1ST EDITION

Internet of Things for Smart Buildings

Leverage IoT for smarter insights for buildings in the new and built environments

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Foreword by Marc Petock
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Chapter 1

Tables

Building Category	**Building Examples**	**Focused Smart Building Applications**
Agricultural buildings	Barns, greenhouses, silos, coops	Temperature, humidity, lighting
Commercial buildings	Multistory with at least 50% used for commercial activities such as restaurants, retail, shops	HVAC, energy, occupancy, asset tracking
Data centers	Standalone and mixed-use data centers	Temperature, humidity, security
Education	Universities, schools, colleges, daycare, technical	Air quality, occupancy, access, security
Event buildings	Stadiums, arenas, theaters, auditoriums, conference centers,	Occupancy, safety, security systems
Government or civic buildings	Courts, post offices, tax offices, jails, admin buildings, museums, police and fire stations, military, community centers, libraries, and so on	Air quality, occupancy, access controls
Hospitality	Lodging, hotels, motels, resorts, historic inns, boutique hotels, B&Bs, cruise ships	Guest amenities, cleaning, security, energy
Industrial or manufacturing	Buildings for manufacturing, production, assembly, repairs, altering, renovating, ornamenting, power plants, water plants, and so on	Asset tracking, wayfinding, spills, leaks, preventative maintenance
Medical	Hospitals, medical offices, local ER shops, doctors' offices, clinics	Navigation, patient tracking, wayfinding
Office buildings	One-story, multistory, campuses, mostly used for offices	HVAC, energy, air-quality systems, workflow
Owner occupied	Typically, a company owns and uses the building for its company's needs	Employee workflow tools. Air quality
Residential / **Multi-Dwelling Units (MDUs)**	Apartments, condominiums, townhomes, dormitories, MDUs, nursing homes	Access, security, safety systems, air quality
Recreational buildings	Fitness centers, bowling alleys, gyms, ice rinks, indoor swimming pools	Access, security, safety, cleaning

Building Category	Building Examples	Focused Smart Building Applications
Religious	Churches, temples, synagogues, temples, mosques, cathedrals, monasteries	Access, security, safety, air quality
Retail	Stores, malls, shops, big-box stores, grocery stores	Occupancy, security, asset tracking
Transportation	Airports, train stations, bus terminals, subway stations, ferry stations, others	Occupancy, security, safety systems
Warehouses	Private, public, climate-controlled, distribution centers, storage	Asset tracking, wayfinding

Table 1.1 – Types of smart buildings and their applications

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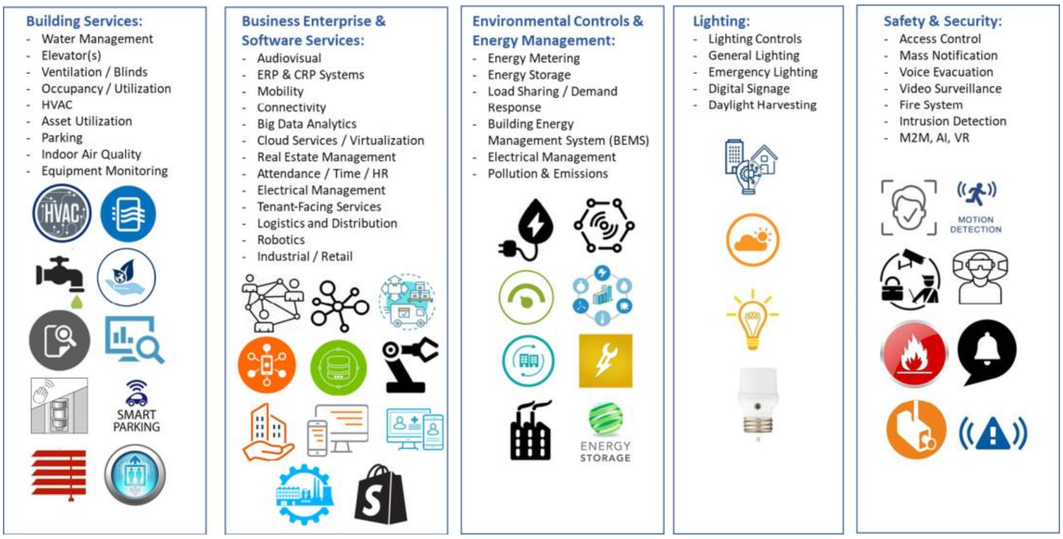

Figure 1.1 – IoT applications in today's commercial buildings

Figure 1.2 – Smart building stakeholders

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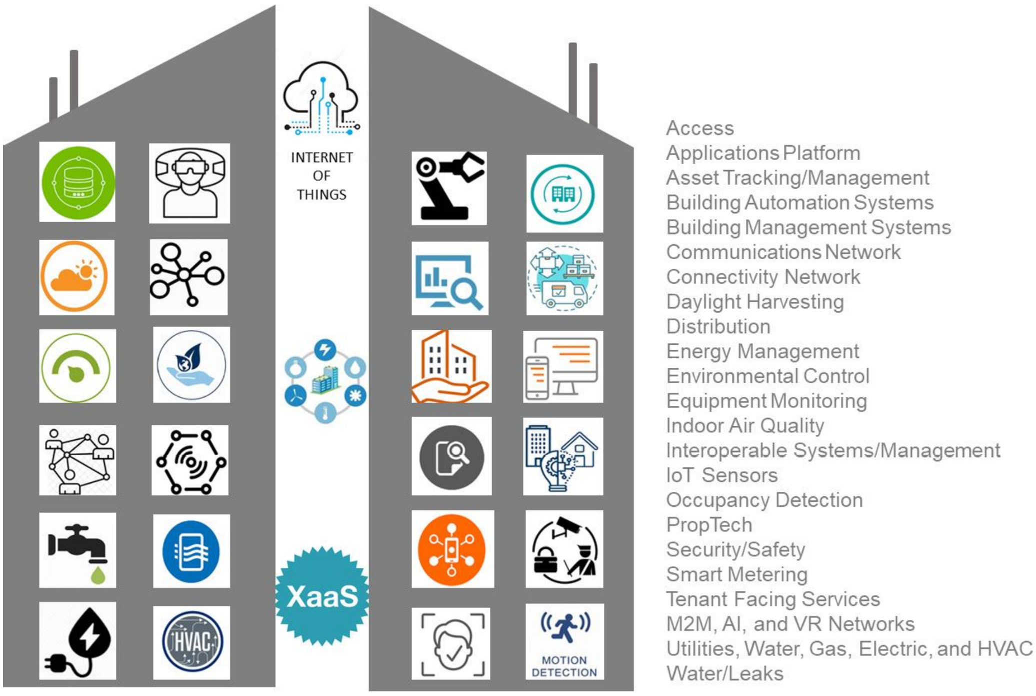

Figure 2.1 – A building system of subsystems

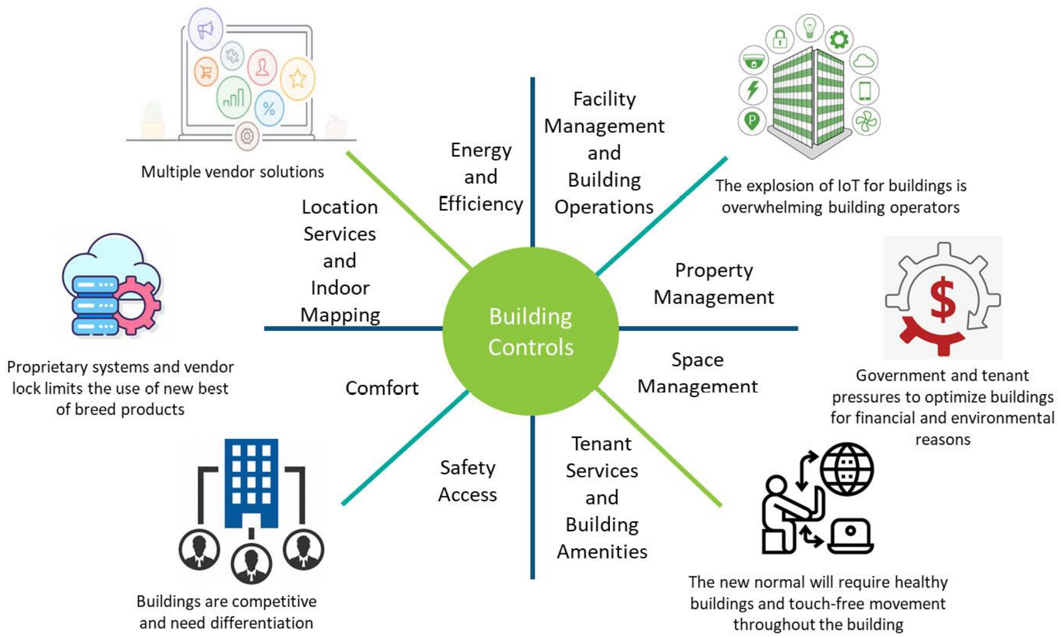

Figure 2.2 – A building's control system challenges

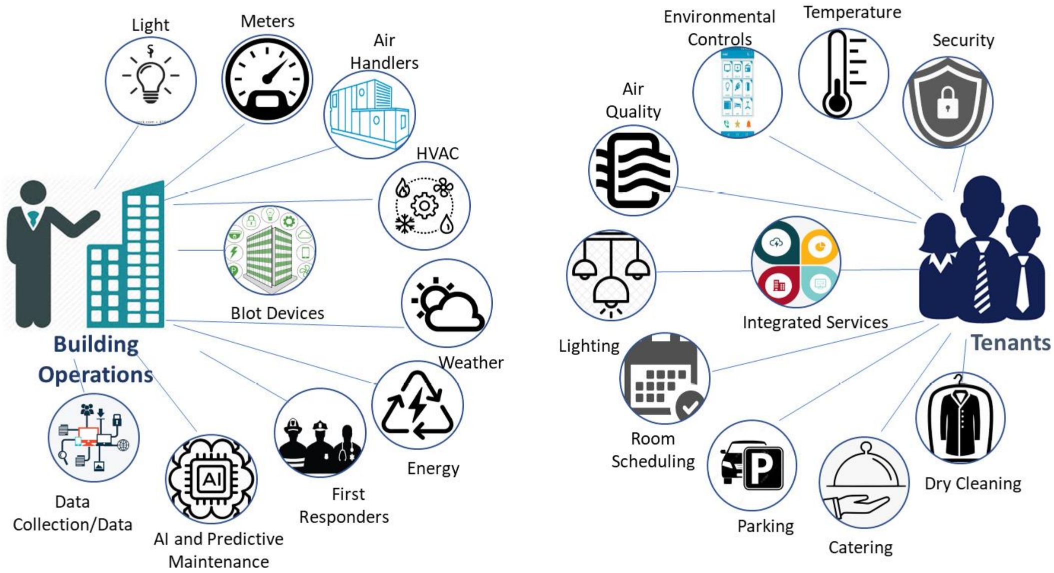

Figure 2.3 – A building's operations and tenant services

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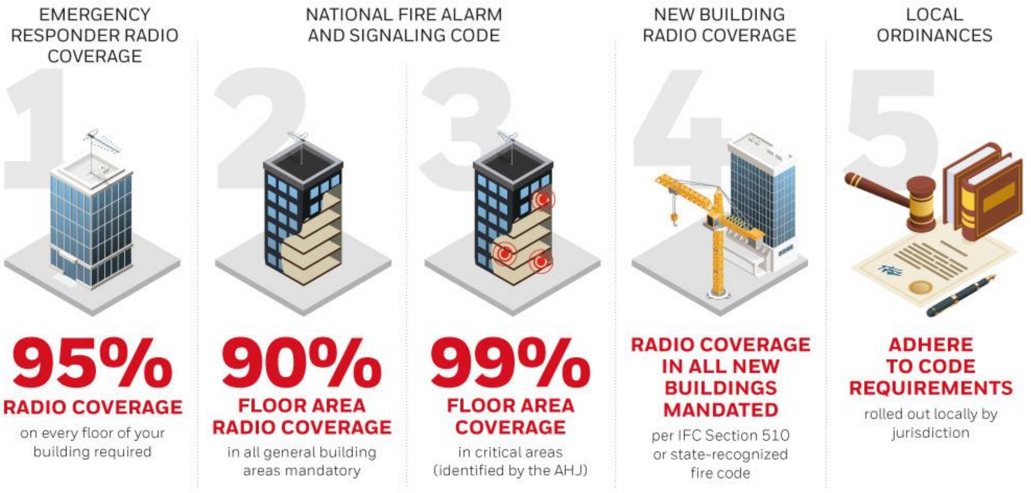

Figure 3.1 – Five crucial RF code requirements to protect first responders

Tables

Central nervous system symptoms:	**Mucous membrane irritation:**
Headaches Fatigue Difficulty in concentrating Lethargy Skin itching and irritation Diarrhea	Itching and inflammation of the eyes, nose, and throat Chest tightness and asthma-like symptoms (without wheezing) Sinus congestion Sneezing Nasal congestion

Table 3.1 – IAQ-related health effects

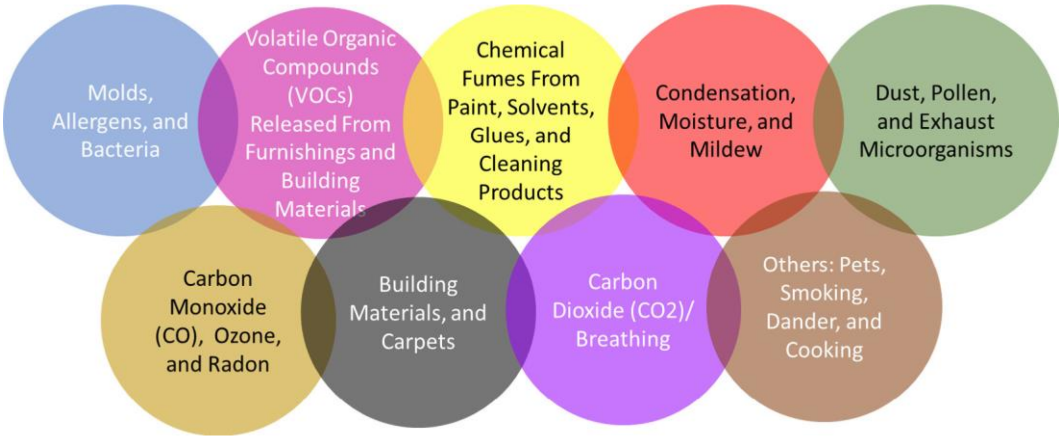

Figure 3.2 – Sources of indoor pollutants

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Figure 4.1 – Way-finding, navigation, and real-time asset location

Figure 4.2 – Major asset tracking technologies

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TENANT MAINTENANCE REQUEST FORM

TENANT INSTRUCTIONS

All general maintenance must be reported to our office in writing. In order for a repair to be attended to, please complete this form and fax, post, email or deliver to our office.

In the event of an emergency repair, contact our office immediately!

Once we have received the request, either our office or a tradesperson will contact you.

Date: ____________________

Time: ____________________

Address: ____________________

Concern: ____________________

ACCESS DETAILS

Tenant Name(s): ____________________

Phone Home:____________________Work: ____________________ Mobile: ____________________

Access to property: ☐Take office key ☐Tenant will be home

Tenant preferred time and date: ____________________ Tenant authorises entry Yes☐

I hereby authorise your office and/or the tradespeople to enter the property with the keys in order to carry out the repair or view the repair.

Signed____________________

If the repair relates to any of the following appliances, please list the make and model

Stove____________________ Washing Machine____________________

Oven____________________ Microwave ____________________

Dryer____________________ Fridge____________________

Dishwasher____________________ Air Conditioning____________________

Hot Water Service____________________ ☐ Gas☐ Electric

Figure 5.1 – A sample tenant request form

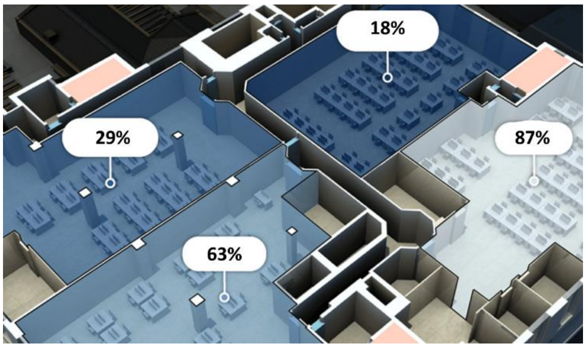

Figure 5.2 – Space utilization

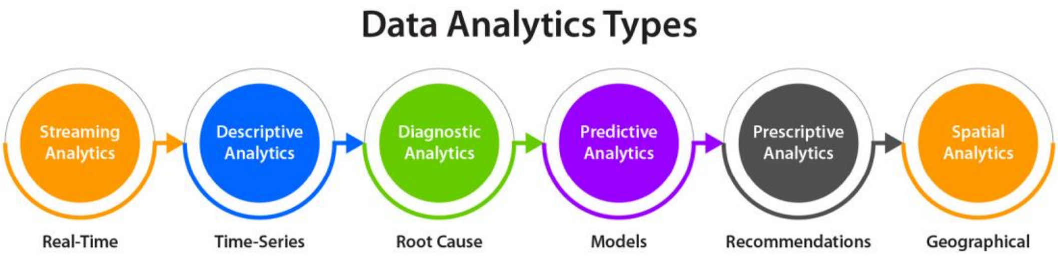

Figure 5.3 – DA types

- Online Reservation
- Automatic HVAC and Lighting
- Smart Glass and Privacy Glass
- Smart Windows with IP
- Collaborative Conferencing Technology
- Audio and Visual Presets
- Presentation-Ready
- Conference call Autocall
- Shared Data
- Airplay
- Smart Jamboard
- Wireless Broadband
- Auto-Transcription
- AI Tools

Figure 5.4 – Smart conference room – smart amenities

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	BACnet	LonWorks	DALI	KNX	Enocean	Zigbee	MQTT	AMQP
Applications	HVAC, lighting, security, and fire systems	HVAC, lighting, process control, and automation	Lighting, motion detectors, and gateways to other protocols	HVAC, lighting, remote access, security, and energy management	Occupancy sensors, key cards, lighting controls, and other room controls	HVAC controllers, room controllers, and occupancy sensors	IoT messaging, HVAC controllers, occupancy sensors, and other room controllers	IoT messaging, HVAC controllers, occupancy sensors, and other room controllers
Developed and supported by	ASHRAE	Echelon Corporation	Philips	Konnex Association	Siemens AG	Zigbee Alliance	OASIS and ISO Standard	OASIS and ISO Standard
Type	Wired and Wireless	Wired and Wireless	Wired and Wireless	Wired and Wireless	Wireless	Wireless	Wired	Wired
Medium	Twisted-pair, wireless mesh, and fiber optic	Twisted-pair, wireless mesh, fiber optic, and power lines	Single cable pairs create the network bus	Twisted-pair, radio frequency, IP/Ethernet, and power lines	Wireless	Wireless	Hardwired	Hardwired
Transmission Mode	IP, Ethernet, LonTalk, ARCnet, Zigbee, and MS/TP	Predictive p-persistent CSMA	Gateways	Gateways	Carrier Sense Multiple Access (CSMA) with collision detection	TCP or UDP	TCP/IP	TCP/IP
Security	Transport layer security (TLS) and Open Authorization (OAuth)	No data encryption. Implements sender authentication	No security measures	Implements data encryption and authentication	Encrypted data using AES algorithm with 128-bit key	Encrypted data using AES algorithm with 128-bit key	TLS encrypted messaging and authentication, OAuth	Integration of TLS and Simple Authentication and Security Layer (SASL)

Figure 6.1 – A comparison of traditional building communications protocols

Wired

BACnet BACnet
1987 – this low cost, has no licensing fees, and is used to communicate between building devices. Defines 60 standard object types. The protocol services include Who-Is, Who-Has, I-Have.

Modbus Modbus
1979 – as a communications protocol, this is a common means of connecting electronic devices. It is low-cost, has no usage fees, and is used in HVAC, lighting, life safety, access controls, transportation and maintenance.

LonWorks LonWorks
1990 – designed as a low-bandwidth protocol that supports five communications media: twisted pair, power line, radio frequency, coaxial cabling, and fiber optics. It is the highest costs and comes with licensing fees.

MQTT MQTT
A lightweight, publish-subscribe network protocol that transports messages between devices and usually runs over TCP/IP. Designed for connections with remote locations or where the network bandwidth is limited.

Wireless

Wi-Fi WiFi
With wireless internet available, Wi-Fi is one cost-effective and easily accessible way to connect IoT devices. Drawbacks include interference, limited bandwidth due to many connected devices, and the amount of power it requires. Used for thermostats, lighting, smart devices, and broadband internet access.

Bluetooth Bluetooth
1989 – Bluetooth uses radio waves to communicate. Bluetooth devices contain computer chips with radios to allow everything to talk to each other. Hundreds of products are compatible with Bluetooth automation. The main drawback is its range restriction.

Zigbee ZigBee
1998 – a protocol created specifically for commercial use, this is the most widely used for building automation. It uses a mesh network to create long ranges and fast communications via radio frequency with minimal power usage, lasting several years on a single set of batteries.

LoRa LoRa
A proprietary low-power, wide-area network modulation technique. It is based on spread-spectrum modulation techniques derived from chirp spread spectrum (CSS) technology.

Near-field communication (NFC)
A set of communication protocols that enables communication between two electronic devices over a distance of 4 cm ($1\ ^1/_2$ in) or less. NFC offers a low-speed connection through a simple setup that can be used to bootstrap more-capable wireless connections.

Narrowband Internet of things (NB-IoT) NB-IoT
A low-power wide-area network (LPWAN) radio technology for cellular devices and services. Focuses specifically on indoor coverage, is low cost, and has a long battery life and a high connection density. NB-IoT uses a subset of the LTE standard.

Figure 6.2 – Common IoT communication protocols

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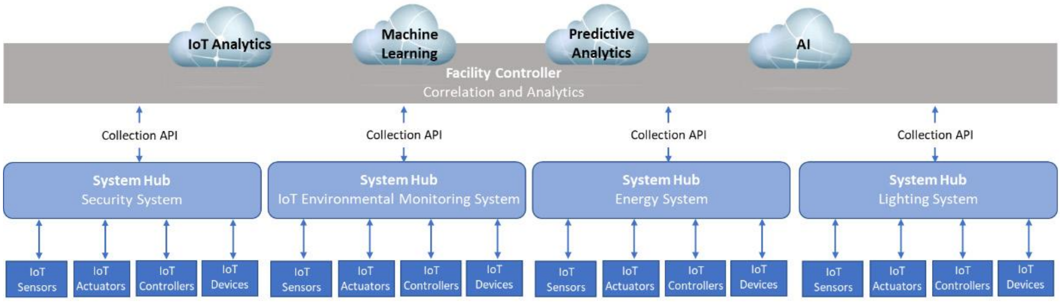

Figure 7.1 – Smart building architecture

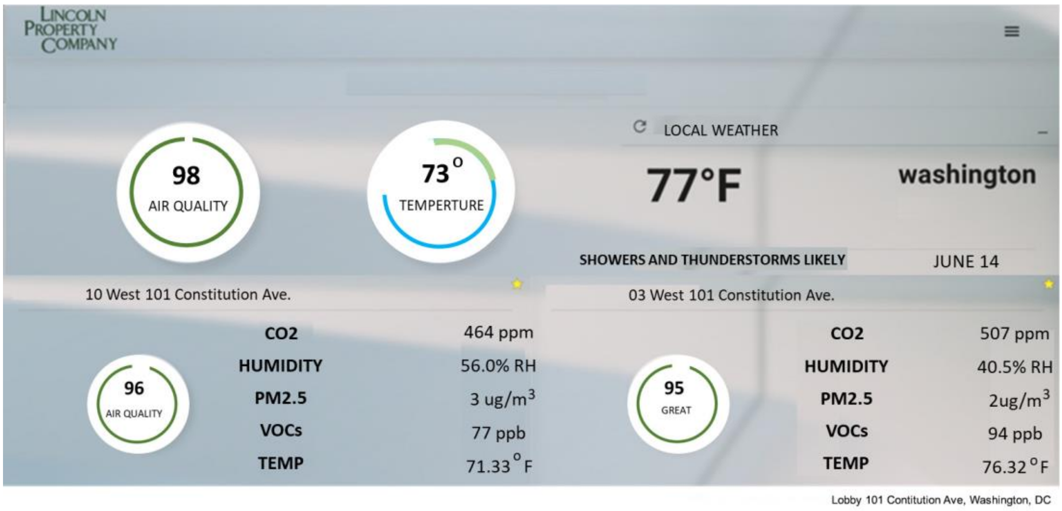

Figure 7.2 – LPC 101 Constitution Ave IAQ readings

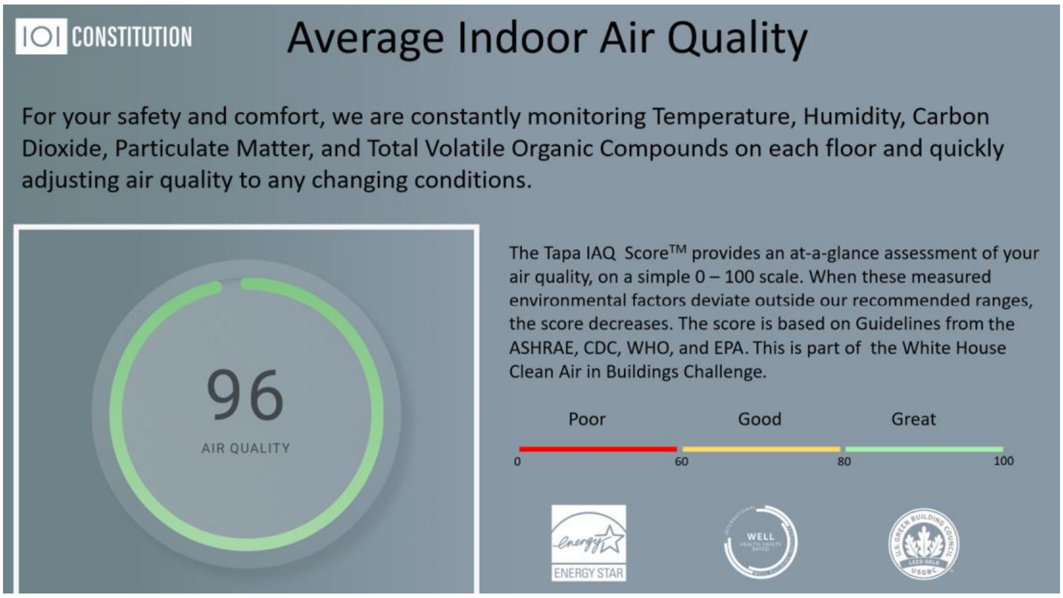

Figure 7.3 – Lobby digital sign displaying IAQ information

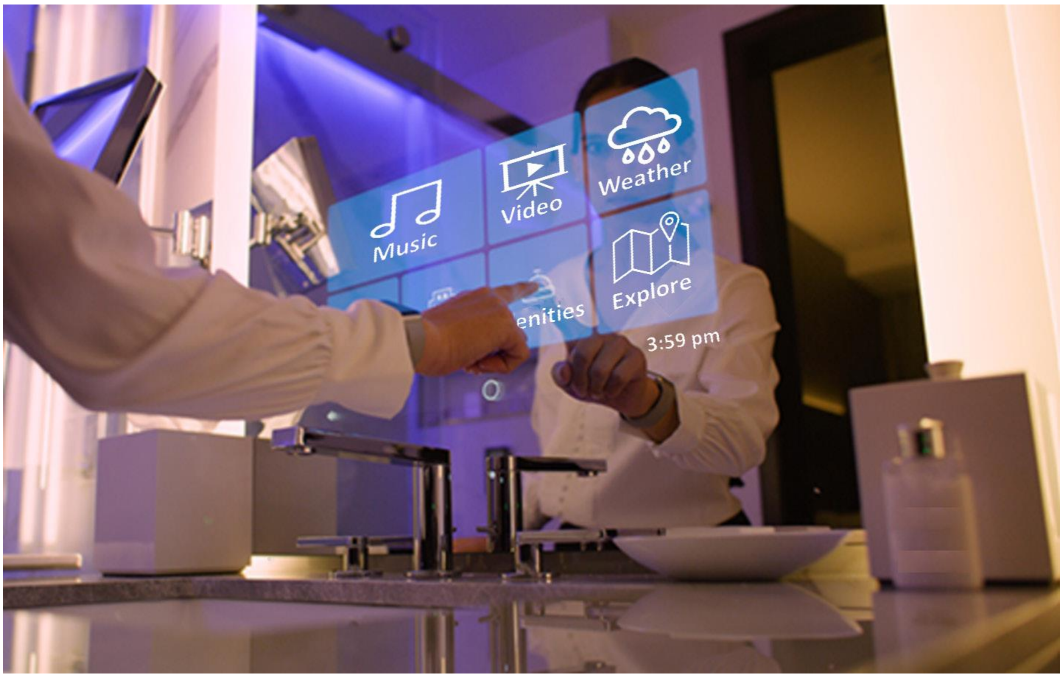

Figure 7.4 – Smart mirror technology (Image credit: https://electricmirror.com/savvy/)

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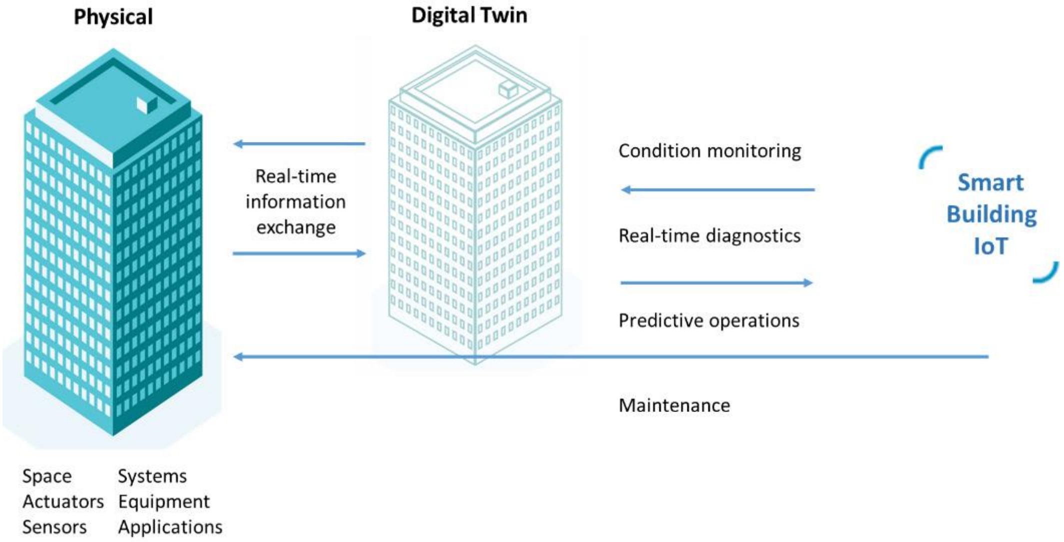

Figure 8.1 – A digital twin overview

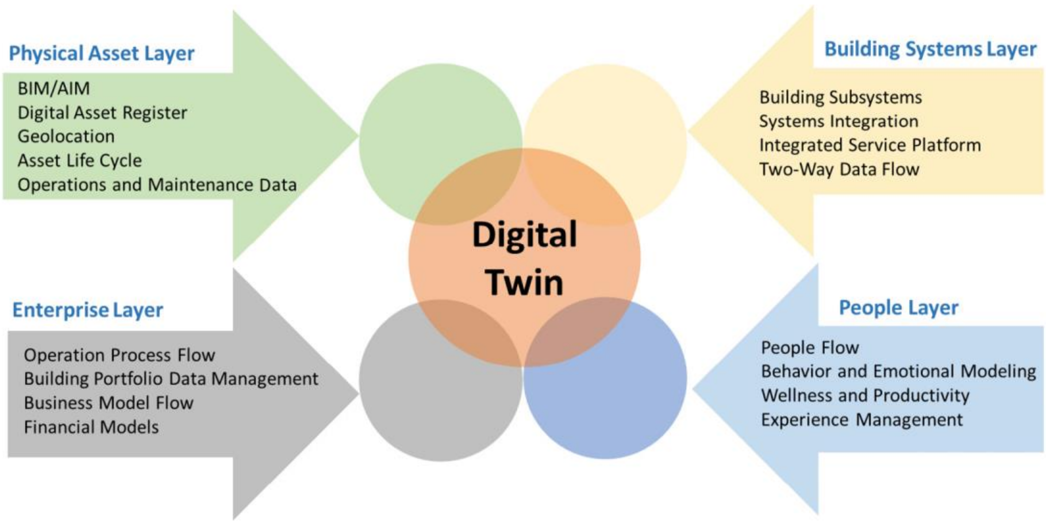

Figure 8.2 – Digital twin information layers

Links

Best practices have been developed on how to use the ontology, which are located at https://github.com/azure/opendigitaltwins-building.

Chapter 9

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Users		All those who occupy, operate, own, or otherwise consume the building.	**Needs** buildings to be operated to be safe, healthy and productive environments.
Smarts	Apps	The applications designed to make buildings smart.	**Needs** to deliver apps to users and access data about the building.
Smarts	Data	The data about the building regardless where it is located.	**Need** to securely gather, store and make available for applications and users.
Building		The building and its control and automation systems.	**Needs** to be available 24/7.

Figure 9.1 – The Smarter Stack's stack of needs

	Purpose Why is this being done?	The outcomes desired by owners, managers and occupants
	Operations How it is operated daily?	The operations to manage the building on a daily basis
Smarts	Delivery How the smarts is delivered?	The delivery of smarts to the operations and other users
Smarts	Apps What makes it smart?	The smart digital applications designed to improve the building
Smarts	Exchange What makes it work together?	The exchange, integration & matching of apps, data, & services
Smarts	Data What makes it valuable?	The storage, normalization, governance & management of data
	Systems What makes it work 24/7?	The automation/control & devices to operate the building
	Physical What is being made smarter?	The steel, concrete and equipment that makes the building

Figure 9.2 – The Smarter Stack

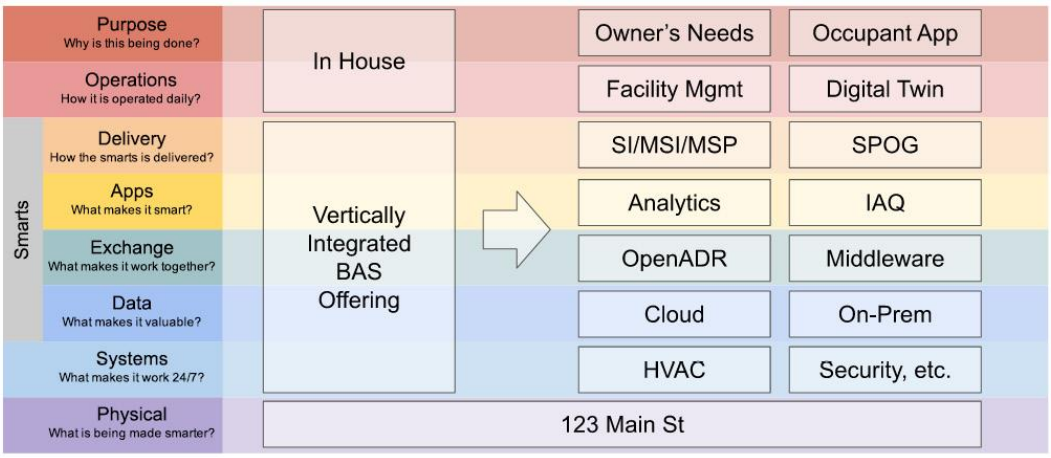

Figure 9.3 – A traditional versus smarter model

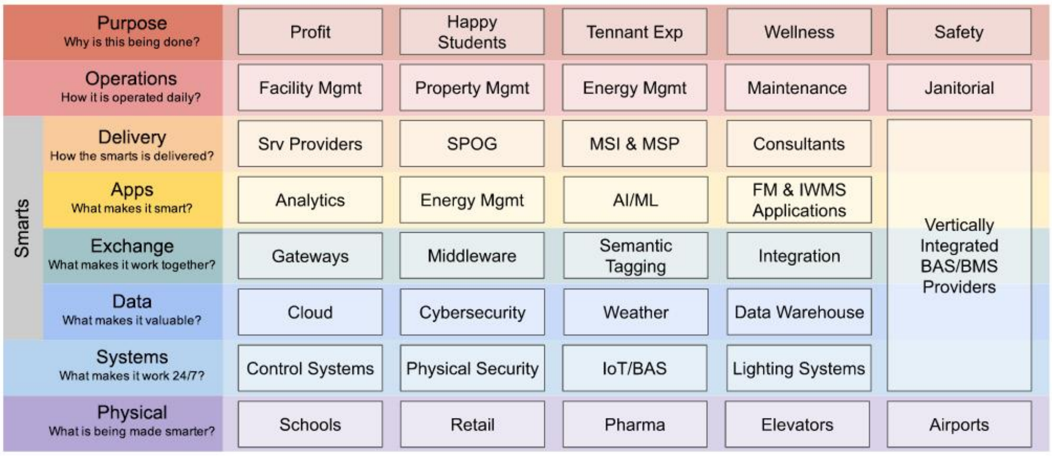

Figure 9.4 – Sample business categories

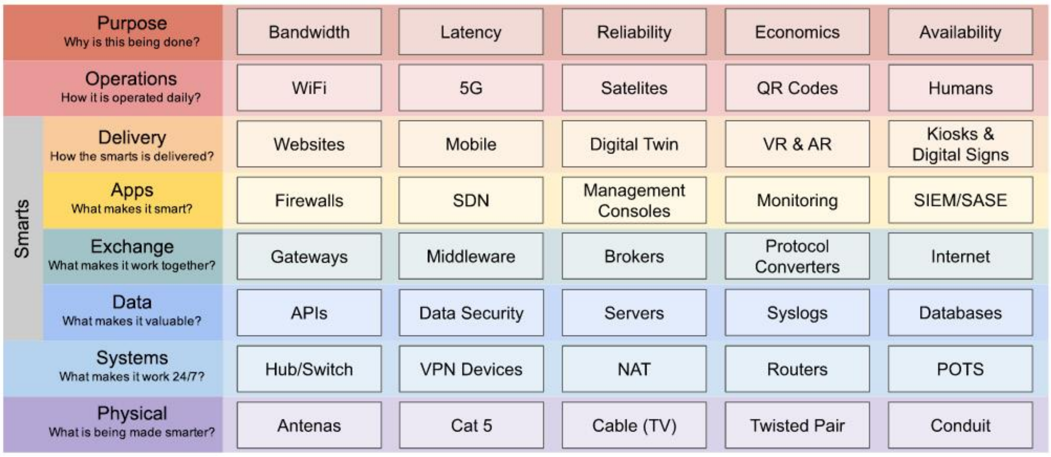

Figure 9.5 – Connectivity and communications

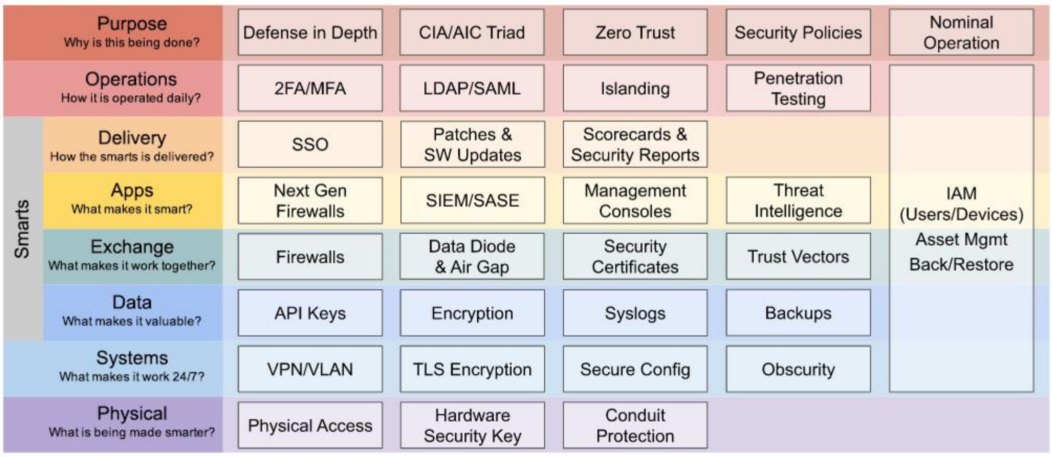

Figure 9.6 – A cybersecurity example on the Smarter Stack

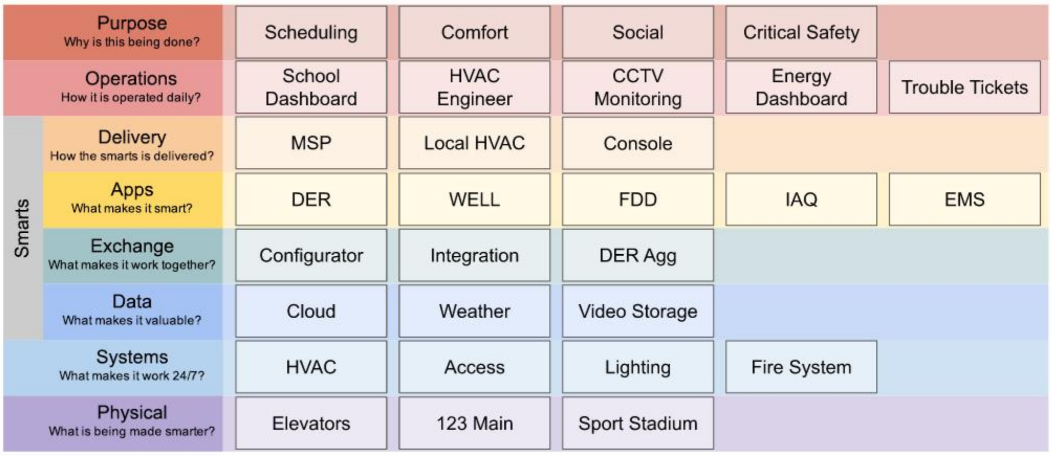

Figure 9.7 – The Smarter Stack requirements categories

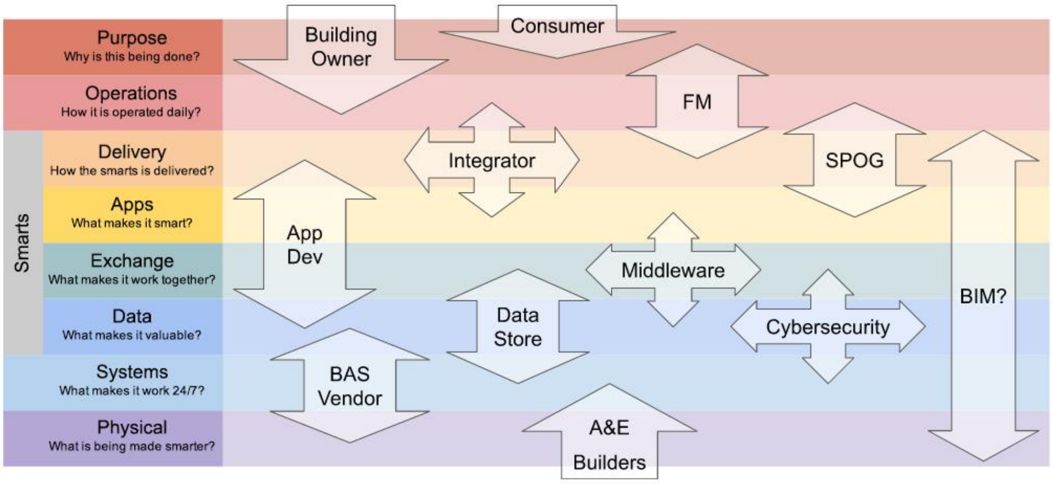

Figure 9.8 – The Smart Stacker perspectives

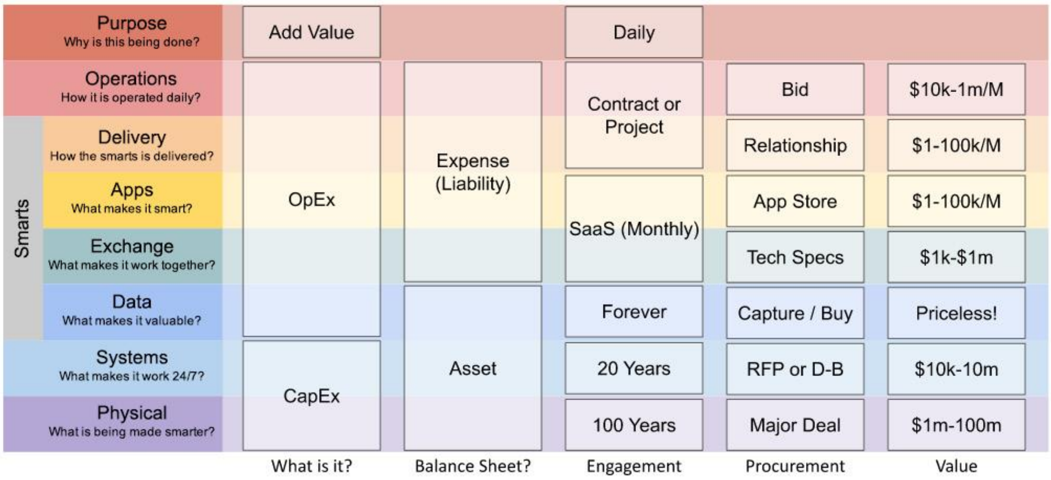

Figure 9.9 – Financials

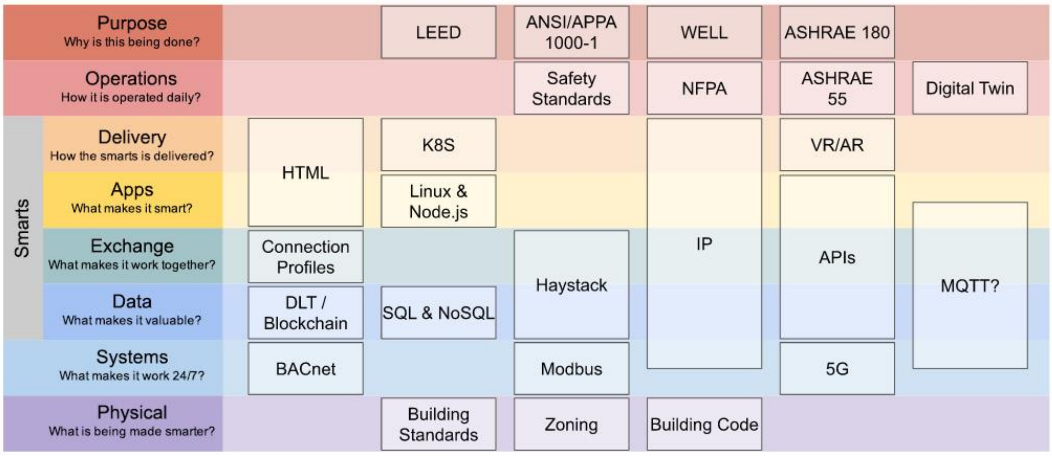

Figure 9.10 – The Smarter Stack to review technologies, standards, and protocols

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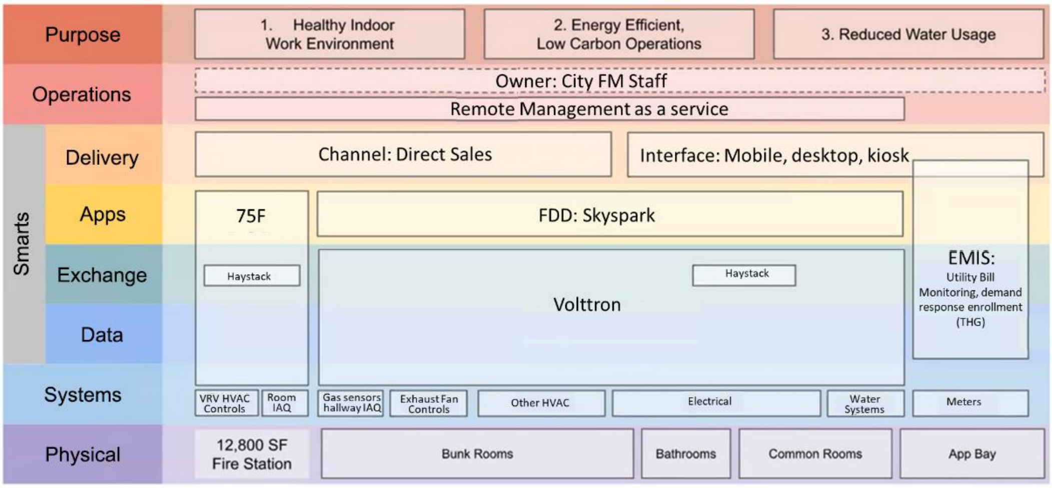

Figure 10.1 – Existing fire station assessment using the Smarter Stack

Beams	Framing systems	Roofing system
Concrete	Landscaping	Soils
Curtain walls	Lintels and chajjas	Stairs and lifts
Fencing and external works	Loads and load paths	Utilities
Floor system	Pathways	Wall systems
Foundation	Plinth	

Figure 10.2 – Civil systems

Building framing types	Footings and foundations
Doors and frames	Interior design
Exterior insulation	Roofing
Exterior wall types	Seismic bracing
Floor systems	Windows

Figure 10.3 – Structural systems

Annunciation (alarms)	Elevators	Induction systems
Blowers	Equipment	Laboratory fume hoods
Building central plant systems	Escalators	Life safety systems
Chillers	Evaporative coolers	Mechanical distribution systems
Compressors	Fire protection/smoke detection	Mechanical penthouse
Conduit	HVAC	Motors
Cooling source components	Human thermal comfort	Specialty air systems
Direct expansion systems	Hydronic systems	Variable air volume systems
Dual-duct systems	IAQ systems	Ventilation
Duct system components		

Figure 10.4 – Mechanical systems

AC/DC systems	Electrical wiring	Lighting sources
Conduit systems	Fans	Power distribution
Electric motors	Fire alarm systems	Power system modeling
Electric power	Grounding	Switches
Electric power quality	Lighting applications	Transformers
Electric vehicle (EV) charging		

Figure 10.5 – Electrical systems

Backflow systems	Sewage treatment systems	Vent pipes/ventilation
Drainage systems	Sprinklers	Wastewater systems
Pressure systems	Stack systems	Water cooling/heating systems
Pumps and pipes	Steam and condensation systems	Water heaters and boilers
Re-circulation systems	Storm water systems	Water supply
Septic system	Tanks	Well systems

Figure 10.6 – Energy systems

Backflow systems	Sewage treatment systems	Vent pipes/ventilation
Drainage systems	Sprinklers	Wastewater systems
Pressure systems	Stack systems	Water cooling/heating systems
Pumps and pipes	Steam and condensation systems	Water heaters and boilers
Re-circulation systems	Storm water systems	Water supplies
Septic system	Tanks	Well systems

Figure 10.7 – Plumbing systems

Asset tracking systems	Centralized clock systems	Robotics
Audio visual equipment	Computing systems	Security systems
Building automation systems	Data networks	Servers
Building management systems	Digital signage	Software
Building purpose equipment	Exchange systems	Space planning systems
Cameras	Energy management systems	Television systems
Card access systems	Enterprise systems	Wayfinding/navigation systems
CCTV	Information technology systems	Workflow systems
	Operational technology systems	

Figure 10.8 – Technology systems

Bi-directional amplifiers	EnOcean	Private networks
Bluetooth	GPON optical fiber networking	Signal boosters
Broadcast systems	Intercom systems	Small cells
Cellular coverage system	Internet, gateways, and routers	Telephone system
Communication closets	IoT network	Wireless internet system
Distributed antenna systems	LoRa/LoRaWAN	Zigbee
Emergency communication systems	Neutral host systems	Z-Wave

Figure 10.9 – Communication systems

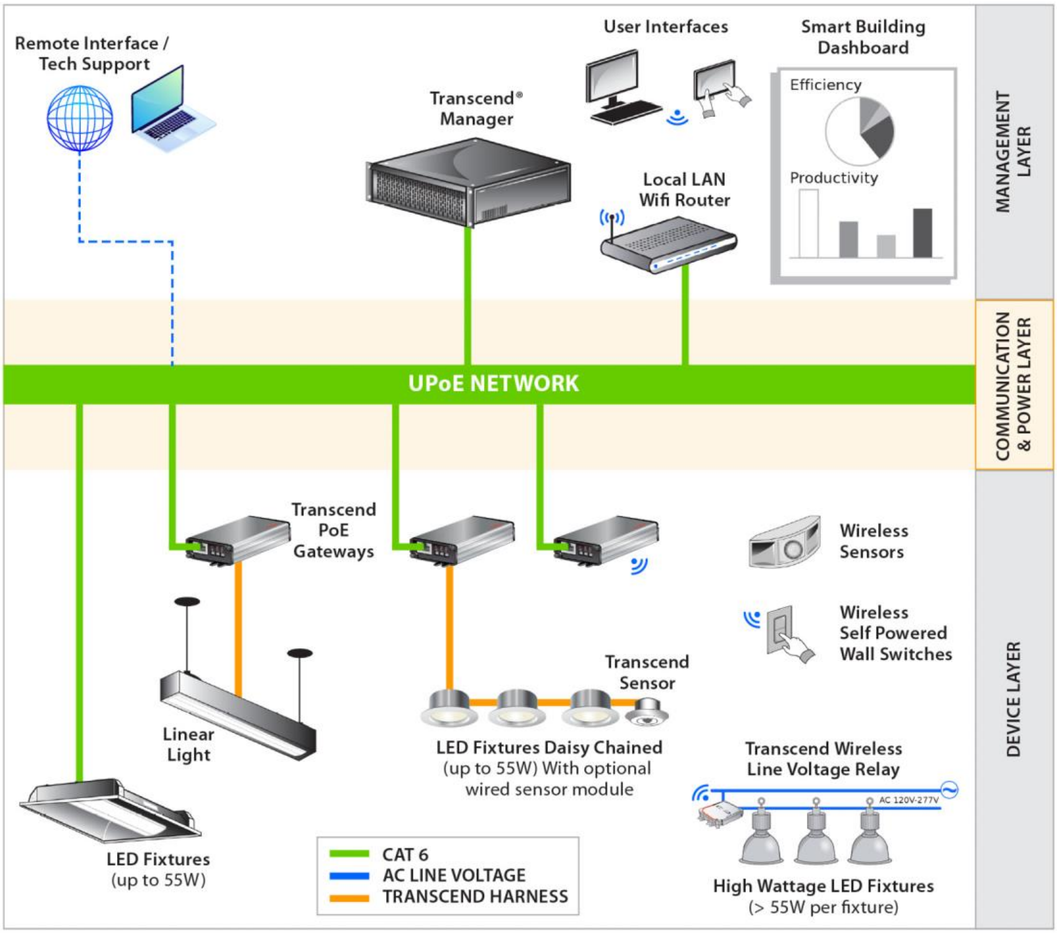

Figure 10.10 – A logical network diagram example (source: Molex Transcend® Network Connected Lighting)

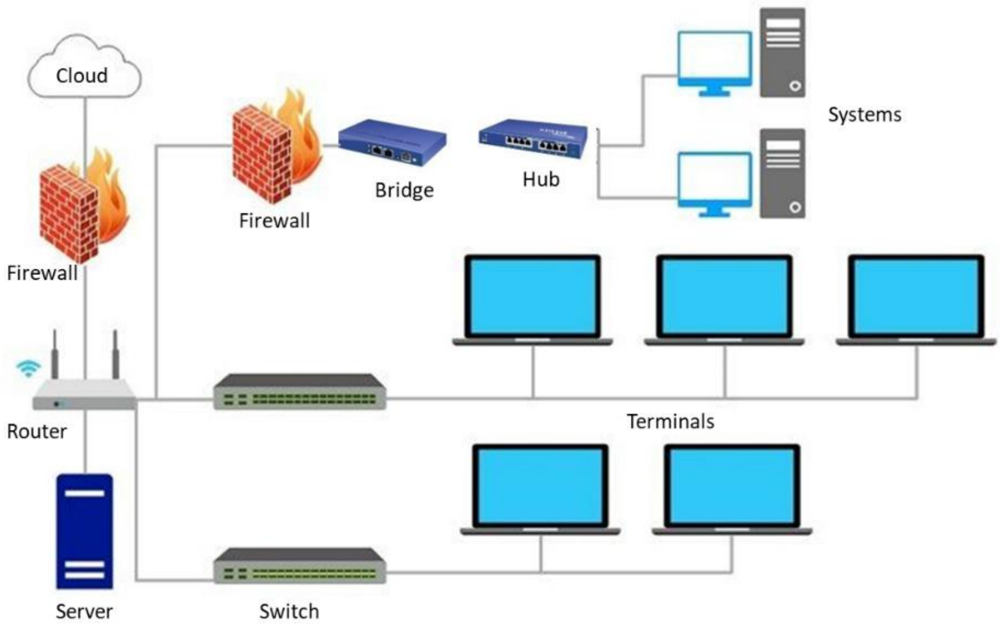

Figure 10.11 – A physical diagram example

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Figure 11.1 – Smart building hardware

Figure 11.2 – Smart conference room

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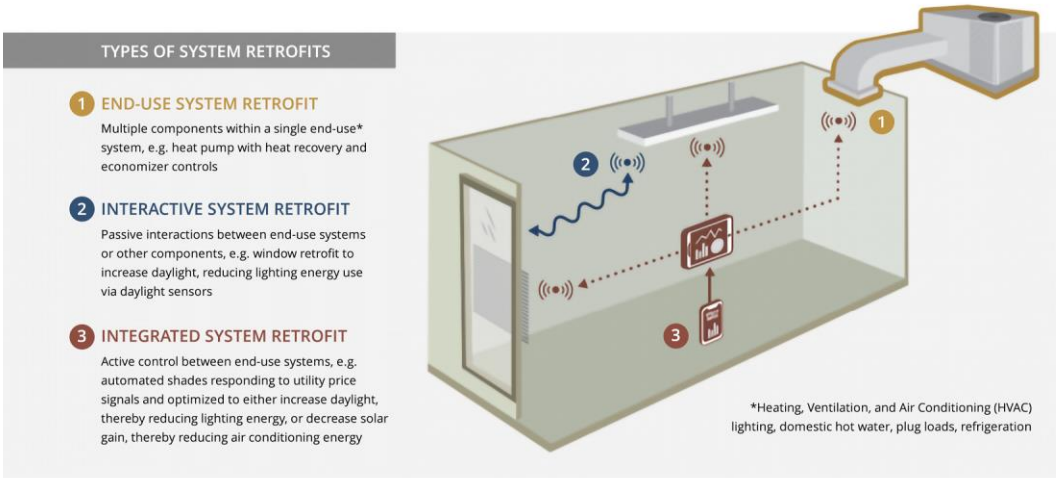

Figure 12.1 – Types of system retrofits (diagram courtesy of the LBNL)

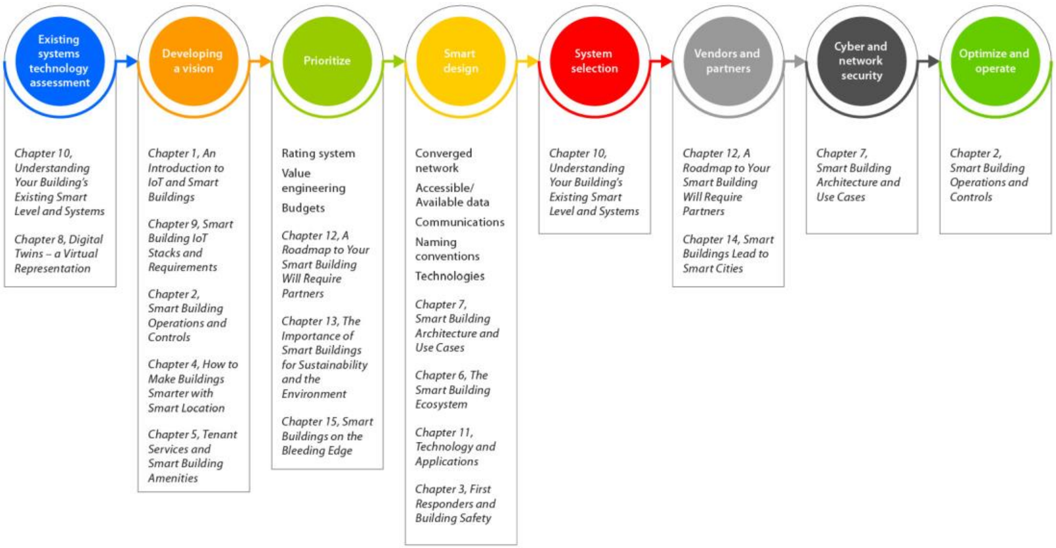

Figure 12.2 – A smart project roadmap and related chapters

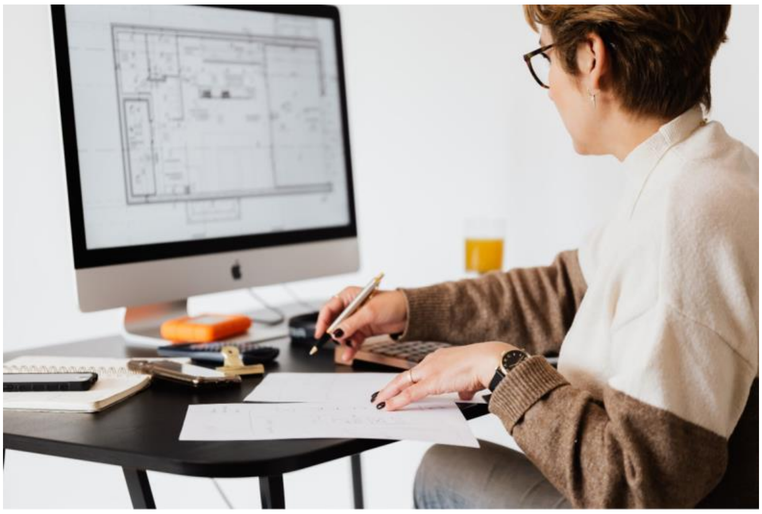

Figure 12.3 – New building smart design begins at the design phase

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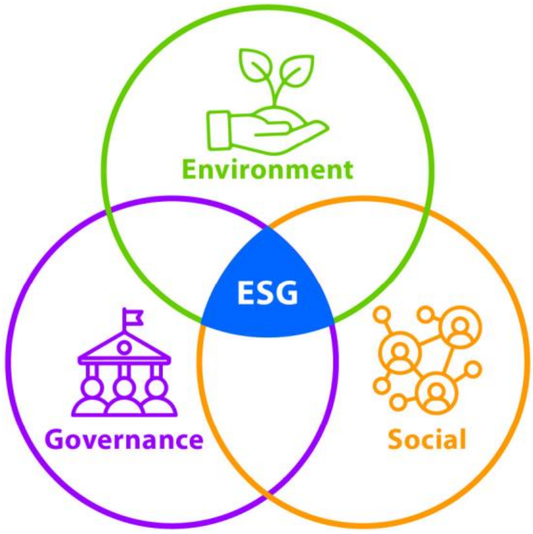

Figure 13.1 – ESG

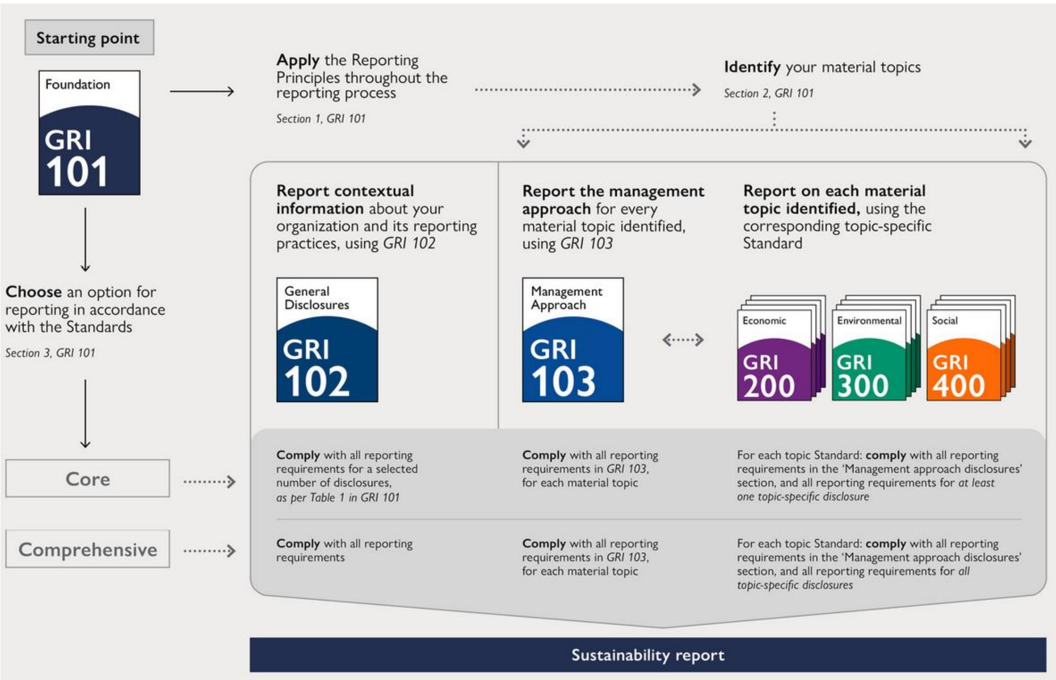

Figure 13.2 – GRI sustainability reporting (courtesy of Global Reporting)

Figure 13.3 – The 3 Ps of sustainability

Chapter 14

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Figure 14.1 – Futuristic city image courtesy of WallpaperAccess

Figure 14.2 – United Nations' 17 SDGs

Economy-Related KPIs	Environmental KPIs	Society and Culture KPIs
Core smart city economic performance KPIs:	**Core smart city environmental performance KPIs:**	**Core smart city society and cultural performance KPIs:**
• Household internet access	• Air pollution	• Cultural expenditure
• Fixed and wireless broadband subscriptions	• Greenhouse gas (GHG) emissions	• Informal settlements
• Wireless broadband coverage	• Electromagnetic fields (EMF) exposure	• Gender income equality
• Smart water meters	• Green areas	• Gini coefficient
• Smart electricity meters	• Renewable energy consumption	• Disaster-related economic losses
• Dynamic public transit information	• Electricity consumption	• Police service
• Traffic monitoring	• Residential thermal energy consumption	• Fire service
• R&D (Research and Development) expenditure	• Public building energy consumption	• Violent crime rate
• Patents		
• Public transport network		
• Bicycle network		

Figure 14.3 – Core smart city KPIs

Economy-Related KPIs	Environmental KPIs	Society and Culture KPIs
Advanced smart city economic KPIs:	**Advanced smart city environmental KPIs:**	**Advanced smart city society and culture**
• Public Wi-Fi	• Noise exposure	• Electronic health records
• Electricity supply ICT monitoring	• Green area accessibility	• In-patient hospital beds
• Open data	• Protected natural areas	• Health insurance/public health coverage
• E-government	• Recreational facilities	• Cultural infrastructure
• Public sector e-procurement	• Residential thermal energy consumption	• Housing expenditure
• Transportation mode share		• Child care availability
• Travel time index		• Resilience plans
• Shared bicycles and vehicles		• At-risk population
• Low carbon emission passenger vehicles		• Emergency service response time
• Public building sustainability		• Traffic fatalities
• Urban development and spatial planning		• Local food production

Figure 14.4 – Advanced smart city KPIs

Chapter 15

Figures

Net Operating Income

$$\text{NOI Formula} = \text{Operating Revenue} - \text{Operating Expense}$$

$$\text{NOI Formula} = \text{Operating Revenue} - \text{COGS} - \text{SG\&A}$$

Figure 15.1 – Formula for NOI

Figure 15.2 – Digital mobile construction drawings

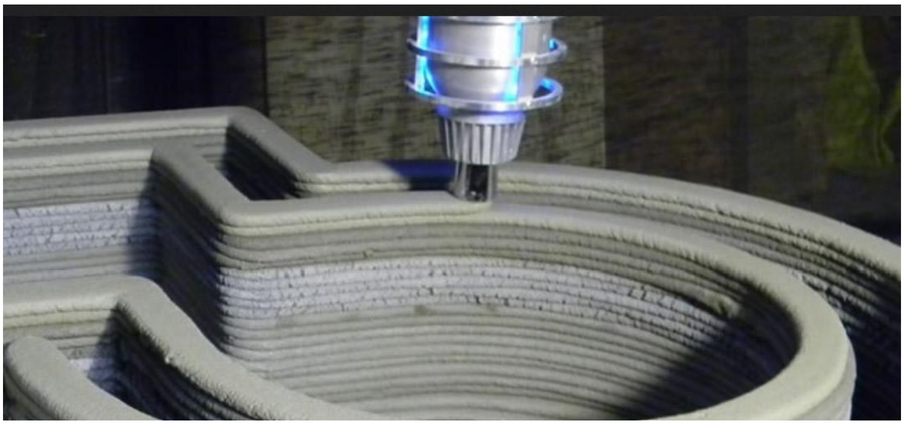

Figure 15.3 – 3D printing

Figure 15.4 – Exoskeleton and robotic vest (sources: Clker and Scottish Construction Now)

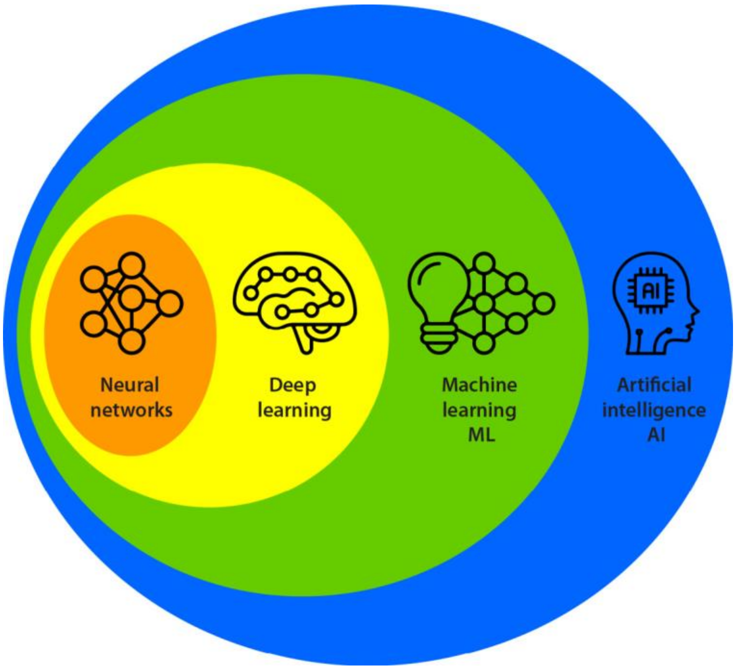

Figure 15.5 – Intelligent learning

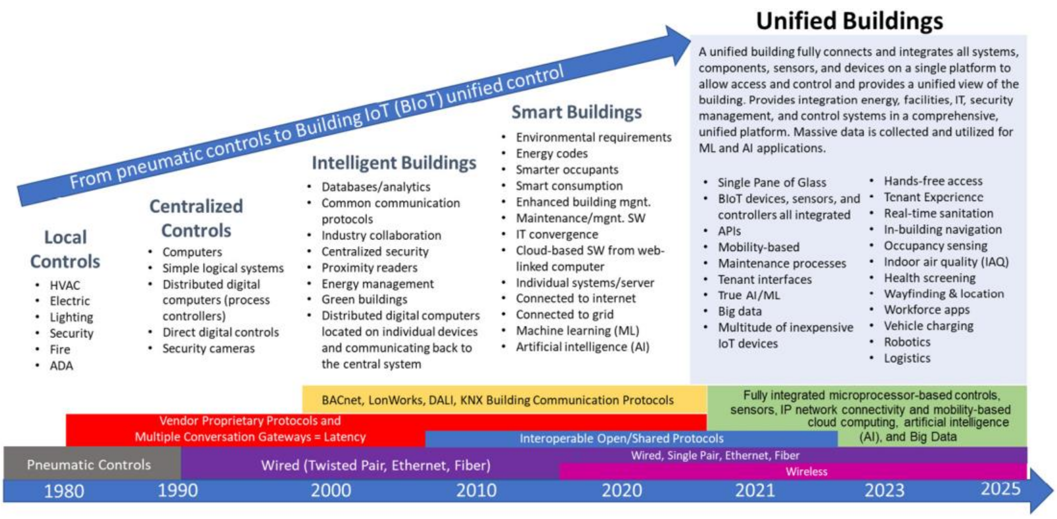

Figure 15.6 – Evolution to unified buildings

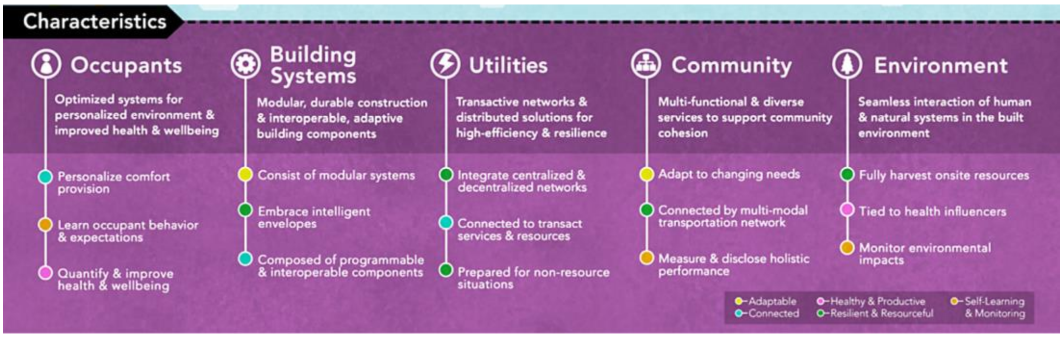

Figure 15.7 – PNNL vision characteristics (image courtesy of PNNL)

Figure 15.8 – CSA Matter standard