, taking into consideration a score that was given to each theme at the workshop. The 10 high priority themes can be separated in two types namely 'Objectives' and 'Means'. These two groups are distinguished for a better understanding of the different themes.

Objectives - The strategic objectives of the EBC TCP are as follows:

– reinforcing the technical and economic basis for refurbishment of existing buildings, including financing, engagement of stakeholders and promotion of co-benefits;
– improvement of planning, construction and management processes to reduce the performance gap between design stage assessments and real-world operation;
– the creation of 'low tech', robust and affordable technologies;
– the further development of energy efficient cooling in hot and humid, or dry climates, avoiding mechanical cooling if possible;
– the creation of holistic solution sets for district level systems taking into account energy grids, overall performance, business models, engagement of stakeholders, and transport energy system implications.

Means - The strategic objectives of the EBC TCP will be achieved by the means listed below:

– the creation of tools for supporting design and construction through to operations and maintenance, including building energy standards and life cycle analysis (LCA);
– benefitting from 'living labs' to provide experience of and overcome barriers to adoption of energy efficiency measures;
– improving smart control of building services technical installations, including occupant and operator interfaces;
– addressing data issues in buildings, including non-intrusive and secure data collection;
– the development of building information modelling (BIM) as a game changer, from design and construction through to operations and maintenance.

The themes in both groups can be the subject for new Annexes, but what distinguishes them is that the 'objectives' themes are final goals or solutions (or part of) for an energy efficient built environment, while the 'means' themes are instruments or enablers to reach such a goal. These themes are explained in more detail in the EBC Strategic Plan 2019-2024.

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*) and joint projects with the IEA Solar Heating and Cooling Technology Collaboration Programme by (☼):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: ☼ Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: ☼ Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: ☼ Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: ☼ Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO2 Equivalent Emissions for Building Construction (*)

Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
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Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - HVAC Energy Calculation Methodologies for Non-residential Buildings (*)
Working Group - Cities and Communities
Working Group - Building Energy Codes

Summary

As the demand for more intelligent and sustainable buildings continues to increase, the integration of advanced technologies and innovative approaches becomes of great importance to optimise building operational and energy efficiency while achieving acceptable levels of occupant comfort. This report presents a comprehensive exploration of modern data platforms and their central role in transforming buildings into smart, data-driven entities. It delves into essential aspects crucial for the successful adoption and deployment of these platforms within the building's data-driven infrastructure. The following key points summarize our findings.

Transition to data-driven smart buildings
The transition from conventional to data-driven buildings constitutes a huge leap forward to achieve smart buildings. This transition allows buildings to move from static structures to dynamic, responsive, smart entities capable of delivering the desired outcomes of enhanced user experiences, operational efficiency, and sustainability. The core enabler to achieve smart buildings are modern data platforms.

Holistic approach for success
To unlock and realise the true potential of smart buildings orchestrated by data platforms, a comprehensive strategy is needed. Such a strategy should embrace a holistic approach, including smart readiness assessment, meticulous establishment of requirements for the data platform, and strategic deployment of the data platform into the building's data-driven infrastructure.

Smart readiness assessment
The basic steps to assess a property's smart readiness involve an exhaustive analysis of technical documentation and physical inspections across different hierarchical levels. Advanced assessments, such as the European Smart Readiness Indicator, are designed to uncover a building's latent, true smart potential.

Procurement considerations
To succeed selecting a purpose-fit data platform, it is essential to consider the minimum set of requirements that enable reaching the goals tailored for data-driven smart buildings. These set encompasses both functional and non-functional requirements. The former focus on the platform's data processing capabilities. The latter plays a vital role in determining the efficiency and effectiveness of the data platform. These set of requirements are presented and described in this report.

Strategic deployment
Meticulous planning and execution are vital for deploying data platforms seamlessly within the buildings' data-driven infrastructures. Onboarding the building into the platform is a crucial step, enabling data acquisition, and providing a unified view of the building's data-driven infrastructure for data-consuming applications.

Industry-centric perspectives
For building owners and managers, aspects related to smart readiness assessment, procurement, and platform deployment are paramount for achieving true data-driven smart buildings. Meanwhile, platform creators must focus on developing robust data processing capabilities, including effective sharing for third-party applications.

In conclusion, this report highlights the need for a unified approach to leveraging modern data platforms for the real estate industry. A comprehensive strategy that combines products, technology, processes, and people enables not only successful implementation but also continuous optimal operation, unlocking the full potential of data-driven smart buildings.

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Abbreviations

Abbreviations	Meaning
AI	Artificial Intelligence
AMQP	Advanced Message Queuing Protocol
API	Application Programming Interface
BAC	Building Automation and Control
BACnet	Building Automation and Control Networks
BACS	Building Automation and Control System
BIM	Building Automation Modelling
BMS	Building Management System
BOS	Building Operating System
CM	Communication Module
CMMS	Computerised Maintenance Management Systems
CO2	Carbon Dioxide
COBie	Construction Operations Building Information Exchange
CP	Communication Processor
DALI	Digital Addressable Lighting Interface
DR	Demand Response
EMOS	Edge Management and Orchestration System
EMS	Energy Management System
EOL	End of Life
ERP	Enterprise Resource Planning
GDPR	General Data Protection Regulation
HVAC	Heating, Ventilation, and Air Conditioning
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
I/O	Input/Output
IoT	Internet of Things
IP	Internet Protocol
M-Bus	Meter-Bus
MQTT	Message Queuing Telemetry Transport
OP4BA	Open Platform for Building Automation
OPC UA	OPC Unified Architecture
PAC	Programmable Automation Controller
PKI	Public Key Infrastructure
PLC	Programmable Logic Controller
PV	Photo Voltaic
REC	Real Estate Core

SCADA	Supervisory Control and Data Acquisition
SDK	Software Development Kit
TM	Technology Module

1. Introduction

The recent coronavirus pandemic highlighted the importance of flexibility, safety, and occupant satisfaction in buildings. A range of other challenges also exist for building owners and managers. In the Nordics and Baltics[1], interviewed building owners and managers refer to (unnecessary in many cases) high operational costs due to (i) inefficient heating, ventilation, and air conditioning (HVAC) systems, (ii) increasingly amount of electrified assets, and (iii) leakages in water pipes and excessive water consumption because of poor monitoring capabilities. Moreover, according to the 2022 Global Status Report for Buildings and Construction[2]: (i) the "buildings and construction sector is not on track to achieve decarbonization by 2050", and (ii) "the gap between the actual climate performance of the sector and the decarbonization pathway is widening". In other words, operational inefficiency at building level not only drives owners' costs unnecessarily up, but also has a negative environmental impact at worldwide level, for all of us.

One key action for achieving the highly beneficial effects on carbon dioxide (CO2) emissions reduction, supported by scientific evidence[3], is to increase energy efficiency. And a well-accepted, almost de facto, key enabler for achieving energy efficiency is the digitalisation of our buildings[4].

The increasing adoption of technological advances, both well-established and emerging technologies, by the construction sector and building owners is enabling more and more buildings to become increasingly intelligent, efficient, and even interconnected. This transformation is what often characterizes buildings as *smart buildings* (Chamari, o.a., 2023), where data and technology work in unison to enhance performance and sustainability. Together, data and technology enable smart buildings to manage itself efficiently, be able to interact with and respond to their occupants, and be able to actively and passively interact with the grid (Märzinger & Österreicher, 2019). As a result, buildings are evolving into complex ecosystems that require careful coordination and governance. Modern data platforms tailored for data-driven automation and control of buildings, referred to as 'data platforms' throughout this document, play a central role in these tasks.

1.1 Modern Data Platforms

In essence, modern data platforms function as a unified software foundation, offering two primary capabilities: data brokerage and data processing. These capabilities drive a foundational four-step process continually executed by the platform. The first step refers to leveraging the platform's extensive integration capabilities to ingest data from a wide range of integrated primary data sources. These primary sources encompass various systems and devices within the building, and even external systems and services. Common primary data sources within the building include metering infrastructure, sensors, and essential building systems, often controlled by a Building Automation System (BAS), sometimes also referred to as a Building Management System (BMS). The controlled building systems span heating, ventilation, air conditioning, cooling, energy management, lighting, shading, occupant safety, and more (Domingues, Carreira, Vieira, & Kastner, 2016). Common external primary data sources include online databases and services that offer information such as weather data and electricity prices.

[1] Digitalization of Buildings in the Nordics & Baltics [Telia]
[2] 2022 Global Status Report Buildings and Construction released at the latest round of climate talks in Egypt, COP27 [UN environment programme]
[3] Multiple Benefits of Energy Efficiency [IEA]
[4] Energy Efficiency and Digitalisation [IEA]

Following data acquisition, the platform ensures seamless, regulated data sharing (White, o.a., 2023) with value-adding applications and other data processing workflows that operate on the platform. These applications and workflows actively process the shared data, yielding fresh insights and valuable information in the form of result data. Subsequently, this data may be sent back to the integrated sources, facilitating control adjustments and fine-tuning of settings for optimal performance.

In this document and context, modern data platforms will ideally feature most of the following characteristics:

- Openness
- Flexible deployment model
- Evolvable
- Robust data management capabilities, including privacy and integrity
- Robust security model, optimally based on *zero trust* principles
- Wide connectivity capabilities
- App-friendly
- Regulations compliancy

Openness is a crucial key enabler in building-related ecosystems for many reasons. First, it enables interoperability by enabling a two-way communication and collaboration – *platform to integration* (integrated systems and devices), and *integration to platform* – in a vendor-agnostic way, by means of open protocols and open standards. Second, it helps avoid vendor lock-in – by keeping that two-way interoperability between the platform and other systems and devices as they evolve driven by new technological and organisational advances. Third, it fosters innovation and competition – by providing functionality extension capabilities, for instance by means of Application Programming Interfaces (APIs) and Software Development Kits (SDKs), that allows third-party actors to create smart applications and even platform-internals artefacts (Teixeira, 2015). Fourth, it contributes to turn data into actionable insights – by providing access to building data to analytics and other smart applications through standardised data models and APIs. Finally, it allows building owners to tailor the platform deployment to their needs – by providing customisation capabilities, again by means of APIs and SDKs.

Flexible deployment model enables these platforms to overcome three important challenges. First, it allows platforms to be deployed to buildings of different sizes, purposes, complexity, and with specific requirements. Second, it makes it easier to integrate with a wide range of systems, devices, and technologies, because the platform is designed to be able to co-exist in an ecosystem. Third, it allows organisations to choose what platform components to deploy on-site (building), on-edge (closed to the building), the organisations intranet (including private cloud), and on-cloud (meaning public cloud).

Evolvable platforms are designed with adaptability in mind. This essential characteristic facilitates the platform vendor to (i) incorporate technological advances, including new protocols, (ii) support new devices, (iii) comply with new standards, (iv) introduce new practices, (v) keep the platform product relevant, competitive and secure, (vi) handle increasing complexity, and (vii) test new features and/or functionalities in a near- or even fully non-intrusive way (e.g., via *feature toggling*); then, based on the gathered validated learning (Ries, 2011), decide whether to (or not to) add them to the platform product. From the building owner’s perspective, evolvability is crucial because it allows them to start small, or alternatively start purpose-fit, and then enrich/extend the platform deployment as budget permits, or/and new needs arise. Another benefit for building owners is less hassle to replace parts of, or even the whole platform, which is especially important in the event of the platform, or parts of it, reaching its *End of Life* (EOL). In its fundamental form, evolvable platforms contribute to the buildings’ adaptive capacities in response to changing conditions over their lifecycle (Askar, Braganca, & Gervasio, 2021).

The task of replacing parts of, or even the whole platform is greatly simplified by having an abstracted, higher-level representation of the building instead of just a list of hardware and software systems (Delgoshaei, Heidarinejad, & Austin, 2022).

Data management capabilities are essential for ingesting, protecting, storing, processing, and analysing data. This data enables actionable insights for purposes like optimizing energy usage and enhancing occupant comfort. Key functions include safeguarding data privacy and integrity against unauthorized access and cybersecurity threats. In essence, data management significantly impacts a building's smart capabilities (Zhang, Lv, Chen, & Hu, 2021).

Zero trust is a modern security approach based on the principle: never trust, always verify (Ray, 2023). A security model based on zero trust assumes that no device or user should be trusted by default, regardless of their location. Constant authentication, and authorisation of devices, systems, and users is required. Constant monitoring throughout the platform, together with all interactions with external systems, is performed. A platform running such a security approach significantly strengthens its capability to withstand cyberattacks aimed at compromise the platform, the building, the occupants, and/or data (user and non-user data).

Wide connectivity capabilities are crucial in today's increasingly amount of interconnected and more intelligent buildings. These capabilities allow, among others: (i) integration of and communication with a wide range of devices, including IoT-specific, (ii) integration of and communication with other systems, ranging from organisation-related (e.g., project management, and enterprise resource planning (ERP)), to technical systems (e.g., photo voltaic- (PV), and demand-response-related (DR) systems), (iii) remote and/or mobile-based monitoring, and in some cases even control, of the building, and (iv) edge- and/or cloud-based deployments.

App-friendly platforms allow building owners and managers to deploy both third-party and own applications within the platform to (i) enrich the platform with more capabilities, such as specialised energy analytics, (ii) ease customisation of the platform according to their specific needs, and even (iii) enhance the performance and efficiency of the governed building systems. Platforms featuring the ability to deploy applications from a (or several) marketplace(s) also contributes to the new data economy (Sestino, Kahlawi, & De Mauro, 2023), together with fostering innovation and collaboration within the platform ecosystem – with application developers competing with each other, and building owners, managers and/or system integrators selecting those applications that best fit their needs. Platforms with this ability will typically provide SDKs and developer-oriented tools to ease the creation of applications, together with marketplace-oriented business models that makes developing applications a lucrative business.

Regulatory compliance is an essential characteristic of modern platforms for building automation for many reasons. It ensures legal adherence, promotes safety and security, supports energy efficiency and sustainability, enables interoperability, protects data privacy and security, and enhances trust and reputation. At platform design time, platform vendors may be subject to comply with certain regulations to be able to target specific markets. Once deployed, at operational time, the ability to extend a platform to comply with new regulations or changes to present ones ensures future-proofing.

1.2 This Document

This document is designed to provide valuable insights and guidance for individuals and organisations looking to leverage the potential of modern data platforms for data-driven smart buildings. As the demand for smart and sustainable buildings continues to increase, these platforms are considered a key enabler, promoting interoperability, scalability, and flexibility for efficient and intelligent monitoring, automation, and control of buildings.

The main objective of this document is to demystify the concept of data platforms for data-driven smart buildings, and to provide the reader with a clear understanding of their benefits, challenges, and best practices currently available on this subject. The document does that by examining key steps connected to the adoption and even enhancement of such platforms, including smart readiness assessment, procurement considerations, and deployment guidance. Equipped with that information, this guide aims to help building owners, managers, and technical personnel make informed decisions that ultimately lead to higher energy efficiency, occupant comfort, and sustainability in buildings. This document may also serve as a valuable resource for platform creators who seek to offer relevant products and services within the rapidly transforming and evolving realm of intelligent buildings.

The document is divided into **four sections that can be read individually**. Each section provides guidance on a key aspect related to the adoption, deployment, and even development of data platforms:

- **Smart Readiness Assessment**. This section aims to provide building managers and other building personnel introductory guidance and practical advice to assess the status of their building's existing data-driven infrastructure in connection to any efforts pursuing infrastructure enhancements and/or increasing effectivity. By conducting a comprehensive assessment, it should be easier to identify key areas where modern data platforms can bring significant improvements and benefits to the management of buildings. The assessment's result may also serve as a valuable resource when planning integration efforts.
- **Procurement Considerations**. This section aims to provide introductory guidance on the process of selecting the most suitable platform for the specific needs. It focuses on the description of a minimum set of requirements to be met by modern data platforms for data-driven smart buildings.
- **Technical Notes**. This section delves into key technical aspects of data platforms, including important architecture and data processing characteristics. Further on, it also provides indicative suggestions on building blocks and software modules that platforms may feature to achieve the introduced architecture and deployment goals.
- **Deployment Guide**. This section aims to provide guidance on the key phases of a deployment process tailored to data platforms for data-driven smart buildings.

The content of the four sections constitutes a synthesis of the authors' and contributors' existing domain knowledge, enriched by new insights drawn from the review of the latest advancements, emerging industry trends, research, and best practices documented in reputable sources. Hopefully, this document will help stakeholders understand and benefit from the potential of modern data platforms for data-driven smart buildings.

Note: The mention of specific organisations in this report is for informational purposes only and does not constitute an endorsement, recommendation, or favouritism. Moreover, the views and opinions expressed in this report do not necessarily state or reflect those of the organisations mentioned.

2. Smart Readiness Assessment

In this chapter, we introduce assessing the smart readiness of buildings. This introduction is divided into two key blocks: "Basic Steps" and "Advanced Assessment." These steps aim to provide a detailed understanding of a building's capacity for smart technology integration, allowing building owners, managers, and other stakeholders to make informed decisions.

2.1 Basic Steps: Laying the Foundation

These steps address the essential groundwork for a comprehensive evaluation, facilitating the gathering of crucial data regarding the building's infrastructure. Upon completion of these basic steps, a preliminary understanding of the building's readiness for smart technologies should have emerged.

2.1.1 Technical Documentation Retrieval

To effectively assess the status of existing building automation infrastructure, it is crucial to begin by gathering all relevant system documentation, such as system engineering diagrams, equipment manuals, network diagrams, maintenance and support practices, maintenance history records, and planned future (preventive) maintenance schedules and inspection routines.

2.1.2 Technical Documentation Analysis

This step delves into the comprehensive gathered technical documentation of the building to gain a deep understanding of its underlying infrastructure. This detailed analysis forms the cornerstone of assessing your building's readiness for the integration of digital technologies.

Key components to consider during this step include, but are not limited to:

- **Control panels and equipment** – Central to managing the critical building functions like ventilation and indoor climate.
- **Sensors and actuators** – Fundamental for monitoring and control, enabling the building to react to changing conditions. They gather real-time data and enact responses to create a smarter, more efficient building.
- **Communication devices** – Crucial for efficient connectivity across the building’s infrastructure.
- **Wiring infrastructure** – Vital for reliable power and data transmission across the building’s infrastructure.
- **Wireless infrastructure** – Wireless technologies like Wi-Fi and Bluetooth ensure mobility and connectivity throughout the building. Mobile devices, and commonly IoT devices, rely on wireless infrastructure for seamless communication.
- **Power supply and backup systems** – Essential not only for providing uninterrupted power to critical building systems but also for managing grid interactions. Uninterruptible power supplies (UPS)

and backup generators offer emergency power during outages, ensuring continuous operation. They also play a crucial role in grid interactions by enabling demand-response strategies and contributing excess power back to the grid when appropriate.

- **Installed systems and platforms** – Including the data platform, energy management systems (EMSs), building automation and control systems (BACSs), and building management systems (BMSs), all contributing to the building's intelligence, and even potentially facilitating grid interactions.

For data platforms, the analysis should go a step further to consider specific aspects, such as:

- **Existence** – Determine whether the building is equipped with a data platform.
- **Purpose(s)** – Identify the intended functions of the data platform, such as data brokerage, data processing, coordination, and governance of integrated building systems.
- **Components and locations** – Investigate whether the data platform comprises multiple interconnected components, potentially deployed to various locations, such as a cloud-based component and an edge node within the building.
- **Building Operating System (BOS)** – Assess whether the data platform can function as a *building operating system*, enabling the installation and operation of third-party applications, similar to popular computer operating systems like Microsoft Windows or Linux distributions.
- **Digital representation** – Evaluate the data platform's capabilities to create and maintain a digital representation of the physical building, encompassing equipment, systems, and data-driven infrastructure.
- **Semantic model** – Consider whether the digital representation relies on a semantic model. If yes, check whether the semantic model is based on an existent building-related metadata schema or ontology, such as BRICK and Real Estate Core (REC).
- **IoT Integration** – Examine the data platform's support for Internet of Things (IoT) technologies and their integration.
- **Interoperability** – Investigate the protocols, information models, and data formats currently in use or planned for use within the data platform.
- **Security** – Analyse the security controls in place to protect sensitive data, maintain operational integrity, and safeguard building automation systems against potential threats and vulnerabilities.

2.1.3 Physical Inspection

The next step is to conduct a thorough physical inspection of the building’s infrastructure, aligning the observations with the previously collected documentation. This step is not only crucial for making informed decisions about repairs, replacements, or upgrades, but it also serves several other purposes. These include identifying inefficiencies within the infrastructure, ensuring compliance with safety and environmental regulations, effective building asset management, and evaluating the performance of existing systems.

It's important to note that a building's infrastructure can be examined from various perspectives. For the purposes of this document, two perspectives are particularly relevant: the *automation-oriented* perspective, and the *data-driven-oriented* perspective. The automation-oriented perspective divides the building's infrastructure in the following six layers: *corporate extranet*, *corporate intranet*, *edge*, *supervisory* (also referred to as *information* layer), *automation* (also referred to as *field controller* layer), and *field* (also referred to as *input/output* layer). The data-driven-oriented perspective divides the building's infrastructure in the following four layers: *application*, *data*, *network*, and *device*. Refer to Boundaries of the Data Platform for further details about these four layers.

For the specific purpose of conducting a thorough physical inspection, the automation-oriented perspective is especially beneficial, as it provides a detailed understanding of the building's operational systems. The figure below illustrates this perspective, including examples of typical components commonly-found within each of the tiers of the hierarchy. It also indicates commonly-found deployment locations where layer and components may be located.

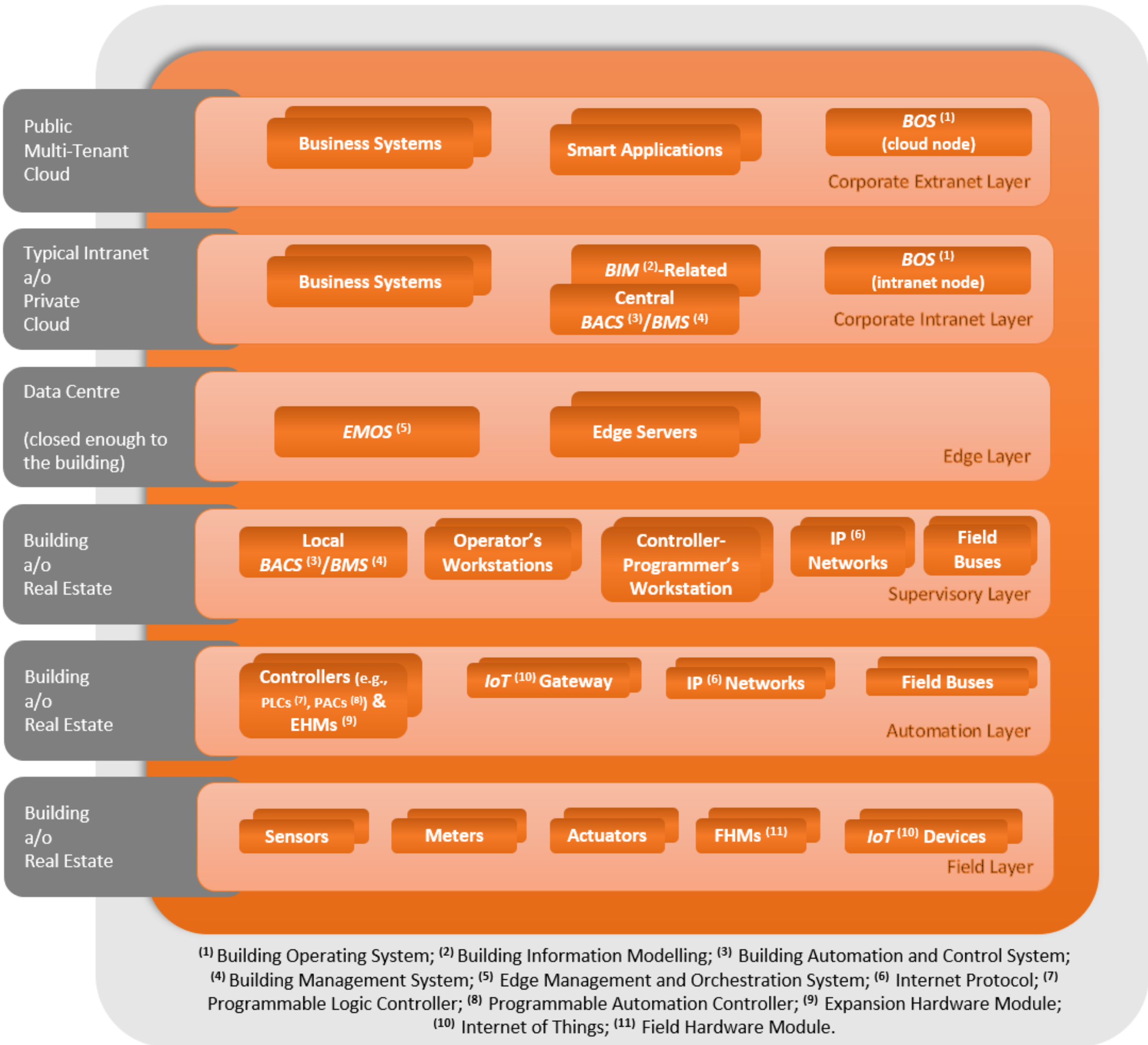

Figure 2.1.3: Automation-oriented perspective of a building's infrastructure. The dark grey boxes indicate commonly found deployment locations for the different tiers and their components.

Edge location and edge devices. Note that the edge location may have different interpretations or uses within this context. Here are a few potential variations:

- Physical building locations: Some may use "edge location" to refer to specific physical locations within the building where edge devices are deployed. These edge devices are positioned close to the building's equipment or sensors to process data locally and reduce latency.
- Network segmentation: "Edge location" could also be associated with the practice of dividing the building's network into segments, with the edge location being the segment closest to the building's perimeter. This segmentation can be used to manage data flow and security.
- Edge computing infrastructure: In the context of edge computing, "edge location" might signify the deployment of computing resources (servers or nodes) outside the building's (or even real estate's) perimeter, however close enough to it, enabling faster data processing and reduced reliance on distant data centres or the cloud.

Throughout this document, unless otherwise specified, references to 'edge location' primarily pertain to the third interpretation, denoting 'edge computing infrastructure'.

Regarding edge devices, some may use this term to specifically refer to Internet of Things (IoT) devices that are deployed within the building's perimeter, particularly those that collect and process data at the source.

2.2 Advanced Assessment: Unveiling Smart Potential

Once the foundational steps are concluded, the tools and methods introduced in this section enable a more detailed and comprehensive evaluation of the building's smart readiness.

2.2.1 Smart Readiness Indicator

The European Smart Readiness Indicator (SRI) functions as an essential tool for this purpose, offering insights into a building's capacity to leverage the advantages of digital technologies. The SRI will enhance understanding of the advantages offered by smart building technologies, which encompass aspects like building automation and electronic supervision of building systems, including but not limited to heating, hot water, ventilation, lighting, and more[5].

It is essential to recognize that while the SRI is a valuable tool, other similar assessment methods and indicators may exist, and their suitability might vary according to the regional and contextual specifics. Building assessments for smart readiness are not confined to a single approach, and global variations exist in terms of applicable tools and methodologies. Therefore, in some areas, alternative methods might be used to achieve the same goal.

The European SRI methodology adopts a multi-level approach founded on impact criteria, domain services, and functionality tiers. As of the drafting of this document, the prevailing European SRI framework encompasses seven primary impact criteria, including energy savings, grid adaptability, comfort, convenience, health, maintenance, fault prediction, and information provision to occupants. Additionally, there are nine domain services covering aspects like heating, cooling, domestic hot water, controlled ventilation, lighting,

[5] What is the SRI? – Energy, Climate change, Environment – European Commission

dynamic building envelope, on-site renewable energy generation, electric vehicle charging, and monitoring and control.

Each of these services exhibits varying degrees of smartness, represented by several functionality levels. For example, functionality level 0 signifies a non-smart service implementation, whereas the highest level (ranging from 2 to 5 depending on the service) indicates advanced functionality, typically demand-based control. For instance, let's consider the 'heat emission control' service, which encompasses five distinct functionality levels from 0 to 4. These levels correspond to configurations like 'no automatic control,' 'central automatic control,' 'individual room control,' 'individual room control with communication between controllers and the building automation control system (BACS),' and 'individual room control with communication and presence control.' In contrast, the 'thermal energy storage' service offers three levels, ranging from 0 to 2, reflecting operational modes like 'continuous,' 'time-scheduled,' and 'load prediction-based' storage.

Smart services can have diverse impacts on occupants, the building itself, and the grid. These impacts are categorized according to the aforementioned impact criteria. However, it's important to note that certain domain services may be irrelevant for specific criteria, and some services might be mutually exclusive. Furthermore, the identification of relevant services can be established through a triage process, defining a priority scheme. In addition to the services included in the aforementioned domains, there is an 'other' domain that encompasses services currently considered beyond the scope or insufficiently mature for inclusion.

The procedure for the SRI assessment involves a two-fold process. First, an inventory of the smart-ready services present in the analysed building must be conducted using a simple checklist approach. Subsequently, the Smart Readiness Indicator (SRI) is calculated using a multi-criteria assessment method. A thorough inventory is essential to ensure the accuracy of the evaluation (Vigna, Pernetti, Pernigotto, & Gasparella, 2020). The Basic Steps block, as described earlier in this chapter, can prove invaluable in this context.

2.2.2 Other Initiatives

While the European Smart Readiness Indicator (SRI) is a notable effort in assessing smart readiness, there are other worldwide initiatives that either wholly or partially address this aspect, or at least consider it within their frameworks. These initiatives encompass various approaches such as rating schemes, standards, tools, and guidance. Rating schemes often lead to associated certifications, underlining the significance of these assessments in verifying a building's smart technology readiness. Here are a few examples for informational purposes.

> Different sources of support and interests drive the development and implementation of these initiatives. Some are backed by **non-profit** organisations, others by **profit-for-purpose** entities, and the rest by **for-profit** organisations.
>
> **Note** – The mention of specific organisations in this report is for informational purposes only and does not constitute an endorsement, recommendation, or favouritism. Moreover, the views and opinions expressed in this report do not necessarily state or reflect those of the organisations mentioned.

WiredScore and **SmartScore** – Together, these certifications aim to prove the buildings' digital capabilities. WiredScore rates a building's digital infrastructure. On the other hand, SmartScore rates the building's ability to seamlessly integrate data and systems to enhance the overall experience for occupants. The WiredScore certification for offices measures key aspects of the building's digital capabilities, such as its ability to adapt to future technologies, resilience, mobile, choice of providers, and even the overall quality of the user experience.

The WiredScore certification for homes measures key aspects, such as connectivity, and the range, flexibility, and quality of available services. SmartScore certification is aligned with WELL Certification, LEED Certification, and BCA Singapore. Both WiredScore and SmartScore certifications are backed by the for-profit organisation WiredScore.

NBI (New Buildings Institute) **GridOptimal Buildings Initiative** – This initiative provides standards, tools, and guidance to improve building-grid interactions in the built environment by empowering owners, architects, and engineers with dedicated metrics, strategies, and pilot projects. The initiative has created new metrics by which building features and operating characteristics that support more effective building-to-grid operation can be measured and quantified. The initiative is backed by the non-profit organisation New Buildings Institute (NBI).

IEC Smart Grid Standards -- While not specifically for buildings, these standards cover smart grid technologies, which often intersect with smart building systems. The standards are backed by the non-profit organisation International Electrotechnical Commission (IEC).

Rating schemes such as LEED, BREEAM, and WELL do not explicitly include criteria for evaluating a building's readiness for smart technologies. However, the fact that a building possesses any of these certifications is still an important indicator. This is because the use of smart technologies can indeed play a significant role in achieving different certification levels.

3. Procurement Considerations

Modern data platforms for data-driven smart buildings serve as the backbone of intelligent building management, and the choices made during its procurement can significantly impact the different objectives, goals and expected outcomes for the smart building.

This section aims to be a valuable resource for analysing and establishing requirements during the procurement of a data platform. It begins by delineating the boundaries of the data platform in relation to the rest of the building's infrastructure, with the goal of supporting the requirement elicitation process.

Subsequently, it introduces the framework used to organize the gathered requirements.

Finally, it outlines the essential requirements that modern data platforms should meet to fulfil their fundamental role within the building's infrastructure. Essentially, these platforms are intended to support the integration, contextualization, and utilization of data for various applications and services. Fulfilling these requirements is crucial to achieving the following goals for a truly data-driven infrastructure: (i) digital-ready building infrastructure, (ii) interoperability-by-design, (iii) robust and accessible building data, (iv) data-driven building management, and (v) leveraging data-driven automation and control for enhanced efficiency, comfort, and sustainability.

Digital readiness. In this document, a building's infrastructure is considered *digital-ready* when it has at least the following characteristics:

- **Scalable architecture**, enabling buildings to seamlessly adapt to future digital requirements.
- **Cloud integration**, enabling centralized capabilities, such as data storage, and analysis.
- **Robust network infrastructure**, enabling high degrees of reliability and be able to handle a large volume of data traffic.
- **Remote monitoring and management**, enabling prompt reaction to unexpected disruptions, and proactive maintenance.
- **Robust data management**, enabling proper governance on all building-related data, including aspects related to data lineage, retention, audit, storage, and sharing.
- **Wide connectivity**, enabling seamless integration of systems, devices, and data throughout the building.
- **Resilience**, enabling withstand and recovering from hardware failures, software errors, network disruptions, and even cybersecurity threats.
- **Robust interoperability**, enabling seamless collaboration between the different building systems.
- **Wide compliance**, enabling adherence to relevant legal requirements and industry standards.

Digital-ready building infrastructure also features *distributed multi-tier deployments*, such as those having an *edge-tier* for conducting data analysis and decision-making tasks closer to the source of the data to minimise latency (refer to Physical Inspection for further details).

3.1 Boundaries of the Data Platform

The *automation-oriented perspective* for a building's infrastructure is particularly advantageous for conducting comprehensive physical inspections of its infrastructure (refer to Physical Inspection for further details). Conversely, the *data-driven-oriented perspective* is better suited for framing the role of a data platform and subsequently establishing the requirements that the platform should meet to fulfil that role.

In this document, the data-driven-oriented perspective for a building's infrastructure offers a four-layer hierarchy. Figure 3.1 illustrates these layers, along with typical, high-level components within them.

Each layer plays a crucial role in the overall functioning of the building's data-driven infrastructure, contributing to its efficiency, sustainability, and adaptability.

- **Application layer** – The topmost layer, hosting value-adding software applications.
- **Data layer** – The layer responsible for providing context and meaning to data. It is also responsible for data storage, processing, and management.
- **Network layer** – The layer responsible for data transmission.

- **Device layer** – The bottommost layer, comprising devices, systems, and equipment that provides data.

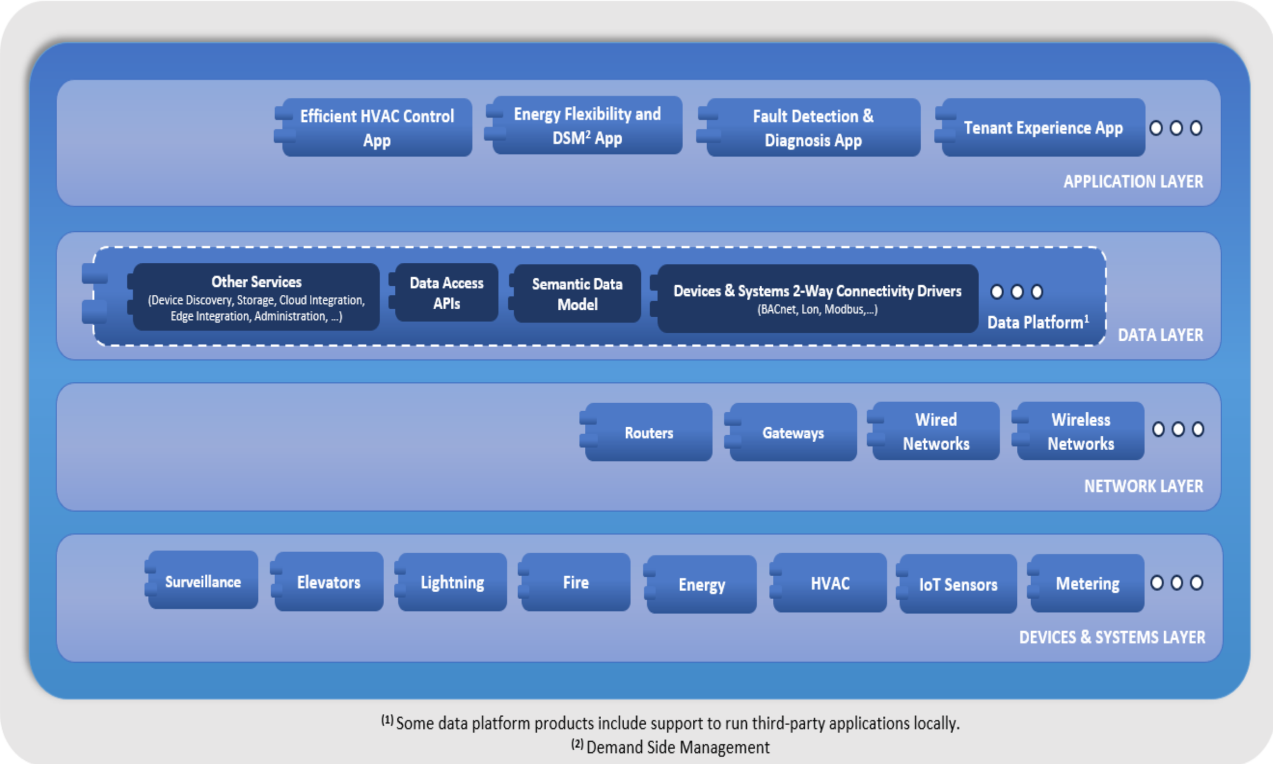

Figure 3.1. The data-driven-oriented perspective divides the building's infrastructure in the following four layers: application, data, network, and device.

Concerning the data layer, Figure 3.1 implies essential functionality required to fulfil its role, namely:

- **Two-way connectivity with relevant peers**, including building-related (systems, devices, and equipment), and also external ones (such as web services). One direction for data acquisition, hence viewing these peers as data sources, and another for control purposes.
- **Generation and maintenance of a semantic data model**, to capture the meaning and relationships between various elements and entities within a building's environment.
- **Ensuring uniform access to data by any external third-party application to which access has been granted**, including operational data and the semantic data model.

Finally, Figure 3.1 also implies that modern data platforms for data-driven smart buildings are expected to provide these essential functionalities.

3.2 Requirements Framework

In crafting and organising the essential requirements for data platforms in smart buildings, we've created and adopted a hierarchical framework that draws inspiration from the Industrial Internet Reference Architecture[6] (IIRA). Figure 3.2 below illustrates this framework.

[6] The Industrial Internet Reference Architecture. Industry IoT Consortium.

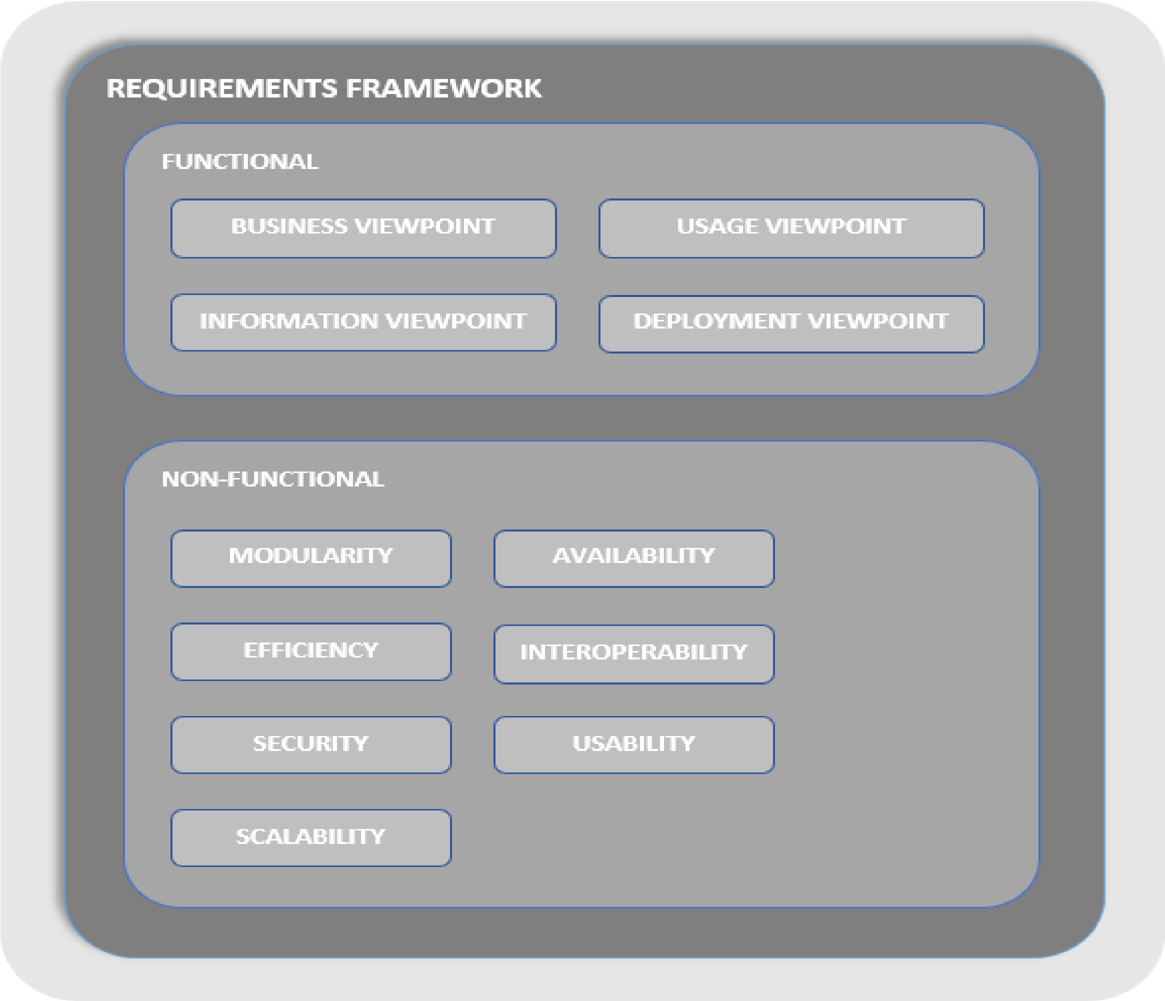

Figure 3.2. Framework used to organise requirements for modern data platforms for data-driven smart buildings.

The framework encompasses two main classic blocks: *Functional requirements* and *Non-Functional requirements*. The *Functional requirements block* is structured around four *viewpoints*, a concept borrowed from IIRA. The *Business*, *Usage*, and *Information* viewpoints are directly adopted from IIRA, while the *Deployment* viewpoint constitutes a unique addition to the framework. These perspectives offer distinct angles for analysing complex systems and architectures, enabling various stakeholders to focus on specific aspects. Additionally, they serve as essential tools for guiding stakeholders to communicate their concerns, which subsequently aids in identifying requirements.

Regarding the *Non-Functional requirements* block, it accommodates requirements related to qualitative attributes and constraints that govern system behaviour, performance, and quality. These attributes, also referred to as *system characteristics*, encompass essential aspects such as reliability, scalability, security, and performance. The framework provides seven groups of non-functional requirements, each group corresponding to one of the generic non-functional requirements given in the Brains for Buildings' deliverable with name Reference Architecture for Smart Buildings (Chamari, o.a., 2023).

This hierarchical framework provides a clear structure for a comprehensive set of essential requirements, addressing various facets of data platforms in data-driven smart buildings. Several of these essential requirements were derived from workshops conducted during the IEA EBC Annex 81 Fifth Plenary Meeting, which was hosted by RISE Research Institutes of Sweden in Gothenburg in fall 2022. Together, the framework and the essential requirements outlined in the following sections will hopefully serve as invaluable tools for building owners and managers, aiding them in navigating the complexities involved in adopting, enhancing, or evaluating data platforms to create more intelligent and efficient buildings.

3.3 Minimum Functional Requirements

3.3.1 Business Viewpoint

Focus	Strategic mission, objectives, and goals of the organisation (typically the building owner's) that the data platform serves.
Considers	Financial aspects, regulatory compliance.
Concern areas	The "why", and strategic value of the data platform.

Cost efficiency – The platform should be cost-effective, both in terms of initial investment and ongoing operational costs. This aligns with the financial objectives of most organizations.

Revenue generation – The platform should enable new services, solutions, or revenue streams. This could include offering value-added services to tenants or using the data for strategic decision-making.

Scalability – The platform should be scalable to support the growth and expansion of the organization. This aligns with the strategic goals of many organizations.

Sustainability – The platform should support sustainability initiatives, such as energy efficiency and waste reduction.

Security and compliance – The platform should ensure data security and help the organization comply with relevant regulations.

Integration with existing systems – The platform should be able to integrate with the organization's existing systems. This can help to protect the organization's investment in its current infrastructure.

User experience – The platform should enhance the user experience for both the building occupants and the management team. This can help to improve tenant satisfaction and retention, which are common goals for building owners.

Future-proofing – The platform should be flexible and adaptable to accommodate future technologies and trends. This can help the organization to stay competitive and achieve its long-term goals.

3.3.2 Usage Viewpoint

Focus	Interaction of the data platform with its environment, including how it is used by end-users or other systems.
Considers	The data platform's interfaces and interactions.
Concern areas	The "what" of the data platform – what it is used for, together with who/what uses it, and how the platform fits into the building ecosystem.

Data source abstraction – The platform should abstract away the intricacies of connecting and communicating with data sources for data extraction/retrieval purposes. Typical data sources include building systems, devices and equipment, and even external sources, such as web services. For further details, this requirement can be broken down into several sub-requirements:

- **Device agnostic** – The platform should be capable of communicating with a wide range of building systems and devices, regardless of the manufacturer or model.

- **Communication protocol agnostic** – The platform should be capable of communicating with a wide range of building systems, devices and even equipment, regardless of the communication protocol(s) that they can use. Typical protocols include BACnet, Modbus, KNX, Zigbee, and MQTT.

- **Data format agnostic** – The platform should be capable of handling different payload data formats used by different communication protocols Typical formats include XML, JSON, CSV.

- **Real-Time data** – The platform should abstract away the intricacies of connecting and communicating with data sources for real-time data collection purposes.

- **Historical data** – The platform should abstract away the intricacies of connecting and communicating with data sources for historical data collection purposes.

- **External data sources** – The platform should abstract away the intricacies of connecting and communicating with external data sources, such as web services for retrieving weather-related data.

Uniform data access – The platform should provide uniform access to data from the integrated diverse data sources to any access-granted external third-party application. For further details, this requirement can be broken down into several sub-requirements:

- **Data access API** – The platform should provide a standard, a single API that abstracts the underlying data sources.

- **Data model representation** – The data access API should accurately represent the semantic data model held by the platform.

Semantic data model. In the context of smart buildings, a semantic data model refers to a structured representation of data that captures the meaning and relationships between various elements and entities within a building's environment. These models are often backed by ontologies and data schemas.

- **Secure data access** – The data access API should ensure secure data access, protecting sensitive building data from unauthorized access.

Autonomous control – The platform should provide mechanisms and interfaces for supporting the building infrastructure's ability to autonomously control target systems and equipment within the building.

Friendly graphical user interface (GUI) – The platform should provide a GUI that is intuitive and easy to navigate by building managers and operators. For further details, this requirement can be broken down into several sub-requirements:

- **Administration GUI** – The GUI should include tools for administration tasks such as user management, role assignment, and access control.

- **Data management GUI** – The GUI should include tools for data management, including tools for configuring communication with data sources, data cleaning, data transformation, and data export.

- **Data governance GUI** – The GUI should include tools for data governance practices, including sections to handle data lineage, and relevant regulations compliance.

- **Search and query GUI** – The GUI should include powerful search and query capabilities, allowing users to easily find the data that they need.

- **Visualisations** – The GUI should include tools for data visualisation, including intuitive visualisation of the semantic data model held by the platform.

- **Application developer support GUI** – The GUI should provide a comprehensive and intuitive API-testing section, including description of the API. Software development kits, and tutorials may also be included.

> **Low-code support.** The platform may provide low-code facilities to empower designated building personnel with less or zero software programming skills to build third-party applications aimed to extend the platform's capabilities, and/or address specific business needs.

- **Help and support** – The GUI should provide help and support features, such as tooltips, help guides, and customer support contact information.

- **Responsive design** – The GUI should work well on various devices and screen sizes.

- **Accessibility** – The GUI should be accessible, complying with standards and guidelines to ensure it can be used by people with various disabilities.

Remote access – The platform should support remote access from any location, using a variety of devices such as smartphones, tablets, and laptops.

Remote troubleshooting – The platform should support conducting certain troubleshooting from any location, especially important in cases demanding prompt intervention.

3.3.3 Information Viewpoint

Focus	The flow of data between the building's systems and the data platform.
Considers	Data generation, ingestion, processing, quality assurance, transmission, storage, and security (including privacy).
Concern areas	Primary data sources (e.g., sensors, databases), data interoperability (including data exchange formats), data governance (including data ownership, data lifecycle management, and different policies, e.g., retention), data sharing to users, software applications, and services (including APIs, and alike mechanisms).

Time series – The platform should provide mechanisms to enable ingestion, and management of *time series data* from integrated, heterogeneous building systems and devices.

Pre-processing and cleansing – The platform should support pre-processing of data, including support for data cleaning- and normalisation-related operations. Clean and healthy data is essential to avoid misleading insights, inaccurate analytical outcomes and unwise decisions that can arise from issues like missing values and outliers. These potential unwise decisions may not only stem from humans but also from machines. For instance, an algorithm trained with poor-quality data might on some occasions lead to unwise automatic control actions.

Secure data storage – The platform should provide comprehensive mechanisms enabling efficient and secure storage of collected data. Efficiency is crucial if high volumes of data must be ingested and analysed, even at real-time basis. Security is also critical to protect unauthorized access to the collected data.

Metadata management – The platform should provide mechanisms to enable ingestion, and management of contextual information (metadata).

Ontology management – The platform should provide support for managing ontologies and metadata schemes to effectively be able to give data context and meaning.

> **Flexibility in ontology options.** Platform vendors have the option to support multiple ontologies used within smart buildings, such as Brick and RealEstateCore. During the installation and configuration of the platform, one of the stages would involve selecting the ontology to construct the building's semantic data model. On the other hand, some platform vendors may support only a single ontology.

Semantic data model – The platform should provide support for creating, evolving, and maintaining a rich semantic data model that defines the relationships, attributes, and meanings of different entities, sensors, systems, and their interactions within the smart building environment.

Operations and context – The platform should provide mechanisms to enable seamless integration of metadata and semantic model with operational data ingested into the platform from various devices in a building.

Data governance and lifecycle management – The platform should provide capabilities that allow for proper governance of all building-related data – from continuously acquired data (e.g., sensing data), to historical data, metadata, and other context-enriching data. Typical capabilities are the establishment and governance of different data-related policies, such as lineage, retention, privacy, audit, storage, and sharing. It also includes capabilities to manage compliance with industry standards and regulations, such as GDPR.

3.3.4 Deployment Viewpoint

Focus	Integration of the data platform within the building's infrastructure (including compatibility and interoperability with existing systems and used technologies), how the deployment of the data platform impacts the infrastructure's resources (including computing and network resources, and even energy usage), and scalability (flexibility) of the platform to adapt to changing needs.
Considers	Building infrastructure, and technical compatibility of the data platform with the infrastructure. Compatibility with other systems outside the building's perimeter (e.g., business systems in intranet).
Concern areas	Adaptability, resource efficiency, performance, and even security (including protecting the data platform and ensuring data privacy and integrity).

Integration for data acquisition – The platform should be able to integrate with relevant building systems, equipment, and devices from different vendors for data acquisition purposes – e.g., systems related to automation and control, HVAC, lighting, occupant access control, fire safety, and energy management.

Integration for control – The platform should be able to integrate with relevant building systems, equipment, and devices from different vendors for smart automation and control purposes – e.g., systems related to automation and control, HVAC, lighting, occupant access control, fire safety, and energy management.

Migration – The platform should provide comprehensive migration capabilities to minimise the effort and complexity involved in the process of replacing the existing platform with a different one.

Communication protocols and standards – The platform should support open communication protocols and (industry) standards. The following protocols and standards should be supported:

- Automation and Control: BACnet, Modbus, M-Bus, KNX, DALI, LonWorks, MQTT, OPC UA.
- IT-Security: IEC 62443 (at minimum level: SL2), BACnet Secure Connect, PKI-based encrypted communication between platform software artefacts and at least for the human interaction with the graphical interface.

3.4 Minimum Non-Functional Requirements

3.4.1 Modularity

In the context of traditional software engineering, modularity entails dividing a software product into distinct units or packages, referred to as modules or libraries. However, within this section of the document, the concept of modularity is presented differently to cater to building owners and managers. This alternative perspective emphasizes two crucial aspects. Firstly, it highlights the data platform's capability to adapt to the evolving realities and specific needs of building owners and managers. Secondly, it focuses on ensuring that modifications or enhancements to one part of the data platform do not disrupt the entire system. Within this context, a module addresses a specific area of functionality within the broader domain of data platforms for data-driven smart buildings. Each module typically represents a distinct business area or sub-domain, encapsulating related logic, behaviour, and functionality. For instance, let's consider a module dedicated to building data analytics. Such a module concentrates on functionalities like data cleaning, preparation, statistical analysis, and predictive modelling, utilizing data collected from various sources within the building's data infrastructure.

Furthermore, data platform providers may offer various variants of a module, following a 'capability ladder' approach. In this approach, each subsequent variant provides enhanced functionality compared to the previous one, thus offering a progression of capabilities.

> **Domain-Driven Design (DDD)** serves as the foundation for the perspective on modularity introduced above, drawing inspiration from Eric Evans' work (Evans, 2003). A module, as discussed in this context and at this level, closely aligns with Eric Evans' concept of *bounded contexts*.

Minimum modularity-related non-functional requirements follow below.

The platform's modules should support separate maintenance and updates, ensuring modifications to one module do not disrupt the entire system.

The platform should allow the addition or removal of modules without compromising system stability or efficiency.

The platform's modules that interact with other parts of the building's data-driven infrastructure should make use of standardised communication protocols and interfaces.

The platform's modules should be back-compatible upon minor revisions to ensure smooth transition during updates.

3.4.2 System Availability

System availability denotes the capacity of the data platform to sustain uninterrupted operation and accessibility for users across its operational duration. This encompasses factors like uptime, responsiveness of the system, and its resilience in managing faults or errors.

Minimum availability-related non-functional requirements follow below.
The platform must maintain uptime compliant with regulations and aligned with user expectations, which vary depending on, among others, the building's criticality, and its data-driven infrastructure.

> In various industries, achieving 99% uptime is often considered a standard benchmark for service availability and reliability. For example: cloud providers, telecommunications service providers, data centres, and industrial IoT.

The platform must maintain quick response times, ensuring that users can access and retrieve data within a predefined timeframe for efficient decision-making.

The platform should feature built-in mechanisms for fault detection, mitigation, and rapid recovery to prevent downtime or service interruptions in case of system faults or failures.

The platform should support redundancy or failover mechanisms to mitigate the impact of potential hardware or software failures, ensuring data continuity and system availability.

The platform should feature tools for continuous monitoring of its availability, providing real-time alerts to administrators for immediate actions upon detecting potential issues threatening system availability.

The platform's architecture should include support for *plug-and-play* platform software modules and/or components, or otherwise minimise the amount of needed personnel intervention when adding and configuring them.

3.4.3 Efficiency

The platform should feature mechanisms to ensure that the platform's operations align with energy-efficient practices to reduce power consumption and promote sustainability within the building infrastructure.

The platform should ensure timely responses to user interactions or data requests within predefined acceptable time frames to maintain operational efficiency.

The platform should have the ability to efficiently scale resources based on demand, ensuring that performance remains consistent even during periods of increased activity or data processing.

The platform should consistently deliver reliable and predictable performance levels under various workload conditions.

> **Common efficiency-related capabilities** found in modern data platforms include support for load balancing requests directed to the platform and data compression techniques aimed at reducing data transfer times. Additionally, employing energy-efficient hardware throughout the building's data-driven infrastructure can significantly amplify the impact and effectiveness of these capabilities.

3.4.4 Interoperability

Interoperability refers to the data platform's abilities to seamlessly integrate and collaborate with various systems and technologies, whether internal or external to the building infrastructure.

Minimum interoperability-related non-functional requirements follow below.

The platform should support widely accepted industry-standard communication protocols (such as MQTT, and BACnet) to ensure seamless integration with various building devices and systems.

The platform should provide open interfaces and APIs for easy connectivity and data exchange with third-party applications, enabling interoperability with different vendors and systems.

The platform should ensure compatibility with various data formats (such as JSON, XML, or CSV) to allow smooth data exchange between the platform and different systems, ensuring flexibility and ease of integration.

The platform should be agnostic to different devices and systems, allowing integration with diverse technologies, regardless of their make or manufacturer.

The platform should support the easy incorporation of new technologies or systems as the building's infrastructure evolves.

The platform should implement robust security measures to ensure safe and controlled data exchange between the platform and external systems, maintaining data integrity and confidentiality.

The platform’s architecture should include support for plug-and-play devices.

3.4.5 Security

Security within the scope of a data platform for data-driven smart buildings encompasses safeguarding against unauthorized access, data breaches, cyber-threats, and ensuring the integrity, confidentiality, and availability of sensitive information. This includes the implementation of robust encryption protocols, multi-factor authentication mechanisms, and precise access control measures. Additionally, it involves continuous monitoring, intrusion detection, and the ability to swiftly respond to and recover from security incidents or breaches. Security measures must comply with industry-standard practices, regulations, and protocols, ensuring comprehensive protection for both the platform and the sensitive data it manages.

Minimum security-related non-functional requirements follow below.

The platform must implement robust access control measures, including *Role-Based Access Control* (RBAC) and strong authentication mechanisms (like *multi-factor*), to ensure only authorized personnel can access specific functionalities and data.

The platform should secure all *in-transit* data, optimally by means of strong encryption (e.g., by securing communication channels between the platform and other systems or devices by means of protocols that support *public key infrastructure* (PKI)).

The platform should secure all *at-rest* data, optimally by means of strong encryption (e.g., by means of PKI-based encryption).

The platform should adhere to relevant security standards (such as GDPR, or other local regulations) to ensure data privacy and protection compliance.

The platform should include real-time monitoring, logging, and auditing capabilities to track user activities, identify anomalies, and enable timely responses to potential security threats.

The platform should include mechanisms to support the organisation's established incidence response and recovery plans in case of breaches or system failures.

The platform should include mechanisms to swiftly implement security updates to ensure the platform's robustness and resilience against emerging security threats and software vulnerabilities.

3.4.6 Usability

Usability refers to the data platform's capability to deliver an intuitive and user-friendly experience for diverse user groups, ensuring ease of use and comprehension.

Minimum usability-related non-functional requirements follow below.

The platform should offer an intuitive and user-friendly interface, allowing easy navigation and interaction with various functionalities and configuration settings, optimally without extensive training or guidance.

The platform should provide easy access to well-designed documentation to assist building owners and managers to operate it properly. This typically includes user manuals that describe the platform's features, functionalities, and configuration parameters.

The platform should ensure convenient access to well-crafted and diverse training resources tailored to empower building owners and managers in effectively utilizing the platform's functionalities. This includes contemporary video-based tutorials, in addition to conventional training materials.

The platform should provide feedback mechanisms enabling users to report issues, and even provide suggestions, or request features, fostering continuous improvement in usability based on user input.

3.4.7 Scalability and Extensibility

Scalability and extensibility denote the data platform's ability to efficiently accommodate growth and adapt to increasing demands, encompassing the seamless integration of new features, systems, or technologies as necessary.

Minimum scalability and extensibility-related non-functional requirements follow below.

The platform should support easy integration of new functionalities or modules without disrupting the existing system, facilitating future expansions or upgrades.

The platform should adhere to widely accepted interoperability standards, enabling seamless integration with various devices, systems, or third-party applications.

The platform should support incremental upgrades (without extensive downtime), allowing the platform to evolve gradually while maintaining operational continuity.

The platform should be able to accommodate a potentially increasing volume of data generated by the building's systems and devices. This will ensure efficient data processing, storage, and analysis as/if data volume grows.

The platform should provide remote, *over-the-air* software update capabilities so that bug fixes, security patches, functionality enhancements, etc can be applied without the need for personnel to be physically and manually applying the updates.

4. Technical Notes

This section introduces diverse technical aspects of modern data platforms for smart buildings. It is designed to be accessible for less-technical readers, while still being informative for platform creators. The section begins by delving into the platform's *data processing pipeline*, an indispensable pillar that shapes the platform's ability to harness data effectively and intelligently. It then describes key architectural characteristics necessary to achieve flexible and scalable architectures capable of supporting a variety of use cases. Next, to illustrate the inner workings of moder platforms, it provides indicative building blocks capable of enabling the introduced architectural characteristics. Lastly, for illustrative purposes, this section provides a comprehensive list of possible software modules that could be plugged into data platforms products to adapt them to specific needs.

4.1 Data Processing Pipeline

Data serves as the lifeblood empowering modern data platforms tailored for data-driven smart buildings. Consequently, these platforms excel in data processing operations, often referred to as *data operations*. These operations are crucial in delivering precise, timely data to power an array of smart, data-driven applications and services.

These data operations typically unfold within the structured framework of the platform's *data processing pipeline*. This pipeline orchestrates a sequence of meticulously designed steps aimed at transforming raw data into actionable insights. Serving as the backbone of the platform, this pipeline meticulously refines, enriches, and harmonizes data streams, thus serving as a catalyst for intelligent decision-making and facilitating tangible outcomes. The next sections delineate a comprehensive, generic data processing pipeline suitable as a reference model within the realm of data platforms for smart buildings. This model draws inspiration from the Top-Level Big Data and AI Pipeline initially introduced by Berre et al. (2022), which is visualised in Figure 4.1 below.

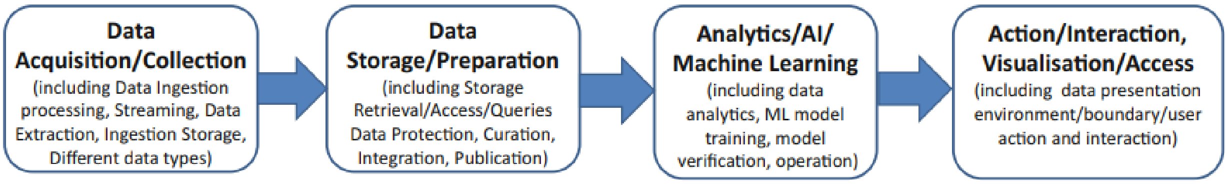

Figure 4.1: The Top-Level Big Data and AI Pipeline introduced by Berre et al. 2021.[Image included in the chapter's Creative Commons license (https://link.springer.com/chapter/10.1007/978-3-030-78307-5_4#rightslink). No changes made to the image. Creative Commons Attribution 4.0 International License: http://creativecommons.org/licenses/by/4.0/)]

Note that within the context of data platforms for smart buildings, the execution of tasks related to the last two steps of this generic pipeline may or may not occur within the platform. Some platform providers may choose to implement a pipeline that concludes with the *data storage/preparation* step. This approach delegates analytics, machine learning, AI, and visualization-related tasks to external data-driven smart applications and/or services. Consequently, the last step primarily involves enabling secure access to the prepared and stored data through typical APIs.

On the other hand, other providers may opt to implement the entire pipeline. In such cases, these platforms typically offer built-in data-driven smart applications, tools, and services allowing analytics, machine learning, AI, and visualization-related tasks. Some platforms even enable the installation and execution of third-party data-driven smart applications, tools, and services for these same purposes.

4.1.1 Data Acquisition/Collection

A prerequisite to process data aiming actionable insights is to acquire it in the first place. Therefore, modern data platforms excel in different aspects related to data acquisition, such as:

- They efficiently gather data from a wide array of sources. These sources, herein *primary data sources*, range from HVAC-related sensors, energy meters, automation and control systems, and IoT devices, to meteorology- and climate-related services provided and hosted by third-party organisations.
- They enable real-time or near-real-time data collection, ensuring that data is captured as events occur. This real-time capability is vital for immediate insights and responsive actions.
- They are designed to scale with ease, accommodating a growing number of data sources while remaining adaptable to various data types and formats.
- They ensure reliable data collection by maintaining data integrity, accuracy, and consistency, crucial for decision-making and analytics.
- They utilize standardized protocols and formats, simplifying integration with different devices and systems, ensuring seamless communication and interoperability.
- They include functionalities for data cleansing and pre-processing, ensuring that the acquired data is optimized for downstream analysis.
- They employ robust security measures to safeguard the acquisition process, protecting data from unauthorized access or cyber threats.

Primary vs Primary internal vs Primary external data sources. In this document, *primary data sources* refer to systems from where data can be requested and acquired for collection and further processing purposes. These primary data sources are categorised as either *internal* or *external*.

Internal primary sources encompass primary sources situated within the building, or otherwise owned and managed by the building owner. They include HVAC-related sensors, energy meters, automation systems and control systems, and various IoT devices. Additionally, they include systems operated within the building owner's intranet, private cloud, or even public cloud, such as databases and business software.

External primary sources, on the other hand, are those owned by actors other than the building owner, such as tenants, other firms or organisations. They include *data spaces* (referenced in IDSA[7], and EU[8]), *data institutions* (as seen in ODI[9]), national agencies

[7] International Data Spaces. https://internationaldataspaces.org/why/data-spaces/
[8] Building Data Economy. Digital Strategy. European Commission. https://digital-strategy.ec.europa.eu/en/library/building-data-economy-brochure#Spaces
[9] Data Institutions. The ODI. https://www.theodi.org/article/what-are-data-institutions-and-why-are-they-important

(e.g., a national meteorology agency), and various other organisations providing relevant services.

The process of connecting a building to a data platform for data acquisition purposes is normally known as ***onboarding***. This process consists of the following main steps: data source configuration, building model development, and test and verification.

Utilizing the platform's interfaces, configuration of a *platform data source* within the platform basically involves registering essential information for communication with a corresponding *primary data source* (refer to the informational box above). This information generally includes an address and a protocol. The address specifies the correct interface of the primary data source, while the protocol dictates the means of communication to exchange messages and data payloads. In terms of protocols, industry-standard machine-to-machine communication protocols are recommended, such as MQTT and AMQP. Data ingestion from other primary data sources can occur via secure APIs. In any case, it's crucial that data payloads are ingested with their corresponding context to facilitate their discovery and subsequent usage.

The subsequent step in the onboarding process involves the development of a comprehensive digital model tailored explicitly to the building connected to the data platform. This model, often referred to as the building's *semantic data model*, is crafted from building metadata, thus encapsulating relevant parts of the building's data-driven infrastructure, including its diverse hardware and software systems, equipment, networks, sensors, and other associated devices. The model also represents diverse aspects of the building's data-driven infrastructure, ranging from sensor placements and device configurations to the overall network topology. System integrators and contractors often rely on semi-automated procedures to aid in the creation of this model.

Semantic data models. From an interoperability standpoint, semantic models serve as standardized, machine-readable descriptors for building metadata. These models are typically constructed using any of the schemas or ontologies prevalent in the industry, such as Brick[10], or RealEstateCore[11]. While there isn't a singular prescribed schema or ontology for building models, ASHRAE 223P aims to provide a unified semantic modelling solution. Also note that developing a robust process for creating semantic models from existing building metadata remains an active area of research.

Once the digital model is constructed, the onboarding process proceeds to the phase of testing and verification. This stage ensures that data is accurately collected from various sources, transmitted securely, and correctly represented within the digital model. Verification also encompasses assessing the functionality and performance of the integrated system. It involves verifying the accuracy of data ingestion, assessing the responsiveness of interfaces, and ensuring the seamless interaction between the building model and the data platform.

Data-related classifications. Data can be classified based on different attributes or perspective. Two classical classifications include:

- **In-motion vs at-rest data.** Data is either in an *in-motion* or *at-rest* state. In-motion data refers to information being actively transported between a source and a recipient, such as data produced and transmitted by HVAC-related sensors, and IoT sensing devices. On the other hand, data is in an at-rest state when it is stored in a repository, for example, data that has been collected, cleaned, and stored in a database for future use.

[10] Brick metadata schema. https://brickschema.org/
[11] RealEstateCore ontology. Brick metadata schema. https://brickschema.org/

- **Batch vs streaming data.** Data classification can also consider the volume of data points acquired or collected in a single data acquisition task. Batch data typically refers to an already-packaged collection of data points provided by a data source. In contrast, streaming data is continuously acquired or collected from sources that transmit single data points (or small collections for efficiency reasons). Typically, streaming data is processed on a data point-by-point basis.

4.1.2 Data Storage/Preparation

The acquired/collected data is typically stored in a scalable and reliable storage infrastructure capable of handling large volumes of data while ensuring efficient retrieval. This infrastructure may take advantage of distributed strategies to ensure resilience and high levels of availability.

Data cleansing techniques may be applied to identify and handle exception conditions, such as inconsistent and missing values.

Data wrangling techniques such as transformation (e.g., converting metering unit) and normalisation may be used to get the collected data in formats suitable for or even demanded by data-driven applications and/or services.

Data aggregation techniques may be used to allow for a more efficient analysis of large volumes of data. A typical example is aggregating data over different building zones.

Lastly, modern data platforms may also typically have capabilities to prepare the acquired/collected data for advanced analytics, and machine learning algorithms. Typical examples of preparation task include encoding categorical variables and splitting the data into training and testing data sets for machine learning tasks.

4.1.3 Analytics/AI/Machine Learning (ML)

This pipeline step is used to (i) unlock data-driven insights through different types of statistical analysis (often referred to as *analytics*) and/or statistical learning techniques (often referred to as *machine learning*), and (ii) package the models derived from the mentioned techniques in such a way that they can be incorporated in different user-targeting visual artefacts. Such artefacts range from dashboards to low-code (self-developed) applications, and third-party applications and services (refer to the next pipeline step).

Different types of analytics may typically be conducted in both a manual and an automated fashion. *Descriptive analyses* may help find patterns, trends, and correlations within the acquired/collected building data. *Predictive analyses* assist making specific predictions, e.g., about equipment failures and expected energy consumption. *Prescriptive analyses* provide recommendations and actionable insights that enable building managers and operators make informed decisions, such as those related to energy management, and equipment maintenance.

Optimisation and control techniques, and algorithms are used to systematically, continuously, and even autonomously optimise different building operations, such as adjusting set points for efficiency, performance, and occupant comfort.

Anomaly and fault detection techniques may help identify deviating behaviour in building equipment, energy inefficiencies, and communication patterns (the latter possibly suggesting ongoing cyberattack).

Modern data platforms for smart buildings also embrace continuous learning practices and related techniques to ensure that the models derived from statistical analysis and learning remains accurate and adapted to changing patterns and requirements in the building.

4.1.4 Action/Interaction, Visualisation/Access

Within the context of smart buildings, this pipeline step involves leveraging advanced dashboards and data-driven smart applications to allow building owners, managers, and operators make informed decisions and conduct efficient management of the building. It also allows granted occupants to monitor and even personalise comfort-related settings.

Interactive dashboards typically provide (i) visual representations of building operations-related information, such as KPIs, and real-time status, together with (ii) capabilities for detailed data exploration through interaction with the user interface. Status monitoring enables building managers and operators to track different parameters and conditions, such as energy consumption, environment (e.g., air quality), and equipment performance (e.g., HVAC).

The possibility to install third-party applications provide a powerful mechanism to extend the platform's built-in capabilities, such as those crafted to deliver actionable insights and even recommendations. In general, these applications make it possible to meet new or updated requirements without having to rely on the platform vendor's ability, resources, or even will to provide the requested functionality. Besides providing a suitable execution environment, including storage and other needed base resources and services, the platform enables these applications to continuously access acquired/collected data that they may require to carry on their duties. This way, applications that leverage AI and machine learning techniques can also keep their models (e.g., for prediction) properly updated, accurate, and effective over time thanks to new data made available by the platform.

Modern platforms usually include remote access capabilities, including mobile devices applications, that allows building managers and operators to monitor and control the platform, hence the building, from anywhere.

Other beneficial capabilities relate to providing communication channels that (i) enable more effective coordination among building personnel (managers and operators) on tasks related to building management, and (ii) foster collaboration among building personnel, tenants, and even occupants to achieve even higher levels of energy efficiency and occupant comfort.

4.2 Architectural Characteristics

Modern data platforms for smart buildings typically have flexible and scalable architectures that can support a variety of building types, and automation and control use cases. These platforms are typically based on architectures that are (i) distributed; (ii) modular; and (iii) service-based.

In a **distributed** architecture, the data platform's components and resources are decentralized across multiple locations interconnected through a network. This decentralized setup ensures scalability, fault tolerance, and enhanced performance by allowing tasks to be executed in parallel across distributed nodes.

A **modular** architecture emphasizes the segmentation of the data platform into discrete, interchangeable, and reusable entities, often referred to as modules or components. This enables independent development, deployment, and updating of components, facilitating seamless integration, and reducing dependencies across the platform. From the building owners and managers perspective, modular platforms tend to facilitate the customisation and evolvability of the deployed platform according to their realities and specific needs. A modular architecture also allows for easier integration of third-party systems, devices, and other equipment.

> Note that the terms “modules” and “components” are sometimes used interchangeably. In other cases, they are given specific definitions that differ depending on the software development context (e.g., firm A defines “module” differently than firm B). Sometimes, their definitions even overlap.

A **service-based** architecture organizes the platform into discrete, interoperable services that communicate through well-defined interfaces. Each service encapsulates specific functionalities or capabilities, promoting agility, scalability, and ease of integration. Services operate independently, facilitating rapid development, deployment, and maintenance.

The convergence of distributed, modular, and service-based architectures within data platforms for smart buildings offers several critical advantages. Together, these architecture styles empower data platforms for smart buildings to efficiently manage data, ensure flexibility, scalability, resilience, and adaptability while supporting the diverse and evolving needs of modern buildings.

4.3 Building Blocks

For indicative purposes only, such a distributed, modular, and service-oriented architecture could be enabled by the following classes of building blocks:

- **Platform node** – A particular, purpose-fit composition of hardware, and software modules (refer to Software Modules) that can be deployed at a specific tier (such as cloud, intranet, edge, or building) to carry on specific capabilities and/or functions.
- **Software module** – Provides one or several node agents and/or related/other services and artefacts (refer to Software Modules).
- **Node agent** – An autonomous, contextual-aware, objective-driven piece of software capable of self-reacting to contextual changes, together with actively communicating and cooperating with other node agents, to pursue its objectives. Typical node agents include plug-and-play device discovery agents, network agents, and platform-health monitoring agents.

These building block classes alone provide sufficient flexibility to address multiple and varied deployments, from simpler to more demanding ones, such as the one described below.

Example. The following example deployment aims to illustrate how the proposed distributed, modular, and service-based architecture, including the above-introduced architecture building blocks classes, allows complex deployments that satisfy modern building automation and control needs. In this example, instances of different architecture building blocks classes are combined and deployed in different tiers, concretely in a public cloud node, an edge datacentre, and a building, the whole deployment featuring fault-tolerance, high-availability, and resilience capabilities.

Figure 4.3.1 below shows a platform node to be deployed in the building’s local datacentre to carry on tasks related to smart automation and control. The picture shows the main software modules required to perform the tasks. This node is equipped in such a way that it can run autonomously in the event of losing connectivity with a supervisory node located in an edge datacentre.

Figure 4.3.1: A platform node for BAC capabilities to be deployed in the building's local datacentre.

Figure 4.3.2 below shows a platform node featuring essential software modules required to conduct tasked related to supervisory building automation and control. Besides its location (an edge datacentre), the main differences with the previous, local node are (i) the addition of the Edge Orchestration Module; and (ii) the simplification of the connectivity module's composition (as, in this case, this module mainly handles communication with the nodes deployed in the building's datacentre). In this example, the supervisory BAC node is capable of starting a new local BAC node if the current one ceases to respond to health-checking signals.

Figure 4.3.2: Indicative modules corresponding to a supervisory BAC platform node deployed to an edge datacentre.

Figure 4.3.3 below displays a platform node deployed in a public cloud. This node hosts essential software modules required to facilitate central operations, including enabling the execution of both third-party and self-developed smart applications. In this instance, the deployed applications help to enhance energy efficiency levels beyond conventional means, such as setpoints and operating times. Notably, the platform includes the App-Execution Environments and App-Markets Modules. The former provides a suitable software infrastructure for running third-party applications, including built-in ones. The latter facilitates browsing and installing applications from different markets.

Figure 4.3.3: Indicative modules corresponding to a central operations platform node deployed on a cloud infrastructure.

Finally, figure 4.3.4 below shows a summary of the whole deployment, including all tiers, and the main involved building blocks instances.

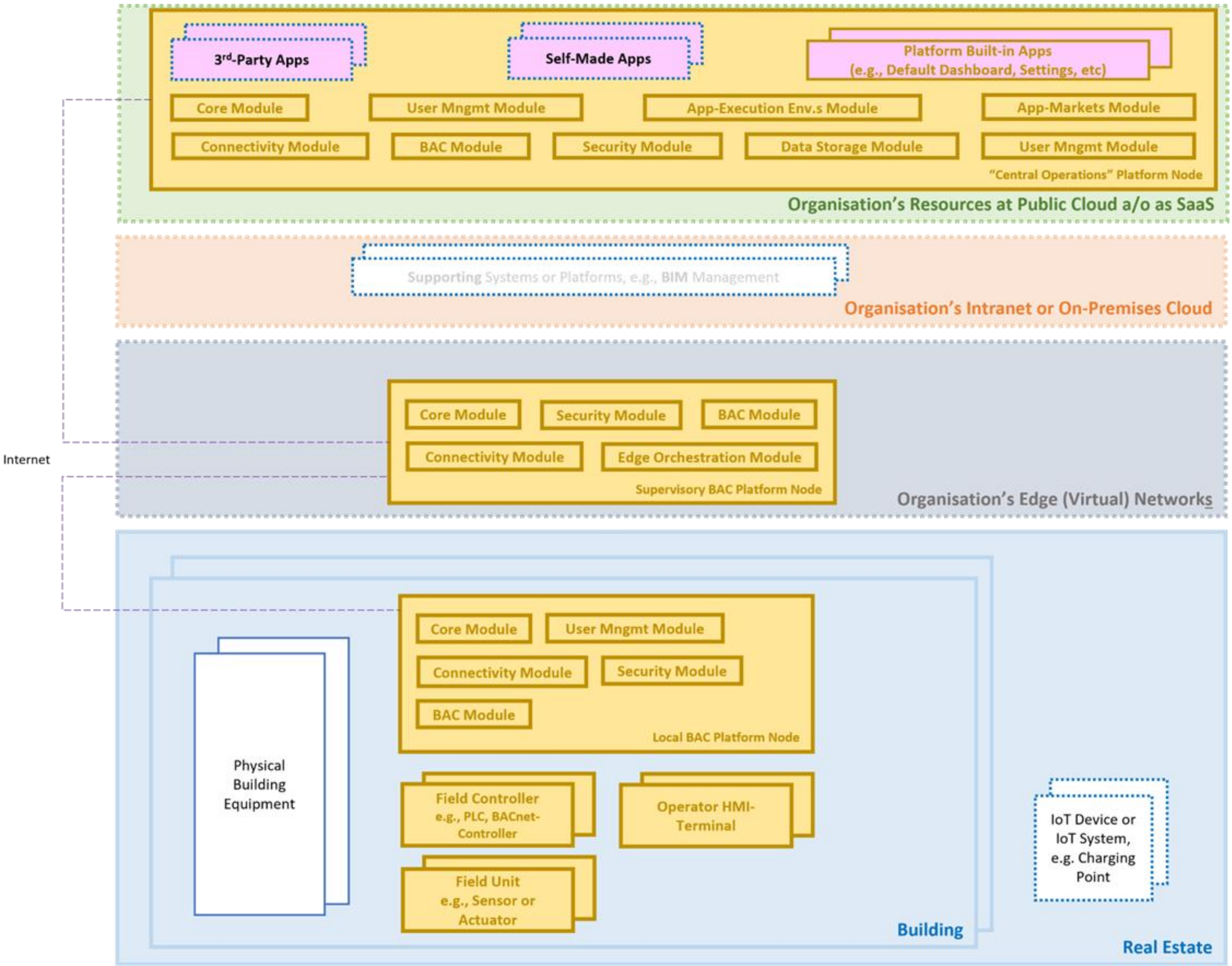

Figure 4.3.4: Deployment example summary (refer to Figure 4.3.1, 4.3.2, and 4.3.3 above).

4.4 Software Modules

For indicative purposes only, this section introduces software modules that building owners may expect to be offered by platform providers that base their platform products on a modular architecture.

> Note that data platform providers may offer various variants of a module, following a 'capability ladder' approach. In this approach, each subsequent variant provides enhanced functionality compared to the previous one, thus offering a progression of capabilities. An example is the *security module* being offered in *Base*, *Enhanced*, and *High* levels.
>
> Data platform providers may then sell ready-made packages where each package is made of a specific combination of the different modules at different levels. The platform vendor may also allow the possibility of designing your own package, and even offering the simplest, capability-poorest one for free. An often-found example is that of a vendor offering a *Small*, a *Medium*, and a *Large* package.

4.4.1 Core Module

This module typically provides system-wide base agents, services, and other related code units, including those for management of central logging, central configuration, scheduling engine, message bus, and notification engine. Services exposed by this module are typically used by other modules and third-party applications deployed to the platform.

4.4.2 User Management Module

This module would typically provide capabilities for managing user profiles, and user accounts. While it may also provide support to authenticate users and authorise them to access specific platform resources and services, this support is normally reduced to basic authentication and authorisation. More advanced mechanisms for authentication and authentication are typically handled by a Security Module.

4.4.3 Building Automation and Control Module

This module would typically comprise agents, services, and related code units for all building automation- and control-related capabilities. Typical capabilities include supporting the platform to effectively transforming insights discovered by third-party applications into feedback commands sent to control and automation systems within the data-driven infrastructure of the building.

4.4.4 App-Execution Environments Module

This module would typically provide the infrastructure and tools needed to run third-party (and even some built-in) applications within the platform. The module would provide a suitable environment per supported application programming language.

Typical capabilities include providing: (i) access to platform resources and services, (ii) abstractions for different platform resources and services, (iii) mechanisms to bundle applications and their dependencies in packages, (iv) mechanisms to allow the management of configuration options for applications, and (v) mechanisms to allow monitoring and diagnostics capabilities, such as those to track the health, performance, and resource usage of applications.

4.4.5 App-Markets Module

This module would typically provide the needed infrastructure to host a repository for third-party software applications that platform managers may install and deploy within the platform. Alternatively, this module may enable access to repositories maintained by other organisations. Some data platform providers may even provide both alternatives.

4.4.6 Data Governance and Management Module

This module would typically provide capabilities that enable proper governance of all building-related data – from continuously acquired data (e.g., sensing data) to stored historical data, metadata, and other context-enriching data.

Typical capabilities include the establishment and governance of different data-related policies, such as lineage, retention, audit, storage, and sharing.

4.4.7 Health Monitoring and Diagnostics Module

This module would typically provide capabilities for monitoring the overall health of the platform, and for providing support for diagnosis analysis and even some level of troubleshooting in case of failures. Incidents covered by this module includes checking whether a service is down or unresponsive, a piece of hardware is not responding, a network device is getting too many collisions or otherwise creating bottlenecks.

4.4.8 Resilience Module

This module would typically comprise agents, services, and related code units that enables the platform to operate in a reliable way despite unexpected disruptions. This module gives the platform the ability to withstand and recover from hardware failures, software errors, network disruptions, and depending on the platform vendor, even cybersecurity threats. This module may also include functionality to facilitate addressing disaster recovery strategies with the final goals of minimising impact on building operations and occupant safety.

4.4.9 Analytics, ML and AI Module

This module would typically comprise agents, services, and related code units for the capabilities aimed to (i) unlock data-driven insights through different types of statistical analysis (commonly aka analytics) and/or statistical learning techniques (commonly aka machine learning), and (ii) package the models derived from the mentioned techniques in such a way that they can be incorporated in different user-targeting visual artefacts, such as dashboards, low-code (self-developed) applications, and third-party applications and services.

4.4.10 Reporting Module

This module would typically comprise agents, services, and related code units that allows generating reports out of analytics to help managers make informed decisions. Typical reports include those containing insights about energy consumption, building equipment status, and maintenance schedules.

4.4.11 Connectivity Module

This module would typically comprise agents, services, and related code units for the capabilities that enable the platform to integrate with other systems, such as BMS, BACS, EMS, BIM systems, IoT management systems, and business-related systems.

This module typically implements a connector-based approach, where each connector specialises in a particular integration (typically given by the following parameters: a target system (e.g., a BMS), a communication method (e.g., direct-call API), and a communication protocol (e.g., MQTT)).

4.4.12 Security Module

This module would typically comprise agents, services, and related code units for the capabilities aimed at protecting the platform from security threats, both intentional and unintentional, such as those because of misconfiguration, and software or hardware sudden failures.

State-of-the-art security modules go beyond classic authentication and authorisation capabilities, instead providing a comprehensive framework that allows developing strategies for tackling security aspects from multiple angles. An example of such security module is one based on a zero-trust framework.

4.4.13 Distributed Deployment Module

This module would typically comprise agents, services, and related code units responsible for the governance, monitoring, and coordination of interactions between various parts of the platform. These parts may include platform nodes that run services and applications distributed across different tiers within the data-driven infrastructure (refer to information note in Physical Inspection). These tiers encompass various locations such an edge network situated outside but in close proximity to the building, and even a public multi-tenant cloud.

The primary aim of this module is to capitalize on the advantages of distributed deployments, offering benefits such as increased fault tolerance, optimized performance, and enhanced flexibility.

4.4.14 Edge Orchestration Module

This module would typically comprise agents, services, and related code units responsible for the management, automation, and coordination of devices, such as computing servers, located at edge network segments of a deployment's complete network infrastructure. These edge network segments may belong to the building's network system (in both a wired and wireless fashion) and/or to a datacentre close in proximity to the building.

Deployments using edge locations typically addresses scenarios demanding high levels of responsiveness, efficiency, and reliability. These deployments are also typically used to relieve platform nodes a/o third-party systems present in upper locations, such as cloud-based ones, from unnecessary data traffic, processing, and storage, e.g., by only sharing pre-processed quality data.

4.4.15 Semantic Model Module

This module would typically comprise agents, services, and related code units responsible for enabling the creation and management of a tailored digital model specific to the building connected to the data platform (refer to *onboarding* within Data Acquisition/Collection). This model, often referred to as the building's semantic model, encapsulates relevant components of the building's data-driven infrastructure, including its diverse hardware and software systems, equipment, networks, sensors, and associated devices. Additionally, the model covers diverse aspects of the building's data-driven infrastructure, such as sensor placements, device configurations, and the overall network topology. The module's sophistication in aiding model creation may vary, with semi-automated assistance often representing the highest level of offered support. Furthermore, the module's sophistication in term of technologies supporting the created models may also vary, with ontologies and knowledge graphs representing the highest level of offered support.

5. Deployment Guidance

This section aims to provide guidance on the deployment process for data platforms for smart buildings. It explains the key phases of the deployment process, emphasising proper planning and collaboration among stakeholders. It also addresses post-deployment activities to ensure the platform operates optimally over time, delivering the desired outcomes of energy efficiency, occupant comfort, and streamlined operations.

5.1 Deployment Planning

This section assumes that the following processes have already being successfully performed: (i) the goals pursued with the deployment are established; and (ii) a market product evaluation process has already been conducted; and iii) this evaluation has led to the selection and purchase of a specific vendor's platform product. Optionally, the selected product's composition (e.g., modules) may need adjustments if so considered when planning the deployment architecture during the first phase below.

Summary of steps within this phase:

- Identify artefacts to integrate into the platform.
- Specify a deployment architecture.
- Estimate and schedule milestones.
- Build teams.
- Start planning post-deployment periodic evaluation.
- Start planning the whole-deployment testing protocol.
- Start planning the handover.

The first step is to conduct a thorough identification of systems, equipment, and devices that need to be integrated into the data platform to achieve the specified goals. Some of the identified artefacts may already exist in the data-driven infrastructure. Other may need to be acquired. These artefacts come under a wide variety of formats and purposes, such as:

- Business software used by the building owner's organisation, e.g., project management software.
- Technical software used by the building owner's organisation, e.g., BIM software.
- BACS and/or BMS and/or IoT-Management System software and hardware.
- Edge orchestration software and hardware.
- On-Building automation and control devices, e.g., Programmable Logic Controllers (PLCs), HMI-display attached to a controller, field sensing devices, field actuation devices, field buses, IP-networks, and HVAC-equipment.

The next step is to specify the deployment architecture. This architecture will basically describe, show, and govern (i) how the platform and the identified artefacts interact with each other (e.g., by means of what protocols and networks), and (ii) where these artefacts are located (e.g., in the building, close to the building (edge), in owner's organisation's intranet, or in a cloud).

The next two steps are closely related to project management. The first one is about scheduling: a timeline for the deployment needs to be agreed and established. The timeline typically specifies milestones along the way, and final delivery date(s). The second step is about establishment of needed teams, including designating proper roles together with stating and assigning responsibilities.

A very important team, that according to best practice should kick off its duties at this point, is the one responsible for the planning and coordination of the test protocol for the whole deployment. This protocol typically comprises a set of underlying subprotocols each of them targeting single artefacts (e.g., a sensing device), or logical aggregations of related artefacts (e.g., a supervisory BACS together with field controllers, sensing devices, and actuation devices), and that may have dependencies between them. This coordinating team may also be responsible for the elaboration of specific protocol test cases.

Other no less important teams that should start working this early are the training team and the handover team. The former is responsible for training the personnel that will operate and maintain the platform. The latter is responsible for planning the handover process, together with executing it once the deployment is ready for production status. An important deliverable of this process is the platform upgrades and enhancements plan – the roadmap to be able to evolve the platform in a consensus-based and controlled way.

5.2 Platform Installation and Configuration

This phase may be executed after the next one, or even in parallel.

Summary of steps within this phase:

- Install the platform software.
- Configure platform settings.
- Verify installation.

The installation of the platform software adheres to the specified deployment architecture. Hence, the hardware needed to support and run the platform software ranges from single bare-metal computer servers located in the building, to virtual machines on edge- and/or cloud-based datacentres.

Once installed, the data platform needs to go through an initial round of settings configuration. Several rounds are typically needed to fine-tune settings, especially when integrating other needed artefacts into the platform (refer to the next phase below).

Each platform product will enable setting and configuring it in particular ways, ranging from manually editing platform files, to advanced guiding graphical user interfaces. The type of entities to be set and configured will also have a strong relation to the technologies, architecture, and approaches used to offer integration capabilities, e.g., configuring a communication protocol connector. In any case, it boils down to setting traditional variable-value pairs to rule: (i) APIs, including authentication and authorisation, (ii) communication protocols, and (iii) supporting mechanisms (e.g., fallback-related, thresholds, etc).

Finally, a series of testing rounds are conducted for each installed piece of software to verify its installation.

5.3 Other Installations, Configurations, and Integrations

Summary of steps within this phase:

- Install dependent artifacts that do not already exist.
- Configure their settings.
- Verify the installation.
- Integrate them into the data platform.

One of the few things in common between the deployments corresponding to different use cases is that the platform will ultimately rely on the rest of the building's data-driven infrastructure, such as IP-network, a BACS, a BMS, or even diverse databases and storage solutions. These critical, underlying artefacts need to be properly installed, configured, preliminary tested, and finally integrated into the platform. Also note that already-existent, active artefacts may need to have their settings reconfigured to ensure that the whole deployment functions properly. In any case, whether configuration of new, or reconfiguration of already-existent artefacts, the affected settings are typically, initially set in this phase, and fine-tuned in the next one.

5.4 Onboarding

Summary of steps within this phase:

- Configuration of data sources.
- Development of the building model.
- Test and verification.

The process of connecting a building to a data platform for data acquisition purposes is normally known as onboarding. This process starts with the identification of primary data sources, i.e., other systems within the building's data-driven infrastructure (e.g., a BMS, or a database) from where data can be retrieved. Once identified, a platform data source is created within the platform per primary data source. This operation usually involves using a graphical user interface to provide values for a set of parameters used to establish connections and be able to communicate with the primary data source. The process continues with the creation of a digital model for the building being connected. Finally, rigorous testing of the data acquisition process is conducted, including the correct representation of the collected data within the digital model. Refer to Data Acquisition/Collection for further information.

5.5 Testing and Fine-Tuning

Summary of steps within this phase:

- Conduct controlled whole-deployment test rounds.
- Fine-tune settings as needed.

Once all the deployment pieces are in place and installation-verified, a series of testing sessions must be conducted to ensure the proper functioning of the platform. Besides functional verification, it is crucial to verify the performance, availability, and security levels that have been previously determined (optimally, no later than during the first phase).

Modern data platforms are typically designed to facilitate comprehensive testing planning and execution. It's crucial that rigorous testing encompasses various scenarios, including normal operations, scenarios with diverse failures, and even major emergency situations, to thoroughly evaluate how the deployment functions and responds in each context.

5.6 Training

This phase may be started earlier if a proper simulation environment is in place.

Summary of steps within this phase:

- Educate platform-dedicated personnel on the use of the platform.
- Optimally, also introduce the platform to other personnel.

The personnel in charge of the operation and maintenance of the platform need to be properly trained. General knowledge about the platform should be built by all users of the platform, whereas certain user roles will need to build specific knowledge needed to operate and maintain specific sections of the platform.

The training material will typically range from pedagogical documentation to spartan specifications, system diagrams, and alike. Regarding the training methodology, a combination of guided and self-pace education is a good practice. Finally, it is also good practice to keep the training material available after the finalisation of this phase.

5.7 Handover

Summary of steps within this phase:

- Verify what's been planned on the deployment-related documentation.
- Verify what's been planned on support.
- Verify what's been planned on post-deployment periodic evaluation.
- Correct issues detected during the steps above if verification does not pass.

It is widely considered best practice to establish and conduct in a disciplinary way the practice of capturing, categorising, and organising construction handover data (such as, spare parts lists, equipment lists, and system diagrams) during the design and construction of a building (most of this information optimally being in digital format), instead of waiting until the building is about to open. The situation can be worsened if this last-minute procedure is conducted by people with poor or even non-existent connection to the building. In the context of data-driven smart buildings, this best practice should also apply to the handover process connected to the deployment of a modern data platform.

At both whole-building and platform level, support from different firms may be needed by relevant building personnel in the event of sudden issues impossible to be fixed in-house, or because of scheduled maintenance that requires very specific knowledge. It is paramount to verify that the support process together with support service level agreements (SLAs) have been communicated to relevant building personnel. It is particularly critical that a clear issue-escalation process, and proper support channels, including the possibility of before-hand designated contact representatives, have been established, tested, and properly made available to relevant personnel. This will ensure that the personnel can receive timely assistance in the event of issues with the platform.

Once the data platform is on production, it will need to be subject to periodic evaluations to at least (i) assess how well the platform is performing against the defined goals and objectives, (ii) check that needed/latest software and firmware updates are in place and being used, (iii) identify opportunities for optimisation of the platform itself by fine-tuning its settings, and optimisation of the building systems being controlled and automated by the platform, and (iv) revise and optionally update the platform upgrades and enhancements plan, i.e., the roadmap to be able to evolve the platform in a consensus-based and controlled way.

6. Final Words

The exhaustive exploration of modern data platforms presented in this report initially aimed to establish a minimum set of requirements necessary for these platforms to facilitate data-driven smart buildings. However, this exploration revealed the importance of considering other equally relevant aspects that different stakeholders may find valuable in their pursuit of smart buildings. The following key points summarize our findings.

Embracing modern data platforms
The transition towards data-driven infrastructures in buildings constitutes a huge leap forward to achieve smart buildings. This transition allows buildings to move from static structures to dynamic, responsive, smart entities capable of delivering the desired outcomes of enhanced user experiences, operational efficiency, and sustainability. The core enabler to achieve smart buildings are modern data platforms. But to fully realise the true potential of smart buildings orchestrated by data platforms, a comprehensive strategy is needed. Such a strategy should embrace a holistic approach encompassing different critical aspects. One crucial aspect refers to the assessment of the smart readiness of the building's infrastructure. Another critical aspect refers to the meticulous evaluation of requirements during the procurement phase. Finally, the strategy should also refer to aspects related to the deployment of the platform into that infrastructure. These deployment-related aspects should address activities to ensure that the platform operates optimally over time, delivering the desired outcomes of energy efficiency, occupant comfort, and streamlined operations.

Smart readiness
The foundational, basic steps for assessing a building's readiness for smart technologies and data-driven infrastructure emphasise the importance of exhaustive analysis of technical documentation, and physical inspection across all hierarchical tiers. But to fully uncover a building's latent, true smart potential, these foundational steps should be complemented with advanced assessments, such as the European Smart Readiness Indicator.

Minimum requirements
A crucial step in the procurement process involves establishing specific requirements for the desired data platform. During this step, it is essential to consider the minimum set of requirements introduced and described in this report. This measure significantly helps in selecting a purpose-fit data platform that aligns with the goals tailored for data-driven smart buildings, including: (i) digital-ready building infrastructure, (ii) high interoperability, (iii) robust and accessible building data, (iv) data-driven building management, and (v) leveraging data-driven automation and control for enhanced operational efficiency, occupant comfort, and sustainability.

Deployment
To ensure a smooth integration within the building's data-driven infrastructure, and sustained optimal performance delivering the desired outcomes, it is crucial to delineate and execute a meticulous platform deployment plan. This requires an approach with certain unique steps compared to that from generic software

deployment. The most crucial new step involves onboarding the building into the platform, i.e., connecting the building to the data platform for data acquisition purposes. This step also involves the development of a comprehensive digital model, crafted from building metadata. Among other purposes, this model has a central role in smart buildings, providing a unified view of the building's data-driven infrastructure for data-consuming applications. Other important steps of the deployment plan refer to the training of relevant personnel, and a robust handover procedure. Training activities should not only address initial training, but also continuous skill development and knowledge enhancement.

From perspective of building owners and managers, aspects related to smart readiness assessment, purpose-fit procurement, and the final deployment of the selected platform are of paramount importance to succeed in achieving a truly smart, data-driven building. From the perspective of platform creators, a strong focus should be concentrated on developing robust data processing capabilities, including ingestion, preparation, storage, and sharing. In particular, the aspect of data sharing holds significant importance, as it involves granting access to authorised third-party applications to analyse data, discover insights, and even provide feedback to the building's infrastructure for automation and control purposes.

In summary, these findings emphasise the need for a holistic approach in harnessing the true potential of modern data platforms for data-driven smart buildings. A cohesive approach where products, technologies, processes, and people converge harmoniously, enabling not only successful, initial production-setting, but also a continuous optimal operation over time that delivers the desired outcomes.

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