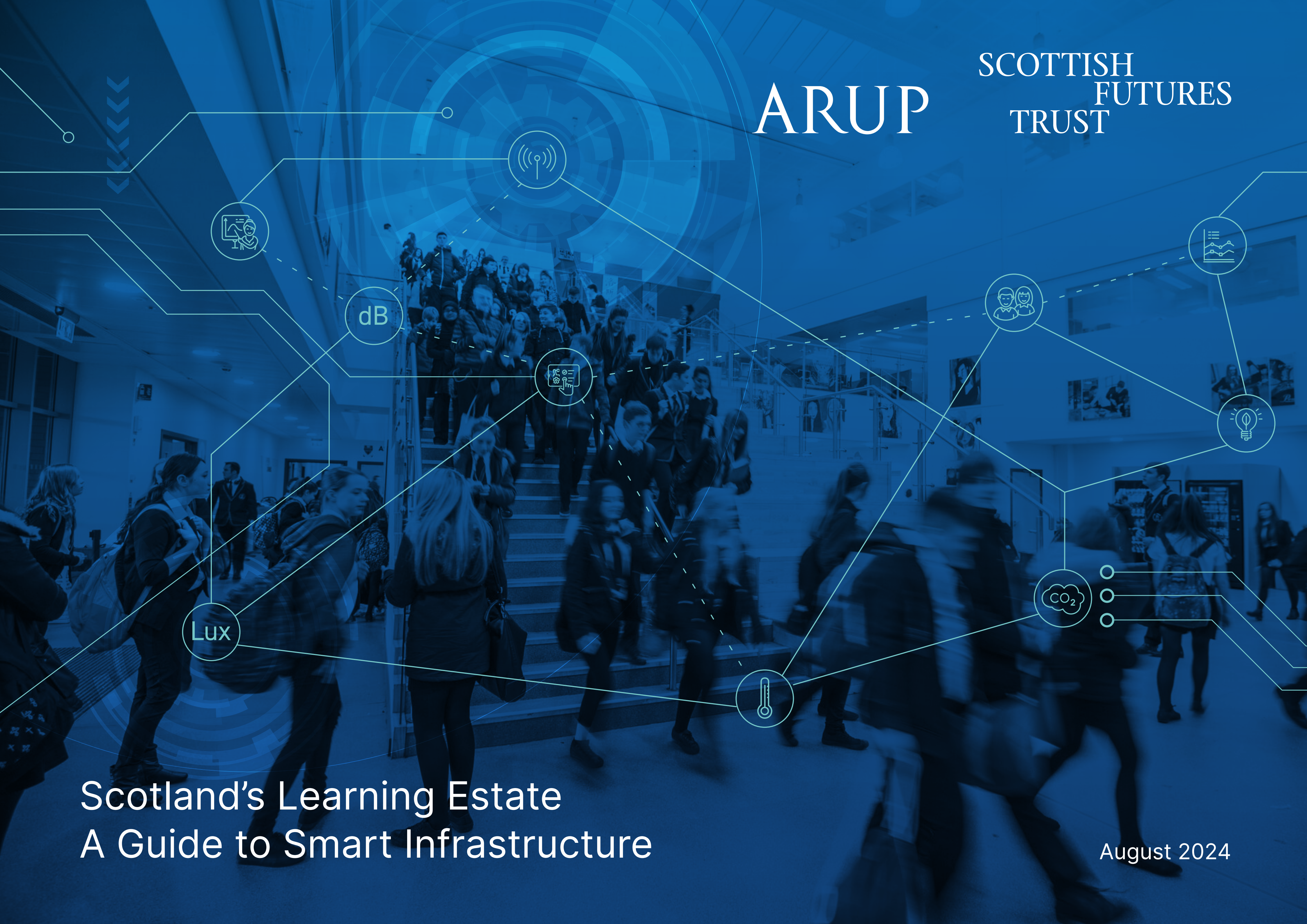

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Scotland's Learning Estate
A Guide to Smart Infrastructure

August 2024

Contents

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Foreword

The way our schools are designed, built and managed is undergoing radical change thanks to the use of ground-breaking digital technologies.

Scotland’s schools and colleges provide a crucial environment for over one million young people and support our communities, public services, wellbeing and economic growth.

Importantly, how well schools perform brings much wider benefits to our society by being able to reduce the carbon they generate or improve the environment for learning. However, the Royal Institute of British Architects[1] estimates that only 5% of our schools operate efficiently as they were intended. Therefore effective performance management of school buildings will be key to deliver against the challenges of a sustainable and inclusive net zero economy.

Never before has technology offered such opportunity to address these challenges. The growth of new solutions and approaches to connect our buildings to digital models and analytics tools allows our buildings to become smarter.

Commonly referred to as ‘smart buildings’ this new capability will improve the performance of our buildings to ultimately improve the outcomes they seek to deliver.

The creation of smart schools is developing quickly and new approaches are being introduced to provide new insights, intelligence and remote interaction with our schools. This new capability will support how well buildings are maintained and perform and ultimately the outcomes they seek to achieve.

This guide is designed to assist asset owners make informed decisions in how they invest, deploy and develop the skills and expertise to leverage the value of smart buildings within the learning estate. This guide is not statutory guidance but offers a best practice approach and resources to begin your journey, support strategic decision making and enable informed investment.

Acknowledgements

The guide has been produced by the Scottish Futures Trust, an infrastructure centre of expertise, and in partnership with authoring partners Ove Arup and Partner Limited (Arup). We would also like to thank steering group partners who have supported the development of this guide. We would also like to thank the industry and public sector partners who have supported the development of the guidance.

[1] Better Spaces Learning RIBA report on school design (architecture.com)

1 Introduction

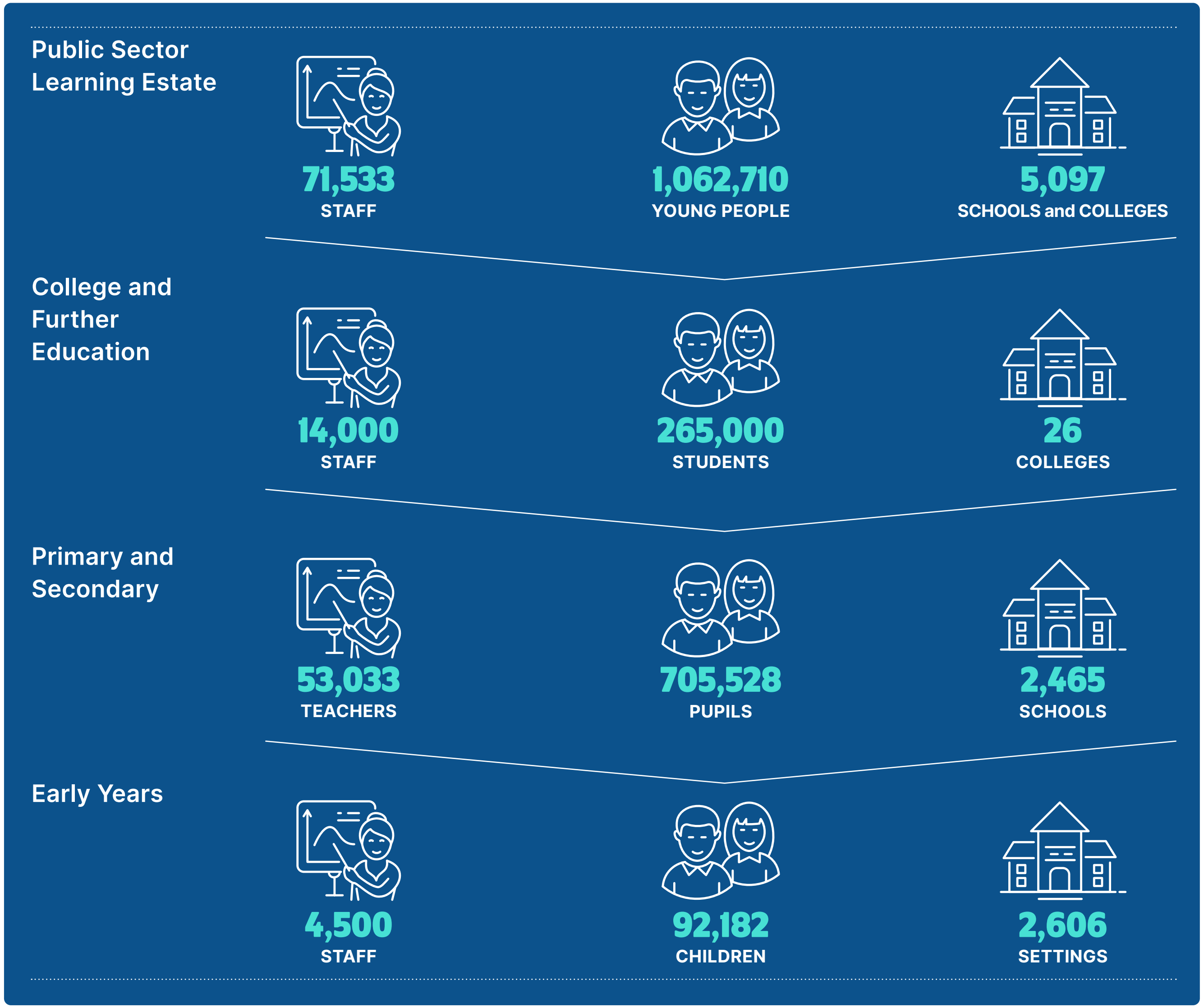
1.1 Scotland's Learning Estate

Scotland's learning estate provides a crucial environment for over one million young people and supports their education and development. The estate comprises a mix of large, multi-campus assets through to smaller assets across all geographies within Scotland.

The public sector learning estate encompasses primary schools, secondary schools, early years facilities and colleges. The estate provides resources for our communities including swimming pools, recreational areas and libraries. Universities are not part of the public sector learning estate and although synergies exist in the application of smart infrastructure, this guide places a focus on the creation of smart infrastructure for the public sector learning estate as outlined in Figure 1.

The learning estate plays a critical part of Scotland's infrastructure and is integral to the success of the communities and economy that it serves. Attractive, digitally enabled and fit-for-purpose estates are essential to deliver successful outcomes for our young people, staff and communities.

Within the early years, primary and secondary school estate, there are over 5,000 schools and facilities, employing approximately 54,000 teachers that provide education for over 800,000 young people. In addition, the college estate encompasses 26 college campuses that employ over 14,000 staff delivering teaching to a further 265,000 young people, of which 40% are aged between 16-24.



Public Sector Learning Estate	71,533 STAFF	1,062,710 YOUNG PEOPLE	5,097 SCHOOLS and COLLEGES
College and Further Education	14,000 STAFF	265,000 STUDENTS	26 COLLEGES
Primary and Secondary	53,033 TEACHERS	705,528 PUPILS	2,465 SCHOOLS
Early Years	4,500 STAFF	92,182 CHILDREN	2,606 SETTINGS

Fig 1. Summary of Scotland's Learning Estate

1.2 What is a Smart Learning Estate?

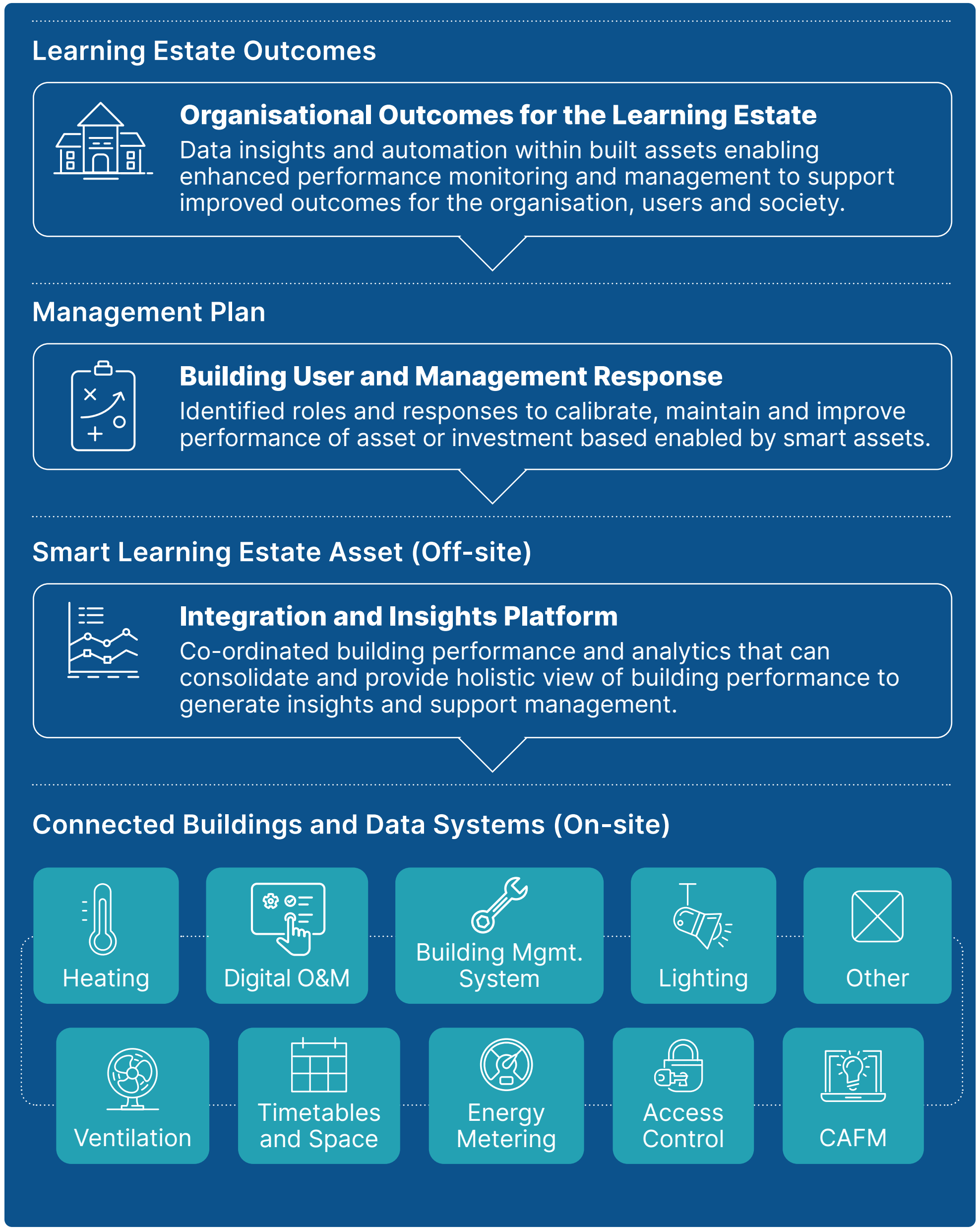
Our built environment is experiencing transformation in how we apply digital technologies and derive new data insights to support how we design, construct and operate our learning estate.

Buildings contain complex systems and components that in isolation can provide insights into the performance of a building across certain systems or functions. These include lighting, ventilation, carbon dioxide and heating systems that all operate autonomously and in some cases communicate periodically or in real-time to building managers, to support them improve the performance of the building.

However, in many instances these building systems are siloed, don't provide real-time feedback and are un-coordinated and their performance is not well understood. In addition, datasets from these systems can not always be integrated which further limits the insights on performance. A smart building looks to address these challenges and will provide a co-ordinated and holistic approach to data management, reporting and analytics to support multiple buildings' users (owners, students, teachers, and communities). In doing so, a building can become smarter and more responsive to the needs of users and in how it operates on a weekly, daily, hourly or minute by minute basis.

The development of a smart building must address key areas of performance that will support the required outcomes. For example, the ability to better monitor and manage the indoor environment has a direct impact on the quality of that learning environment that will support cognitive learning and in doing so support educational outcomes.

This guide provides a high-level implementation framework to support outcomes-led investment for smart building approaches, as summarised in Figure 2. This framework outlines the key thematic layers that require to be aligned and connected to deliver a smart building.



Learning Estate Outcomes

Organisational Outcomes for the Learning Estate
Data insights and automation within built assets enabling enhanced performance monitoring and management to support improved outcomes for the organisation, users and society.

Management Plan

Building User and Management Response
Identified roles and responses to calibrate, maintain and improve performance of asset or investment based enabled by smart assets.

Smart Learning Estate Asset (Off-site)

Integration and Insights Platform
Co-ordinated building performance and analytics that can consolidate and provide holistic view of building performance to generate insights and support management.

Connected Buildings and Data Systems (On-site)

Fig 2. Summary of high level smart learning estate implementation framework

1.3 The Opportunity of a Smart Learning Estate

How well our learning estate performs can bring much wider benefits to our society. Smart building approaches can help reduce the carbon buildings generate, improve the wellbeing of occupants, reduce costs in the delivery and management, and ultimately support improved learning outcomes.

The Fraunhofer Institute of Building Physics[2] has identified that an increase of school children's performance by 2.8% would lead to a 6.7% - 9.5% increase in the conditional economic growth of the country (based on GDP per capita).

The role of smart building technologies and strategies can address key challenges across the learning estate which include:

Wellbeing
Through utilisation sensors, we can understand the flow of pupils within a school, and this can then mitigate overcrowded areas, reduce noise and disruptions to support wellbeing. By measuring indoor air quality, we can ensure that the air quality is optimised for comfort and learning.

Community Access
If we have a detailed understanding of usage we can maximise the use of, for example, 3G pitches or swimming pools for the community.

Energy and Carbon
Through improved understanding of occupancy we can improve our approach in how we heat and light our schools to reduce carbon. Analysis and optimisation of the building control systems can significantly reduce energy consumption. Smart building approaches can also help close the performance gap in buildings. There is significant evidence to suggest that buildings do not perform in operation as they were designed with the UK Government Building Performance Evaluation concluding this gap between design performance and actual being on average four times higher.[3]

Environmental Comfort
A holistic understanding across multiple environmental systems (e.g. lighting, temperature, humidity and other parameters) allows building owners to tailor comfort settings. The system will detect changes in temperature and other environmental metrics and give actionable insights or automate changes. A holistic evidence and design project, funded by the Engineering and Physical Sciences Research Council identified: "Clear evidence has been found that well-designed primary schools boost children's academic performance in reading, writing, and maths. Differences in the physical characteristics of classrooms explain 16% of the variation in learning progress over a year for the 3,766 pupils included in the study."[4]

Future Design
Understanding how people engage and use school buildings can better inform the design of future schools. For example, if the space efficiency improved for future secondary schools by reducing the gross internal area by 5%, this could equate to savings of circa £200k per annum in running costs per secondary school.

Preventative Maintenance
Analytics performed on real-time building data can detect potential issues or required maintenance on buildings' systems. This will mitigate the risk of buildings required to be closed due to failure of systems and provide greater resilience within the estate. For example, this technology allows cost effective wireless sensors to be deployed to detect small water leaks before they become a larger problem that will take more time and money to fix.

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2. V0011947-128-002_Indoor_climate_health_A4_Fraunhofer_2.indd
3. https://www.ukri.org/wp-content/uploads/2021/12/IUK-061221-NonDomesticBuildingPerformanceFullReport2016.pdf
4. Clever classrooms : Summary report of the HEAD project (worktribe.com)

2.0

What We Measure and Why Within the Learning Estate

2 What We Measure and Why Within the Learning Estate

2.1 Outcomes Led Approach to Smart Buildings

The investment in an integrated and smart enabled learning estate should be outcomes led. This line of sight from the data we collect to these outcomes should form the basis of the smart building investment strategy. The ability to develop linkages between the data we capture and the outcomes we seek, can be considered across four steps as outlined in Figure 3.

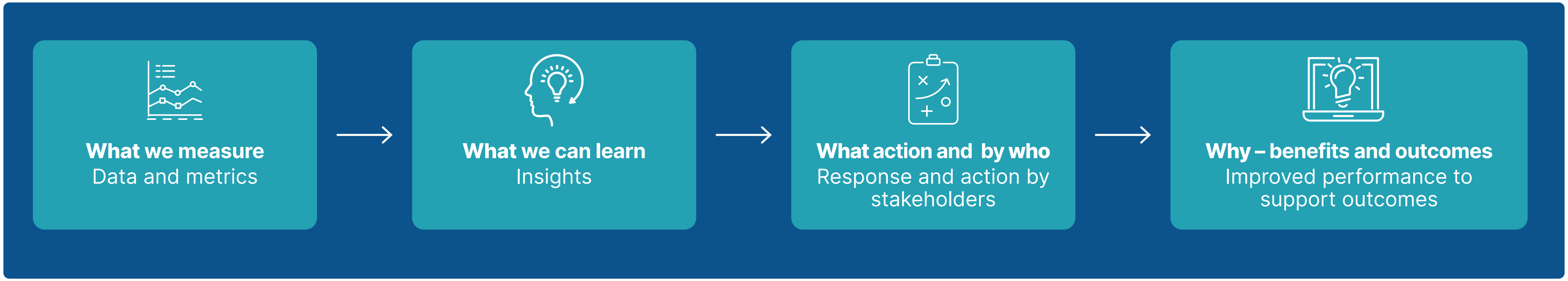
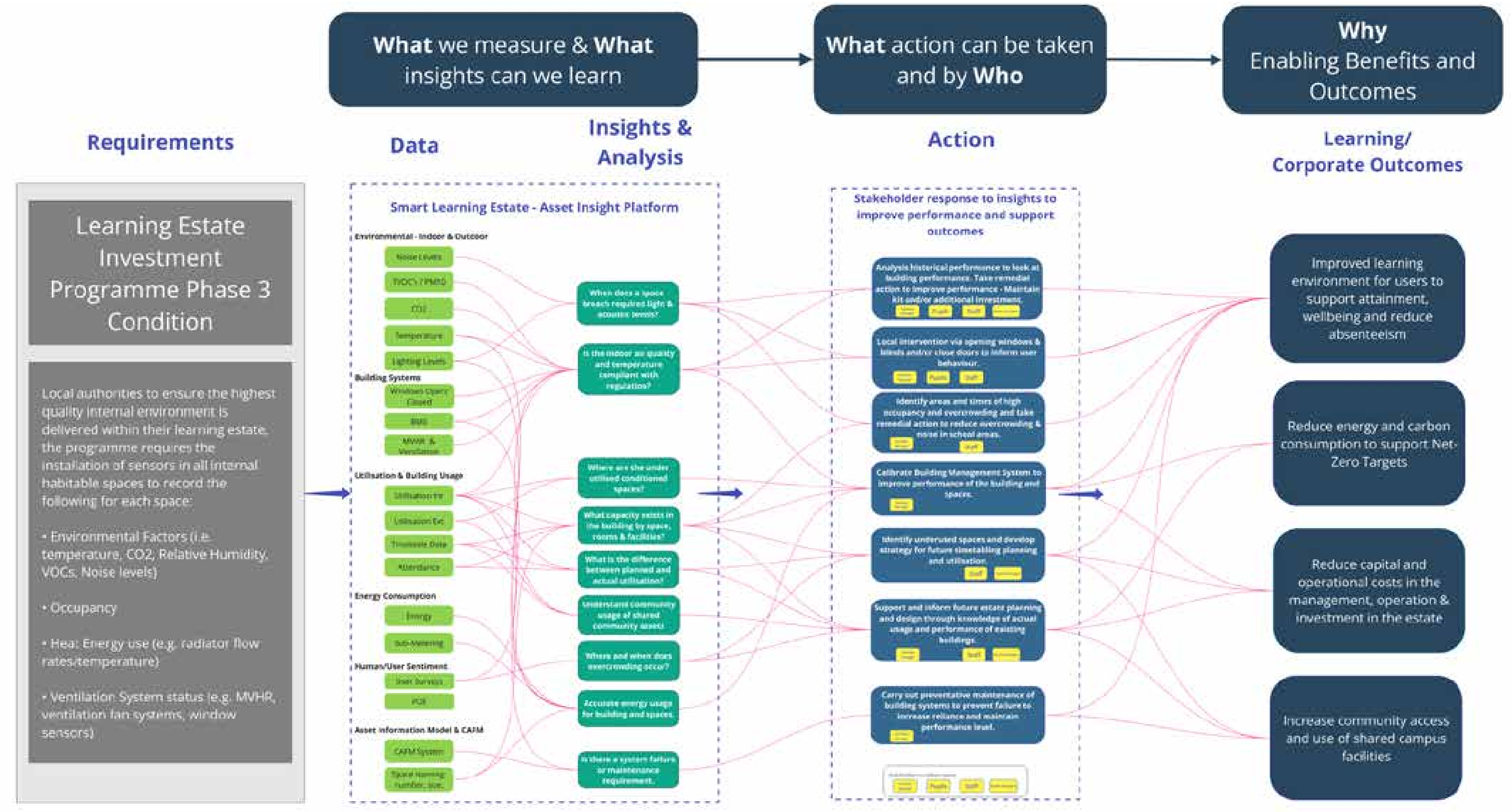


Fig 3. Line of sight between data and outcomes for smart building deployment

To help conceptualise this approach, the logic diagram outlined in Figure 4, provides an example of mapping the data collected by smart building sensors and systems through to the outcomes they seek to support.

This has been developed against the Learning Estate Investment Programme phase 3 funding requirements for monitoring of the environment and utilisation and can be accessed here.



Local authorities to ensure the highest quality internal environment is delivered within their learning estate, the programme requires the installation of sensors in all internal habitable spaces to record the following for each space:

- Environmental Factors (i.e. temperature, CO2, Relative Humidity, VOCs, Noise levels)
- Occupancy
- Heat Energy use (e.g. radiator flow rates/temperature)
- Ventilation System status (e.g. MVHR, ventilation fan systems, window sensors)

When does a space breach required light & acoustic levels?

Is the indoor air quality and temperature compliant with regulation?

Where are the under utilised conditioned spaces?

What capacity exists in the building by space, rooms & facilities?

What is the difference between planned and actual utilisation?

Understand community usage of shared community assets

Where and when does overcrowding occur?

Accurate energy usage for building and spaces.

Is there a system failure or maintenance requirement.

Analysis historical performance to look at building performance. Take remedial action to improve performance - Maintain kit and/or additional investment.

Local intervention via opening windows & blinds and/or close doors to inform user behaviour.

Identify areas and times of high occupancy and overcrowding and take remedial action to reduce overcrowding & noise in school areas.

Calibrate Building Management System to improve performance of the building and spaces.

Identify underused spaces and develop strategy for future timetabling planning and utilisation.

Support and inform future estate planning and design through knowledge of actual usage and performance of existing buildings.

Carry out preventative maintenance of building systems to prevent failure to increase reliance and maintain performance level.

Improved learning environment for users to support attainment, wellbeing and reduce absenteeism

Reduce energy and carbon consumption to support Net-Zero Targets

Reduce capital and operational costs in the management, operation & investment in the estate

Increase community access and use of shared campus facilities

Fig 4. Example logic diagram of data and smart infrastructure supporting outcomes

2.2 Types of Information to Support Asset Performance

Smart buildings can create, consume and report many types of information. The types of information will be determined by the line of sight asset owners wish to create between the data and outcomes. Some key types of information to be considered in your smart learning estate may include:

Indoor Environmental Conditions
Internal environmental monitoring seeks to assess the quality of the internal environment and may include light levels, noise, temperature, CO_2, air quality and humidity.

External Environmental Conditions
Similar to the internal environment, however the focus is on parameters such as air quality, noise levels and supplemented by data points relevant to the external environment of that building. Monitoring of the external environmental conditions can be used in conjunction with the internal conditions to understand the efficacy of mechanical ventilation or the impact of natural ventilation on the indoor environment.

Energy and Utilities Consumption
An established approach to the monitoring of building consumption across electricity, gas, water and thermal energy. The evolution of building standards requirements has placed a greater emphasis on sub metering to provide greater insights in building areas and systems.

Building Occupancy and Utilisation
Space utilisation can be defined simply as the proportion of time a space is used across its scheduled working period. Each space has a different capacity – typically expressed as the maximum number of people that can occupy that space at one time. Due to the variance in when a room is used and what capacity it can hold, the assessment of utilisation needs to account for both frequency of use and occupancy.

Building Systems Monitoring
This area of information management within the context of smart buildings is the ability to enhance and link system and sensor data relating to the performance of systems or assets. Examples include; sensors for pumps, monitoring of air flow within ventilation systems or sensors to confirm if a window is opened or closed. These sensors coupled with the data from the system itself, report and monitor the performance of a product, asset or system. Building management systems provide a varying level of sophistication in this aspect of information management.

Human Sentiment and Opinion
The heart of any smart building is the focus on people. Humans are the greatest sensors and source of real time information. Human sentiment can be captured through manual data collection, user surveys and single button response kiosks as a means for gathering user satisfaction and feedback.

Asset Information Model/ Digital Records of Build Asset
Smart Building solutions and the insights they provide should be supported by and underpinned with the information we hold on that asset to support effective analysis and response. The importance of structured, aligned and searchable information of our assets continues to derive whole life benefits and support effective performance management of our assets. This can be considered through the building information management and modelling process underpinned by ISO standards 19650 series.

3.0

How to Make Your Learning Estate Smart

3 How to Make Your Learning Estate Smart

3.1 A Framework for Implementation

To begin the development of a smart building strategy for an individual building or an estate, this guide has developed a high level framework to support asset owners approach this challenge in a logical and sequential way and help them document what they currently have and what they require to derive value and impact from smart buildings. The high level framework in Figure 5 has been split into five layers that once considered holistically, will enable asset owners to develop outcome led strategies.

There are five key layers to the framework which include:

1. Foundational Layer

This layer considers the overarching standards for appropriate data standards, protocols and technology requirements aligned to organisational processes and requirements to ensure the smart building aligns within the wider organisational strategy.

2. Onsite Data Systems

This layer considers how you then classify the physical assets and dynamic data that is generated from your building systems. This layer looks to identify existing or new building systems, devices and data sources across three data categories:

- **Third Party –** A data source which is created, managed and hosted by a third party provider. For example, this may be an Internet of Things (IoT) supplier who provides data access via a third party platform with limited or no ability to extract the data in a open source format.
- **Open Data –** An open, interoperable data source generated by building systems and IoT devices. The asset owner can access the data via an application programming interface (API).
- **Data Translation –** The data source is not interoperable from its source and requires software to translate the data into a format that can be used by the asset owner.

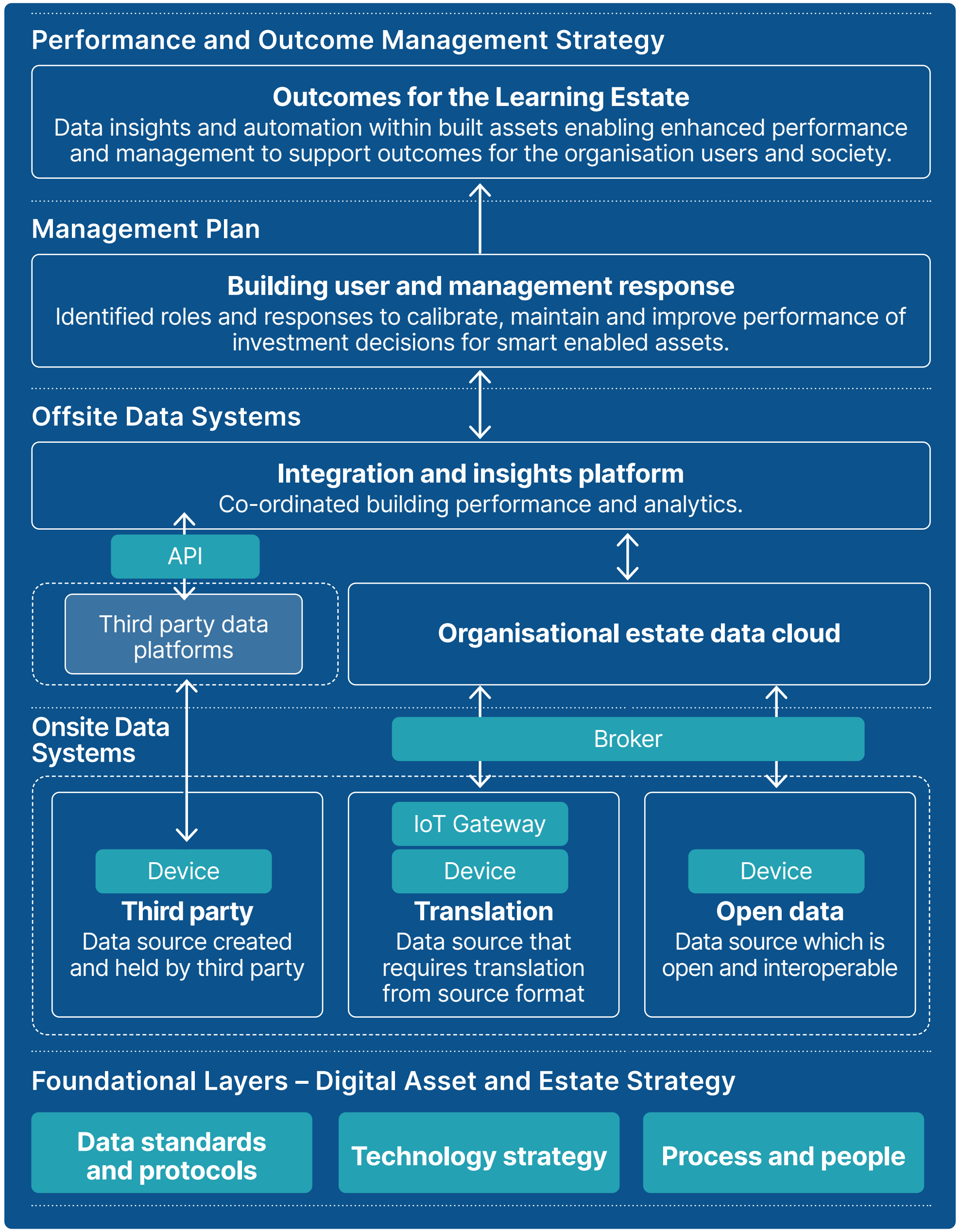


Fig 5. Implementation Framework for Smart Building Strategy

3. Offsite Data Systems

This layer of the framework considers how we curate and co-ordinate the mapped datasets to derive insights. There are three high level ways the data can be engaged with:

- **Third Party Platform –** Where data from a building system is held and hosted by a third party supplier via a proprietary platform.
- **Organisational Estate Data Cloud –** A proprietary or bespoke cloud based platform used by the organisation to co-ordinate and engage with multiple device datasets.
- **Integration and Insights Platform –** A platform which integrates and presents the third party and organisations datasets to derive insights and support decision making. For example, this could be a simple MS office 365 platform that links to or accepts data from multiple system through to a fully integrated system that co-ordinates and presents all datasets.

4. Management Plan

This layer focusses on how existing facilities and asset management approaches may adapt to the new capability smart buildings can provide. For example, should new skills in the management and maintenance of smart building systems be considered? Where new insights are provided, e.g. space utilisation, should this inform asset planning and investment strategies? The value of any smart building solutions will be realised by the human response to that insight.

5. Organisation and National Outcomes

The final layer is the linkage of data, insights and actions to support the required organisational outcomes.

To help conceptualise the framework, a worked example of this approach and how it could be applied within the learning estate, with a focus on utilisation data can be found here.

When developing your strategy for smart buildings, consideration should be made to the required period of deployment. Some smart building technologies might only serve a dedicated purpose over a defined period of time to derive the required insights, whereas other devices and solutions may be required for the whole life of the assets. The distinction can be made as follows:

Deploy and Learn for Fixed Period

Where smart building technology is only deployed for a temporary use case. For example, noise levels in classrooms can be measured over a defined amount of time with local and easy to install sensors that do not require any supporting infrastructure. The data can be interpreted and sensors can be decommissioned once insights and actions are agreed.

Whole Life Deployment

A smart building technology deployed over the lifetime of a building or asset. For example, smart energy meters delivering real-time data to a cloud-based data platform for efficient energy tracking.

3.2 People and Process

3.2.1 Key Roles and Skills

To successfully deliver a smart building solution for your learning estate, you will need to ensure the right skills, capabilities and processes are in place for the design, deployment and long-term management of the smart solutions and their data outputs.

Given the complex and specialist nature of smart building technologies, asset owners will have a varying range of existing skills and knowledge and may need to appoint a smart building consultant or similar to help navigate and develop a strategy for their new or existing facilities. Key roles in the design and delivery of smart building solutions include:

M&E Designer
This role will need to support and define the services requirement and alignment with the smart building brief and strategy.

Smart Building Consultant
Appointing a smart building consultant early will ensure they are engaged in initial discussions with key building stakeholders and end users, and through their knowledge and experience, can help identify any technical limitations or constraints, such as the compatibility or interoperability of existing software platforms, network sensors and data formats. This type of intel can help reduce the risk of redesign or rework during the later development stages. A Scope of Services template can be found under Section 4.0.

Contractor and Supply Chain
To support integration, co-ordination and commissioning of smart building technologies in retro fit, refurbishment or new build.

Sensor System Specialist
Specialist contractor responsible for the supply, installation and commissioning of sensor networks.

Master System Integrator (MSI)
Specialist contractor responsible for ensuring all sub-contractor trades adhere to the smart building requirements and for device testing and data validation. The MSI shall additionally supply, install and commission sensor networks as well as the on-premise broker.

Commissioning Manager
A commissioning manager is responsible for managing and overseeing the commissioning process of large-scale projects. They ensure that systems, facilities, or equipment are installed, tested, and functioning as intended before being handed over to the client.

Facilities Manager (FM)
It is important that the FM is engaged in the handover of the building to ensure information and knowledge are successfully transferred from the contractor and supply chain to manage and leverage value and insights from the smart building systems.

3.2.2 Development of the Brief

In the development of smart buildings and a smart learning estate, it is important that the requirements for the smart infrastructure are defined early in the process and validated during the design, procurement and construction stages.

The implementation framework included within this guide may provide a useful starting point for asset owners to begin to understand and develop their thinking as to the smart building requirements.

In addition this guide has developed a *'Smart Building Template Brief'* that provides the basis to support development of an informed smart building brief.

The phrases 'human-centric' or 'socio-technical' are often used to describe the role of people within the heart of any smart building solution. Clearly understanding all the stakeholders' needs and requirements at an early stage will support the development of 'user journeys' which can be mapped to target benefits and outcomes. Early user engagement will also support the development of a clear business case and help inform the functional requirements and technical specification of the smart building solution.

The brief should also be developed to respond to wider organisational requirements such as programme level funding requirements (i.e. the Learning Estate Investment Programme Phase 3 conditions) or where the smart building technology can support and evidence compliance to other project level standards (i.e. Net Zero Public Sector Buildings Standard).

3.2.3 Validation Through the Delivery Process

During the design and construction phase, the smart building requirements for a new or existing building, should be monitored and validated by a suitable qualified person to ensure compliance.

The Royal Institute of British Architects (RIBA) has published the Smart Building Overlay to the RIBA Plan of Work. This provides a useful guide into the development of smart building through the delivery process and sets out key considerations for delivery and validation through the delivery stage.

3.2.4 Maintain and Realise Value During the Operational Stage

Through the operational stage, any smart building solution will require to be maintained with sufficient resources, skills and expertise to maintain the systems and derive value and impact. This may include new skills sets in the management of the systems or leveraging insights from the analytics software. Skills gaps can be supplemented by external consultancy, additional support through service maintenance agreements, or direct development of in-house capability.

Once the smart building technology is operational, there will need to be resource and budget provisions available to periodically test, inspect and service the physical hardware and components. For example, IOT sensors will need to be regularly calibrated to maintain accuracy and quality of data for analysis and reporting. These arrangements may be done internally, through FM agreements or through the supplier of the sensors.

There will likely be ongoing costs for software platforms and licenses which may include the need to ensure they are updated or upgraded to keep aligned with newer technology or security requirements.

The solutions can also support compliance against parallel standards and process that may be undertaken during the investment lifecycle including, post occupancy evaluation; commissioning, delivery of standards like the Net Zero Public Sector Building Standard, or administering Government Soft Landing processes.

3.3 Data strategy

3.3.1 Data ethics and security

Smart buildings will lead to an increase in the amount of data being generated and utilised by asset owners. Ensuring ethical handling of this data is crucial for maintaining privacy, security, and trust among occupants and stakeholders. Data ethics and security in buildings refer to the principles and practices governing the collection, storage, usage, and protection of data. Some areas to consider when developing an ethical approach to smart buildings includes:

Privacy Protections
Building occupants have a right to privacy regarding their personal data being collected within the building environment. This includes information such as occupancy patterns, movement tracking and usage of facilities. Transparent policies should be established to inform occupants about data collection practices and to obtain their consent where necessary. Whenever possible, anonymise or de-identify personal data to protect individual privacy. This involves removing or encrypting identification information so that data cannot be linked back to specific individuals.

Proportionate Data
Collect only the data that is necessary for building operations and tenant services. Minimising data collection reduces the risk of unauthorized access and misuse. Additionally, it simplifies compliance with data protection regulations such as GDPR (General Data Protection Regulation).

Security Measures
Implement robust security measures to safeguard data against unauthorised access, breaches, and cyber attacks. This includes encryption, access controls, intrusion detection systems, and regular security audits.

Consents
Obtain explicit consent from building occupants before collecting their personal data, especially sensitive information. Clearly communicate the purposes of data collection, how it will be used, and who will have access to it. Transparency builds trust and allows occupants to make informed decisions about their privacy. Personal data collection is an essential part of use-cases such as access control. However, in the case of an individual not consenting to secondary use-cases, their use and enjoyment of the facility should not be degraded in a way that is punitive or disproportionate to the missing data.

Data Ownership
Clarify ownership and control rights over building data between users, building owners, and service providers. Contracts and agreements should explicitly address data ownership, usage rights, and responsibilities.

Data Retention
Establish policies for the retention and disposal of building data in accordance with legal requirements and ethical standards. Data should only be retained for as long as necessary to fulfil its intended purposes and securely disposed of when no longer needed.

Regularly monitor data practices and security measures to identify and address any ethical concerns or vulnerabilities. Building management should be proactive in addressing emerging risks and evolving ethical standards in data and security practices. By adhering to these themes, building owners, operators, and occupants can ensure that data and security ethics are prioritised in building environments, fostering trust, privacy, and responsible data stewardship.

3.3.2 Making use of Existing Data Sources

Before the procurement and installation of any new IoT sensors, consideration should be given to what data sources already exist. For example, a Building Management System (BMS) may capture and utilise temperature, relative humidity and carbon dioxide data to control the building systems. Deployment of a gateway device could make the BMS data available for wider monitoring and analysis.

In doing this, consideration should be made to the quality of existing sensors or systems. It is important to validate the accuracy of any existing datasets or devices. Unreliable data will produce unreliable analysis results. It is advisable to develop consistent standards for sensor accuracy across the estate to enable reliable comparison of data across building sets.

An example of this approach was through the work by Smartviz and Midlothian Council on the aggregation and analysis of existing asset dataset and systems on Lasswade High School as summarised in Figure 6 and outlined in the case study that can be accessed here.

Fig 6. Analysis by Smartviz on Lasswade High School of valid existing datasets

3.3.3 Data Standards and Protocols

A sustainable, scalable smart building strategy should place an emphasis on data standards and protocols. How we develop a consistent approach to the naming and identification of assets, devices and point naming is essential to enable querying, analysis, management, tracking of building devices and application deployment. This can be achieved through the adoption of a consistent naming schema across both physical devices and digital control points. With this, each building receives a unique code and each device in the building receives a "unique name". The unique name allows the device (and associated data) to be identified and addressed within local specific systems, as well as any data platform in the cloud, allowing analysis and comparison of devices in the building but also across building portfolios.

A good example for industry best practice naming standards is the Building Device and Asset Naming Standard (BDNS) – an open initiative that provides a publicly available specification for naming syntax, as well as a register of building device type abbreviations.

Similar to devices, datapoints need to be named consistently. This can be achieved by implementing the Digital Building Ontology (DBO) – an openly available point naming schema based around the concatenation of specific "subfields" to generate consistent point names.

A further barrier to using data collected from various devices is knowing what it means. For example, a temperature reading value is only helpful if its unit of measurement and the system it is related to are known. This crucial associated data is commonly referred to as metadata. Data standards should be considered in relation to the **tagging** and **metadata** for device information. As the number of devices generating and publishing data increases, data semantics become increasingly important.

The concept of tags to represent the metadata can be used to achieve this. Tags represent information about data items and can be associated with the point names to provide information that describe the point. In this way they give meaning to the point, but they do not replace or change the point name in any way. Standardised models for metadata tagging and schemas are:

Project Haystack
Open semantic model that defines standard tags and relationships to represent HVAC, lighting and other IoT systems – e.g. a point related to a piece of equipment related to a specific building. While providing a standard semantic model for typical equipment, Haystack is designed to be extensible, allowing for expansion and coverage of a wide range of equipment.

BRICK Schema
A proposal for a unified metadata schema for buildings which has two main components: a class hierarchy describing the family of building subsystems and the entities and equipment therein.

3.4 Technology

3.4.1 Principles and Approach

In the deployment of technology for a smart buildings, the following four key principles should be considered:

Being Open
Using open and commonly/freely available protocols is essential for interoperability between different building systems as well as outward facing communication, e.g. to cloud-hosted data platforms. This also facilitates avoiding any "lock in" scenarios with vendor specific hardware and software and helps future-proof the building.

Being Scalable
As a direct consequence of the above, scalability and extendibility are massively enhanced. Another considerable factor is the efficient design of the network and associated infrastructure.

Being Secure
As the main driver of a smart building is the efficient and meaningful use of its data, this needs to be handled in a secure way and can be achieved by means of industry standard encryption processes (see below section).

Being Flexible
Using the principles of being open and structuring the data in a consistent defined method ensures that the system is flexible and able to easily be adopted to utilise future applications.

A further industry best practice approach to the principles in technology adoption for Smart Buildings is the Gemini Principles, released in 2018. This proposes principles to guide the national digital twin. Enshrined in these principles is the notion that all digital twins must have clear purpose, must be trustworthy and must function effectively. All the Gemini Principles flow from this. They are deliberately simple, but their implications are far-reaching and challenging. They are descriptive of intent, but agnostic on solutions, to encourage innovation and development over time.

Given the fact that a building typically consists of several subsystems, the idea and general benefit of a smart building is to unify the systems and data out of these various subsystems in order to make use of it more efficiently. This can be viewed as a layered approach:

Building Systems Layer
Each building subsystem is considered as an individual source of data. These may be capable of communicating with a cloud-hosted data platform natively or require a gateway ("Smart Integration Interface") for this purpose. IoT devices such as sensors are considered part of this layer as well.

Data Platform Layer
Semantic "data lake" that is typically hosted on a cloud. This unifies all data from all building subsystems and IoT devices in a consistent way.

Application Layer
Any third-party application that interprets the building data in order to provide meaningful insights such as dashboards, energy performance metrics, integration between systems, etc.

Figure 7 shows an indicative arrangement where the sub-systems have been identified and linked through a IoT gateway. The dashed line representing the delineation between onside systems and offsite systems and platforms held in the cloud.

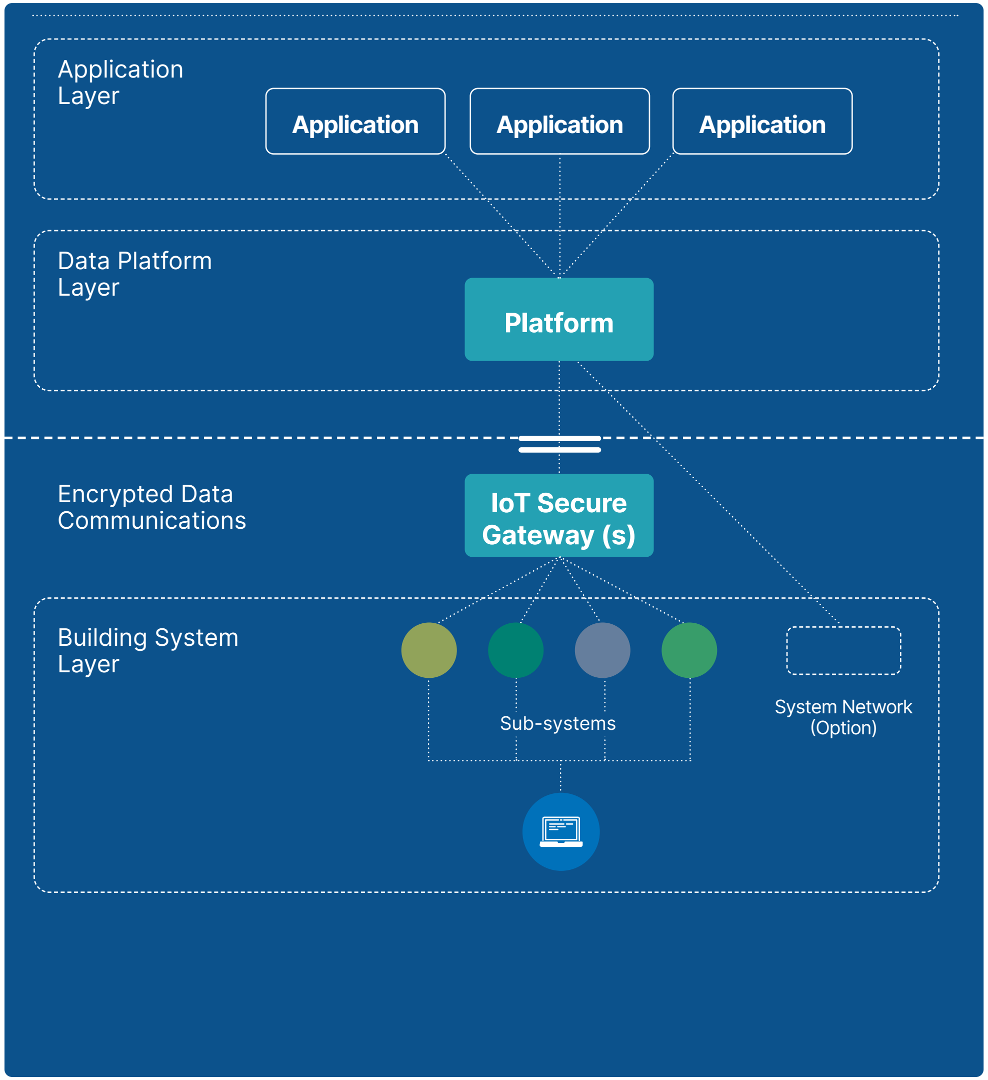


Fig 7. Smart building indicative system layers

3.4.2 Technology Stack for Smart Buildings

Smart buildings contain an array of technology types which can range from various building subsystems IoT sensors, infrastructure hardware and software. Some key technologies that will enable a smart building solution include:-

Building Systems
Each building subsystem that provides data such as HVAC and lighting control, access control and security systems, etc.

Internet of Things (IoT) Systems
This could be indoor air quality sensors (e.g. CO_2/VOC/ PM/noise levels), people counting sensors, smart energy meters, etc.

Data Platform/Cloud
Common data environment for smart building applications to operate.

Building Applications
Third-party applications to enable user functionality such as centralised controls, advanced dashboards, analytics of all collected data for visualisation and reporting purposes.

The role of IoT will be crucial to enable the ambition that smart building approaches can provide. Developed by Censis and Scottish Futures Trust, the IoT for social infrastructure: a how to guide provides a useful guidance on IoT and considerations in its deployment.

3.4.3 Integration, Interoperability and Cyber Security

One of the key principles of smart building system integration is the **Internet Protocol** (IP) network management. When it comes to the physical infrastructure (i.e. structured cabling), there is generally three ways of enabling smart systems to efficiently operate and communicate:

Existing IP Network
This can be any network already present in the building, however this needs to be properly managed in order to allow smart devices to operate securely and efficiently, such as Virtual Local Area Network (VLAN) management in order to logically separate smart building system devices from other devices on the network. Examples of systems that may use the existing IP network include:

- Operational (reception, voice, collaboration software, etc.)
- WiFi for teachers, students, etc.
- AV (in-classroom technology)

Dedicated "Building Management Network"
A physically separated network for smart building system devices only with a bespoke interface to the corporate or common network. This network can be shared by all building systems such as:

- Facilities management (BMS, HVAC, lighting control, etc.)
- Security (Video surveillance, etc.)
- Smart Building devices (e.g. Indoor Air Quality sensors)

Low Range Wide Area Network (LoRaWAN)
Specific IoT/smart building devices such as sensors support the LoRaWAN standard and operate wirelessly in the building. A dedicated wireless IP gateway will be required to pick up the data.

To support networking strategies, **Edge Devices** may be deployed to support the smart building strategy. Edge devices include IoT devices such as indoor air quality sensors and typically include a microprocessor system capable of supporting IP network technologies. Sometimes the device will support wireless networking and this can take the form of a local network (such as WiFi, Bluetooth mesh or Thread) or a public network.

Edge Devices will generally be required to support the recognised Internet Engineering Task Force (IETF) standards in order to implement essential network.

Dynamic Host Configuration Protocol (Dhcp) IP Address Assignment
Edge devices will be dynamically assigned with IP addresses on a managed network. This is especially important on large networks with great numbers of IoT devices where manual IP address assignment would simply not be feasible.

Encryption and Authentication
Edge devices will allow for state-of-the-art encryption in order to communicate securely. An example of this would be Transport Layer Security (TLS) Protocol that provides end-to-end security of data sent between applications over the internet, where a server and client would use "keys" to unlock encrypted communication.

A further area of focus to support security, is certificate-based authentication. This is strongly preferred and should be specified where suitable products are available. Further common cyber security standards and industry best practice for Edge Devices include but are not limited to the following:

Network Time Protocol (NTP)
NTP is used to synchronise clocks on computer networks with a server that provides an accurate time (e.g. from atomic clock as a time source) to clients on the network. This is important, as datasets can only be interpreted when they are synchronised to the same time source.

- **Internet Protocol v6 (IPv6)**
  Latest version (successor of Ipv4) of the communications protocol providing the identification and location for computing devices on the internet. Since the eventual exhaustion of available IPv4 addresses and increasing quantity of IoT devices, this is becoming the standard for modern IP devices.
- **Domain Name System (DNS)**
  Protocol to match IP addresses to a corresponding human readable name. Large numbers of IoT devices and their queries on DNS can challenge the network and also be subject for possible cyber security attacks. Proper DNS filtering is crucial for efficient and secure IoT device communication on a network.

Some existing building systems do not adhere to the above or are not capable of any IP connectivity, IP gateways or smart integration interfaces. In order to map the required connectivity holistically across building systems, **network topologies** that describe the layout of a network can help communicating the strategy or requirements for a smart building. Figure 8 shows different types of devices connected to a converged Building Management Network.

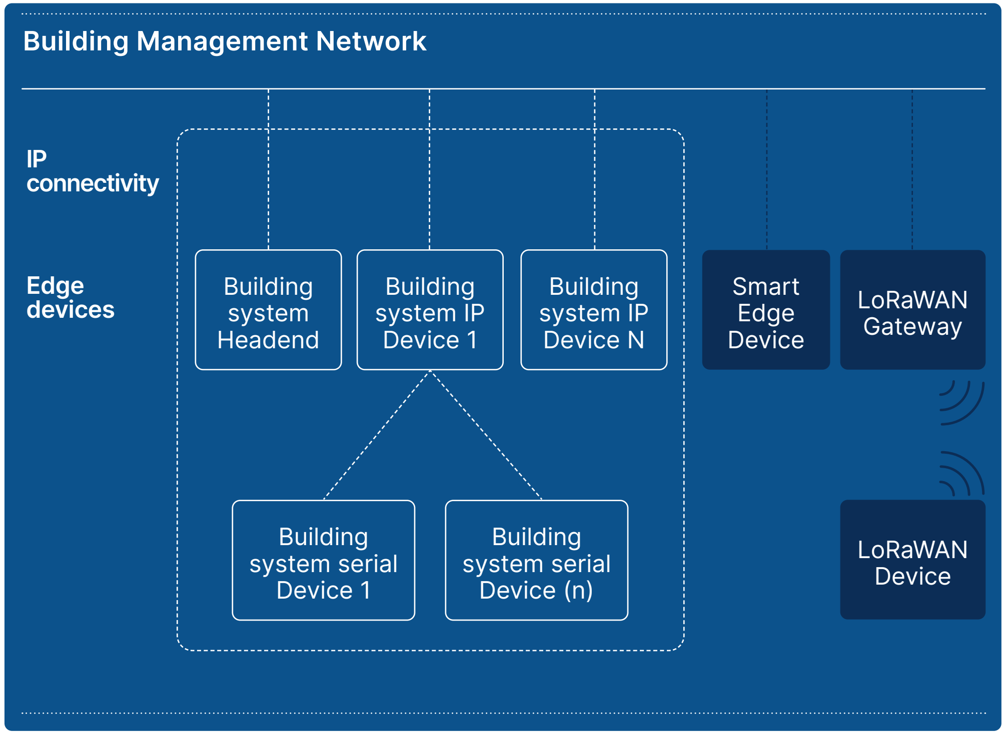


Fig 8. Network typology of multiple devices connected to a Building Management Network

Smart building communication protocols are another key enabler for the use of smart building devices. This is required from an interoperability point of view to support open communication between devices and ensuring flexibility and scalability. It also ensures devices communicating securely. Smart building communication protocols can be classified into two typical categories:

Compliant Protocols

Communication protocols that comply with the above mentioned standards natively. For example, MQ Telemetry Transport (MQTT) - The protocol supports standard solutions for encryption of communications (TLS) and great flexibility over the type of messages that can be delivered. It follows a publish/subscribe model, which increases the efficiency of network usage due to e.g. being able to handle change-of-value (COV) publication rather than time-interval (i.e. constant flooding of data). MQTT is the most popular protocol for IoT engineering in industrial applications and is supported in the IoT solutions provided by all leading cloud service vendors.

Legacy Building Protocols

Communication protocols that do not support the above mentioned standards natively and would need to be translated – e.g. by a smart integration interface to a compliant protocol such as MQTT for data extraction. For example:

- **BACnet IP and MS/TP** – BACnet is the most widely adopted and supported interoperability protocol for building services systems and is available internationally. While it is sufficiently scalable for in-building messaging within and between systems, the nature of its implementation is not suitable for internet communications leaving the building. BACnet can be utilised via IP or via RS485 field bus (BACnet MS/TP).
- **Modbus** – general purpose digital communications bus which suits devices with very constrained capabilities. The field bus for Modbus RTU is RS485, which is still commonly used as part of building systems and can be picked up via suitable IP gateways (see Smart Integration Interface).
- **KNX - KNX** is a European-oriented field protocol similar to BACnet, mainly used for lighting and audio-visual integration.

- **M-Bus** – communications interface specifically for consumption meters and limited number of other applications.
- **LON** – Local Operating Network (LON) is a standardised (ANSI/CEA-709.1-B) device communication and automation networking platform built on a protocol created by the Echelon Corporation for networking devices over media such as twisted pair, power-line, fibre optics, and RF.
- **DALI 2** – Network based protocol for lighting in building automation specified by technical standards IEC 62386 and IEC 60929.

The protocols and devices sources provide a combination of scenarios for the communication to a preferred cloud. Figure 10 below outlines these various data flow scenarios adopting the protocols set out above.

Linked to the implementation framework outlined in section 3.1, the diagram outlines the system architecture for the three on-premise-data and device pathways which include third-party data, data subject to translation and open data.

4.0

Resources and Tools

4 Resources and Tools

4.1 Summary of Resources

To compliment this guide, a number of resources have been developed to support asset owners define, deliver and realise the value of smart building solutions within their learning estate and be accessed here. The resources available include:

- Smart Learning Estate Briefing Workbook
- Smart Learning Estate Briefing Workbook – Appendices
- Smart Building Consultant Scope of Services
- Case Studies

All these resources as well as this guidance can be access via the web page at the following link.

4.2 Smart Building Briefing Template

To support asset owners, specify their requirements and investment in a smart learning estate, this guide has developed a smart building briefing template. The templates seeks to:

- Support asset owners define clear smart building requirements early,
- Drive a proportionate and outcome led approach to investment and
- Share best practice and mitigate risk,

The template contains three key sections that asset owners can develop with appropriate skills and support:

Smart Building Briefing Template (link)
This briefing template provides an indicative approach to help define and document the needs of asset owners in the development of their Smart Building investment strategy. The template contains proposed sections and guidance for populating. It considers the required outcomes, existing and proposed data requirements, technology requirements and associated roles and responsibilities.

Appendix 1 (link)
Smart Building Outcomes and Opportunities – This outlines where the asset owner can define the benefits and outcomes being sought by the smart building solutions.

Appendix 2 (link)
Smart Data Deliverables – This allows the asset owner to define the data being sought from smart building devices. For each required data field, the asset owner can clearly state their requirements, parameters and link to the opportunities identified. The appendix then allows for the supply chain to respond and document their response to the requirements and outlines the proposed smart building technologies to deliver the requirements.

4.3 Glossary and Definitions

Term	**Meaning**
API	Application Programming Interface – Software to allow applications to talk to each other.
BACnet	Communications protocol for building automation and control based on the ASHRAE, ANSI, and ISO 16484-5 standard, designed to allow communication of building automation and control systems for applications such as HVAC control, lighting control, access control systems etc. and their associated equipment. BACnet references in this document relate to native BACnet that adhere to the standards; proprietary implementations are not acceptable.
BIM	Building Information Modelling – Standards and process for the management of information across the building lifecycle.
Cloud	Internet-based computing architecture that provides shared processing and data storage resources to computers and other devices on demand.
Edge Device	(IP network definition) - Device which provides an entry point into enterprise or service provider core networks, such as IoT gateways and IP based controllers or servers.
HVAC	Heating, ventilation and air-conditioning.
IoT	Internet of Things
Smart Integration Interface / IoT gateway	An IP network edge device that acts as a communication bridge between devices in the field and the Cloud, using IoT protocols such as MQTT. The IoT gateway can provide a communication link between the field and the Cloud by doing physical protocol translation and can also offer local processing and storage capabilities to provide offline services and if required real time control over the devices in the field.
Information Technology	Computers, storage, networking and other physical devices, infrastructure and processes to create, process, store, secure and exchange all forms of electronic data.
NTP	Network Time Protocol is a networking protocol for clock synchronization between computer systems.
Operational Technology	Hardware and software dedicated to detecting or causing changes in physical processes through direct monitoring and/or control of physical devices such as valves, pumps, etc.
RFC	Request for Comments, an Internet Engineering Task Force memorandum on Internet standards and protocols.
Sensor	An electronic component, module, or subsystem whose purpose is to detect events or changes in its environment and send the information to other electronic components or computing systems.
TLS	Transport Layer Security is a cryptographic protocol used throughout most internet services and most often used to secure communications between servers and clients on the world wide web.

4.4 Standards

Reference	Name
ISO 12006	Building construction
ISO 16484	Building automation and control systems (BACS)
ISO 19650	Organisation and digitisation of information about buildings and civil engineering works, including building information modelling (BIM)
ISO 37173: 2023	Smart Community Infrastructure – Guidance for the development of smart building information systems.
ISO 41001: 2018	Facility Management Systems
ISO 12911	Organisation and digitisation of information about buildings and civil engineering works, including building information modelling (BIM)
ISO 27001	Information Security Management
RFC 1034	Domain Names – Concepts and Facilities
RFC 1035	Domain Names – Implementation and Specification
RFC 2131	Dynamic Host Configuration Protocol (DHCP)
RFC 2132	DHCP Options and BOOTP Vendor Extensions
RFC 3596	DNS Extensions to Support IP Version 6
RFC 4122	A Universally Unique IDentifier (UUID)
RFC 4443	Internet Control Message Protocol (ICMPv6)
RFC 5216	The EAP-TLS Authentication Protocol
RFC 5280	Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile
RFC 5905	Network Time Protocol Version 4: Protocol and Algorithms Specification
RFC 6066	Transport Layer Security (TLS) Extensions: Extension Definitions
RFC 8106	IPv6 Router Advertisement Options for DNS Configuration
RFC 8200	Internet Protocol, Version 6 (IPv6)

4.5 Resources

Title	Meaning
Digital Twin Toolkit	Toolkit and business case for digital twin.
Digital Twins Ethics and Gemini Principles	This work into digital twin ethics is intrinsic to the National Digital Twin programme and the foundation for future discussion.
Building Device and Asset Naming Standard (BDNS)	Open standard for naming of building devices.
Digital Building Ontology	Open naming schema for building datapoint names.
Project Haystack	Project Haystack encompasses the entire value chain of building systems and related intelligent devices.
BRICK	Brick is an open-source effort to standardize semantic descriptions of the physical, logical and virtual assets in buildings and the relationships between them.
Smart Building Overlay to the RIBA Plan of Works	Smart Building Overlay provides guidance on smart building technology through each RIBA Plan of Work stage; aligning decision-making with project outcomes and helping designers integrate the technology to support them.

The above links are to external resources to which the authors of this paper have no control over.

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