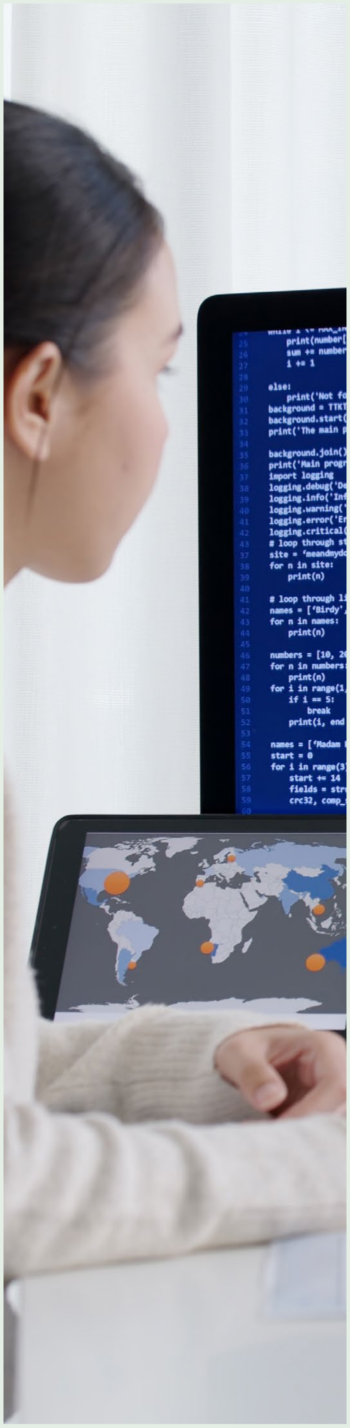
WHITE PAPER



DIGITAL TRANSFORMATION OF BUILDINGS TOWARDS MAINSTREAM SUSTAINABILITY JOURNEY

Abstract

Commercial, residential and industrial buildings are categorized amongst the most energy-intensive consumers, accounting for 40% of global energy usage, while building operations contribute to 33% of global carbon emissions. Digitalization holds a tremendous potential to mainstream sustainability in building operations and accelerate the clean energy transition by reducing energy consumption and the resulting greenhouse gas (GHG) emissions. As per the study by the International Energy Agency (IEA), digitalization in the residential and commercial building sector can reduce total energy use to around 10% by 2040. The digitalization of buildings requires synergized interplay between hardware, software and communication technologies to ensure advanced monitoring, controlling, optimizing and maintaining of building operations. Consequently, digitalization results in sustainable, maximized building energy efficiency, optimized human comfort, and increased building value. Digitalization in building operations will also result in smart energy management of building systems. Energy efficiency gains through digitalization are reported to be up to 30% of total building energy usage.

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Enabling smart energy management through digitalization can:

Improve the responsiveness of energy services.

Facilitate demand response by reducing or shedding peak loads and storing energy in response to dynamic energy prices.

Predict, measure and monitor the real-time building energy performance, allowing relevant stakeholders to prepare, plan and perform well for achieving optimized energy operations.

Despite remarkable advancements in digital technologies and related services, declining costs and easy connectivity, a large portion of the building industry relies mainly on manual operations and legacy field-level devices. Operating building systems, such as air conditioning and lighting, is based on the operator's understanding instead of defined performance indicators, leading to errors, inaccuracies, reactive response to failures, high energy wastage and poor visibility of asset/building performance.

The resulting energy-intensive and/or comfort-compromised building operations are disobliged to various self/national/international commitments such as sustainable development goals (SDG) and environmental, social, and corporate governance (ESG) goals.

This white paper aims to systematically review the technologies, solutions, and business models capable of bringing digital transformation to the operation of commercial buildings. Solutions and technologies in the market include smart and connected devices (smart thermostats, occupancy sensors, photo sensors, smart lighting), smart digital products and building automation systems. The authors aim to list the opportunities, barriers and essential requirements to facilitate the shift from conventional building operations toward sustainable and energy optimized building operations.

Innovative business models (X-as-a-Service business models) for digitalizing energy services and building operations are emerging and focus on the organization's entire value chain from energy generation to consumption. Cloud-based digital platforms are the backbone of such service-based business models. These digital platforms require the setup of multiple intelligent devices and deploy artificial intelligence (AI) and machine learning (ML) algorithms for optimized energy use in building operations. The authors aim to capture these innovative business models in building operations. Such digital solutions pave the way for enhanced energy efficiency and sustainability for future buildings. This paper presents a holistic viewpoint for shifting towards sustainable and digital building operations based on the existing research-based evidence, industrial statistics and success stories.

Digital transformation, sustainability, energy efficiency, buildings, digital technologies

INTRODUCTION

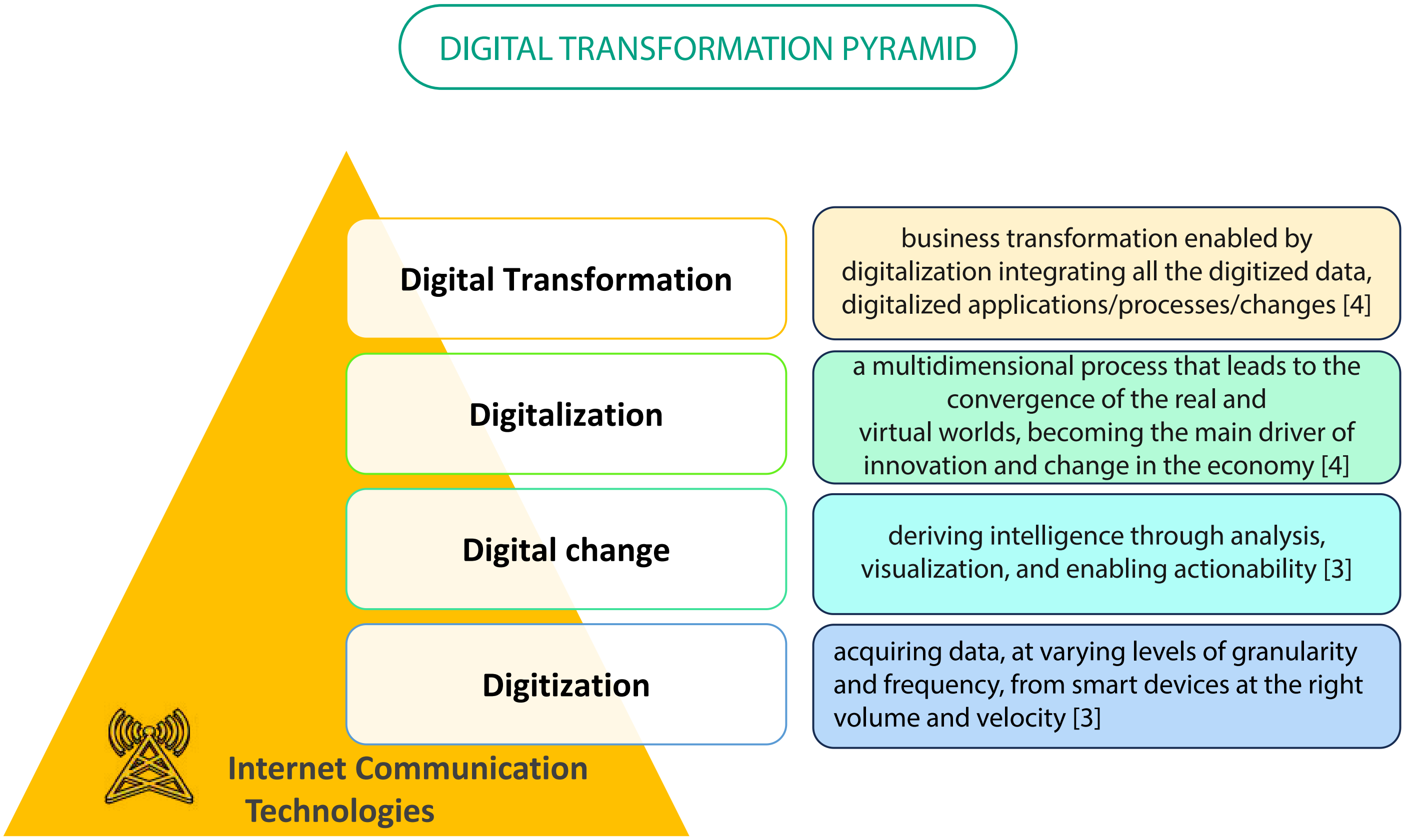
The building sector is a significant energy guzzler responsible for nearly one-third of global energy consumption and almost 40% of carbon emissions [1]. Digitalization holds tremendous potential to advance the safety, efficiency and sustainability of building energy systems worldwide. As per IEA research, digitalization in the commercial building sector can reduce energy use by up to 10% compared with the Central Scenario, which claims electricity use in buildings is set to nearly double from 11 petawatt hours (PWh) in 2014 to around 20 PWh in 2040 [2]. Cumulative energy savings of about 65 PWh calculated from 2017 to 2040 can be achieved by improving the operational efficiency of buildings.

India's building stock is tripling its energy use intensity (EUI), with commercial buildings slated to average an EUI of ~100+ kWh/sqm/year [3]. Enabling digitalization to mainstream sustainability in building operations and accelerating the clean energy transition can significantly reduce energy consumption, maximize building energy efficiency, optimize human comfort, and increase building value. Combining hardware, software, information, and communication technologies such as AI, Cloud, IoT and 5G can enable building automation, monitoring and control of operational assets to drive efficiencies across buildings, energy, water, lighting, air quality and acoustic systems through data-driven predictive analytics.

The first step towards digitally transformed building operations is digitization, i.e., creating a digital representation of physical objects or attributes using Information and Communication Technologies (ICT) and embracing digital change and mainstreaming the appropriate digital technologies to enable more connected, intelligent, efficient and sustainable building operations ultimately leading to digital business transformation.

Figure 1 shows the digital transformation pyramid to illustrate the relationship between digitization, digitalization and digital transformation. Digital transformation can be holistically achieved only if it is driven by advancements in all three stages, viz-a-viz data gathering, data analysis and physical action. The design principles for the digital transformation must be future-ready and adaptable to technology and innovation changes.

Through this white paper, the authors intend to present a holistic viewpoint of shifting towards sustainable and digital building operations based on the existing research-based evidence, industrial statistics and success stories. A unique framework has been developed to assess the digital maturity of commercial buildings. A case study is also provided to showcase the power of the framework.



DIGITAL TRANSFORMATION STAGES (adapted from [5])

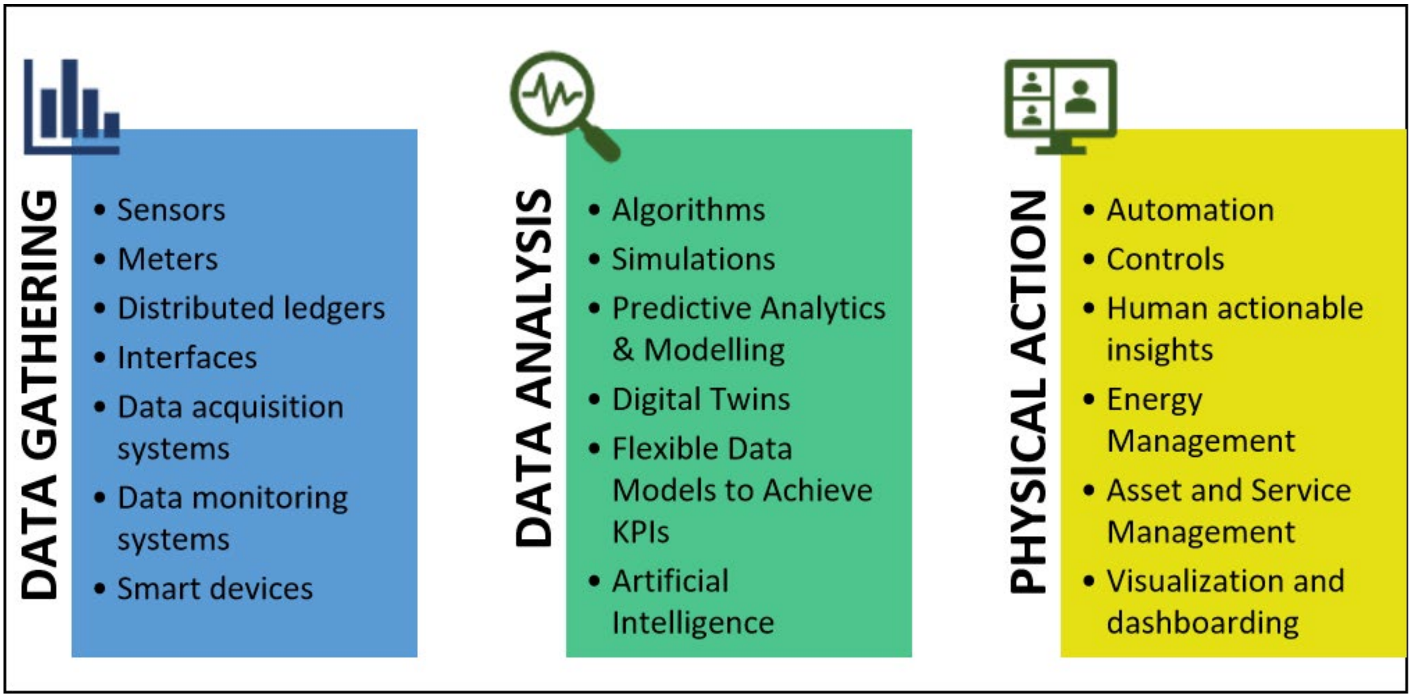


Fig. 1 Digital transformation pyramid and critical stages to achieve digital transformation.

II. CURRENT DIGITAL MATURITY LEVEL IN COMMERCIAL BUILDINGS

The commercial building sector remains one of the slowest changing industries in the world, where digitalization levels range from zero to moderate. Massive amounts of heterogeneous data are produced by disparate sources, which makes data management challenging without the requisite digital tools. Digital transformation in real estate is difficult to quantify and comprehensively measure since it has evolved into a complex and interconnected system. Maturity assessment is an approach that has seen widespread use in technology, making it an ideal candidate for assessing the digital capability of a building [6].

A. Framework for Assessing Building Digital Maturity Level

The concept of digital maturity for commercial buildings was gaining momentum but had not yet been widely standardized or universally recognized. According to a market survey, only 15% of companies implemented "systematically implemented" digital transformation [9]. Digital maturity in commercial buildings refers to the extent of technological integration and sophistication in operations and management. It involves implementing various smart technologies and data-driven systems to enhance efficiency, sustainability, occupant comfort and overall performance. Digital maturity levels in commercial buildings can vary widely depending on factors such as building age, location, industry and investment in technology. Table 1 shows the factors that can be used to assess the digital maturity of a commercial building.

DIGITAL MATURITY ASSESSMENT FACTORS

Factors	Description
Connectivity	The extent to which the building is equipped with sensors, devices and systems that are interconnected and can communicate with each other to gather and exchange data
Energy Efficiency	The adoption of energy efficient technologies and practices, including real-time energy monitoring and demand management
Environmental Sustainability	The building's effort to reduce its environmental impact by using strategies such as renewable energy integration and waste reduction.
Data Analytics	The ability to collect and analyze data from various building systems to gain insights into energy usage patterns, occupant behavior and operational efficiency.
Occupant Comfort Experience	Using technology that enhances the experience of occupants, such as mobile apps for building access, indoor navigation and personalized environmental settings (occupancy)
Maintenance Management	Using data analytics and AI to predict and prevent equipment failures, reducing downtime and maintenance costs.
Automation and Control	Integrating automation systems to optimize building operations, such as smart lighting, HVAC controls and security.
Security and Privacy	Implementing robust cyber security measures to protect the building systems and data, as well as safeguarding occupant privacy

A systematic approach will allow for a smooth and value-oriented calibrated transformation. This follows into a stepped and staged process to enable accelerated deployment and realization of benefits. Each stage is progressively more connected and integrated than its predecessor. Here are various levels of digital maturity of a building.

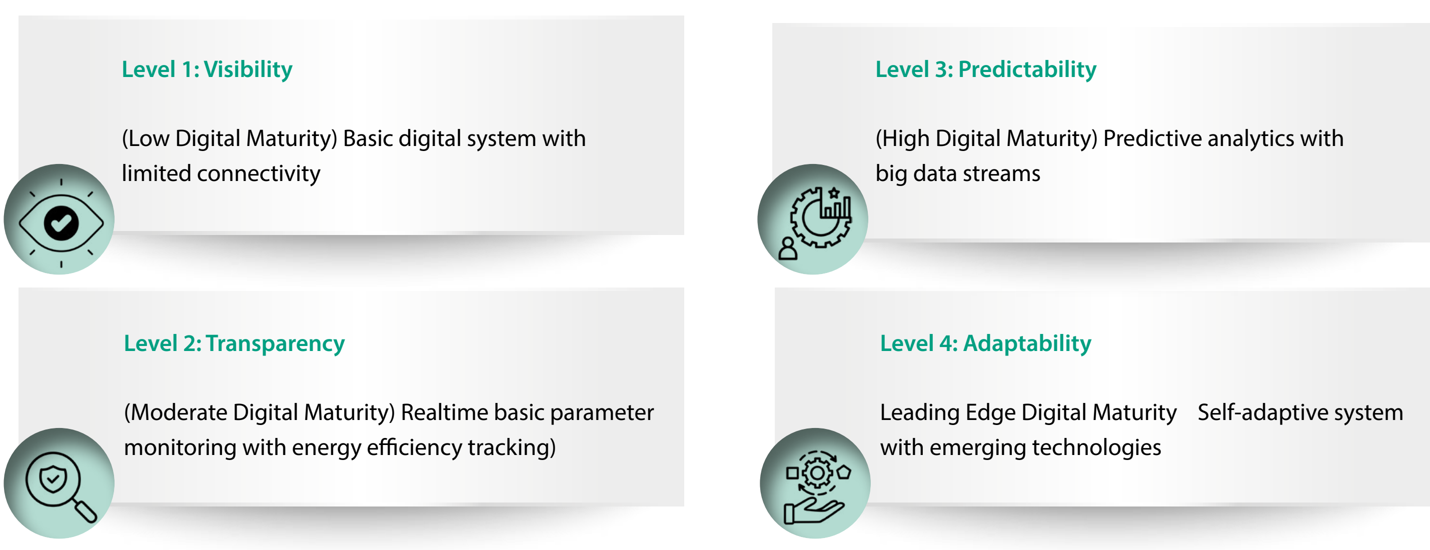


Fig. 2 Digital maturity levels of a building

Level 1 – Visibility (Low Digital Maturity):

Many older buildings or buildings in regions with limited technology adoption might have a low level of digital maturity. These buildings may have basic digital systems like basic HVAC controls, lighting, and limited connectivity. Data collection and analysis may be limited, and automation may not be widespread.

Level 2 – Transparency (Moderate Digital Maturity):

Many commercial buildings fall into this category. They have real-time data collection capability that gives visibility to their operational parameters in real-time. A 'digital shadow/twin' is implemented at this stage that has all the relevant information with adequate quality and in real-time for the decision-making purpose of improving energy efficiency, security, and comfort. These buildings may have more sensors, IoT devices, advanced HVAC controls, smart lighting, access control systems, and limited use of data analytics for optimizing operations—for example, equipment conditioning monitoring by tracking its efficiency against the industry benchmark.

Level 3 – Predictability (High Digital Maturity):

These buildings have focused more on how they are seeing the information, basically starting to analyze the results. Therefore, data analytics methods, such as detecting even or abnormal patterns in real-time in significant data streams. Abnormal patterns are then stored and categorized systematically for further analysis. The often-used term big data is not precise enough since only filtered, combined, and enriched information is helpful. The result is rather smart data than big data enriched and context-sensitive to gain knowledge about future events. Those are derived from predictions based on a comprehensive understanding of the system dynamics within the company.

Level 4 – Adaptability (Leading Edge Digital Maturity):

This level represents an extreme level of connectivity and automation of the system to react automatically to changing environmental conditions. Those environmental conditions need not be the ones that occurred in the past, but the system is trained to self-adapt and adjust to entirely new circumstances. Therefore, a deep understanding of all interdependencies within the system and all its influences is critical. They heavily leverage emerging technologies and may have AI-driven systems to predict and optimize energy consumption and maintenance schedules [8].

III. CHALLENGES AND OPPORTUNITIES

Digital technologies can accelerate sustainability in building operations depending on an organization's ability to collect, manage, analyze, apply, and report sustainability performance information. Digitalization requires infrastructure, regulation and innovation support to diminish the challenges beforehand.

CHALLENGES

Some of the critical challenges to digitalize the building operations include:

A. Poor digital infrastructure readiness may include redundant or non-existent digital technologies (sensors, meters, monitoring mechanisms etc.) required for digital building operations.

- No centralized management system: Multiple systems like BMS, EMS, PMS, and LMS work in silos with separate controllers and management software.
- Outdated digital infrastructure: These may not allow necessary upgrades, resulting in integration, performance and coverage issues. Weak or unreliable connectivity disrupts communication, hindering the transmission of metering data and interrupting online payments and electricity-trading platforms.
- Sub-par availability of real-time data: Data does not flow to a centralized location and is on different networks. As a result, there is a significant time spent feeding the data to analyze, report generation and benchmarking to evaluate energy efficiency.
- Inefficient and unreliable electricity infrastructure: Real-time digital communication also depends on an efficient and reliable electricity infrastructure.

B. Network setups inhibit cross-system optimization strategies:

Lower-level field devices and equipment like sensors and energy meters communicate with systems using standard protocols like BACnet/OPC/Modbus/IP. The network policy may sometimes restrict data sharing inside and outside the network. This leads to less visibility for operators and stakeholders and limits the execution of cross-system optimization strategies.

C. Low awareness

of benefits to various stakeholders, particularly end users: Greater effort is needed to communicate the benefits of digitalization to end users in the form of improved comfort and cost savings. Building owners and occupants may not trust the technology to reduce energy consumption without compromising energy services and comfort.

D. Standards for connected devices:

Policymakers and companies must ensure that devices can provide and receive information using open source or compatible software to facilitate technology interoperability. Common technical standards for connected devices will help ensure interoperability at different levels (e.g., with other devices, building management systems, and the grid). Standards could also help ensure user-friendliness and product operability; design, interface and ergonomics can influence how well the devices are used and the energy that can be saved.

OPPORTUNITIES

Digitalizing building operations can offer various opportunities to stakeholders, such as:

A. Visibility: Accessibility to real-time building operations data offers complete visibility into operational parameters and performance. Digital technology solutions, including smart devices, sensors, digital energy meters, flow meters and energy/building management systems, can capture data from assets, systems and equipment. Creating a digital twin of the building system can produce relevant information of advanced quality for real-time decision-making. Some use cases include energy data visualization, facility asset management, and facility and occupancy management.

B. Transparency: With the relevant data, facilities can elevate transparency, which helps derive insights. Information and operational transparency at all levels of the facility provide greater perspective to the stakeholders on resource optimization, energy end use, sustainability maturity, ESG initiatives, awareness and many more aspects related to building operations. It is a prerequisite to understanding current performance and spotting new opportunities.

C. Predictability: Data collected on key performance indicators (KPIs) of buildings, systems and equipment helps understand their operational and performance characteristics. Any significant deviation or abnormal patterns in the historical data can be stored, scrutinized and categorized systematically for further analysis. Big data is not precise until processed into "smart" data, which can be used to schedule building operations. This is achieved by extracting the best relevant information through due diligence, mathematical operations and analytical thinking to predict future events such as predictive maintenance, fault detection and diagnostics, and energy management. For example, predictive asset analysis can be utilized in various ways, including root cause analysis for failure or fault detection, energy demand response management, renewable energy generation forecasting and dynamic energy management.

D. Adaptability: Adaptability in digital building operations refers to an extreme level of automation and connectivity of the building systems to react automatically to changing environmental conditions and building operations characteristics such as occupancy, space management and space function.

E. Human-centric, sustainability and resiliency: Industry 5.0 emphasizes the need to regularly accommodate the interaction, engagement and collaboration between machines and humans. Human-centric building operations exhibiting an advanced degree of sustainability and resiliency can be mainstreamed through digital technologies. Digital building operations can disclose, decide, and achieve sustainability and ESG goals and resilience through data-driven practices and evidence-based decision-making.

IV. REVIEW OF LATEST DIGITAL TECHNOLOGIES AND BUSINESS MODELS

Digital transformation increasingly turns into a game-changer for the building industry. Digital technologies first appeared as basic software or 'the internet.' This first wave of digital technologies allowed for simple levels of automation, analytics and digital communication that primarily improved process efficiency. In the second wave, digital technologies such as Big Data analytics, cloud computing, Artificial Intelligence (AI), or the Internet-of-Things (IoT) were adopted across the building industry and customized to the use cases of the industry. The digital building technologies that are emerging in the industry are broadly categorized as:

A. Software-based complementary technologies are standalone software solutions without direct link to the physical environment. It accounts for the highest maturity level among all digital building technologies and has relatively low technological complexity. These technologies are task-specific and, therefore, rarely require substantive changes to the overall organizational structures or processes. Examples: computer-aided design (CAD), building performance simulation, logistic management software, and VR in design and planning.

B. Software-based platform technologies can integrate multiple complementary technologies via shared databases and standard interfaces. They primarily appear as project management platforms (e.g., BIM). BIMs create digital twins of buildings throughout their lifecycle. Through improvements in transparency, these technologies also increase efficiency and planning reliability, potentially reducing costs and delays in building projects. Examples include predictive maintenance, RFID tracking devices, 3D printing, onsite drones and robotics, and augmented reality (AR) in operations.

C. Cyber-physical complementary technologies are standalone devices that carry out specific tasks by either using digital data as input to execute a physical task or by generating digital data as output of a physical environment. Cyber-physical technologies, primarily related to robotics, can simultaneously perform both tasks. Examples: digital documentation, enterprise-resource planning (ERP), building information modeling (BIM) and blockchain in the project documentation.

D. Cyber-physical platform technologies are integrated systems that connect an ecosystem of complementary technologies that may interact with each other and be holistically controlled by users. These technologies can facilitate operations and maintenance and help identify energy saving potential — for example, building automation, cloud-based logistic platforms, smart building systems, and automated building condition analysis.

Digital building technologies can potentially change the industry towards a more sustainable built environment. Companies are already experimenting with new business models. Technology developers are looking to shift from merely selling a product to acquiring subsequent services using leasing, performance-based contracts or sharing models to overcome potential investment requirements [9].

BUSINESS MODELS

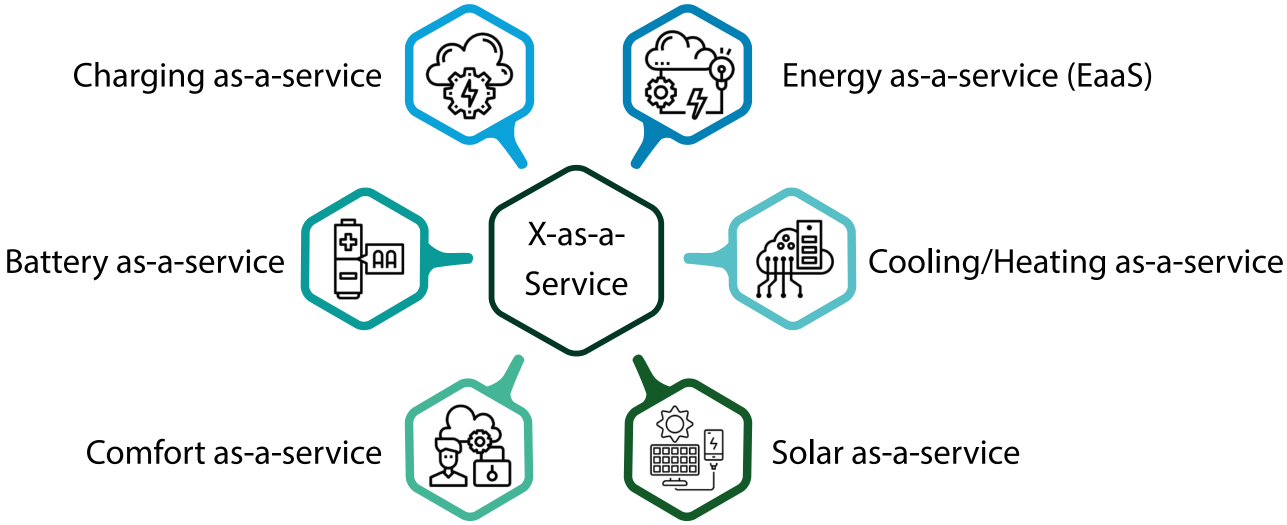
Innovative service-based business models that build revenue mainly from reducing the operational costs of the facilities by mainstreaming renewable energy integration, energy efficiency related upgrades, retrofits and installations are revolutionizing the digital landscape of building industry . This section discusses various business models followed in the building energy sector.

Energy performance contracting (EPC): EPC is a conventional financial mechanism constituting a partnership between a facility owner and an energy service company (ESCO). More than 100 companies in India are enrolled with the Bureau of Energy Efficiency (BEE) as Energy Service Companies (ESCO). They are offering a turnkey package of energy efficiency services, including retrofitting, equipment upgrades, and digital and non-digital solutions by demonstrating innovative business models such as energy efficiency as-a-service, cooling as-a-service etc. ESCO model implements energy efficiency improvement projects by carrying out Energy Audits, Feasibility Studies, Financing Options, Performance Contracting, Project Engineering, Implementation and Measurement & Verification (M&V) and Demand Side Management. The shared savings and guaranteed savings are two different business models under EPC. However, despite the availability of various players offering multiple energy services, there is an absence of an integrated end-to-end offering. However, innovative business models are emerging with increasing advancements in digital technologies.

Digital business models: Digital business models are software-driven models that support deploying innovative technologies and creating new revenue streams. Access to more granular data, combined with advanced analytics capability, allows digitally enabled companies to quantify their solutions' benefits to customers more accurately. This can also help speed the development of new products and services. Digital tools and platforms can ease and accelerate the energy transition by facilitating efficiency and demand-side flexibility. At the same time, digitalization creates new business opportunities and revenue streams for energy service providers while helping consumers better understand their energy use and lower their bills.

In recent decades, **service-based business models** have gained popularity across various traditionally product-based industries. The model typically involves a subscription-based service where the customer can enjoy the benefits of a product without purchasing it outright or directly managing its use.

Software-as-a-service (SaaS) is a software-driven digital business model that relies on **licenses or subscriptions** instead of investing upfront in the software itself. SaaS can enhance grid planning and dynamically monitor assets. Furthermore, the inherent flexibility of SaaS facilitates upgrades or other system changes as technologies evolve. A few examples include:

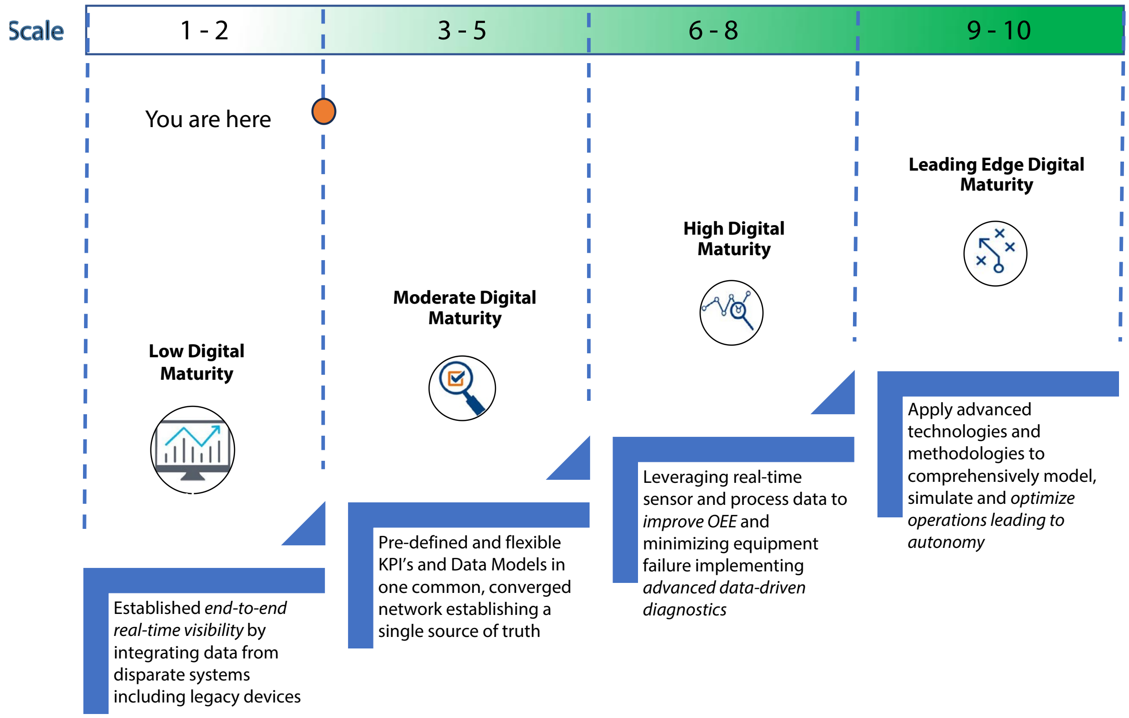


EaaS as a business model spans all three domains of energy and sustainability vis-à-vis the economy, the environment, and the social. It is the most exercised business model in the energy sector. While it looks like a power purchase agreement from a sustainability and renewable standpoint, it can be a shared savings agreement from the energy supply side. With energy efficiency being a focus on the energy demand side, it converts a traditional CAPEX model into an OPEX model with performance linked commitment behind it. Various tech startups such as Zenatix, ZedBee, Greenovative and many others are deploying AI, ML and IoT techniques in the commercial and industrial solar (C&I) sector to create a digitally connected infrastructure that is smart, reliable, and energy efficient. Renewable energy companies like ReNew Power enable clean energy transition in the C&I sector through hassle-free switch to renewable energy. Instruments such as On-site Power Purchase Agreements (PPA), Virtual Power Purchase Agreements (VPPA) and international renewable energy certificates (I-REC) are widely used to facilitate a round-the-clock supply of clean energy. AI-enabled grid management and load forecasting are also emerging as an innovative offering from some renewable energy companies.

Commercial and industrial customers increasingly opt for pay-for-performance contracts with EaaS companies to retrofit their premises. Under these arrangements, they pay a contracted rate based on energy savings verified, for example, through smart metering. This approach is compatible with efforts by national regulators to introduce more ambitious energy efficiency requirements and creates incentives for entrepreneurs to introduce new and more nimble business approaches that better meet the needs of end-users.

V. CASE STUDY: SYSTEMATIC FRAMEWORK FOR BUILDING DIGITAL TRANSFORMATION

Infosys helped a UK-based financial service company with digital transformation to modernize its prime office space globally to reduce operative costs using a data-driven approach. The company had key challenges like manual KPI processing, unavailability of central dashboards, absence of analytical tools, manual work order management, no condition-based operations, and lack of centralized management system and network setups inhibiting cross-system optimization strategies. Infosys brought systematic digital transformation through a digital maturity assessment model for the smart space application. It defined a building automation maturity scale of 1 to 10 and rated different buildings according to the scale definition.



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VI. COMMON QUESTIONS DURING DIGITAL TRANSFORMATIONS

A. What are the infrastructure readiness measures required for digital transformation?

Digital transformation can impact the functionality of building automation systems. Hence, it is essential to address all critical, high-priority upgrades and consider the following to ensure complete smart building digital transformation:

- Open software protocols - allow integration with all third-party building automation systems to maximize efficiency and ease of installation.
- Installation of protocol converters – for integrating non-standard protocol third-party system
- A flexible enterprise level software platform that can consume billions of data points—from a single building to an entire enterprise—enables cost efficiency and better building management as an organization grows.
- Integration of non-BMS systems, such as access control, security and surveillance, and ERP, to enterprise level software
- A cloud-based SaaS data analytics solution is a cost-effective alternative to a custom solution.

B. What is the role of the latest technologies in digital transformation?

Various technologies mentioned in the previous section are currently penetrating the industry. Among those, digital twins and AI/ML are widely considered technologies in digital transformation.

Digital Twin is a virtual model/representation of any physical domain object/asset. There are four critical components of the digital twin -data (such as building systems, external data and blueprint data), KPIs (such as efficiency, emissions, net operating income and safety indicators), context (such as occupant behavior, system/device behavior and workflows), and reasoning (such as AI/ML models or non-linear rules). When these four components are mapped meaningfully, an organization has a true digital twin.

AI and ML help predict issues and make decisions on treatment action. ML helps define effective maintenance strategies. To enable the above, the pre-requisites are:

- real-time and historical data of equipment/sensors and systems,
- external data that directly or indirectly influences the smart building, like weather and season
- configuration information on the buildings and equipment
- Data across all the systems and processes are integrated into a common platform [7].

VII. CONCLUSION

Digitally transformed buildings look very different from the leading buildings of ten years ago. Advances in data and analytics, AI, and ML and the array of technology vendors in the market imply that manufacturers can choose from hundreds of potential technology solutions to improve their working methods. Successful and right implementation of solutions described in Section 4.0 delivers attractive returns through digital transformation across a wide range of sectors, as referred to in [10].

TABLE II

Value Potential of Digital Transformation

Benefits	Range
Inventory-holding cost reduction	15–20%
Energy Efficiency increase	10–30%
Employee productivity increase	15–30%
Forecasting accuracy improvement	85%
Equipment downtime reduction	30–50%
Cost-of-quality improvement	10-20%

Also, digital transformation leads to more empowered decision-making, new opportunities for upskilling, reskilling, and cross-functional collaboration, better talent attraction and retention and improved workplace safety and employee satisfaction.

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