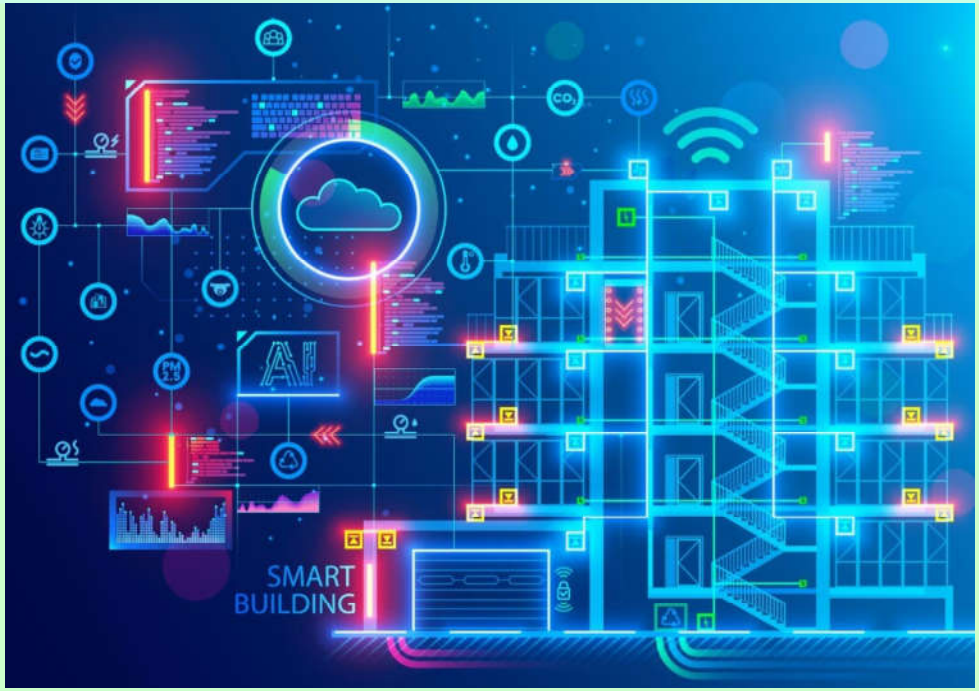
IDAT7219 Smart Building Technology

http://ibse.hk/IDAT7219/



Key Technologies

智能大廈科技

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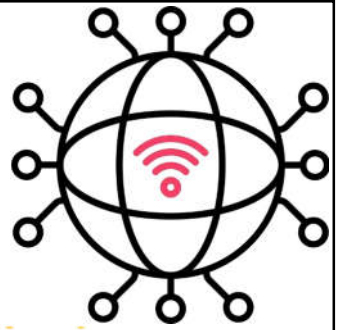
Sep 2024

Contents

- Internet of Things (IoT)
- IoT for smart buildings
- Cloud-based services
- Data analytics & AI
- Digital twin technology

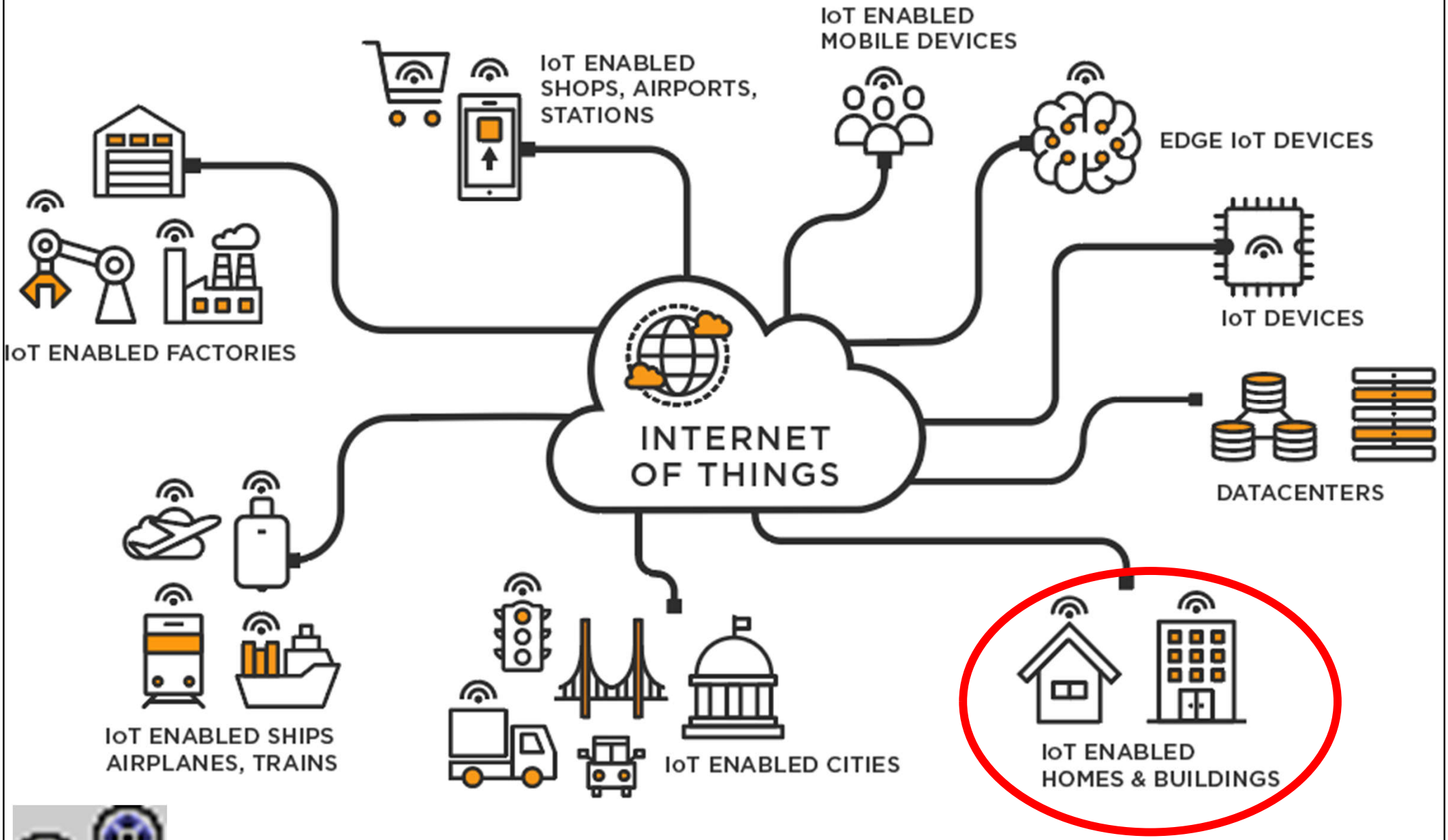
Internet of Things (IoT)



- Internet of Things (IoT) involves connecting everyday objects & devices to the Internet, enabling them to gather & exchange data
  - From machinery & tools to sensors & wearable devices, they can communicate & collaborate seamlessly to create better insights
  - Leverage IoT technology to establish a sophisticated network of sensors, controls & systems that work together to create an intelligent & responsive environment

物聯網

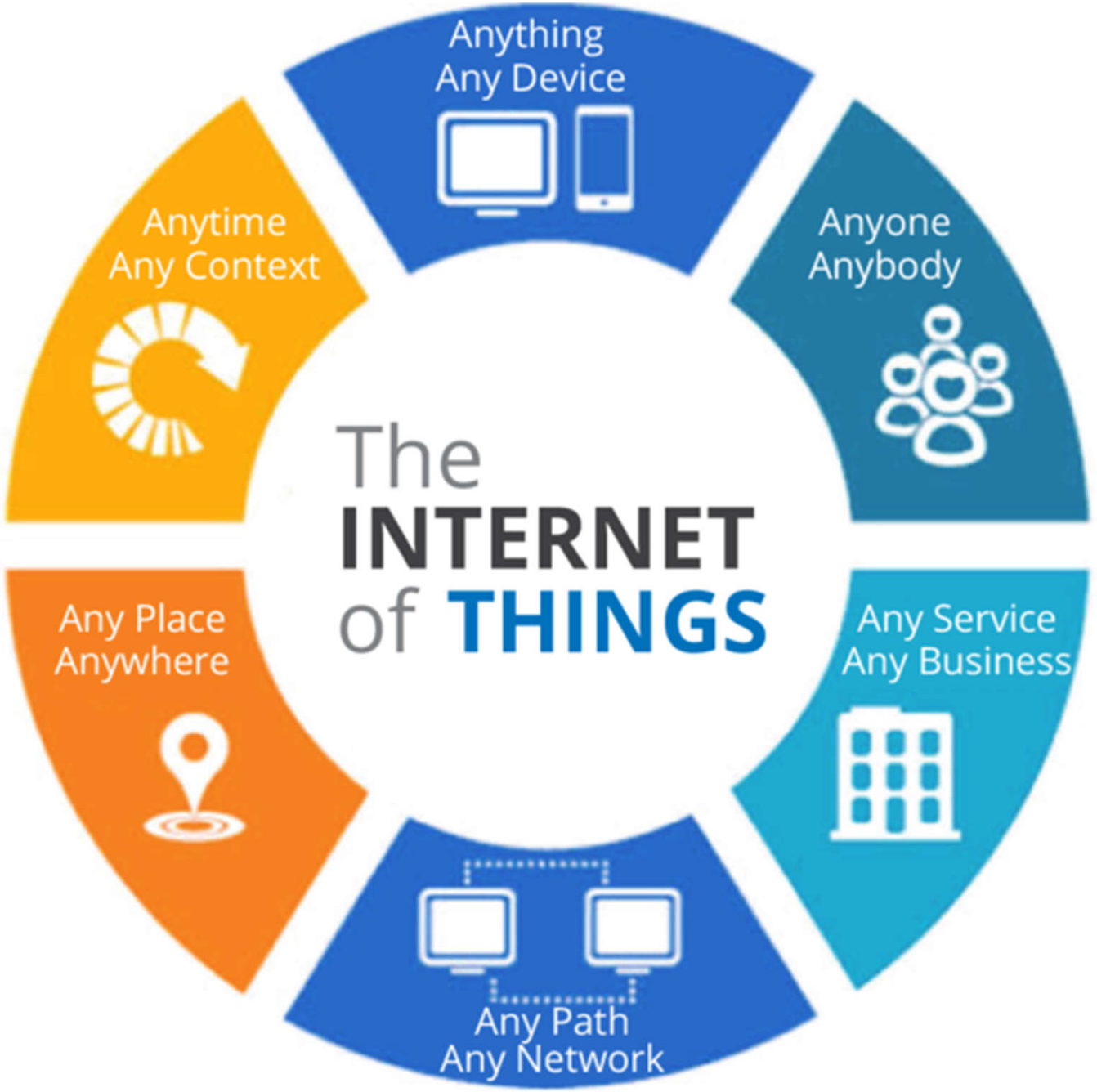
What is Internet of Things (IoT)?



Video: Internet of Things (IoT) | What is IoT | How it Works | IoT Explained | Edureka (3:21) https://youtu.be/LlhmzVL5bm8

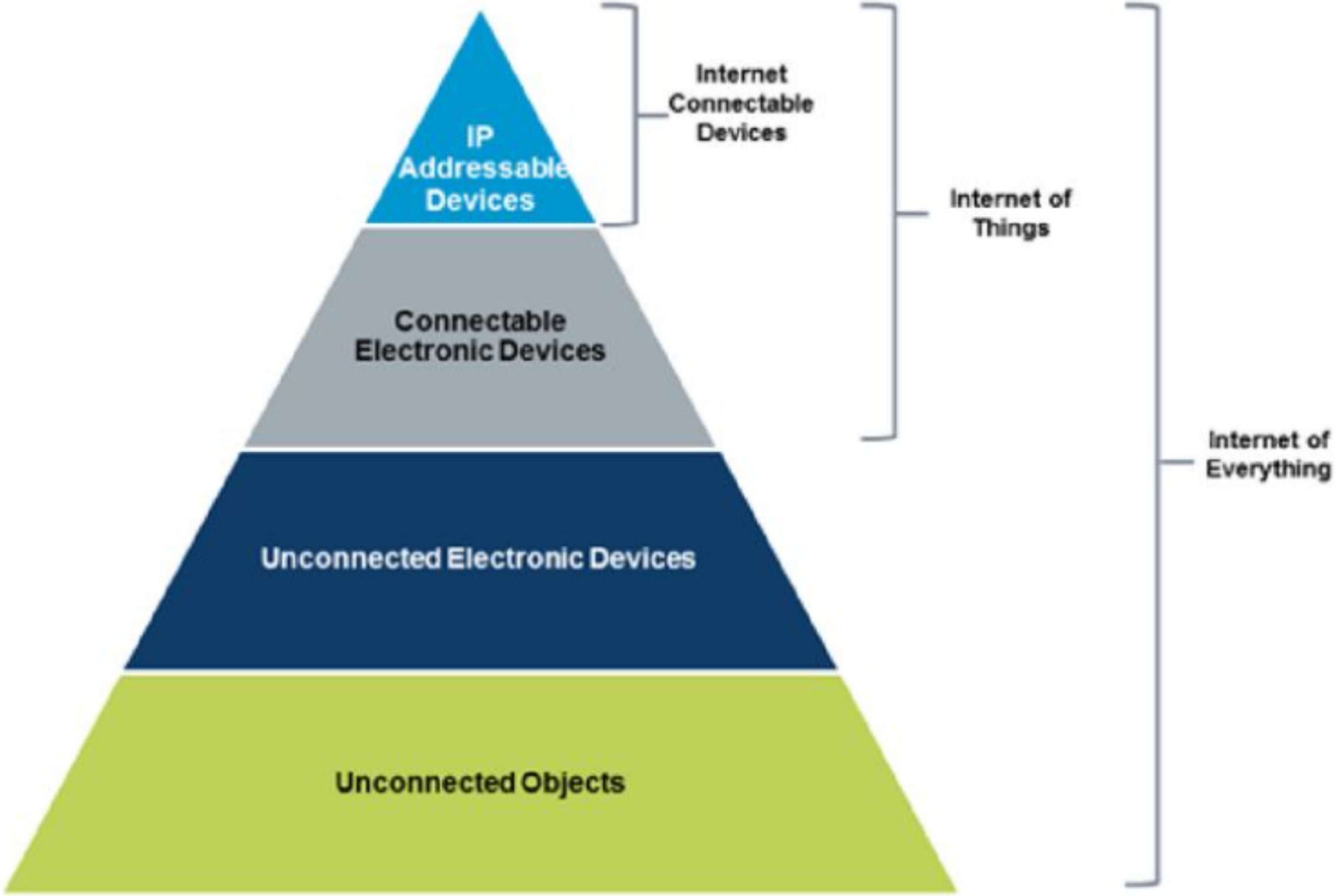
(Source: https://www.tibco.com/reference-center/what-is-the-internet-of-things-iot)

Internet of Things takes all the things in the information from the world & connects them through the Internet



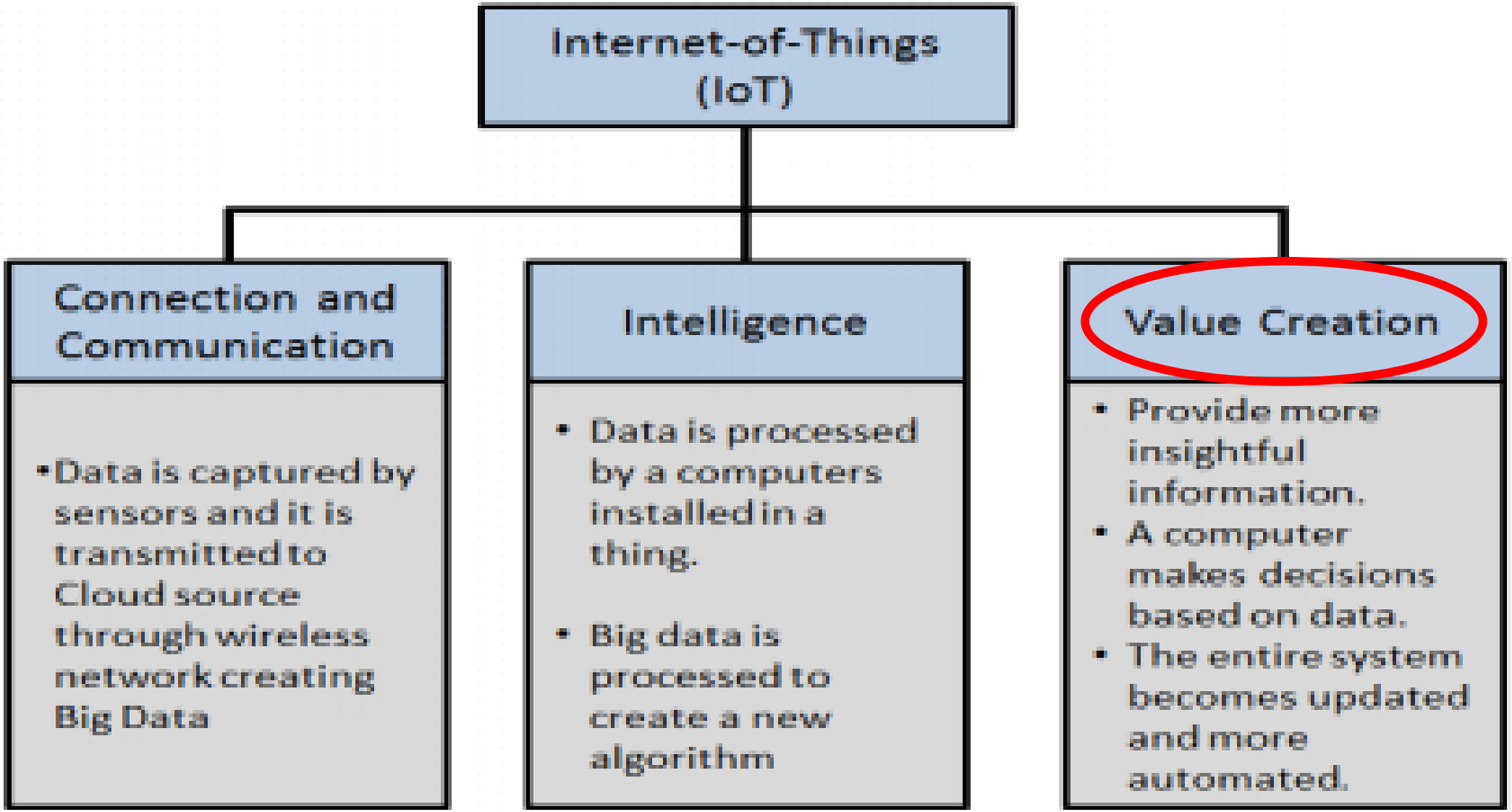
(Source: https://medium.com/@kunalmohta/what-is-meant-by-the-term-internet-of-things-iot-287cfc233865)

From Internet of Things (IoT) to Internet of EveryThing (IoET)



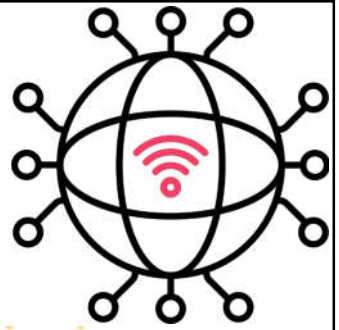
(Source: Continental Automated Buildings Association (CABA))

Hierarchy of Internet of Things (IoT)



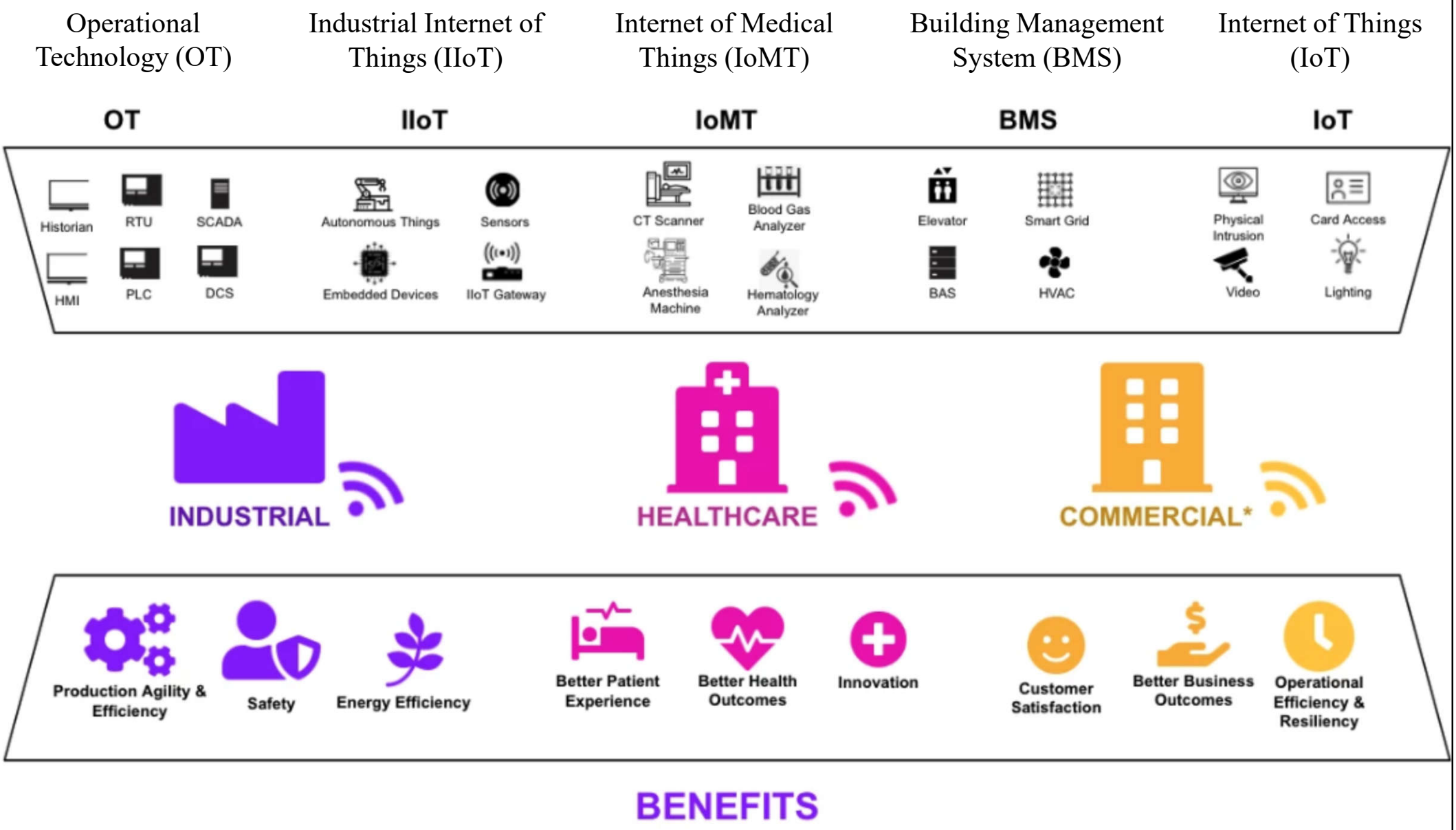
(Source: https://www.researchgate.net/figure/Hierarchy-of-Internet-of-Things-IoT_fig1_331353248)

Internet of Things (IoT)



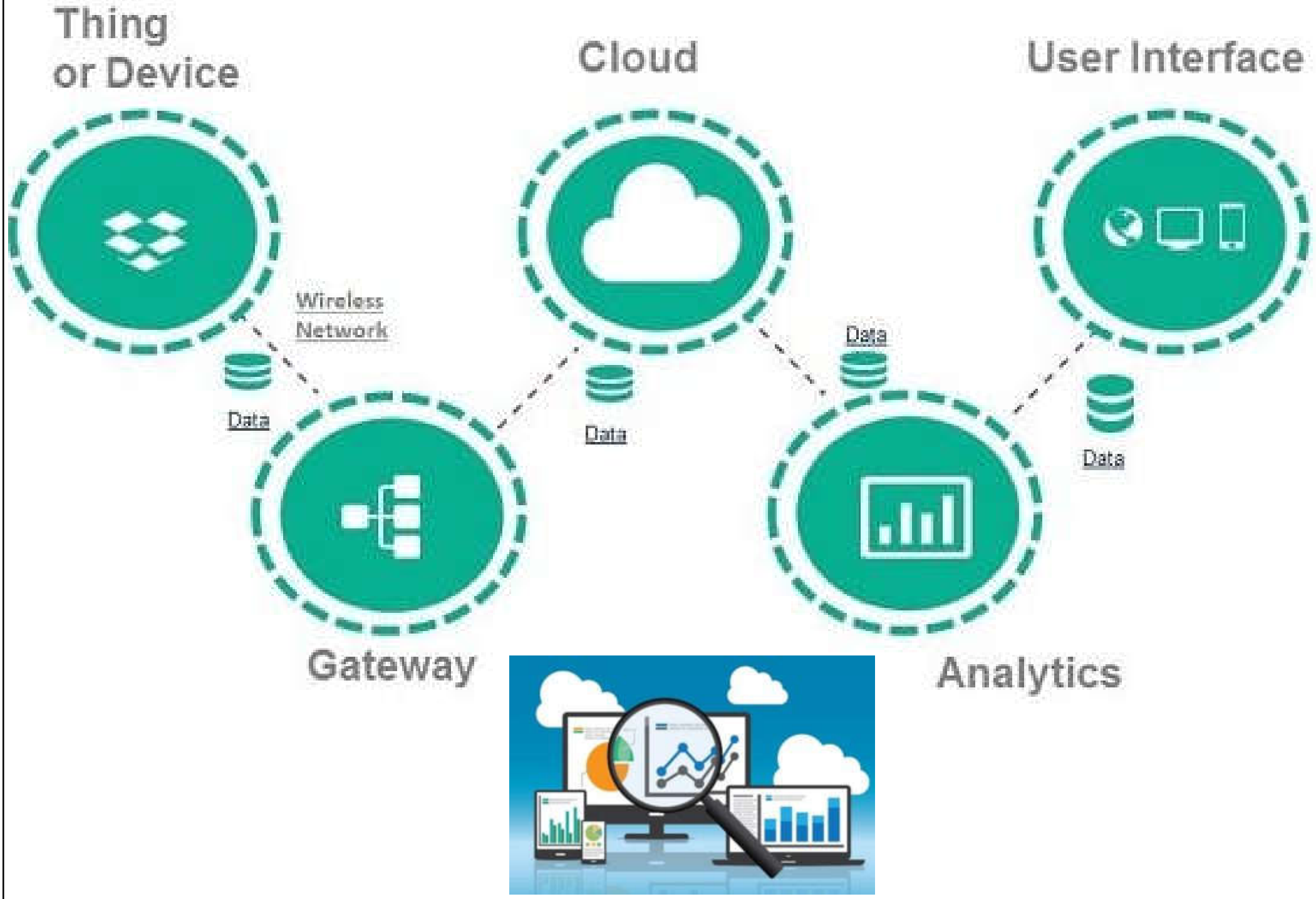
- Benefits of Internet of Things (IoT):
  - 1. Easy access (real-time) & quick operation
  - 2. Enhance connectivity, efficiency & safety
  - 3. Monitor remote & hard-to-access equipment
  - 4. Automate & improve processes
  - 5. Enable insights & predictive analysis
  - 6. Better user experience & satisfaction
  - 7. Operational efficiency & resiliency
  - 8. Reduce costs, time & environmental impacts

Benefits of applying Internet of Things (IoT) in industrial, healthcare, & commercial environments



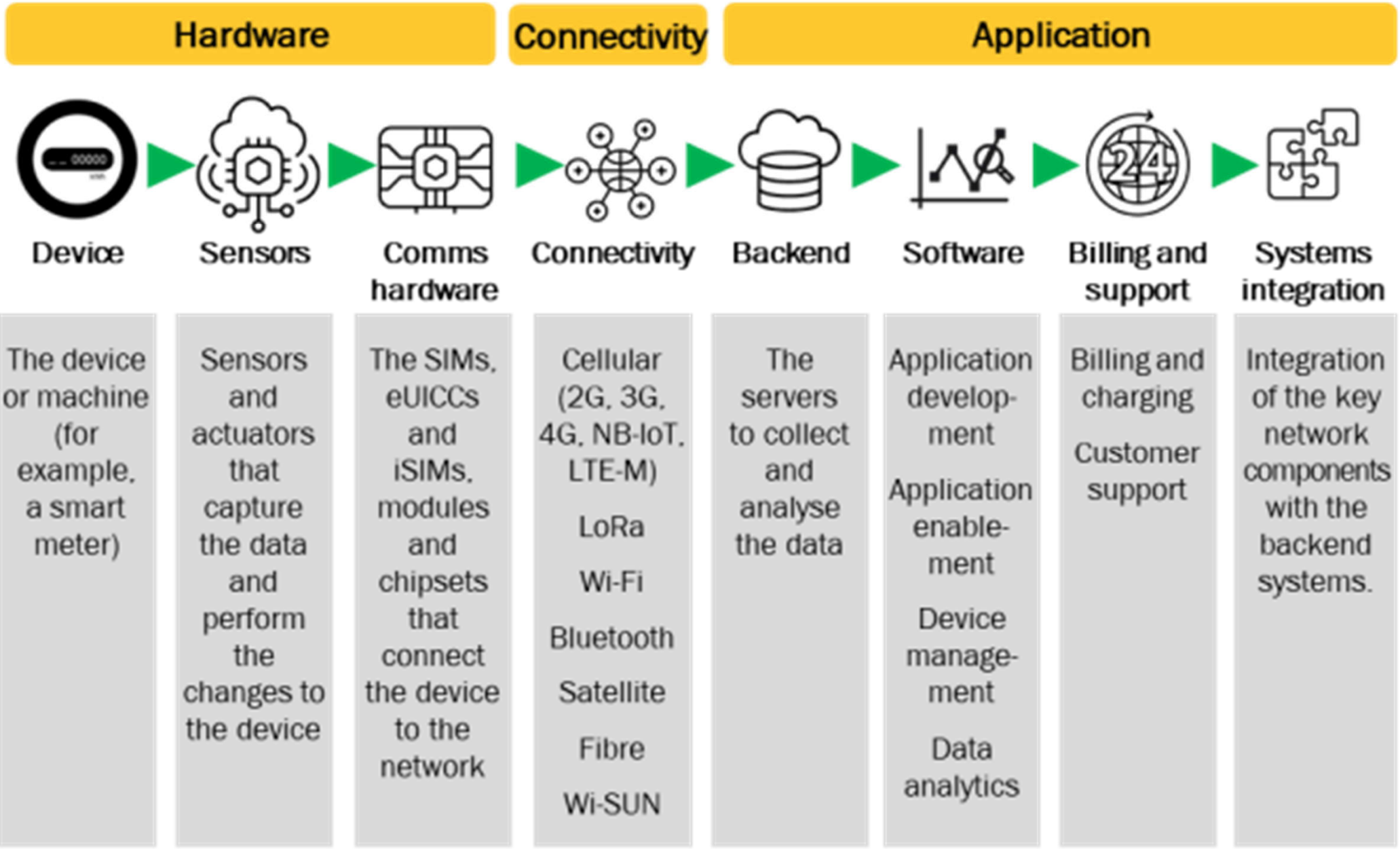
(Source: https://claroty.com/blog/extended-internet-of-things-xiot-faq)

Major components of Internet of Things (IoT)

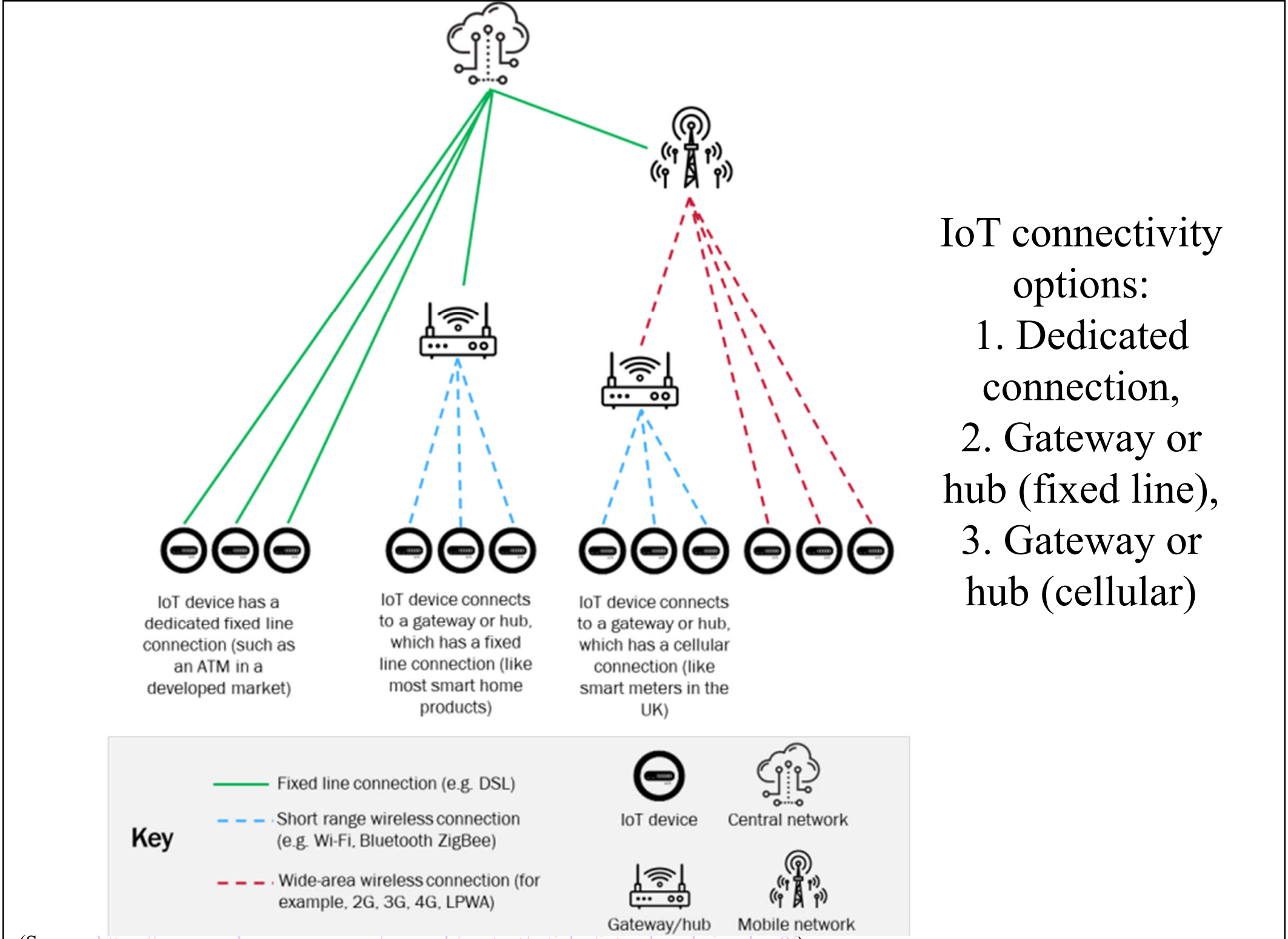


(Source: https://www.rfpage.com/what-are-the-major-components-of-internet-of-things/)

Components of the IoT value chain



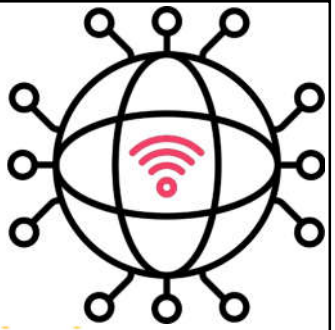
(Source: https://www.analysysmason.com/research/content/articles/iot-value-chain-rdme0/)



IoT connectivity options:
1. Dedicated connection,
2. Gateway or hub (fixed line),
3. Gateway or hub (cellular)

(Source: https://www.analysysmason.com/research/content/articles/iot-value-chain-rdme0/)

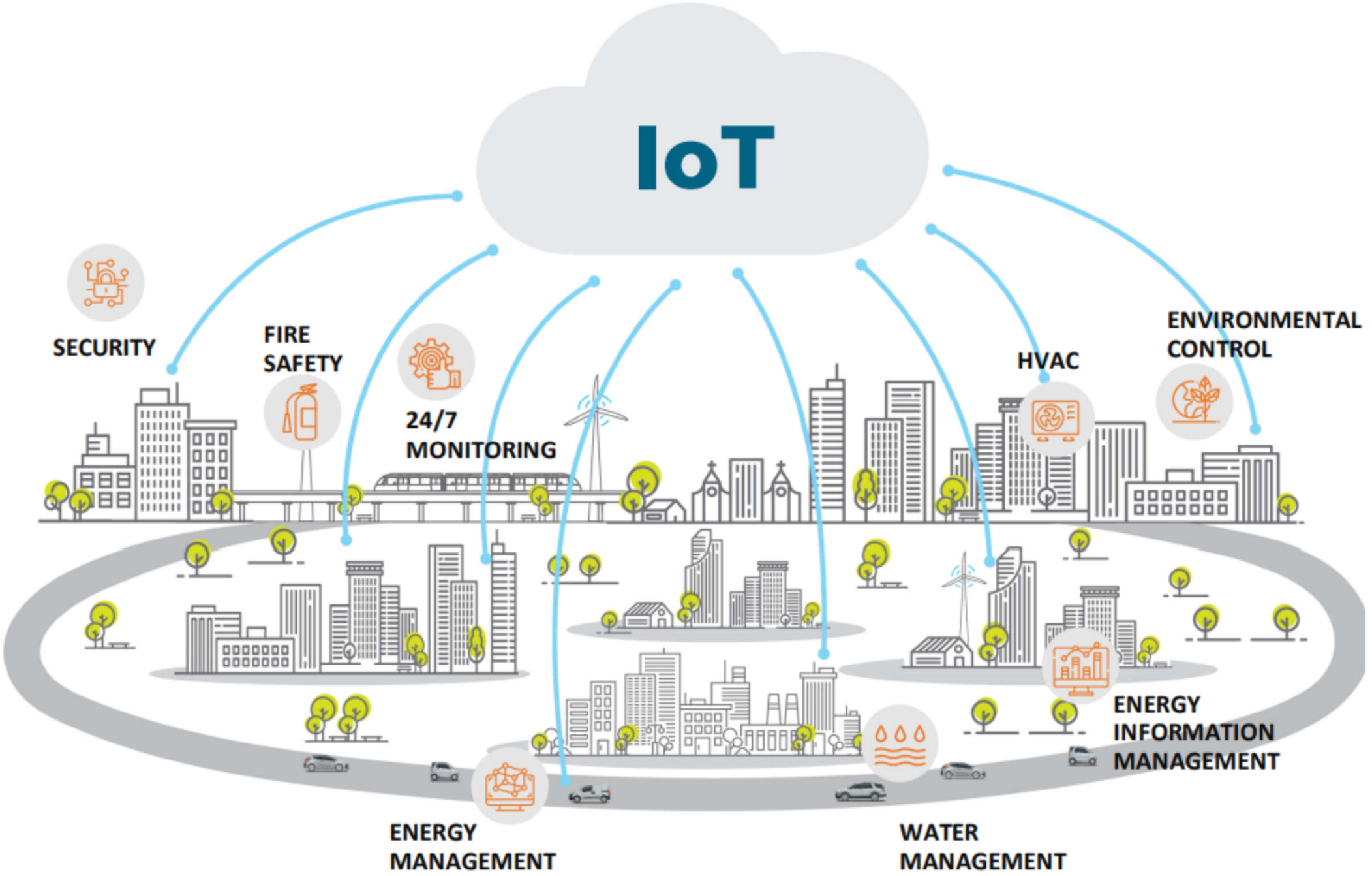
Internet of Things (IoT)



- IoT protocols:
  - 1. MQTT (Message Queue Telemetry Transport)
  - 2. DDS (Data Distribution Service)
  - 3. AMQP (Advanced Message Queuing Protocol)
  - 4. Constrained Application Protocol (CoAP)
- IoT communication technologies:
  - Bluetooth, Zigbee, Wi-Fi, Cellular (3G, 4G, 5G), LoRaWAN (Long Range Wide Area Network)

(Further info: https://medium.com/@kunalmohta/what-is-meant-by-the-term-internet-of-things-iot-287cfc233865)

Internet of Things (IoT) as a ‘backbone’ to smart green buildings



(Source: https://www.hkgbc.org.hk/eng/resources/publications/Files/HKGBC_Smart-Green-Building-Design-Best-Practice-Guidebook.pdf)

IoT for smart buildings

- IoT in smart buildings can simplify tasks:
  - Building temperature control
  - Smart water usage
  - Pest control
  - Fire detection
  - Security & access control
  - Structural health monitoring

- Enable the collection & analysis of real-time data for improving operation & maintenance

Different IoT-based systems in smart buildings

(Source: Shah S. F. A., Iqbal M., Aziz Z., Rana T. A., Khalid A., Cheah Y.-N. & Arif M., 2022. The role of machine learning and the Internet of Things in smart buildings for energy efficiency, *Applied Sciences*, 12: 7882. https://doi.org/10.3390/app12157882)

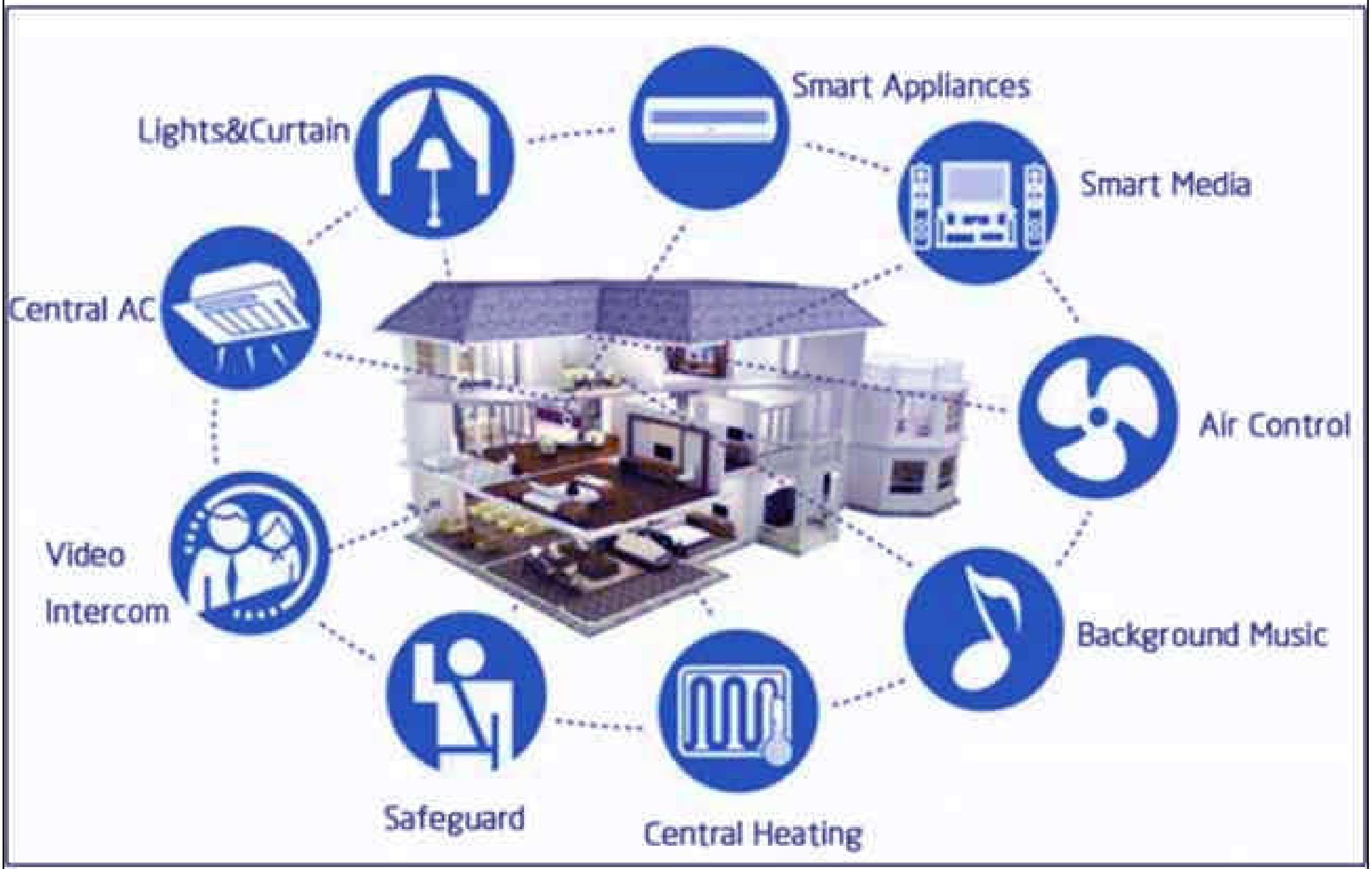
IoT for smart buildings

- How IoT enables smart building automation
  - Security & emergency: Smart IoT access control with ID or face recognition; IoT sensors on fire, chemical leakage, or flood
  - Advanced maintenance: Setting IoT alerts for state tracking & conducting predictive maintenance
  - Energy management: Optimise energy use with customized settings for greater energy efficiency
  - Water & waste management: Optimise resource use to reduce utility bills & carbon footprint

The Internet of Things in smart commercial buildings

(Source: https://memoori.com/portfolio/iot-devices-smart-commercial-buildings-2023/)

Internet of Things (IoT) applications in buildings & houses

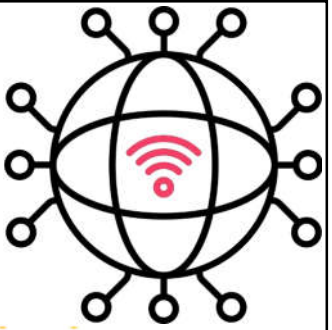


(Source: https://data-flair.training/blogs/internet-of-things-applications-in-building/)

Possible functions provided by Internet of Things (IoT) in buildings

(Source: https://data-flair.training/blogs/internet-of-things-applications-in-building/)

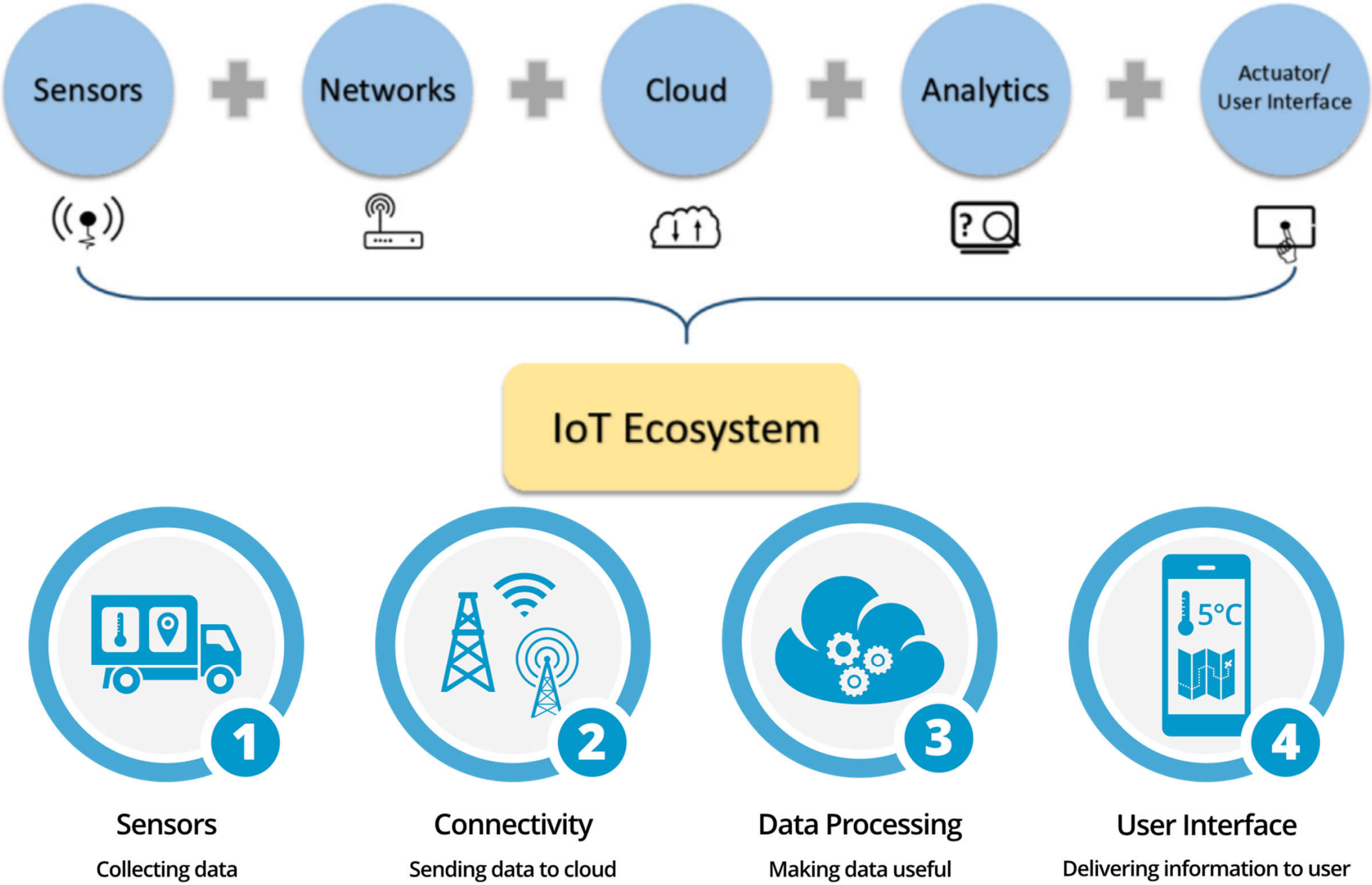
IoT for smart buildings



- Key components in IoT-powered building automation system:
  - 1. IoT sensors
  - 2. Smart devices/actuators
  - 3. Cloud computing
  - 4. Artificial intelligence & data analytics

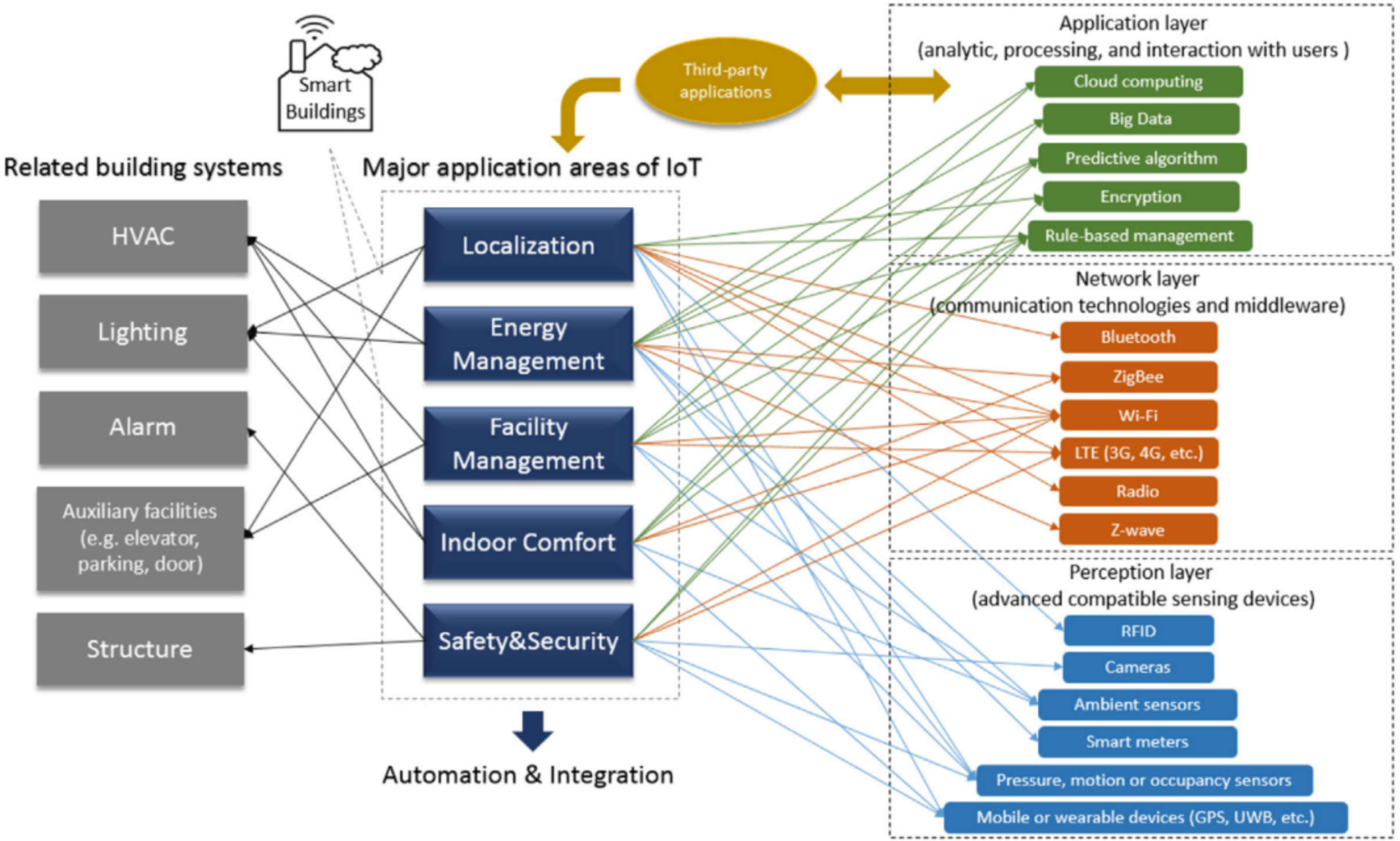
(See also: The role of IoT in Building Automation Systems https://www.zenatix.com/the-role-of-iot-in-building-automation-systems/)

Components of an IoT system



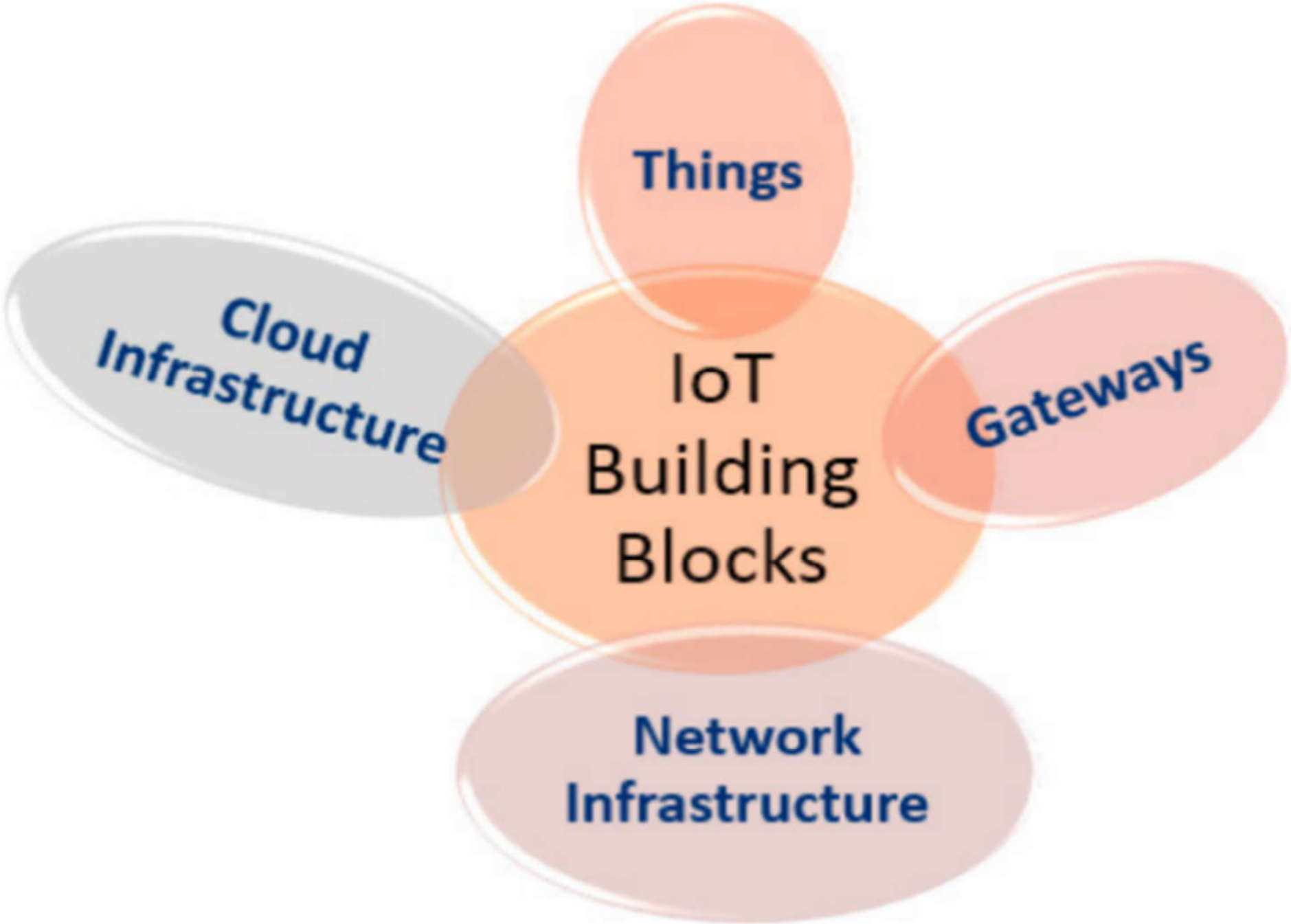
(Source: Jia M., Komeily A., Wang Y. & Srinivasan R. S., 2019. Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications, *Automation in Construction*, 101: 111-126. https://doi.org/10.1016/j.autcon.2019.01.023)

Application of IoT on smart buildings (goals, technologies & related building systems)



(Source: Jia M., Komeily A., Wang Y. & Srinivasan R. S., 2019. Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications, *Automation in Construction*, 101: 111-126. https://doi.org/10.1016/j.autcon.2019.01.023)

Basic components of an effective IoT system



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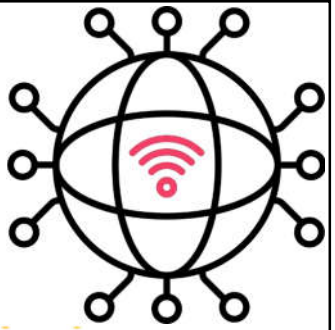
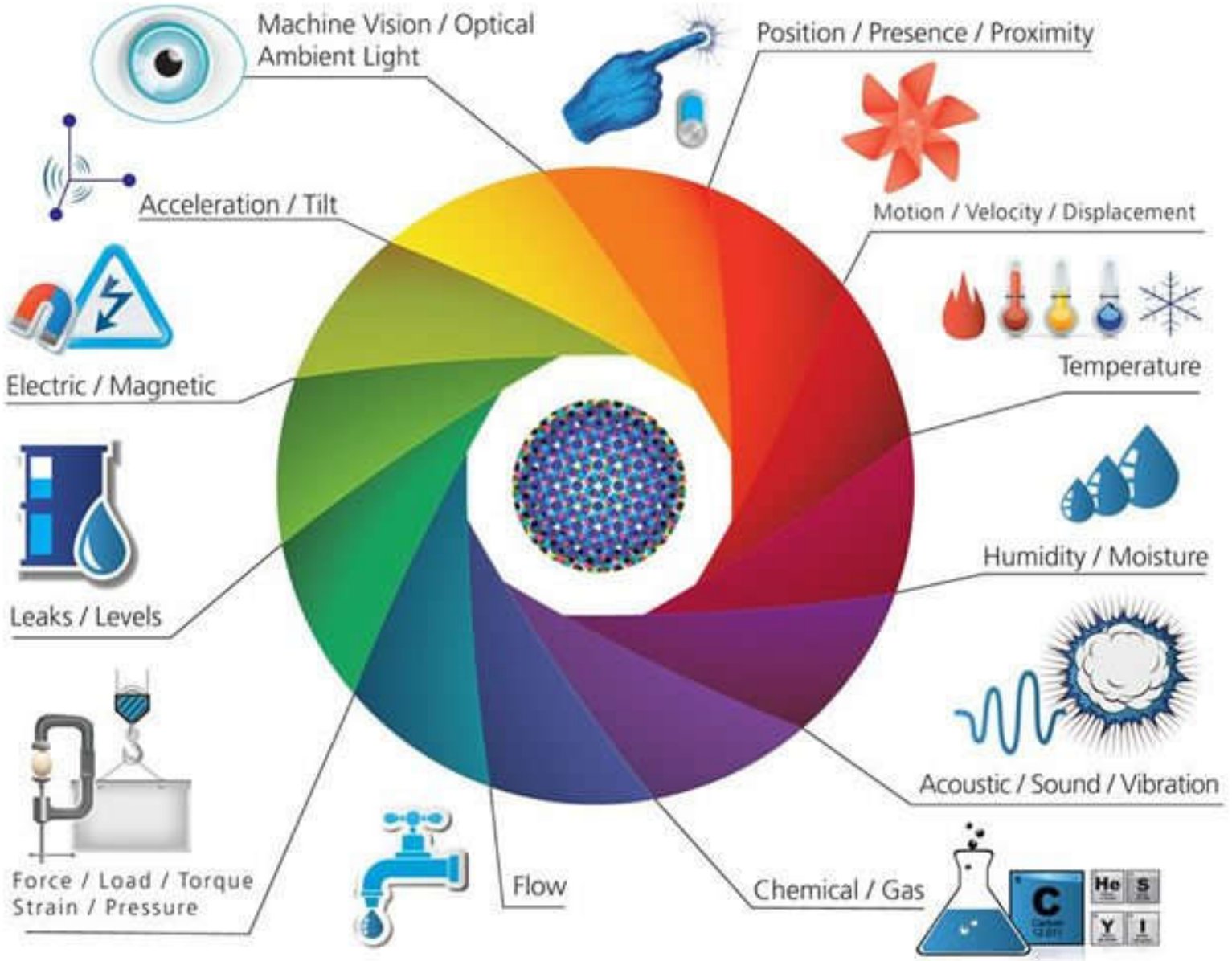
IoT for smart buildings



- Internet of Things (IoT) networks building technologies
  - Sensing technology
  - Wireless communication technology
  - Cloud computing technology
  - Radio-frequency identification (RFID) intelligent identification technology
  - Internet Protocol version 6 (IPv6) technology

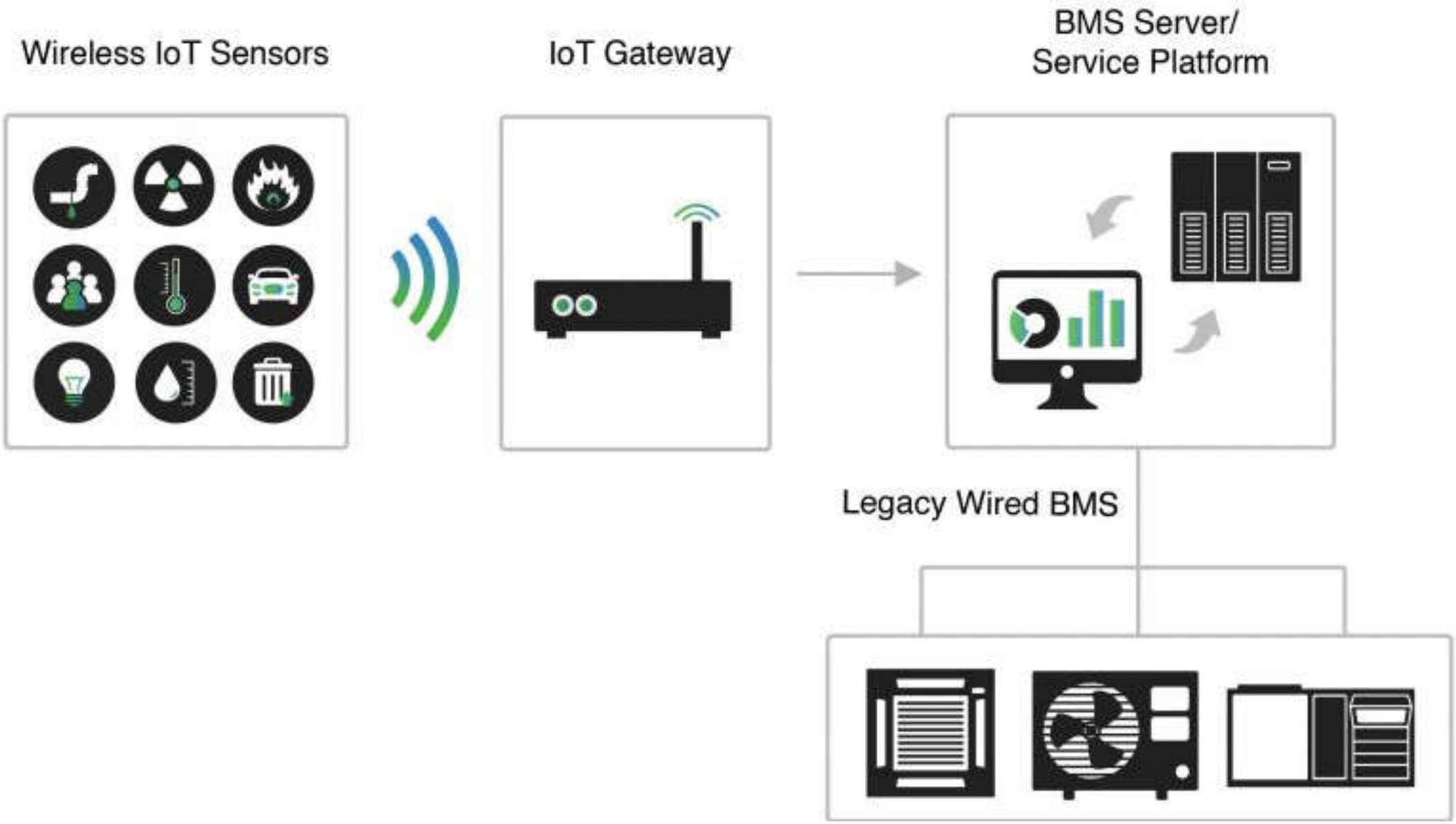
1 SENSORS & *ACTUATORS*

We are giving our world a digital nervous system. Location data using GPS sensors. Eyes and ears using cameras and microphones, along with sensory organs that can measure everything from temperature to pressure changes.



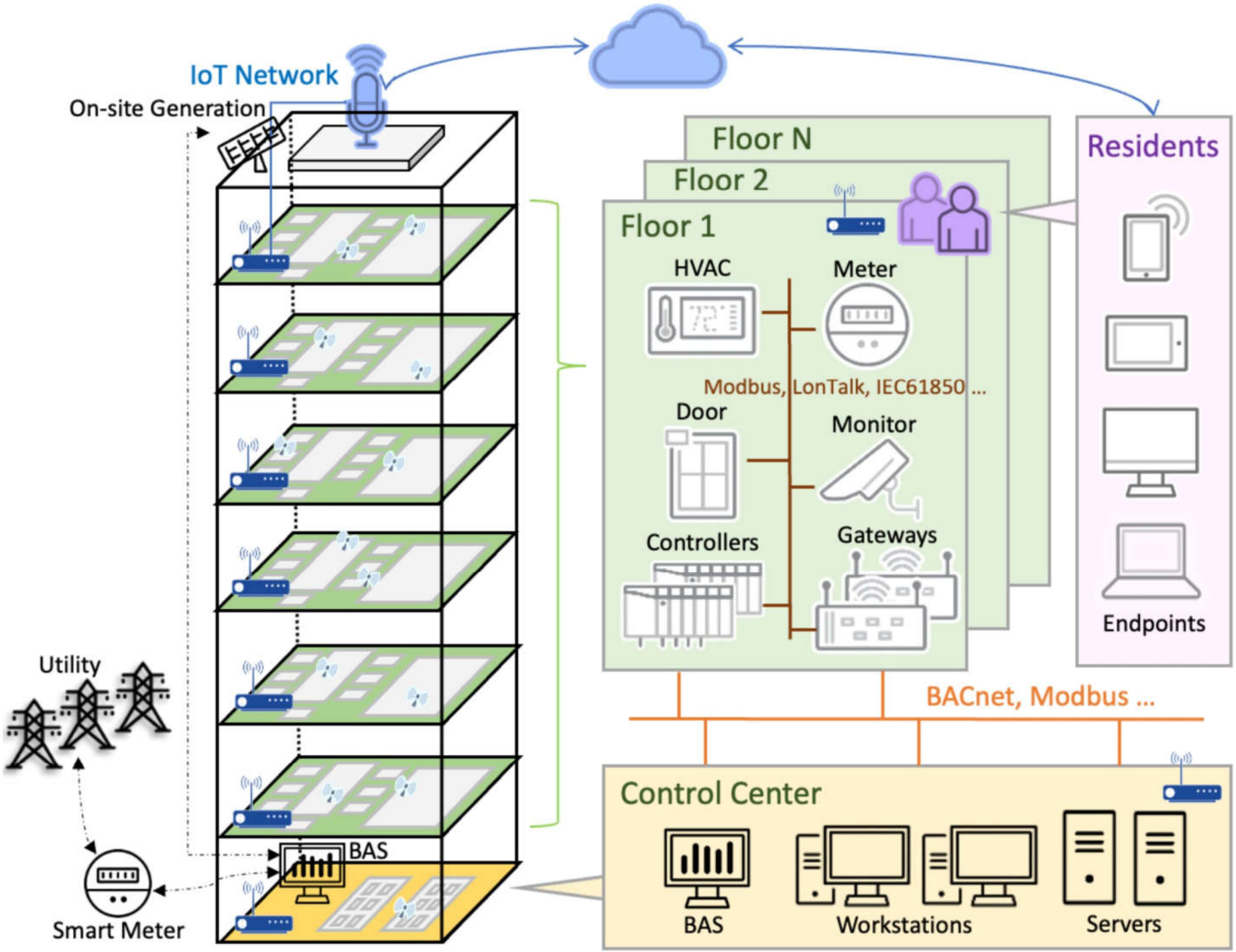
(Source: https://www.i-scoop.eu/internet-of-things-iot/iot-technology-stack-devices-gateways-platforms/)

Wirelsss IoT sensors to support BAS/BMS functions



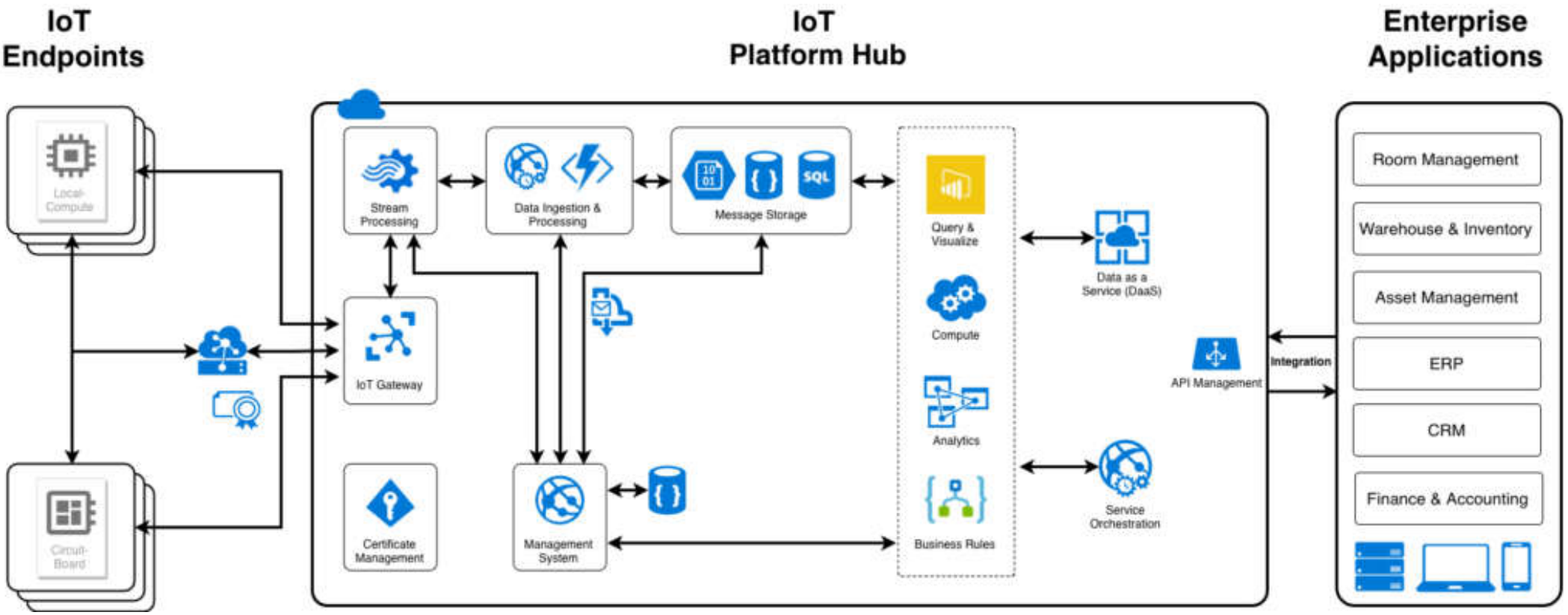
(Source: https://gemvietnam.com/internet-of-things/smart-building-automation-system/)

Buildings network architecture overview



(Source: https://www.txone.com/blog/potential-threats-to-building-automation-systems/)

IoT platform hub to store, process & analyze the data before streamlining insights into enterprise management applications

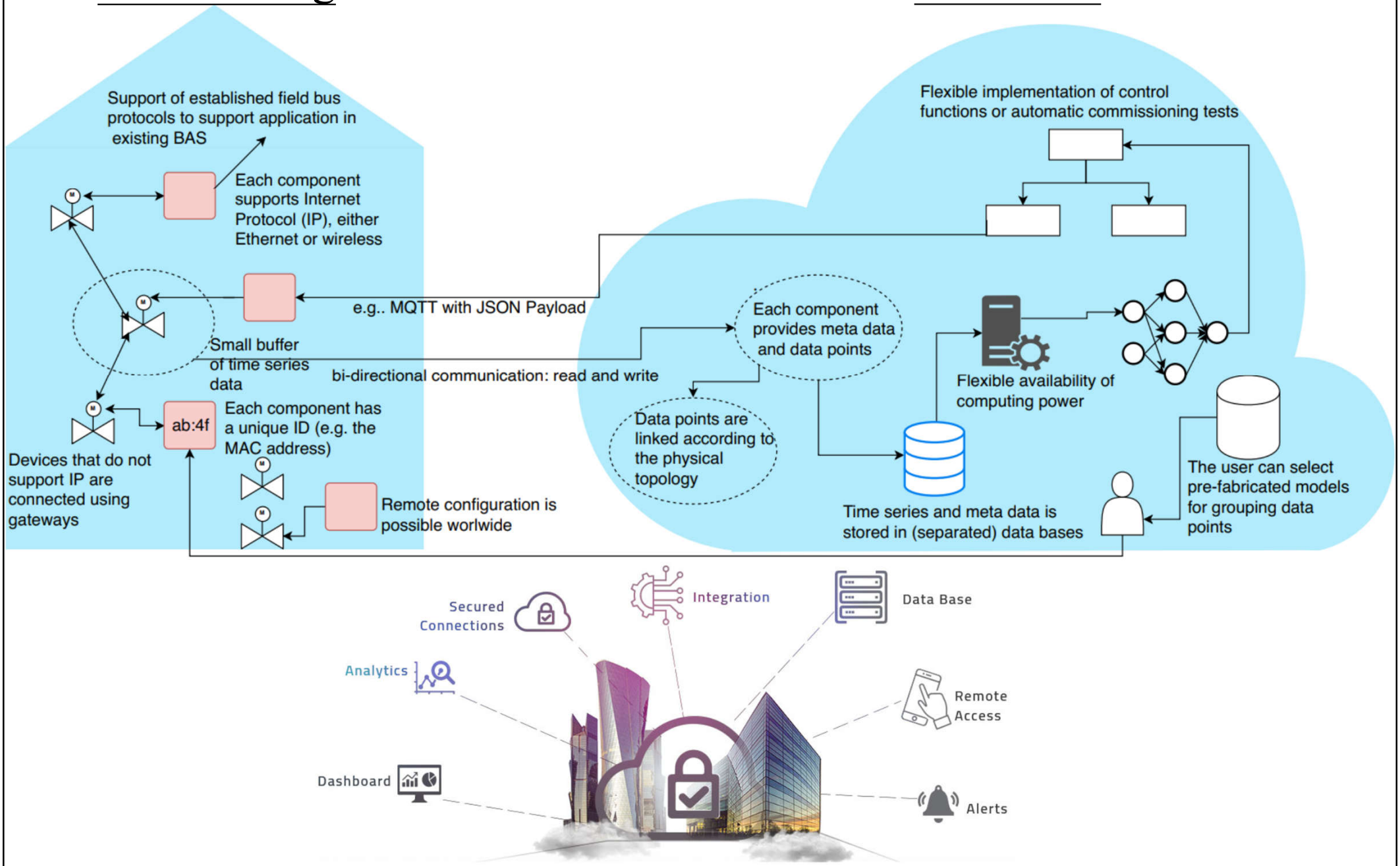


(Source: https://gemvietnam.com/internet-of-things/smart-building-automation-system/)

The proposed architecture for IoT BAS

The building

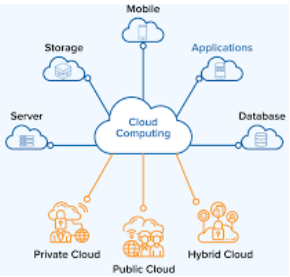
The cloud



(Source: Bode G., *et al.*, 2019. Cloud, wireless technology, internet of things: the next generation of building automation systems?, *Journal of Physics: Conference Series*, 1343 (1) 12059. https://doi.org/10.1088/1742-6596/1343/1/012059)

Cloud-based services

- Cloud computing 雲端運算
  - The delivery of computing services -- including servers, storage, databases, networking, software, analytics & intelligence -- over the Internet (“the cloud”) to offer faster innovation, flexible resources & economies of scale



  - Can lower operating costs, run the infrastructure more efficiently & scale as the business needs change
  - 3 types: public cloud, private cloud, hybrid cloud

Cloud-based services

- Four types of cloud services:
  - 1. Infrastructure as a service (IaaS)
    - Rent IT infrastructure -- servers & virtual machines (VMs), storage, networks, operating systems) -- from a cloud provider on a pay-as-you-go basis
  - 2. Platform as a service (PaaS)
    - Supply an on-demand environment for developing, testing, delivering & managing software applications
    - Make it easier for developers to quickly create web or mobile apps

(Source: https://azure.microsoft.com/en-us/resources/cloud-computing-dictionary/what-is-cloud-computing)

Cloud-based services

- Four types of cloud services: (cont'd)
  - 3. Software as a service (SaaS)
    - Deliver software applications over the internet, on demand & typically on a subscription basis
  - 4. Serverless computing
    - Focus on building app functionality without spending time continually managing the servers & infrastructure
    - The cloud provider handles the setup, capacity planning & server management
    - Highly scalable & event-driven, only using resources when a specific function or trigger occurs

Cloud-based, remote building automation systems (BAS) for commercial buildings

(Source: https://www.esmagazine.com/articles/100953-building-automation-systems-to-the-rescue-creating-a-remote-world)

Cloud-based services

- Using a cloud-based system, people can monitor & control their buildings from a PC or smart device from anywhere in the world
- A cloud-based BAS also provides high-level analytical reporting that is fully automated
- It can model environmental data several days into the future to automatically & continuously update settings

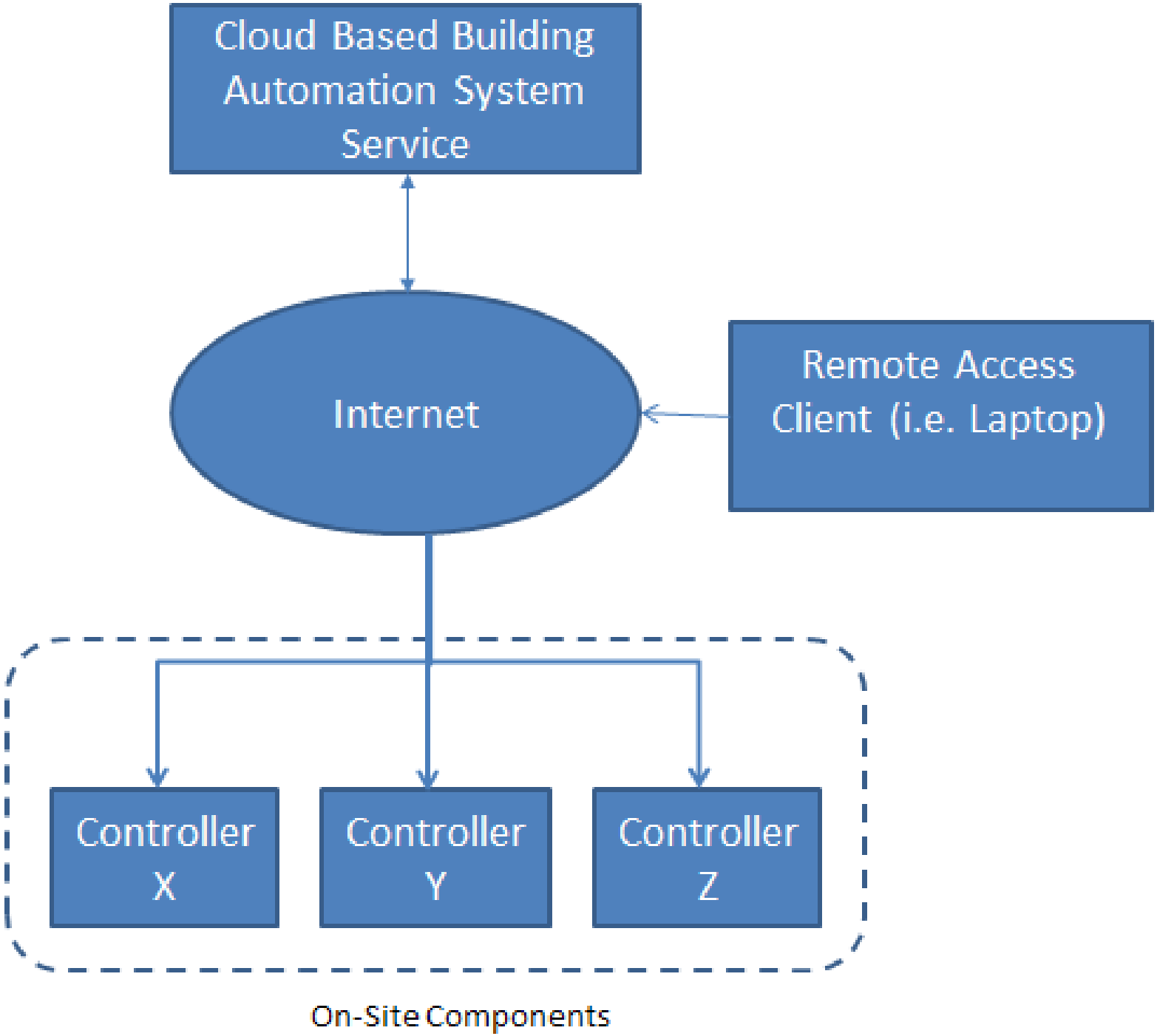
Cloud-based services

- The future of BAS is cloud-hosted, software-as-a-service (SaaS) solutions
  - Allow for simple integration of new building equipment, deployment of new features & automatic upgrades via the cloud
  - Improved flexibility via open application programming interfaces (APIs)
  - Offer remote access & control to contractors without visiting the site

Cloud-based services

- Cloud-based services also permitted more flexible access to building data
  - Building automation consists of networked sensors & actuators. The systems & how they communicate have been standardized to the point that they can easily connect to many cloud-based services. Smart buildings interact with users & operators, their systems & their environment. Digital twins of buildings & intelligent technologies are giving rise to additional networked services

Cloud-based building automation system (BAS) service

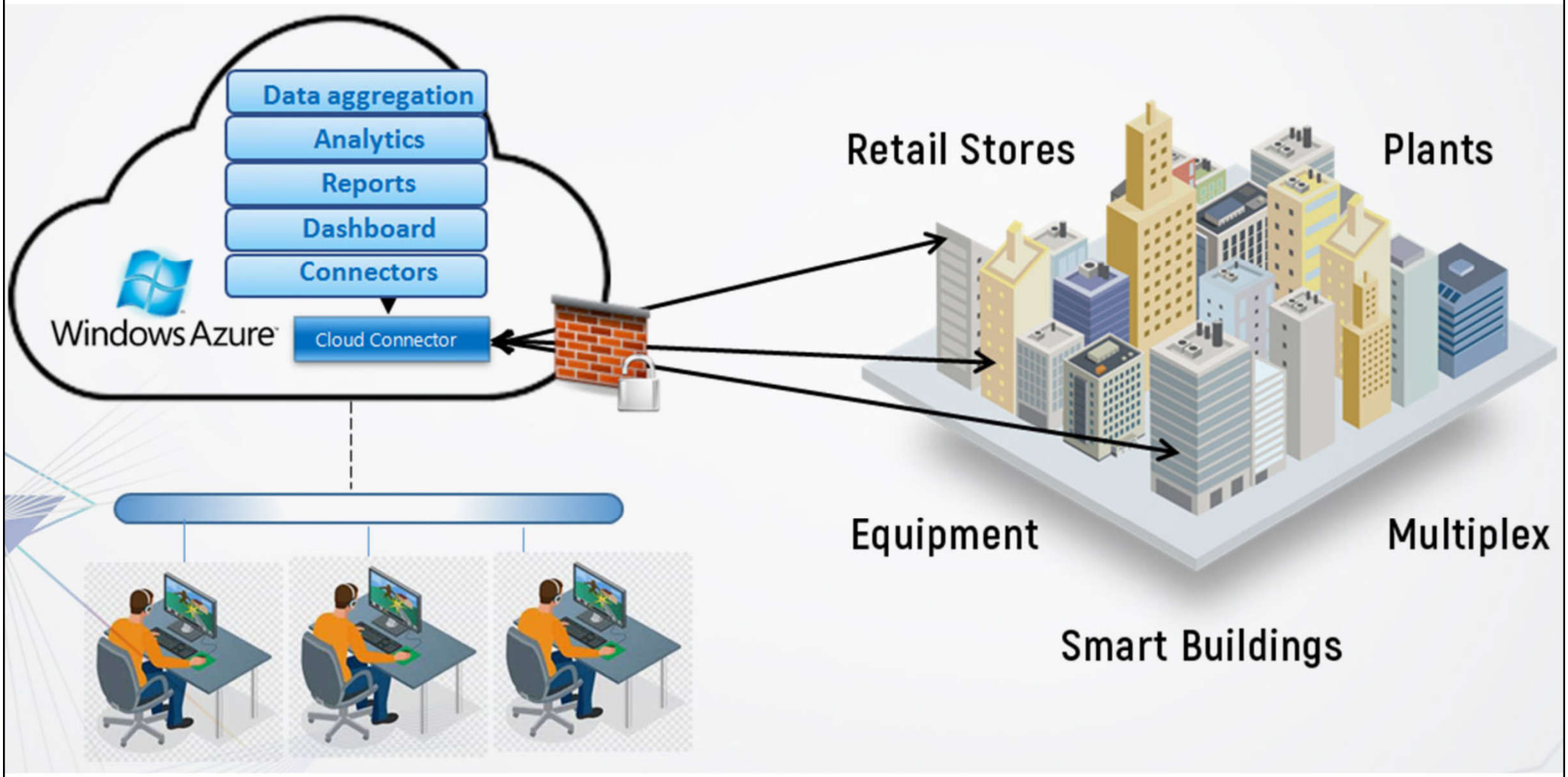


(Source: https://buildingenergy.cx-associates.com/2012/11/cloud-based-building-automation-building-control-evolution/)

Internet of Things (IoT) & cloud analytics

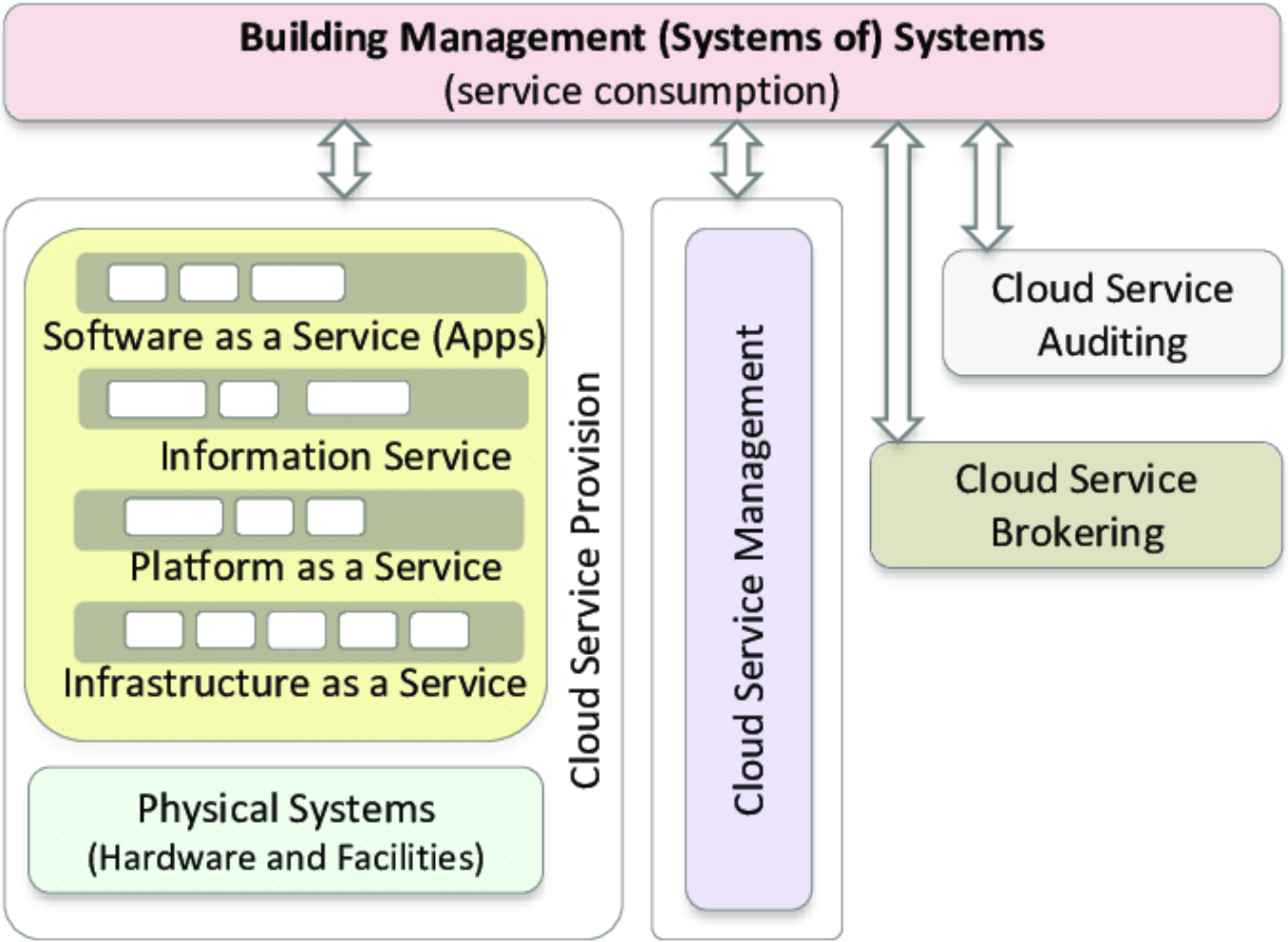
(Source: https://www.messungbacd.com/iot.php)

Cloud platform for smart building automation



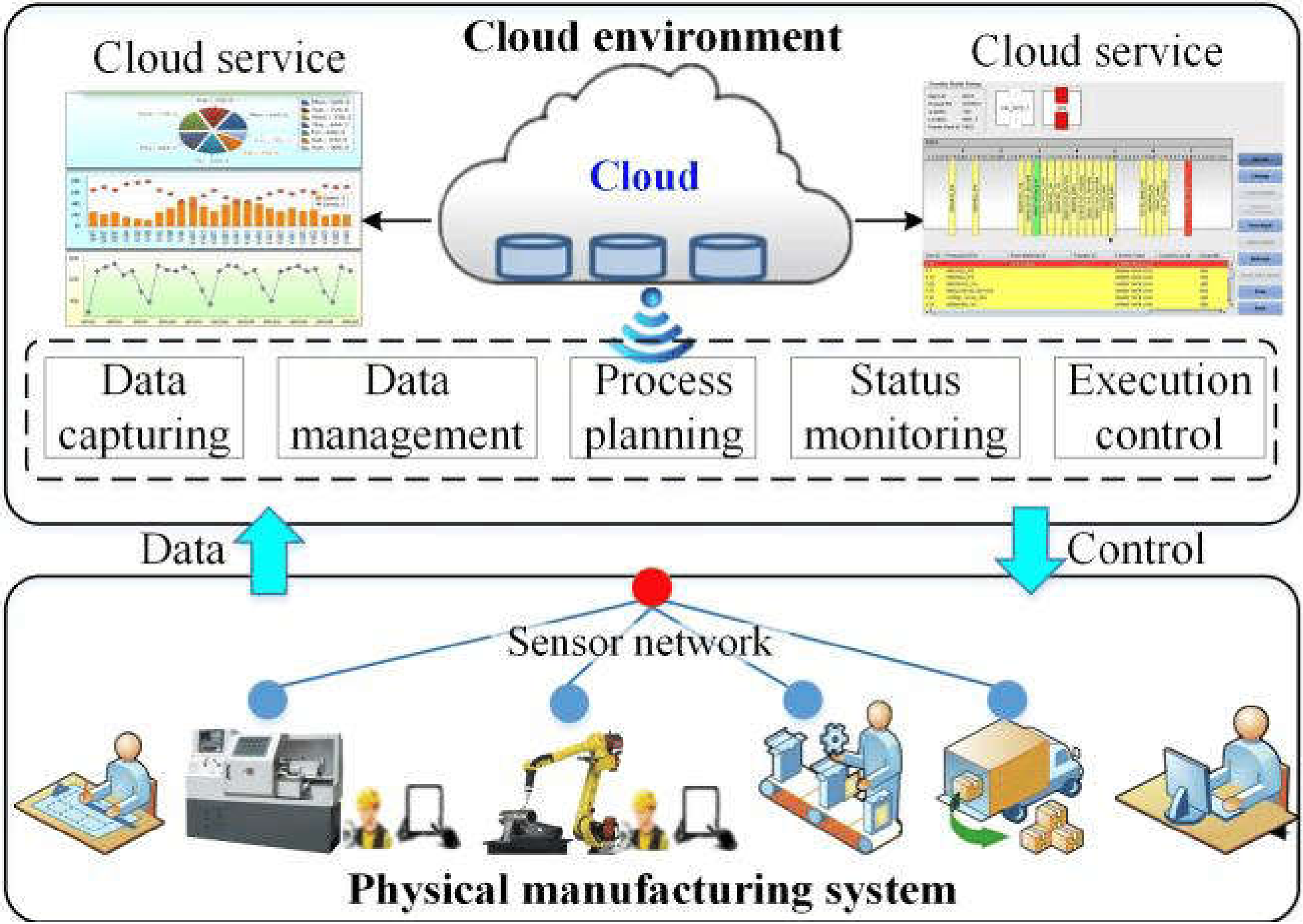
(Source: https://www.messungbacd.com/iot.php)

Possible cloud architecture for BAS/BMS



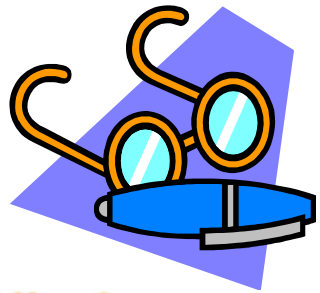
(Source: Noran O., Sota I. & Bernus P., 2019. Towards next generation building management systems, *E3S Web of Conferences*, 111 (20) 05004. https://doi.org/10.1051/e3sconf/2019111050)

Reference to a cloud-based manufacturing system architecture



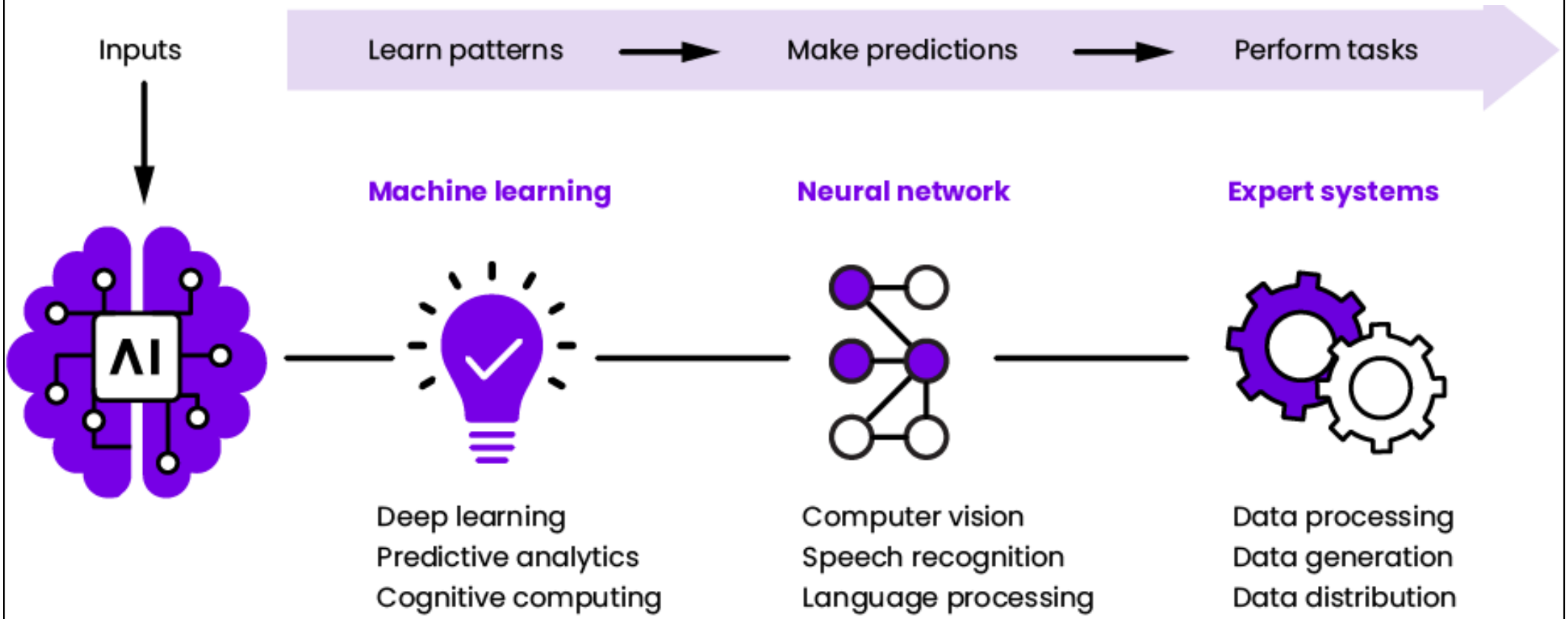
(Source: Qi Q. & Tao F., 2019. A smart manufacturing service system based on edge computing, fog computing and cloud computing, *IEEE Access*, 7: 86769-86777. https://doi.org/10.1109/ACCESS.2019.2923610)

Data analytics & AI



- Data analytics 數據分析
  - Process of examining large sets of data to uncover patterns, correlations & insights
  - Involve using statistical & quantitative methods to extract meaningful information from raw data
- Artificial intelligence (AI) 人工智能
  - Simulation of human intelligence that are programmed to learn & mimic human behaviour
  - To enhance business operations & improve customer experiences

How artificial intelligence (AI) works?

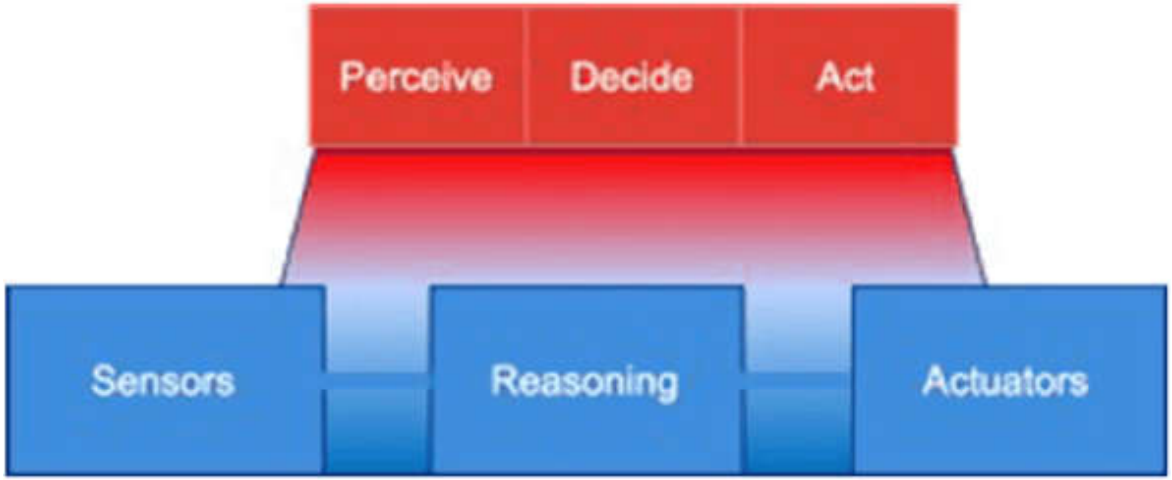


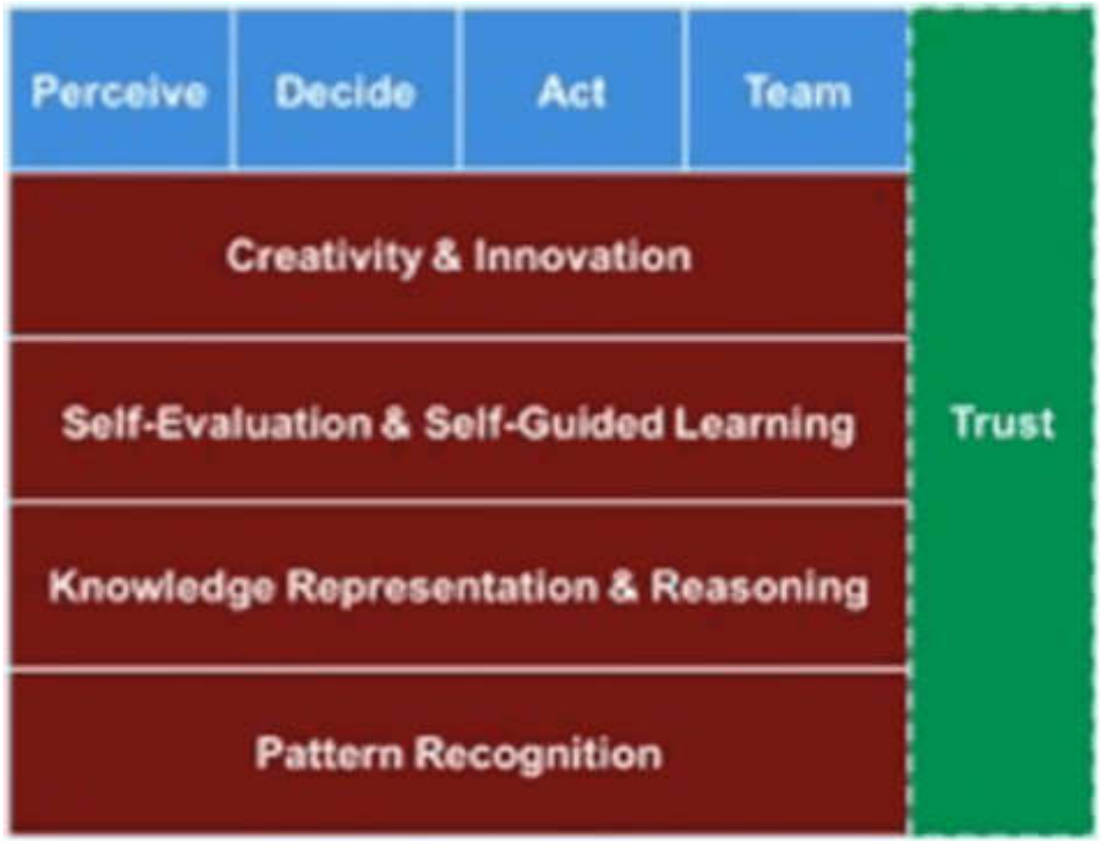
Common types of AI models:

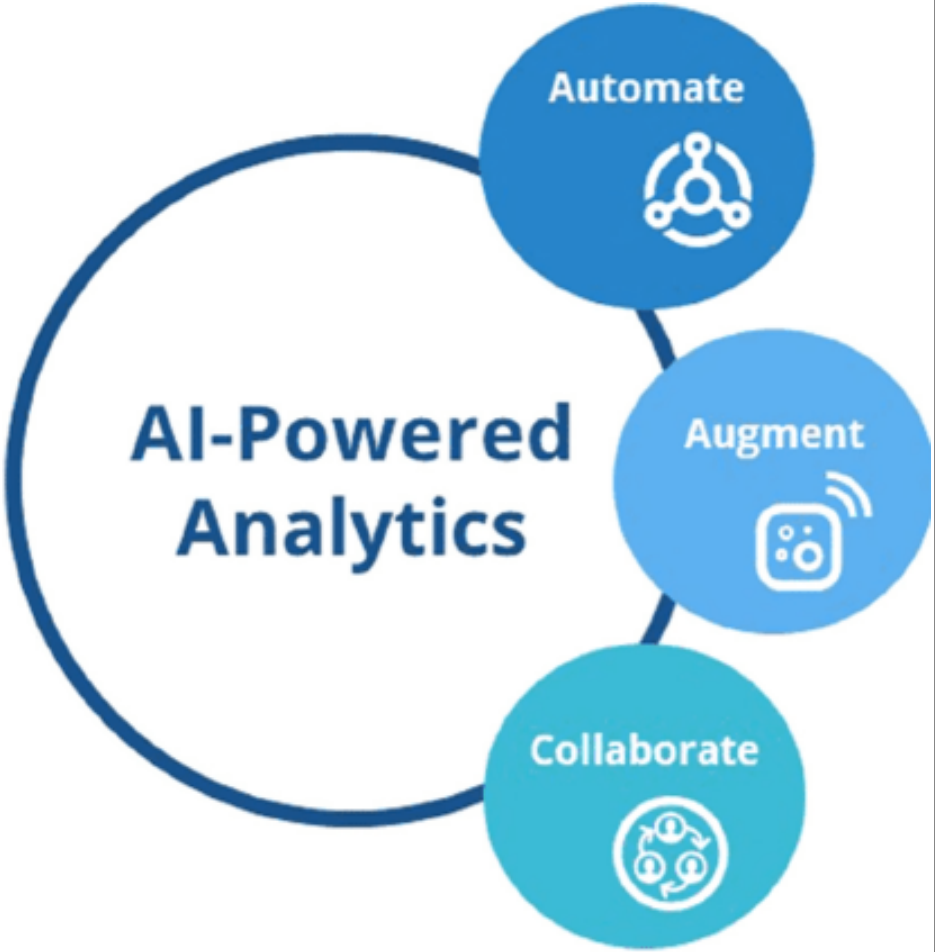
1. Statistical models (using mathematical models & statistical techniques)
2. Machine learning models (MLMs) (learn patterns & relationships from data)
3. Deep learning models (DLMs) (based on artificial neural networks)
4. Reinforcement learning models (RLMs) (by interacting with an environment)
5. Generative models (generate new data similar to the training data distribution)

(Source: https://www.weka.io/learn/ai-ml/what-is-ai/)

Intelligent systems framework & AI-powered analytics

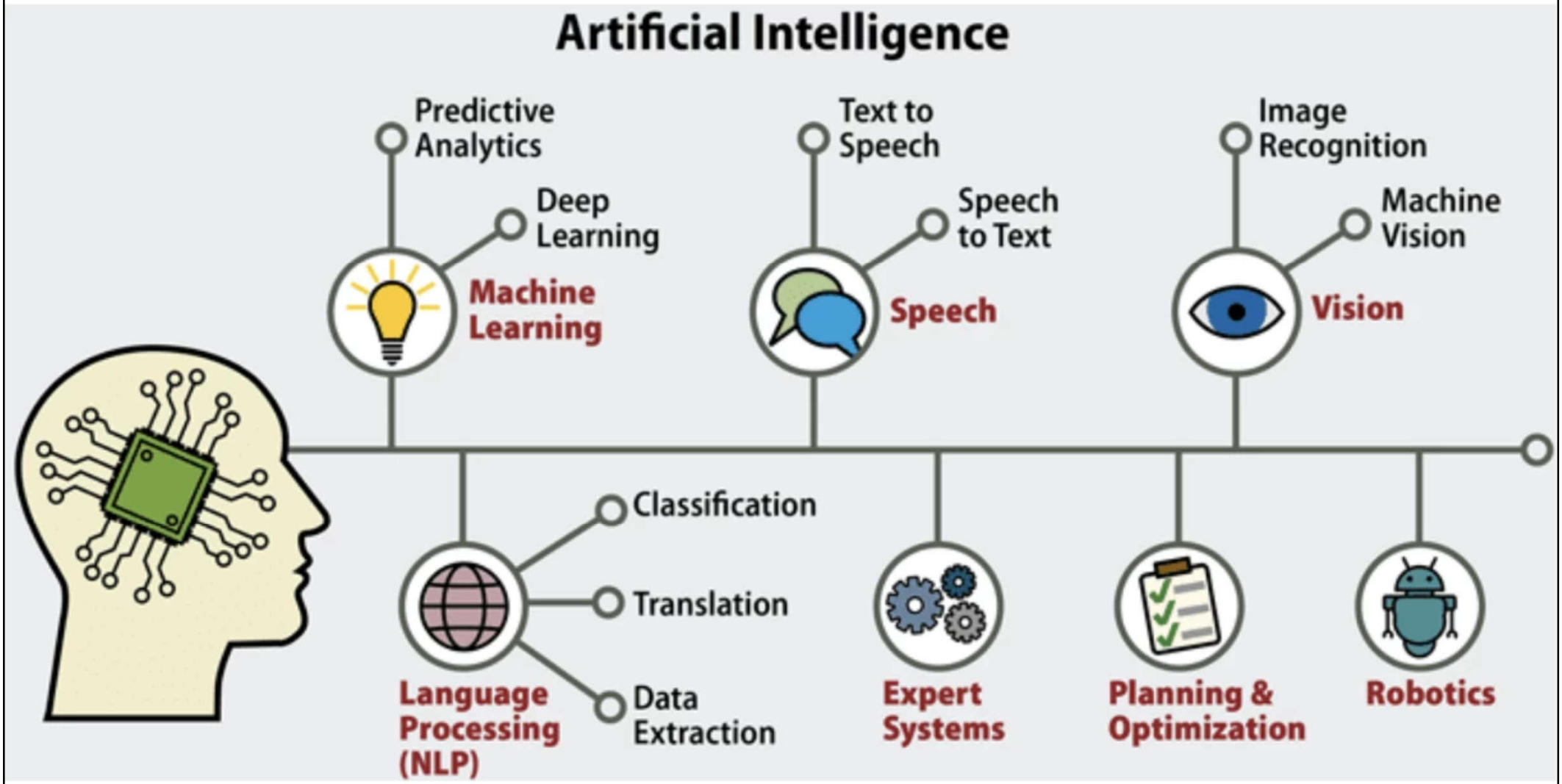






(Source: Data Analytics and AI https://ebrary.net/195870/engineering/data_analytics_and_ai)

Uses of data analytics & artificial intelligence



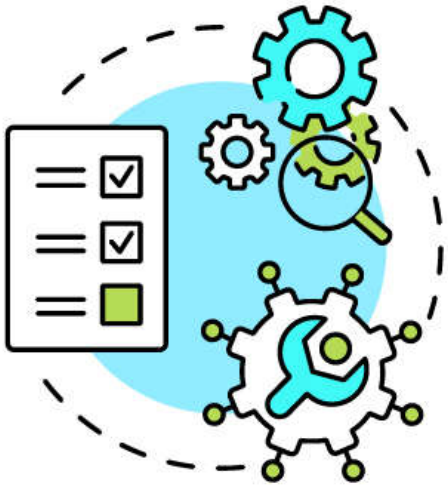
(Source: https://arekskuza.com/the-innovation-blog/data-analytics-and-artificial-antelligence-what-tt-means-for-your-business/)

Examples of functions for data analytics & artificial intelligence

(Source: https://www.itk-engineering.de/en/expertise-2/data-analytics-artificial-intelligence/)

3 key benefits of data analytics & artificial intelligence (AI) in auditing

Big Data Modernization for Operational Efficiency

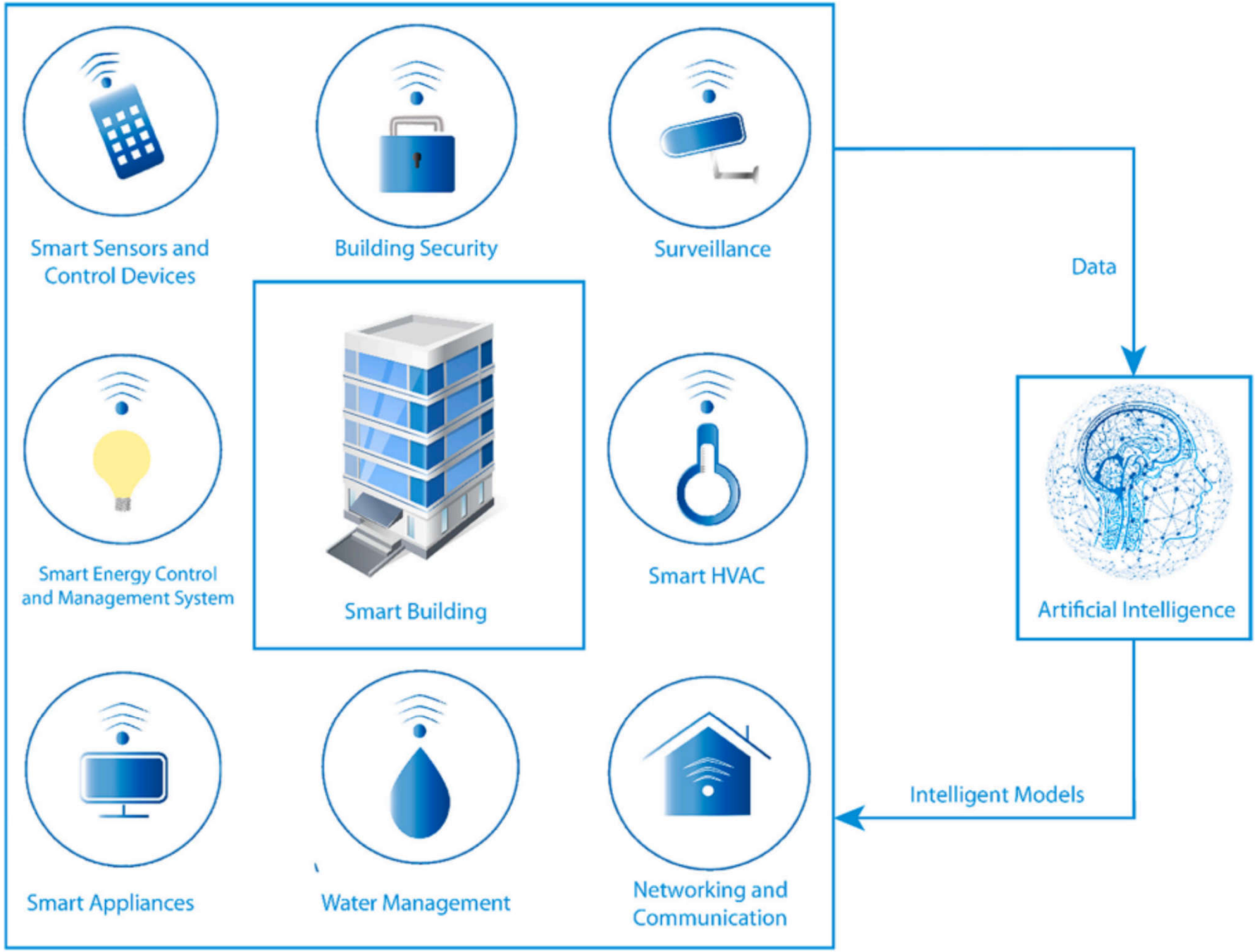


Advanced Data Visualization Capabilities

Intelligent Document Processing

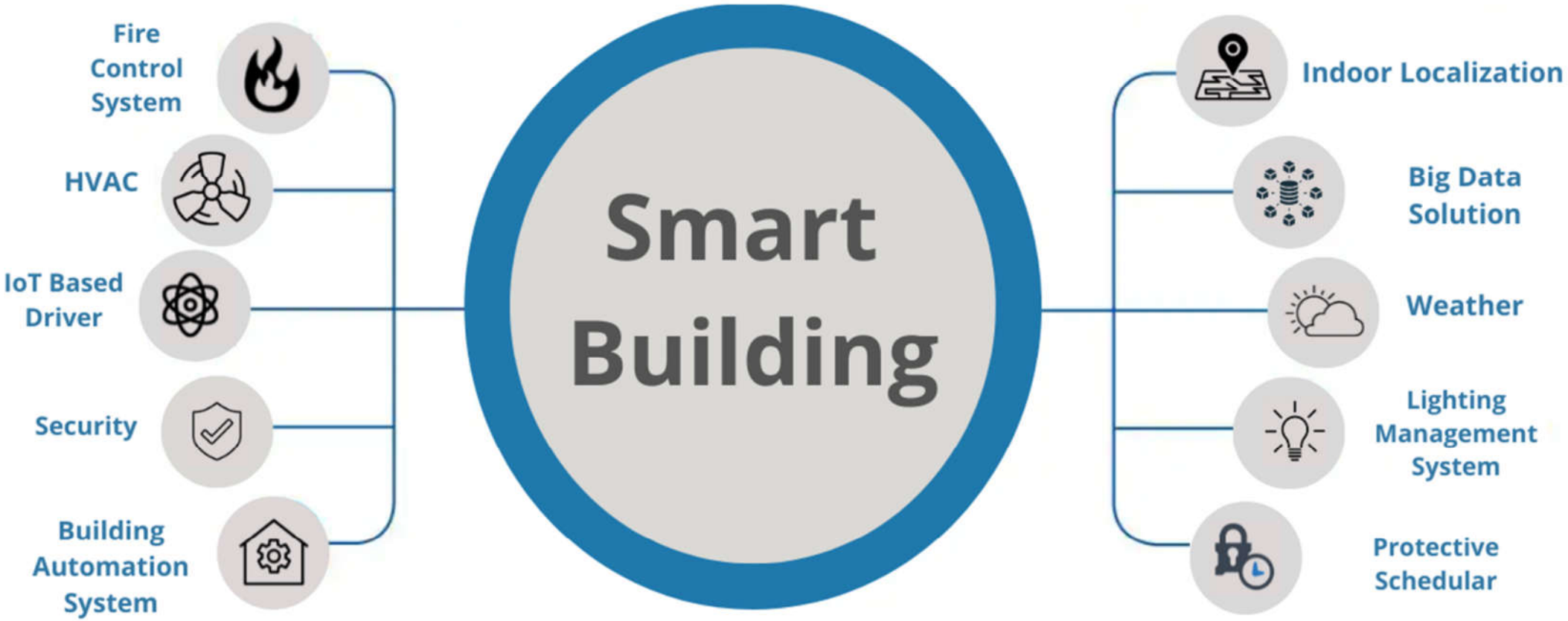
(Source: https://kanini.com/blog/how-ai-powered-data-analytics-redefines-audit-processes-an-intelligent-operating-model/)

Components of a smart building & integration of artificial intelligence



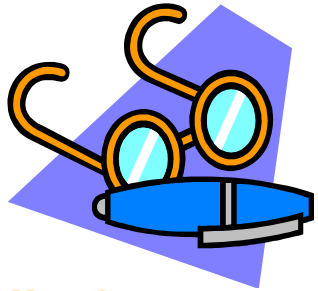
(Source: Baduge S. K., Thilakarathna S., Perera J. S., Arashpour M., Sharafi P., Teodosio B., Shringi A. & Mendis P., 2022. Artificial intelligence and smart vision for building and construction 4.0: Machine and deep learning methods and applications, *Automation in Construction*, 141: 104440. https://doi.org/10.1016/j.autcon.2022.104440)

AI-based systems for smart buildings



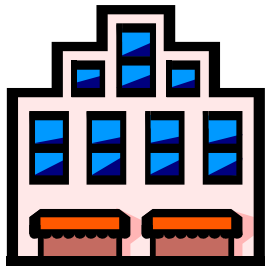
(Source: Shah S. F. A., Iqbal M., Aziz Z., Rana T. A., Khalid A., Cheah Y.-N. & Arif M., 2022. The role of machine learning and the Internet of Things in smart buildings for energy efficiency, *Applied Sciences*, 12: 7882. https://doi.org/10.3390/app12157882)

Data analytics & AI

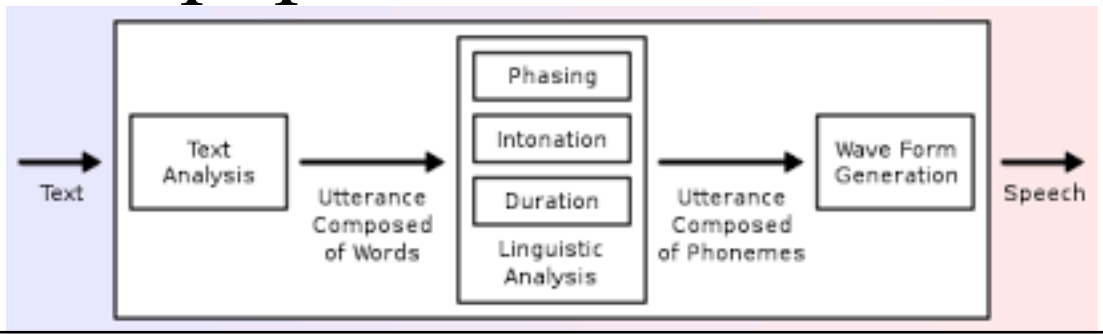


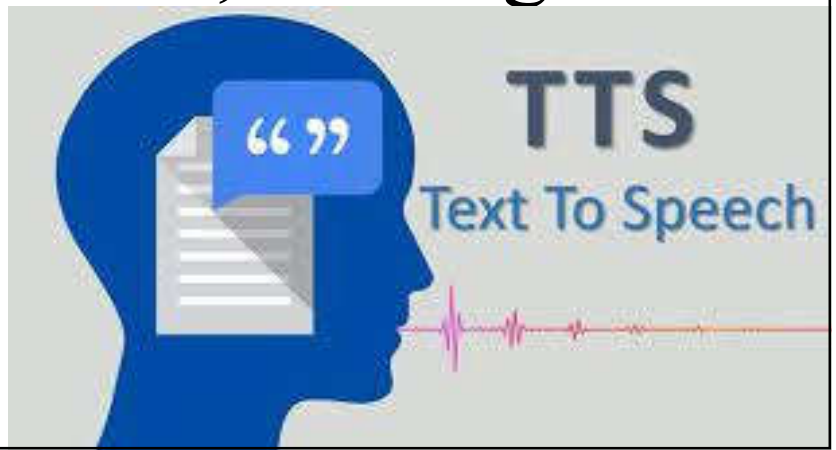
- Technology progress during the past 15 years
  - 2007: Smart phones propel a great leap forward
  - 2008: Building automation joins the cloud
  - 2009: Wireless control of lighting
  - 2010: Always on the go, always online
  - 2014: Text-to-speech (TTS) technology
  - 2015: The Internet of Thing (IoT) smart building
  - 2018: A “brain” for buildings
  - 2020: Turnkey artificial intelligence (AI)

Data analytics & AI

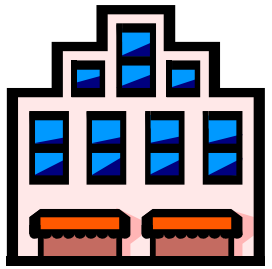


- Text-to-speech (TTS) technology
  - With voice-controlled email & text messages, audio files found their way into building automation: TTS began supporting preventive maintenance & inspections, service requests, work contracts, bidding & equipment audits



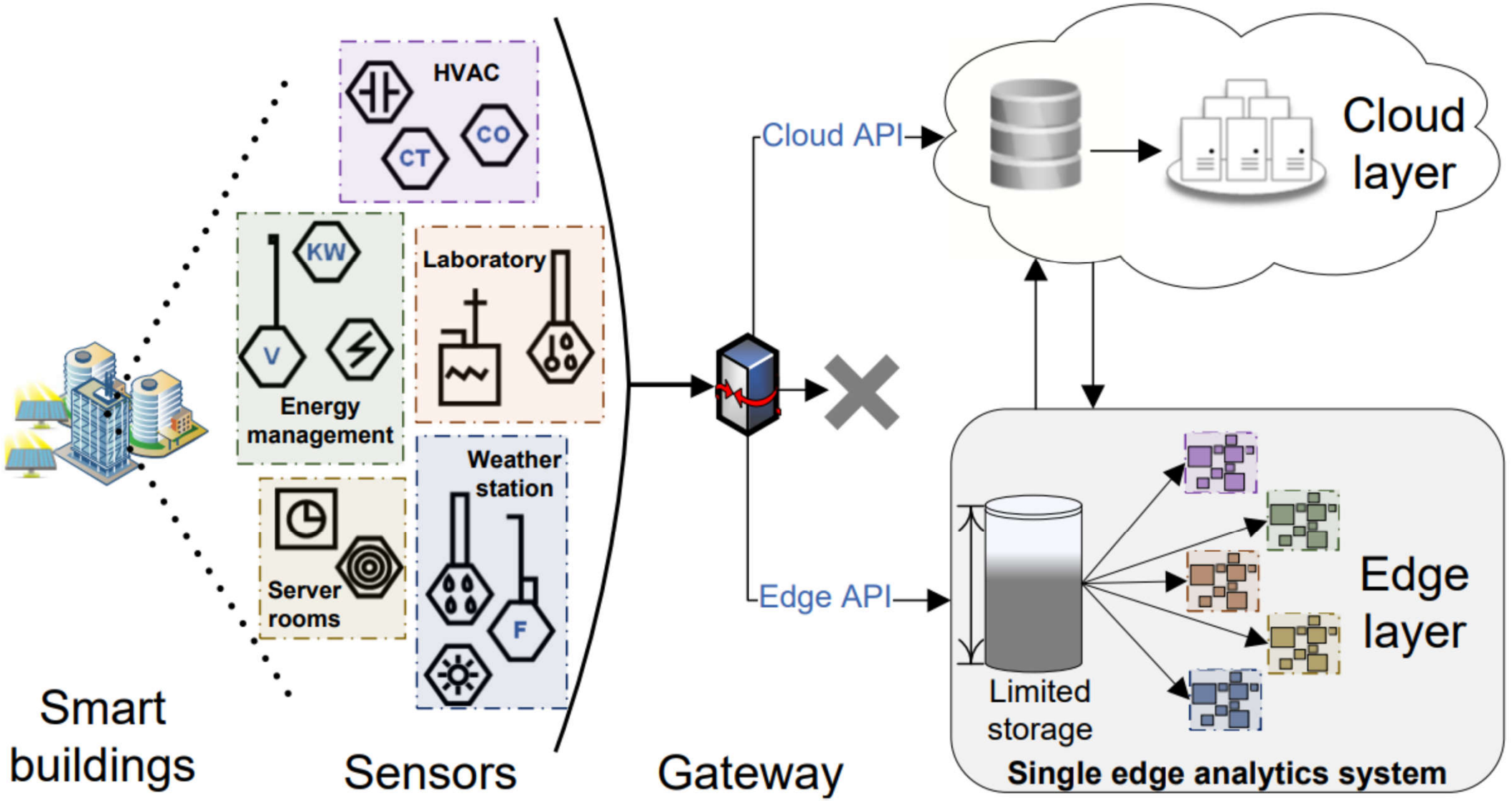


Data analytics & AI



- Turnkey artificial intelligence (AI)
  - AI joined the spectrum of building systems
    - Intelligent video technology helps detect fires early & clever algorithms predict future energy consumption
    - Behavioral patterns are identified by analyzing real-time data
    - The systems learn from all this & automatically adjust to conditions as appropriate

Basic concept of an analytics system for smart buildings



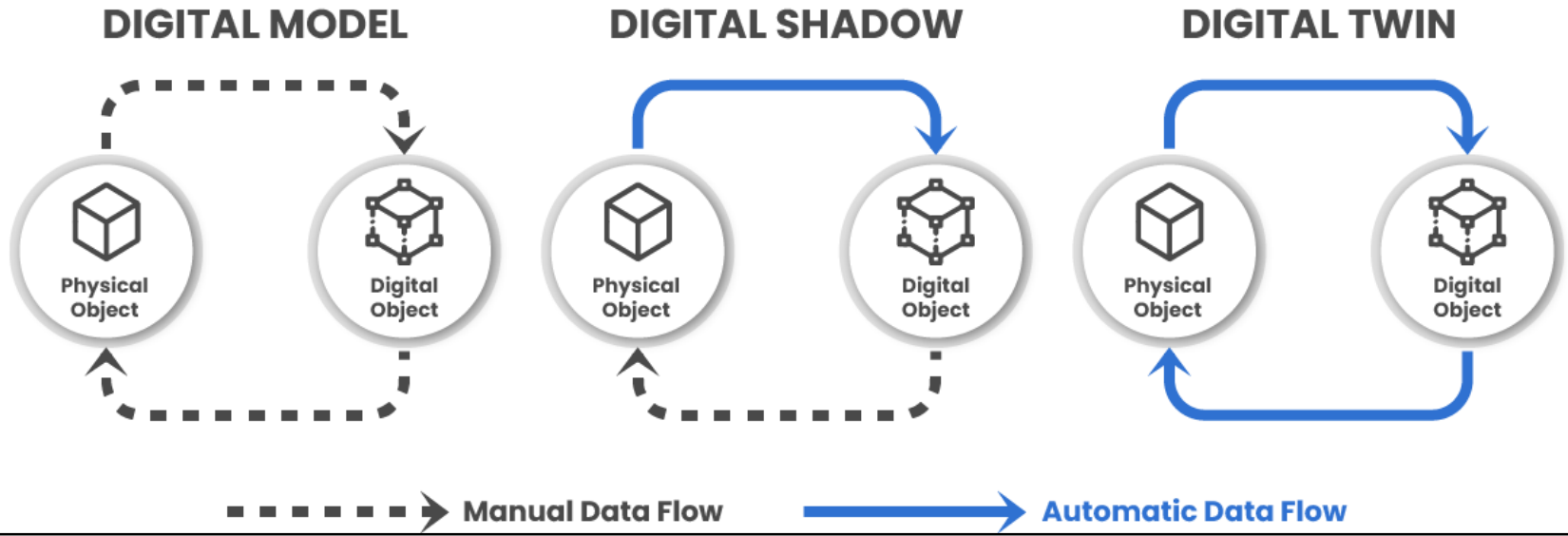
(Source: Lujic I. & Truong H.-L., 2019. Architecturing elastic edge storage services for data-driven decision making, In Bures T., Duchien L. & Inverardi P. (eds), *Software Architecture: 13th European Conference, ECSA 2019*, Paris, France, September 9-13, 2019 Proceedings, Lecture Notes in Computer Science, vol. 11681, p. 97-105, Springer, Cham. https://doi.org/10.1007/978-3-030-29983-5_7)

Digital twin technology

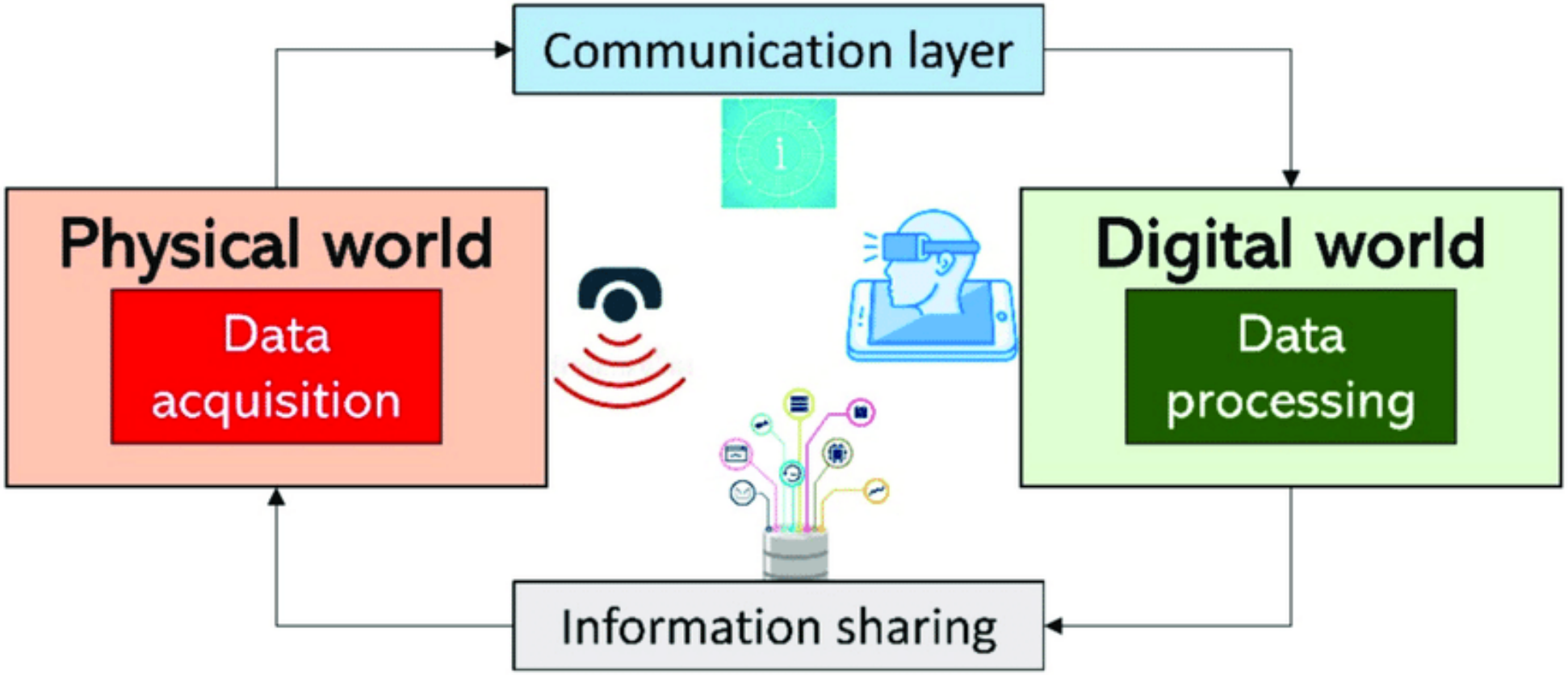
- A digital twin is a virtual representation of a physical object or system across its lifecycle, using real-time data to enable understanding, learning & reasoning
  - It brings together data from subsystems & from real-time interaction between people, process & connected things
  - It is a complex model of how people & processes interact with their environment

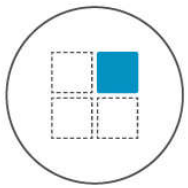
Digital twin technology

- Digital twins
  - They represent an object or process virtually & help to predict key factors like the running time or foreseeable performance
- The 3 Levels of digital twin technology:



Digital twin concept & four types of digital twins





Component/Parts Twins

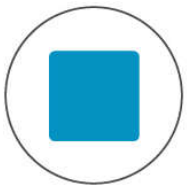
E.g. rotor, bulb

Asset Twins

E.g. engine or pump

System/Unit Twins

Combines all production units



Process Twins

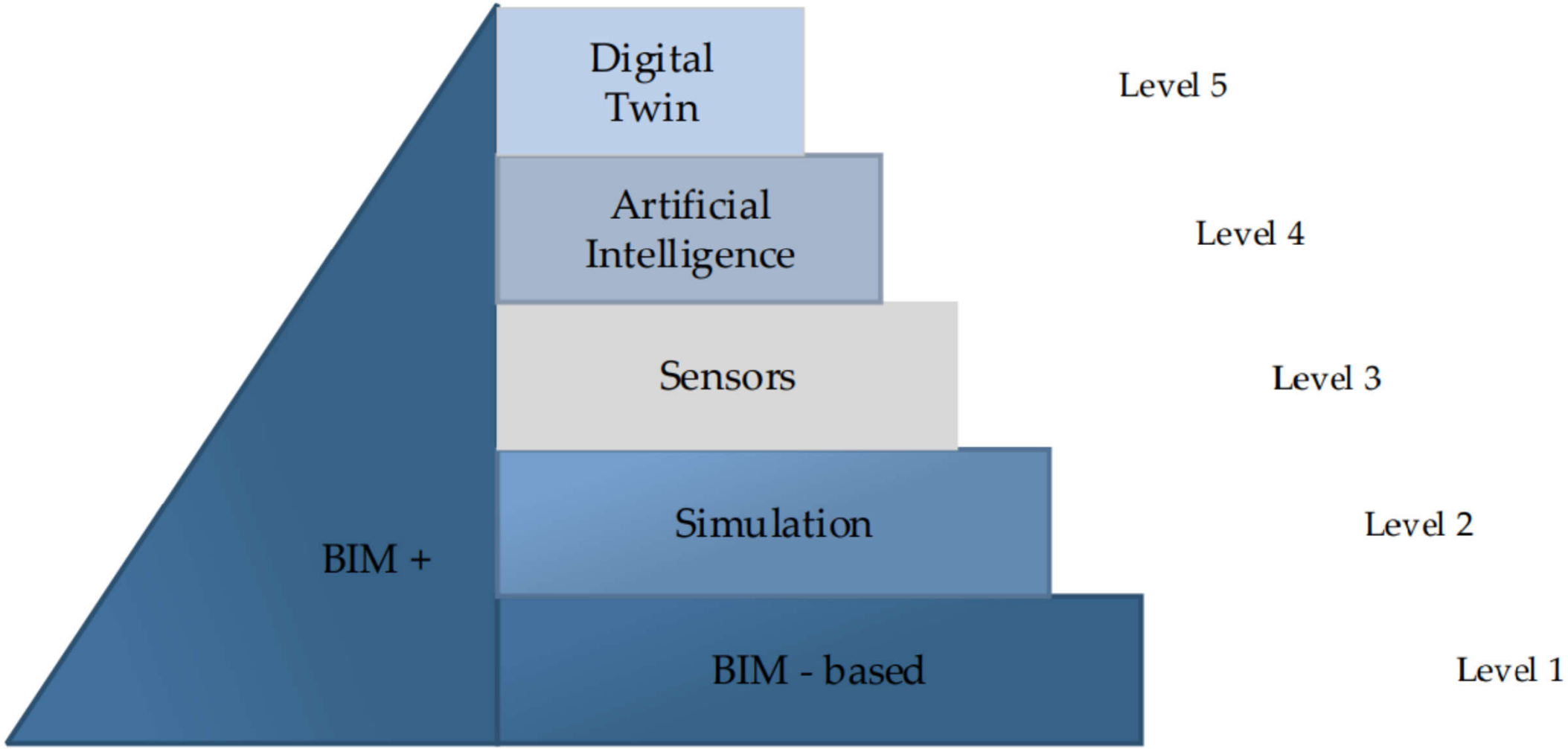
E.g. entire manufacturing process

(Source: Agnusdei G. P., Elia V. & Gnoni M. G., 2021. Is digital twin technology supporting safety management? a bibliometric and systematic review, *Applied Sciences*, 11: 2767. https://doi.org/10.3390/app11062767 and https://www.tributech.io/blog/the-4-types-of-digital-twins)

Digital twin technology

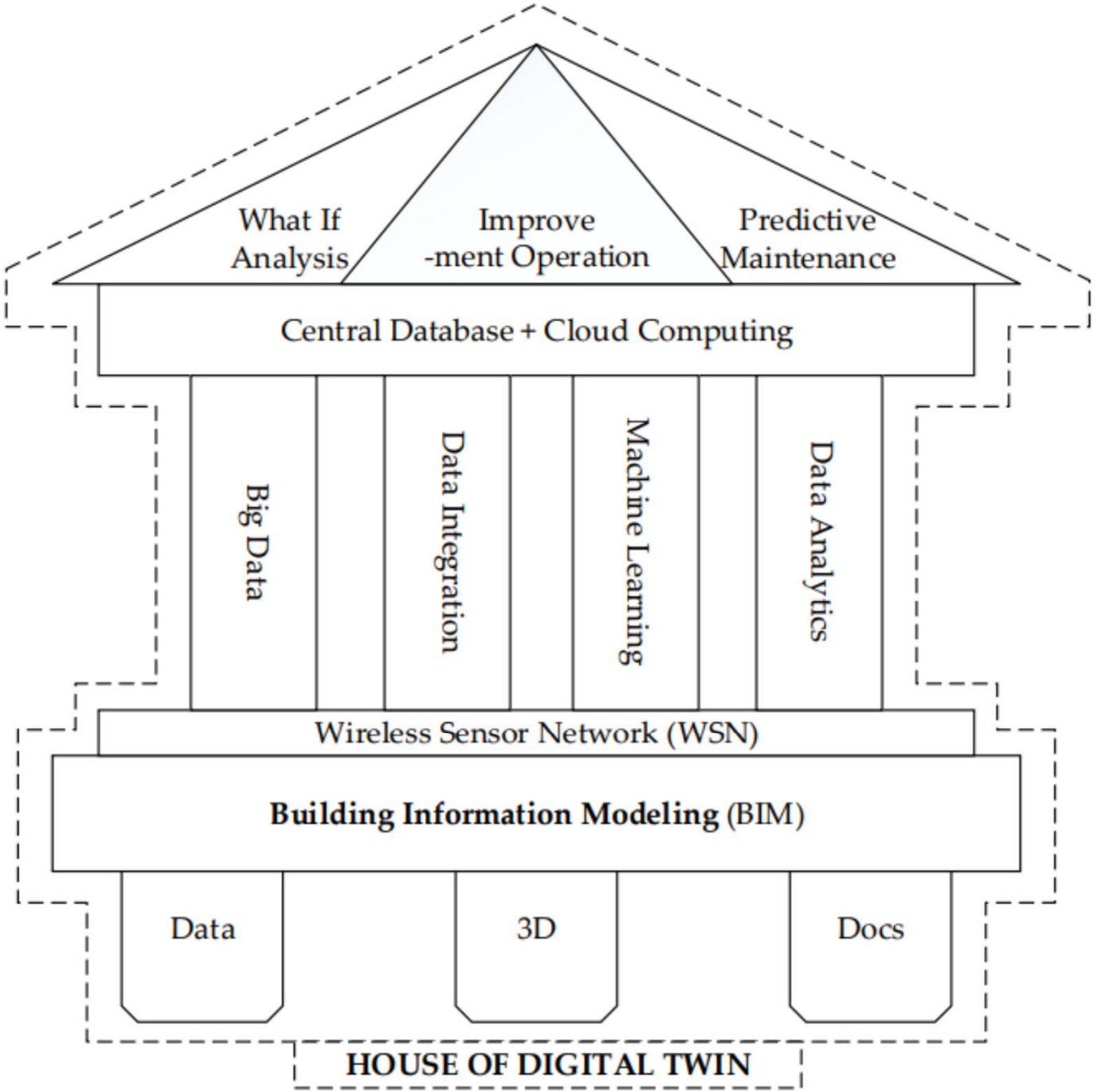
- The 5 Levels of digital twins:
  - Level 1: Descriptive Twin
    - A visual replica of a built asset
  - Level 2: Informative Twin
    - With an added layer of operational & sensory data
  - Level 3: Predictive Twin
    - Can use operational data to gain insights
  - Level 4: Comprehensive Twin
    - Simulate future scenarios & considers “what-if” questions
  - Level 5: Autonomous Twin
    - Has the ability to learn & act on behalf of users

Evolution of building information modelling (BIM) to digital twin (DT) in the built environment



(Source: Nguyen T. D. & Adhikari S., 2023. The role of BIM in integrating digital twin in building construction: a literature review, *Sustainability*, 15 (13) 10462. https://doi.org/10.3390/su151310462)

Essential components to creating a digital twin of building



(Source: Nguyen T. D. & Adhikari S., 2023. The role of BIM in integrating digital twin in building construction: a literature review, *Sustainability*, 15 (13) 10462. https://doi.org/10.3390/su151310462)

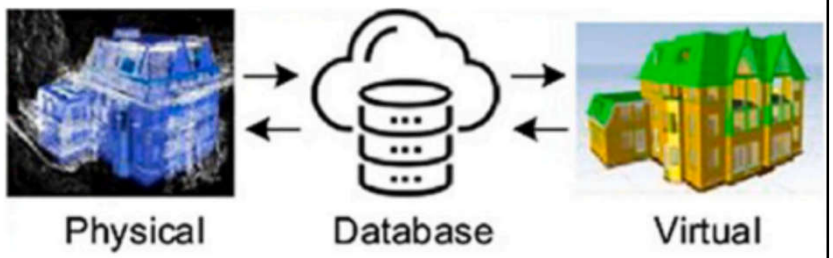
Digital twin technology

- Smart building digital twins can offer:
  - Transformative spatial awareness
  - Analyses of root causes
  - Intelligent recommendations
  - Ability to self-tune
  - Insight needed for predictive maintenance

- They are valuable at every stage of the asset value chain, including design, build, commission, operate & maintain stages

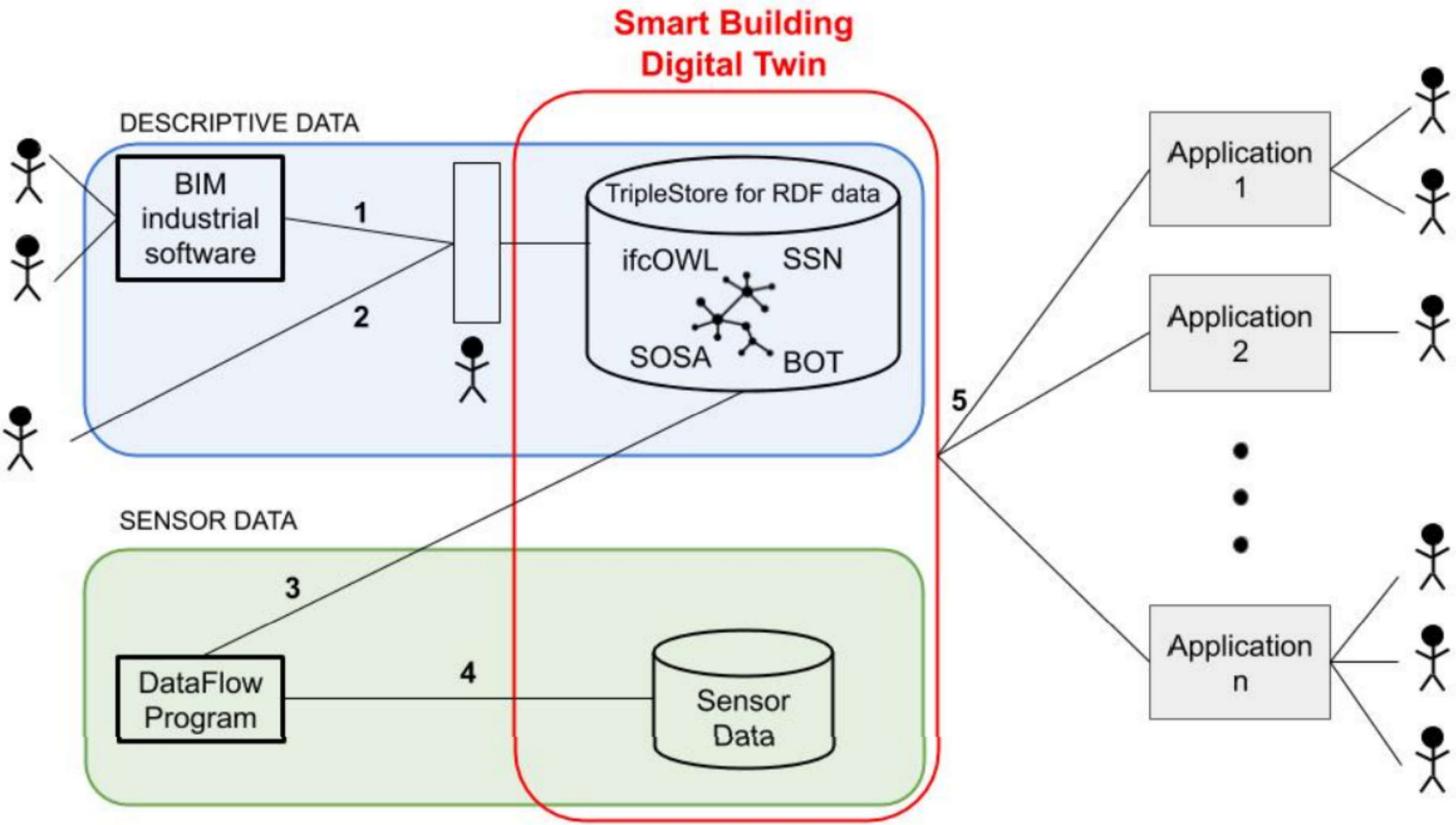
Digital twin technology

- Functions of digital twins in smart buildings:
  - 1. Simulation
    - Simulate the real via the digital



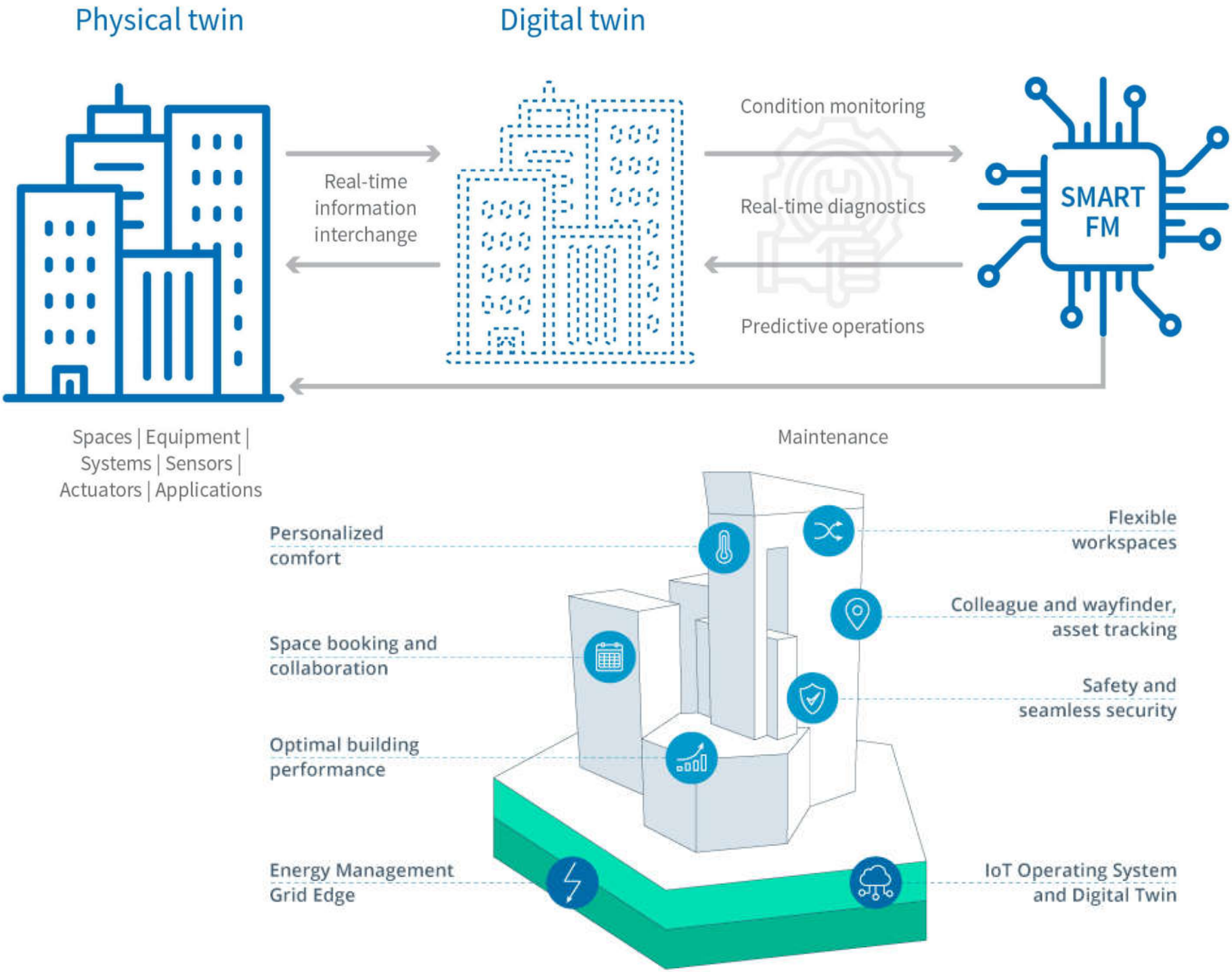
  - 2. Prediction
    - Predict possible issues, like structural & fire risk, safety hazards, conflicts, bottlenecks, etc.
  - 3. Optimization
    - Facilitate smart resource allocation, lower costs, accelerate process, raise cooperation

Basic concept of smart building digital twin



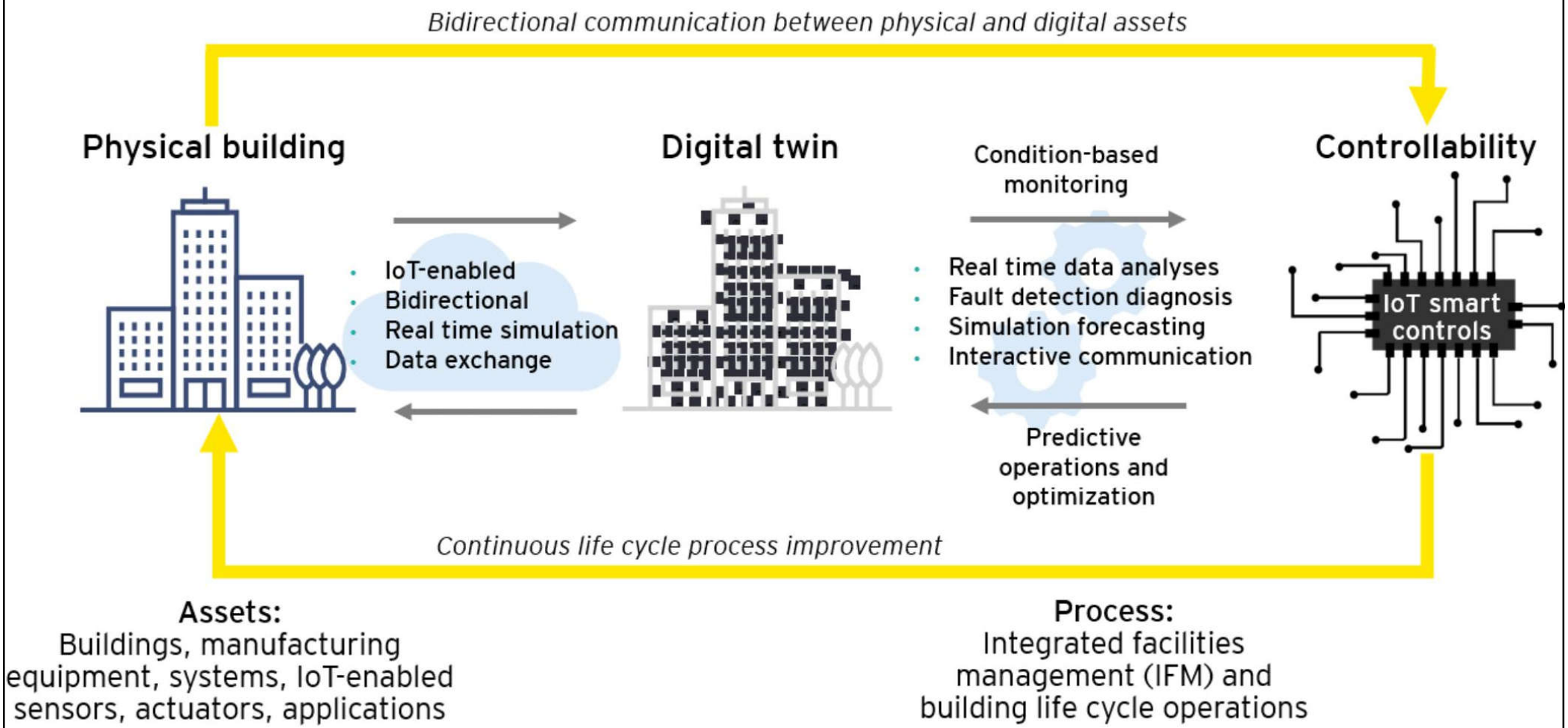
(Source: A Reference Architecture for Smart Building Digital Twin https://ceur-ws.org/Vol-2615/paper2.pdf)

Using digital twin for smart facilities management (FM)



(Source: https://intellias.com/digital-twins-in-facility-management-the-clear-path-forward-for-intelligent-buildings/)

Using digital twin & IoT for smart buildings & facilities management



Assets:
Buildings, manufacturing equipment, systems, IoT-enabled sensors, actuators, applications

Process:
Integrated facilities management (IFM) and building life cycle operations

(Source: https://nhance.ai/resource/using-iot-digital-twin-for-cost-optimization)

Further Reading

- The role of IoT in Building Automation Systems https://www.zenatix.com/the-role-of-iot-in-building-automation-systems/
- What is cloud computing? https://azure.microsoft.com/en-us/resources/cloud-computing-dictionary/what-is-cloud-computing
- What is a Smart Building Digital Twin? https://blog.thoughtwire.com/what-is-a-smart-building-digital-twin
- What Is a Digital Twin? How Intelligent Data Models Can Shape the Built World https://www.autodesk.com/design-make/articles/what-is-a-digital-twin