Chapter 14
X-IoT: Architecture and Use Cases for an IoT Platform in the Area of Smart Cities

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14.1 Introduction

Throughout history, cities have defined the way societies and citizens live, interact, work, create, and consume resources. Large, dense, highly organized, and self-governing communities, cities have emerged thousands of years ago and have been gaining in importance ever since. As depicted by Jeremy Rifkin in "The Third Industrial Revolution: How Lateral Power is Transforming Energy, the Economy, and the World," cities now stand on the brink of a new historical transformation, driven by digital tools and channels [1]. Today, cities are an integral part of our connected

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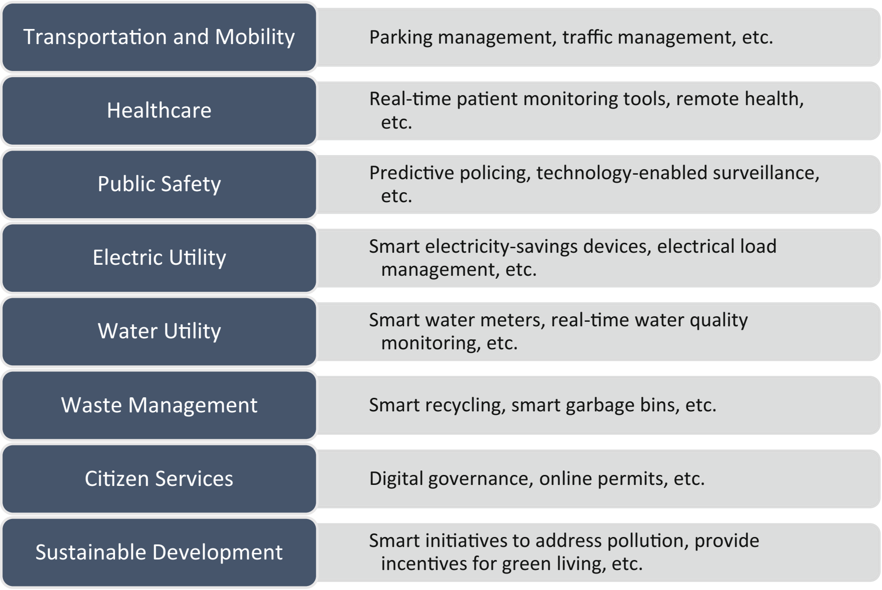
world, housing more than half of the world's population and increasingly adopting innovative technologies to improve the quality, efficiency, and competitiveness of urban environments. Remodeling the elements of city life and advancing qualities of cities for learning, innovation, doing business, and creating jobs are crucial qualities for location competitiveness, growth, and investments. This makes the European Union, for example, pay particular attention to making urban areas smarter and more sustainable [2, 3]. This is the dawn of the new era of smart cities, as defined by the United Nations Economic Commission for Europe: *"A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness while ensuring that it meets the needs of present and future generations with respect to economic, social, cultural and environmental aspects"* [4].

Smart city definitions from the existing academic literature emphasize different facets of the concept: improving people's quality of life, enhancing interactions among businesses and citizens, improving government and participation, and optimizing transportation networks and resource utilization [5]. Common among the variety of definitions of a smart city are the concepts of data-driven improvements in living standards, integrated information and systems, better awareness, and maximization of sustainability and environmental conservation [6]. The practitioner perspectives on smart cities contain similar definitions—with particular emphasis on improving the social, environmental, and infrastructure aspects of a city, including citizen services, public security, healthcare, transportation and mobility, electric, water and waste management, and sustainable development [2, 3, 7], as Fig. 14.1 indicates. The development of smart city solutions is supported by the emergence of new ICTs including, among others, the Internet of Things (IoT) for data collection through sensors, cloud computing for storing and processing big amounts of data, and artificial intelligence (AI) for deriving insights from data [5, 8, 9].

In this chapter, we discuss smart city problems and solutions as well as technical implementation challenges and best practices using insights from the practical work several of the chapter co-authors are involved in every day as well as from relevant academic literature. We then propose that a general-purpose practitioner-developed IoT ecosystem solution, X-IoT [11], can be used to support smart city development.

This chapter is organized as follows. Section 14.2 explains how smart city IoT data can be captured and processed using a data and AI platform. Section 14.3 describes typical technological challenges and best practices for implementing smart city solutions, and describes a reference architecture for a smart city platform. Finally, Section 14.4 provides conclusions and future research directions.



Transportation and Mobility	Parking management, traffic management, etc.
Healthcare	Real-time patient monitoring tools, remote health, etc.
Public Safety	Predictive policing, technology-enabled surveillance, etc.
Electric Utility	Smart electricity-savings devices, electrical load management, etc.
Water Utility	Smart water meters, real-time water quality monitoring, etc.
Waste Management	Smart recycling, smart garbage bins, etc.
Citizen Services	Digital governance, online permits, etc.
Sustainable Development	Smart initiatives to address pollution, provide incentives for green living, etc.

Fig. 14.1 Smart city initiatives (source: [7, 10])

14.2 Role of Data and AI Platform in Collecting IoT Information in Smart Cities

14.2.1 Literature Overview

Smart city solutions are built using a variety of technologies [8, 9]. A keyword analysis of over 3500 articles on smart cities published between 1996 and 2018 reveals that IoT is the most central concept in the literature, followed by big data, analytics, security, privacy, as well as cloud computing, among others [12]. Sensors and sensor networks, as well as other smart objects connected through IoT, help collect a variety of data from their environment. Motion, position, and parameters such as temperature, pressure, light, sound, speed, and many others can monitor buildings, vehicles and transportation networks, resource consumption and its environmental impacts, and human behavior and health [13, 14]. Edge computing enables processing of contextually rich local data in near real time. Cloud computing (together with related technologies such as fog computing or cloudlets) provides the on-demand infrastructure to analyze data and process transactions. And AI and related analytics technologies—especially those designed to handle big data volumes—extract patterns and make recommendations for improving the operational efficiency of smart cities as well as the effectiveness of offering their services to citizens [8, 9, 15]. Open data portals allow smart cities to share data with businesses and citizens to support problem resolution [13, 16]. Marketplaces where data and services can be traded can further ensure that the smart city services are useful, of high quality and competitively priced [8]. Geospatial technology (GPS, geographical information systems, remote sensing, and Internet mapping) can support collaboration and coordination among different smart city elements [9]. The data can be secured and authenticated with customized security mechanisms or even with blockchain technology [9].

Data enables cities to become smart—or, in other words, to be ubiquitous, digital, information and knowledge driven, and intelligent [17]. Smart cities create big data—data that is large in volume, high in variety, and fast moving and growing. Despite its complexity, proper harnessing of this big data, however, can improve city governance—by increasing efficiency and transparency, reducing hassles for citizens, increasing timeliness, and decreasing errors and costs, and even leading to sustainable economic development [5, 17].

One of the most promising technologies for smart city solutions is AI. In a recent literature review of 79 AI in smart city articles, the authors found that the numbers of academic publications in this area are increasing exponentially, with healthcare, transportation, and resource and utility management applications being the most popular [18]. A similar systematic review of 39 data mining and machine learning (ML) papers identified predictive analytics as the most common technique and the smart mobility and smart environment areas as the most popular [19]. Emerging AI techniques such as deep learning can be used for extracting insights from data in a variety of areas such as urban modeling, infrastructure management, and governance, among others [20].

According to these studies, AI can support and improve decision-making based on accurate and detailed data, provide insights into complex and often time-sensitive problems, improve monitoring levels as well as improve economic outcomes and relationships with citizens, and reduce the city's environmental impact [18–20]. In smart city contexts, data also comes from multiple sources in heterogeneous formats [21], and AI can help make sense of this complexity and derive new insights. For example, key performance indicators from multiple governmental agencies can be used to predict variables of interest, such as crime, which in turn can lead to inter-agency collaboration for a coordinated response that leads to better efficiency and optimal services in multiple areas [22].

However, AI technology also presents a number of challenges, including barriers to data collection, poor design, complexity, inflexibility, lack of explanations, and most importantly ethics (both in terms of design and use) [18]. There is a need to develop new approaches that enable both big and fast data analytics and to design smart devices capable of running complex AI algorithms at the edge [23]. Security and privacy also remain ongoing concerns, especially for mobile devices used to interact with a smart city infrastructure, the infrastructure itself (the collection of specialized hardware and software that collect and process data), and its power grid, as well as for specific applications such as healthcare which are subject to additional security and privacy rules [6, 23, 24].

To capture the complexity of deploying technology in cities, researchers have proposed using systems theory to build smart city models. Some models depict a smart city environment consisting of various systems focused on transportation, energy, etc., which are in turn composed of networked sub-systems (such as vehicles and infrastructure for transportation, or power plants and electric grids for energy, etc.). This allows for simulating the behavior of the systems and sub-systems in light of varying smart city strategies and selecting the best configurations and technologies for actual implementation [25]. Other models view smart city development from the lens of (a) inputs (resources) such as human resources and entrepreneurship, data, ICT infrastructure, and financial resources; (b) transformational processes such as management of data, infrastructure, knowledge, innovation, and financial assets and governance and leadership through relationships among governmental entities, coordination among actors, and leadership capabilities; and c) outputs, such as applications developed (mobility, energy, healthcare, etc.) and externalities (environmental sustainability, economic sustainability, and quality of life, among others) [12].

14.2.2 Practitioner Context

A smart city with a population of one million inhabitants may generate 200 million gigabytes of data every day [26] originating from different smart city initiatives: healthcare, public security, energy, water and waste services, as well as transport and weather forecasting and monitoring. The data is generated in structured and unstructured formats, from sources ranging from IoT sensors to surveillance cameras to patients' data in natural text or voice.

Analytics applications that create value for smart city citizens require data ingestion, data cleaning, data modeling, and often combining data from different domains (i.e., electricity demand, generation capacity, and weather conditions in order to perform electric power grid balancing). Data should be securely transmitted and stored. The solution should allow for possible interruption in network connectivity (queuing of messages), data retrieval by analytics applications, and data audits or backtracking. Given the size and the speed of the data, as well as the need to apply complex AI and ML models, smart cities need to make use of cloud computing and storage for data processing [5, 8, 9]. Based on Capgemini internal research, the path from data source to analytics insights for the citizens, as reflected in practice, is depicted in Fig. 14.2.

In each step of this journey, the data should be secure, accessible, and trustworthy, allowing for transformation, data quality checks, data pipeline, and analytics orchestration. The best practices of implementing the data journey in real-world projects [27, 28] suggest that this is possible by deploying a next-gen data and an AI platform based on a reference architecture with five main layers, all underpinned by secure data:

1. "Platform foundation: hybrid cloud platform implementation, cloud strategy and end-to-end provisioning, and platform infrastructure management

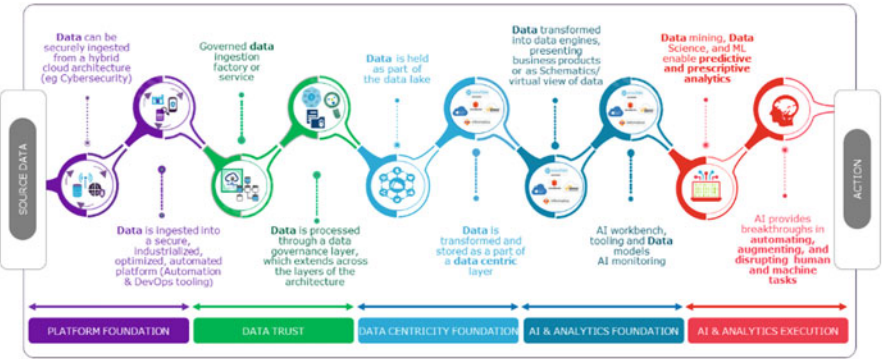


Fig. 14.2 The journey from data acquisition to action (source: [27])

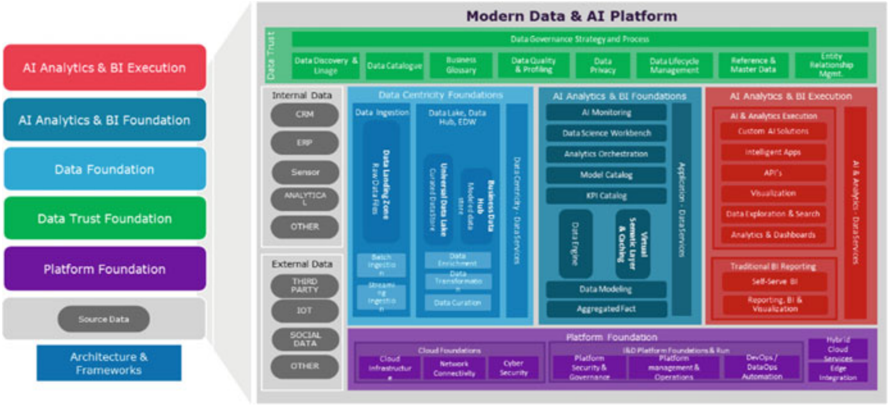


Fig. 14.3 Five-color structured architecture for modern enterprise data and AI platform (source: Capgemini)

2. Data trust: accelerators, frameworks, and services to define and implement data life cycle management.
3. Data-centricity foundation: capabilities for data preparation, transformation, and storage.
4. AI and analytics foundation: capabilities to design and deploy AI/ML services supported by the data-centricity foundation.
5. AI and analytics execution: capabilities to deploy and execute custom AI and BI applications in production at scale [28].

This modern data and AI platform emerging from Capgemini research, depicted in Fig. 14.3, allows for data centricity, bringing together technology, people, and processes to govern, utilize, and extract value from the omni-structured smart city data. In future sections, we will take a deep dive into the business, analytics, and technological aspects of the platform implementation, giving priority to the most important data generated in the smart city environment: IoT data from sensors. However, before considering the technological aspects of the platform architecture, we must first understand the business applications of a smart city and the corresponding data processing requirements, as described in the following sections.

14.2.3 Safe, Healthy, and Livable: Smart City Solutions and Problems They Solve

Smart city designs vary depending on the needs of a city's inhabitants and the city's priorities. These needs and priorities result in solutions for emergency services (medical, police, and firefighting), healthcare, public transportation, public asset management (such as roads, parks, museums, etc.), waste management, public administration (inclusive of permits and licenses), and utility networks (such as water, gas, and electricity supply networks), as well as smart city initiatives for sustainable development [7]. Some solutions could be built from the perspective of a green smart city in order to minimize negative environmental impacts such as pollution or wasted resources. Other solutions could emphasize seamless mobility and minimize traffic or transportation availability issues [10]. And other solutions could focus on ensuring citizen's safety and minimizing their exposure to and fear of crimes. Surveys conducted by the Capgemini Research Institute indicate that city dwellers have several main concerns: cultural and personal, financial, health and sustainability, as well as infrastructural issues, as depicted in Fig. 14.4 [7, 10]. Not surprisingly, healthcare, public security, utilities (electric, water), waste management, transportation, citizen services, and sustainable development are the areas where smart solutions are being developed to address citizen needs [5, 7, 10, 18, 19].

At the center of this journey to build a smart urban environment lies one very important lever to activate: data. Just as in other fields of digitized services, the ability of cities to make effective use of their data and to build themselves as a data-powered structure (cf. Figs. 14.2 and 14.3) is the key to the promises of smart cities—whether at an airport, a hospital, or the city center. Once the smart city has determined its data governance and organized its data space, AI and analytics can be fostered in various ways. Depending on the needs of a particular city, the following four fields for operationalized AI can be established:

1. Intelligently automating the city's processes: With intelligent process automation and an end-to-end view on case management, the city's most trivial processes can be automated, giving citizens and city officials more time with more complex tasks.
2. Augmenting the interaction with the city's actors: AI can enhance citizens' interactions with security authorities (for reporting and resolution of incidents),

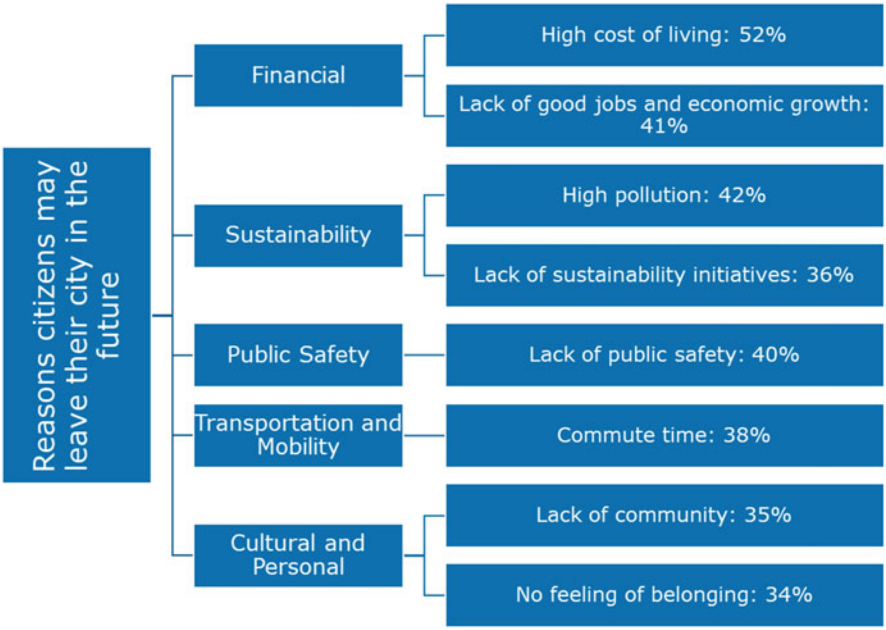


Fig. 14.4 Reasons for citizen to leave their city (source: [7, 10])

public servants for administrative queries, or others during daily life activities in the city.

3. Detecting anomalies: A city can leverage AI and analytics to more quickly detect situations of danger with its infrastructure, public safety, and real-time events.
4. Helping in the decision-making process: With its ability to identify patterns, predict occurrences, and prescript changes, AI technology can be an enabler for better informed decisions at the city level (Table 14.1).

14.2.4 Real-Life Implementation Examples

When Dijon announced its strategy “OnDijon” in 2018, the famous newspaper Le Monde described the city as the first smart city in France [29]. Since then, the city has lived up to this label and deployed an ambitious plan built on the goal to go from six separate data centers to only one, the central command center. The Dijon smart city initiative relied on the federation (or integration) of actors (industry, citizens, and regional authorities) and data (such as water, electricity, and mobility data among others) to reflect the real-world environment. The overall approach was based on a data platform and use cases à la carte: streetlights, traffic lights, parking spots, CCTV cameras, buildings, and air quality monitoring systems were

Table 14.1 Four fields for operationalized AI for different city needs

AI fields for a more . . .	Greener city	Safer city	Inclusive city	Seamless city
Intelligently automating administration processes	Automated energy utilization alerts	Automated public safety alerts	Customized processes for different citizens' needs	Public transport schedules and real-time updates
Augmented interaction	Chatbot for queries on air quality monitoring	Mobile app for safety issues	Multi-language communication/translation	Tourist app about tailor-made flow journey
Detecting anomalies	Garbage detection	Acoustic gunshot detection	Detecting inequalities in access to/utilization of city services	Detection of fallen trees on trackways
Helping decision-making process	Optimized traffic flow	Predictive policing	Optimized urban planning for disabled people	"Best way to work"—Driving app based on personal preferences and real-time traffic

all digitized. Additionally, a mobile app was developed for citizen communication (incidents, commuting to work). As a result, OnDijon created energy savings of 65% and infrastructure maintenance cost savings of 50% [30, 31].

From the perspective of a safe smart city, Traffic Agent [32] showcases the ability to empower the most vulnerable part of the population, such as children, and to turn them into connected and protected smart citizens. Traffic Agent is an app in Norway which enables primary school children to map their route to school in order to register positive and negative spots along the way. Thanks to the kids' digital feedback, the city receives the necessary intelligence to plan for further measures regarding mobility and safety.

From the perspective of green smart cities, Singapore has leveraged IoT and sensing to transform the Tengah forest territory [33], enabling smart lighting and helping generate energy savings of more than 40%. Working with an integrated environmental modeler and creating an insight-driven platform for urban planning, the Singapore Government's Housing and Development Board implemented its green city purpose around four pillars [34]: smart planning and design of buildings for optimal wind flow and minimum heat generation, smart energy management for optimal energy use and increased energy conservation, smart lighting adjusted based on real-time traffic analyses, and automated waste collection using high-speed air technology.

From the perspective of more connected smart cities, the city of Chennai has tackled the issue of long searches for a parking spot, which slows down the traffic and also harms the environment due to increased pollution. By developing a smart parking app connecting over 4300 parking spaces in 80 areas throughout the city, the city created a solution that minimizes wait times and offers a seamless citizen experience, including cashless payments and ability to find the appropriate parking slot before even leaving home [35].

Table 14.2 summarizes a selection of smart city applications around the world. In these real-life examples, federating the relevant stakeholders and data was key to success. In regard to the latter dimension, to build a smart ecosystem means to assess all aspects of data, along all stages, from the solution design through development, operations, and end customer use.

14.3 Typical Technological Challenges and Best Practices of Smart City Implementations

14.3.1 Data Availability, Open Data, and Data Sharing

Open data is data that is available online, in its entirety, in a machine-readable form, and for universal use and distribution [16]. Without open data, there is no smart city. Making collected data public and sharing it within and across the boundaries of smart cities are an integral part of developing and improving smart cities [13, 16]. It allows for building trust, making cities' undertakings more transparent, and interacting with citizens more efficiently. Real-time data collection can provide value for both the city and its citizens, help tackle societal and environmental issues, and support sustainable economic growth [36–38]. In addition, the data being used needs to be easily accessible (preferably already via open APIs), in high quality, and have informative metadata and permanent availability (permalinks, and up to date). Examples of such open access are the European Data Portal, which provides easy access to all data published within the union, and the European Urban Data Platform [38]. Cities like Dublin in Ireland, Amsterdam in the Netherlands, or Louisville, KY, in the United States have all implemented open data portals [36–38].

Despite its clear value, many obstacles to open data remain, including concerns regarding ownership and privacy, lack of high-quality data, or political and regulatory burdens [39]. As a result, "data openness" in smart city applications is a multidimensional concept that is just now starting to be investigated. For example, in the context of air quality, data openness has been defined as a combination of availability of real-time data and historical and forecast data, centralization of data, and connections with other related data sources (such as meteorological data) [39]. Adopting this approach indicates that different smart cities exhibit different levels of openness, and highlights best practices with respect to data centralization, data delivery, and useful developments (such as mobile applications, forecasting, or sensor deployment) [39].

Even when open data exists, it is usually siloed to one governmental agency. Better smart city solutions will need data orchestration—the coordination of initiatives

Table 14.2 Examples of smart city applications (based on [36–38])

Name of application	Location	Description of application	Smart city area
CitySDK	Amsterdam, the Netherlands, and other European cities	Toolkit for developing smart city digital services	All smart city areas
Dublinked	Dublin, Ireland	Open data portal	All smart city areas
City enabler for digital urban services (CEDUS)	Trento, Italy Malaga, Spain Rennes, France	Open data portal	All smart city areas
Open data portal	Louisville, KY, USA	Open data portal	All smart city areas
SacPark	Sacramento, CA, USA	Parking mobile app	Transport and mobility
Bike use data and maps	San Francisco, CA, USA	Bike traffic monitoring	Transport and mobility
GXBus	Montevideo, Uruguay	Route mapping application for public transport	Transport and mobility
Open transport net	Multiple cities around the world	Road conditions and traffic monitoring	Transport and mobility
Unmanned traffic management initiative	Kansas, KS, USA	Drone-based traffic monitoring	Transport and mobility
BlindSquare	Locations worldwide	GPS navigation for visually impaired individuals	Transport and mobility
Check my barangay	Philippines	Participatory governance initiative	Citizen services Sustainable development
InfoAmazonia Colombia	Colombia	Deforestation monitoring	Citizen services Sustainable development
Poverty in NYC	New York, NY, USA	Map/open data	Citizen services
Savvy citizen alerts	Richland, PA, USA	Location and smart device data integration	Citizen services
Energy block	Copenhagen, Denmark	Renewable energy sources	Sustainable development
Baltimore open air	Baltimore, MA, USA	Climate monitoring and analysis	Sustainable development

across many government entities in order to achieve a collective goal through data openness and supporting elements [40]. Data orchestration includes (a) openness—from a technology perspective (open interfaces, standards, and technologies) and an organizational perspective (open data portals, community sharing of plans and outcomes, exchanges with businesses); (b) diffusion—learning and knowledge mobility (small teams, ad hoc structures, and on-demand access to skills and expertise) and legitimacy and trust building (agile development, problem-based procurement, and pilot projects); and (c) shared vision—through governance tools (wider ecosystem values, wide representation on boards, incentives, and defined deliverables) and central coordinating structures (support for core capabilities and co-design) [40].

14.3.2 Data Governance and Life Cycle Management for Smart Cities

Smart cities generate huge amounts of data that needs to be managed using appropriate data governance processes and guidelines (the “who” of how data is managed, rather than the actual implementation of data-processing systems and processes) [41]. Data governance for smart cities needs to cover relevant data collection and generation, data management, data sharing, and data use, as well as legacy data and stakeholder collaboration issues. Overall, the smart city data governance approach needs to be responsive and collaborative in order to reflect the views and needs of all stakeholders—but also integrated in order to allow for broad data sharing. In addition, local data governance, even if part of multilevel governance structures, is best for ensuring relevant, understandable, and timely data [41].

Smart cities also need to use a life cycle management for data, services, and underlying components. Smart cities are ecosystems of stakeholders, information flows, systems, and processes, with both digital and physical components. At its core, such an ecosystem has the heterogeneous, uniquely identified, and connected objects. The principles of life cycle management can be applied to both the tangible and intangible components of this ecosystem [42]. From a product (tangible or intangible) perspective, life cycle management needs to focus on beginning-of-life activities (imagine, define, and realize), middle-of-life activities (use and support), and end-of-life activities (retire and dispose). From a service perspective, life cycle management needs to focus on beginning-of-life activities (ideation and requirements), middle-of-life activities (design, implementation, and testing), and operations and end-of-life activities (delivery and evolution). Finally, from a product-service system perspective (i.e., from the perspective of an extended product consisting of a complex combination of tangible and intangible elements), life cycle management needs to focus on the same activities as in service life cycle management [42], supported by product life cycle management activities as well.

Several characteristics of smart city life cycle management stand out. First, all components of the smart city ecosystem can be covered by life cycle management, but since they are developed and implemented independently and at different times, they will be in their own life cycle; as a result, “the life cycle of smart city is a life cycle of life cycles” [42]. Second, the design of the smart city components should allow for “loose coupling, modularity, composability, scalability, interdependency, and dynamic complexity” in order to support repurposing and reusing of the smart city components [42]. Third, data can be generated and used across different life cycle phases (in-work, in-process, in-review, released, as-designed, as-planned, as-built, as-installed, as-maintained, and as-operated) of the interdependent systems of a smart city [42]. Fourth, data can belong to multiple smart city ecosystem components (as a result of repurposing and reusing), and rights to access, create, modify, approve, and promote data may change during each component's life cycle as well [42]. Fifth, data is subject to a variety of policies and regulation related to security and privacy throughout the life cycle [42]. Sixth, smart city ecosystem components can have several versions, variants, or options due to modifications or upgrades performed during the life cycle [42]. Seventh and last, but not least, processes to report problems, make changes, and notify relevant stakeholders are needed throughout the life cycle [42].

14.3.3 Operationalization of Analytics and AI for Smart Cities

The implementation of the ambitious Dijon smart city plan in France uncovered core obstacles in obtaining the value from analytics use cases which are described in the following section.

A wide variety of stakeholders create an essential difficulty of establishing connectivity with each party involved, and even organizational alignment slows down almost any analytics application development that requires multiple data sources to be leveraged. Data from citizens to police to parking lot operators and beyond leads to hundreds and thousands of data sources that need to be connected in order to orchestrate the analytics. For instance, forecasting a parking lot availability will require to ingest the data of different types: the parking spot IoT sensor (time series data) and/or CCTV cameras (images and video streams), current weather conditions (time series) as well as weather forecast (geospatial and structured data), and any public events scheduled close to the parking location. HTTP, TCP, Modbus, or IoT protocols like MQTT can be used to connect the smart city devices. Generating RESTful API endpoints for accessing the data looks almost as the only viable path to establish data pipelines.

Data models and data management practices across such a big variety of stakeholders differ tremendously. Establishing the data connections with multiple organizations does not necessarily mean that the data can be immediately made available for analysis. It is unrealistic to establish any type of unified data model and data governance operations for the siloed and heterogeneous data sources that exist in smart city domains. Several prominent international organizations have been developing standards for smart city applications and data, but such work has just started, and we cannot expect a fast adoption of the proposed standards. Lai et al. [6] provide an overview of several important standards for smart cities. They note that, according to the IEC (International Electrotechnical Commission), there are over 1800 standards impacting smart cities, and that new standards specific to smart cities are also being created. For example, the International Organization for Standardization (ISO) introduced the ISO 37122:2019 (Sustainable Cities and Communities—Indicators for Smart Cities) standard comprising indicators for a variety of smart city domains. The World Council on City Data is another initiative which uses standardized city data to support smart city developments through the ISO 37120 (Sustainable Development of Communities—Indicators for City Services and Quality of Life) city data standard. And the International Telecommunications Union (ITU) overseeing standards for global communication and connectivity established Study Group 20 to develop international standards for IoT, smart cities, and communities covering the data layer, communication layer, and sensing/IoT layer. Finally, the Institute of Electrical and Electronics Engineers (IEEE) has launched the Smart City Planning Guide IEEE P2784 as a framework for smart city processes and technologies to allow for agile, interoperable, and scalable analytics solutions [6]. IEEE has further detailed it for specific smart city domains of smart grid, smart energy, smart health, smart mobility, smart education, and smart governance [6].

Given a slow speed of data standard adoption, real-life use cases utilize extract-load-transform (ELT) framework in order to ingest the data in its raw format into the data landing zone and store it in the unchanged form for further processing. Transformations most often will be designed based on a specific analytics requirement allowing for agile use case development and implementation. In case of another analytic target, the same raw data store can be reused, but transformations may change, adding more data pipelines and complexity on the one hand, while providing flexibility to data scientists and software developers on the other hand. Data quality and data trust can be ensured by additional checks and rules both during the data ingestion into the raw data store and during the transformation of data into the target data model.

API availability exposes data to security risks. To control API access and exchange authorization tokens, JWT (JSON Web Token) is widely adopted by the developers of modern applications with microservice architecture. JWT has its own vulnerabilities (such as the ability to copy a JWT string of characters and use it in an auth header). At the same time, authors capture another important security topic of smart cities related to the governance/access control that should be established for such a federated model of data exchange [43]. This can be addressed by setting up proper identity management components of the data and AI platform used for data ingestion, analytics orchestration, and execution.

Smart city use cases can often be solved with AI algorithms across multiple domains: anomaly detection with deep learning in time series IoT data or in video streams, augmenting the interaction with the city's actors through natural language processing (NLP) or voice recognition, routing algorithms, or geospatial analytics. Modular microservice-based architecture of smart city applications with data APIs is considered a mainstream approach for solution development. The feasibility of developing atomic services that are packaged as stand-alone services and can be reused by other cities has been demonstrated as part of a project covering 27 different cities and 35 different city services in Europe and South Korea [44]. The ability to reuse application in different locations/cities is one of the benefits of such

Fig. 14.5 Scaling AI (source: [45])

an approach. This leads to an essential requirement of cloud-based orchestration of analytics or data-processing modules into a bespoke use case solution, allowing to access open-source libraries or commercial analytics APIs. According to Capgemini Research Institute analyses, analytics and AI models for a variety of domains, including smart cities, can only be deployed in production at scale when the right IT infrastructure, tools, and processes are in place [45], as depicted in Fig. 14.5.

Even though a custom machine learning model for a point solution (i.e., a parking lot occupancy forecasting as mentioned above) could be developed by a data science team provided with historical data, retraining of such a model for many other locations could be of challenge. There might be thousands of parking lots in a city, and each of them may require organization of a separate data pipeline for data ingestion and transformations, as well as a new ML model deployment. Exploring historical datasets for each location and evaluating models to verify the applicability of it for a specific parking lot can be a resource-consuming and cumbersome exercise. Moreover, even if this step is successful and the ML model can be moved to production environment, monitoring the incoming real-time data drifts is necessary to ensure the required model accuracy. As such, automation in data operations (DataOps) and machine learning operations (MLOps) is a prerequisite for smart city analytics at scale. With DataOps, all data ingestion and transformation operations are considered as separate jobs that can be scheduled, monitored, and resolved. MLOps, in turn, do the same with machine learning development cycle: from training dataset version control to model evaluation and retraining, allowing users to trace back from model scoring results to initial historical subset of data used in training AI. Bias detection, fairness in the data, and model explainability at scale are all possible only with MLOps in place. Operationalization of DataOps and MLOps is achieved with different open-source or COTS tools available, with big cloud vendors offering their own cloud-native solutions for the same purpose. Given that administration of such tools is itself not an easy task for IT organizations, our experience demonstrates that leveraging a data and AI platform that has a consistent way of managing DataOps and MLOps instruments significantly reduces the effort required to develop and maintain smart city analytics applications.

Finally, flexibility in computing and storage resources is important for running smart city application in real time. This can be achieved with cloud resources that enable high data-processing throughput as well as analytics execution, at scale, and at a reasonable cost. The use of cloud is inevitable, also given the upcoming 5G networks. Some of the smart cities use cases, such as autonomous driving or safety applications, which will require data preprocessing and analytics execution at the edge, but even in this case, cloud resources remain the core infrastructure enabler as all edge devices will require remote management and firmware upgrades.

14.3.4 Reference Architecture for Data and AI Platform: X-IoT by Capgemini

Given the preceding considerations, the implementation of smart city solutions requires a technical platform capable of supporting the entire smart city ecosystem and the data it generates in a reliable and secure manner and of enabling execution of AI and analytics processes. An example of such a platform is X-IoT, a general-purpose, configurable, and secured end-to-end IoT ecosystem solution developed by Capgemini in collaboration with Intel and available for deployment in a variety of industries [11].

The platform is characterized by scalability, business agility, and continuous innovation potential (due to its design using proven standards, supporting millions of global connections of devices, delivering edge-to-cloud data, and reduced complexity) [46]. X-IoT also offers modularity and flexibility (such as choosing the cloud provider—private, public, or hybrid, integrating third-party providers, or running analytics from multiple sources) [46]. It also offers value-added digital services such as end-to-end cloud-connected digital services (including IoT strategy, innovation portfolio management, solution design and delivery, rapid concept and design prototyping, and global deployment) [46].

X-IoT is 100% dedicated to device management, ready to configure and securely connect the physical to the digital realms to improve product and asset performance and usage. Main characteristics are the focus on device management; the agnostication to devices, protocols, and cloud; the high security level including ANSSI accreditation; the edge and cloud mirroring architecture; the multi-tenant capability; the edge analytics management; the plug-and-play deployment; and the stringent use of open source with no third-party licensing.

For the sake of consistency, we assign the X-IoT elements, which we will describe in the following, to the five-color architecture that we introduced in the beginning of this chapter. Figure 14.6 maps these elements to each area of the five-color model. The interplay of the components itself is described by the functional architecture and shown in Fig. 14.7.

Fundamentally, the platform foundation enables the enterprise to integrate X-IoT into the cloud—either AWS, Azure, Google, or Bluemix or even private

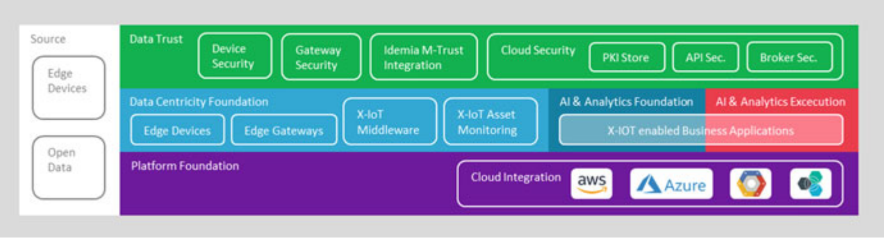


Fig. 14.6 Mapping the X-IoT components to the five colors (source: Capgemini)

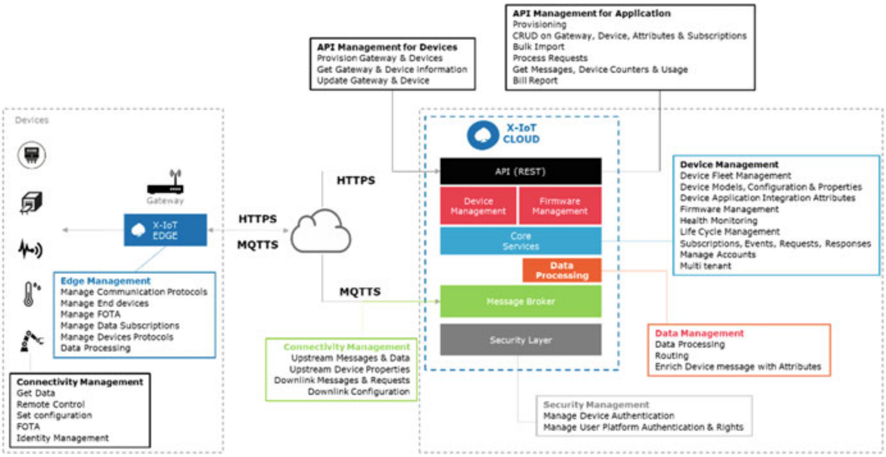


Fig. 14.7 Functional architecture of X-IoT (source: Capgemini)

cloud scenarios. An application based on the open X-IoT platform we associate with the AI and analytics foundation and execution layer—here is the starting point for generating business value. These X-IOT-enabled business applications capture a variety of types of data from different types of sensors, IoT devices, and business applications. These are part of the data-centricity foundation. Data trust encompasses security functionality which is implemented on devices, within the cloud, and essential security and trust features are provided by the IDEMIA M-TRUST solution.

Edge devices are IoT sensors that monitor and track the health and performance of relevant assets. Edge gateways (such as the Intel IoT gateways used in the solution) are located at the edge of the network and contain hardware and software capable of connecting a variety of end customer devices to the cloud, seamlessly transferring data back and forth, and providing security and intelligence at the edge [46]. Data aggregation and transmission to the cloud are supported by an X-IoT edge for device connectivity agent. X-IoT edge supports a comprehensive set of communication protocols with over 100 plug-ins between heterogeneous devices [46]. To name some examples of the variety of supported protocols, they include

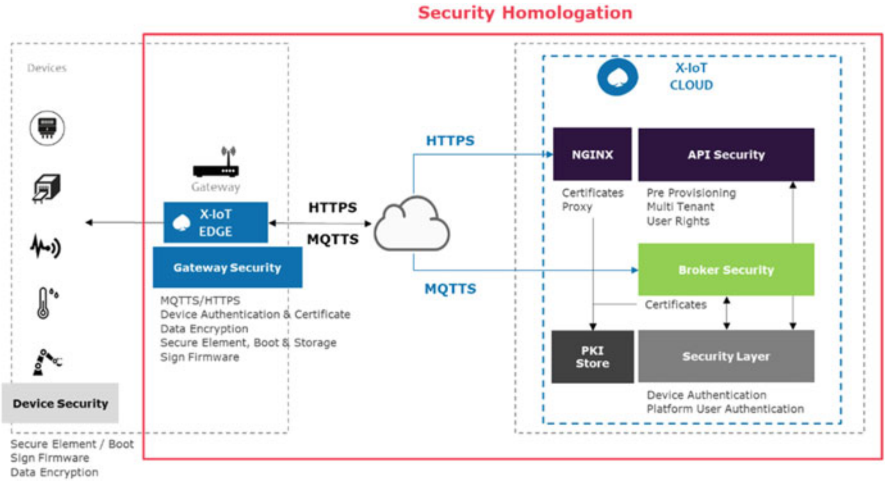


Fig. 14.8 X-IOT security architecture (source: Capgemini)

industrial protocols OPC, OPC UA, Profile bus, Modbus, and Operators LPWAN such as Sigfox and LoRa; wireless protocols like ZigBee, Enocean, Libelium, Bluetooth, iBeacon, AllJoyn, DLNA, and UPnP; and protocols for communication and smart energy including DLMS and 3GPP: 3G, 4G, and NB-IoT. Data flow from multiple gateways is managed by X-IoT middleware for device management, which enables device management and provisioning, firmware upgrades, fleet management, message management, health monitoring, and event processing, and enables data synchronization between systems with a connector library [46]. Finally, X-IoT intelligent asset monitoring is an analytics component that enables real-time asset monitoring and decision-making based on dashboards and real-time 2D and 3D data [46]. Thus, X-IoT enables the collection and analysis of data from all devices, sensors, machines, and people connected to the platform and related decision-making.

Security is an extremely important consideration for smart city solutions, and the X-IoT platform puts security at its core, offering end-to-end data security from edge devices to the cloud, and at each level in the architecture in order to provide the highest levels of protection. For example, each gateway and middleware component have hardware-implemented security (device attestation, configuration and management, asset information, policies, and metadata) [46]. Figure 14.8 shows the security architecture and Fig. 14.9 the IDEMIA M-TRUST Integration. M-TRUST is a solution to ensure end-to-end security from the connected device to the cloud. It is a cloud-based platform that enables the secure management of connected objects ensuring that data exchanged will not be tampered or read by unauthorized parties.

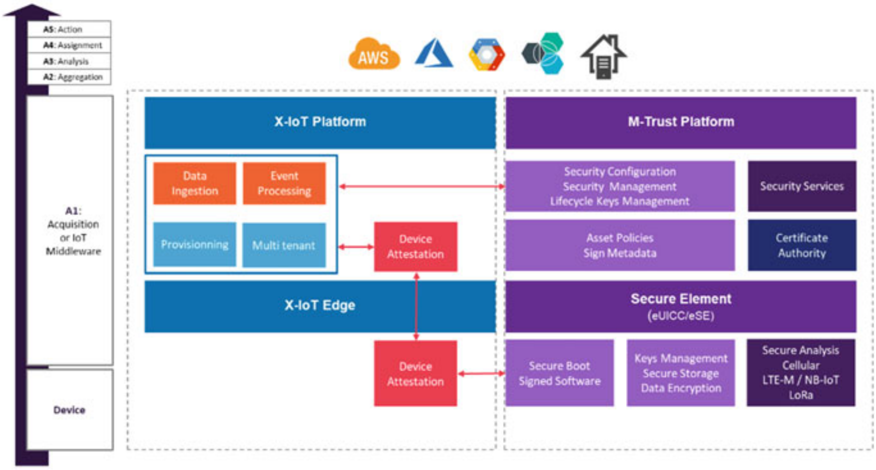


Fig. 14.9 IDEMIA M-TRUST integration (source: Capgemini)

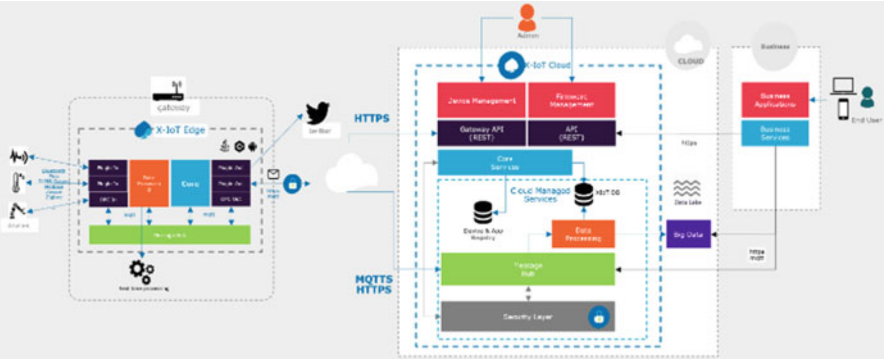


Fig. 14.10 Cloud and edge mirroring architecture (source: Capgemini)

The platform is cloud agnostic and can be independently integrated into Amazon Web Services (AWS), Microsoft Azure, Google Cloud Platform, or any private cloud. The cloud and edge mirroring architecture is shown in Fig. 14.10.

With the Internet of Things, new use cases are developing for companies from various industries. Predictive maintenance, connected logistics, and smart health monitoring, as well as smart cities, are some examples. An IoT platform such as X-IoT enables the IoT strategy to be implemented quickly and efficiently by connecting devices to people and processes and implementing concrete use cases with little development effort. X-IoT serves as a communication platform between the IoT hardware objects and the IoT apps. It combines connectivity, security, and analytics in a central software package that forms the core of any IoT solution. The use of cloud for the utilization of infrastructural resources, such as storage

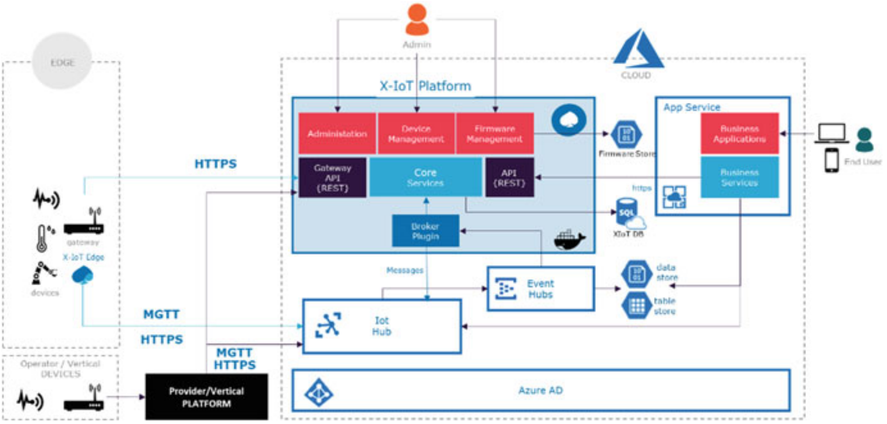


Fig. 14.11 Microsoft Azure architecture (source: Capgemini)

capacities and computing power, is what makes the management and processing of these huge volumes of data possible. The cloud provides immense computation capacity for analysis and evaluation of datasets. The results from these analyses are used to forecast events, make decisions, initiate actions, and optimize processes. Data, sourced from disparate devices, can be examined in real time for dependencies and patterns and transformed into usable insights. The results can then be output to the end user in any visualization options, enabling real-time monitoring of relevant information remotely.

Now, ultimately, every cloud, such as AWS, Azure, Google, and Bluemix, has cloud-native components and services that X-IoT must attach to or in other words integrate with. How this integration is accomplished and using which components is shown in Fig. 14.11 (the architecture for integrating X-IoT into Azure cloud), Fig. 14.12 (depicting the AWS architecture of X-IoT), and finally Fig. 14.13 (that shows the Google cloud architecture).

Openness wins—this is the guiding principle that has prevailed in practice. In the past, manufacturers have tried to establish themselves in the IoT market with their own proprietary standards. That was a shot in the dark. Today we have cross-company working groups such as Eclipse IoT Working Group including DB, Ubuntu, Bosch.IO, IBM, and Red Hat, or the Industrial Internet Consortium (IIC) including DELL, Microsoft, and General Electric along many more. Standards for the communication of devices, respectively, for the communication of interconnected smart city items have to be jointly developed, maintained, and openly provided. Otherwise, particular interests aimed at attempting to secure individual markets will oppose any overall progress.

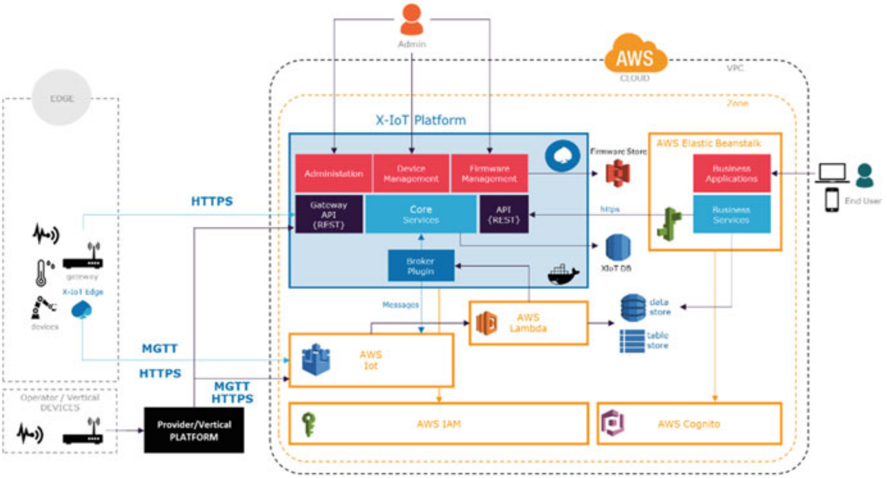


Fig. 14.12 AWS architecture (source: Capgemini)

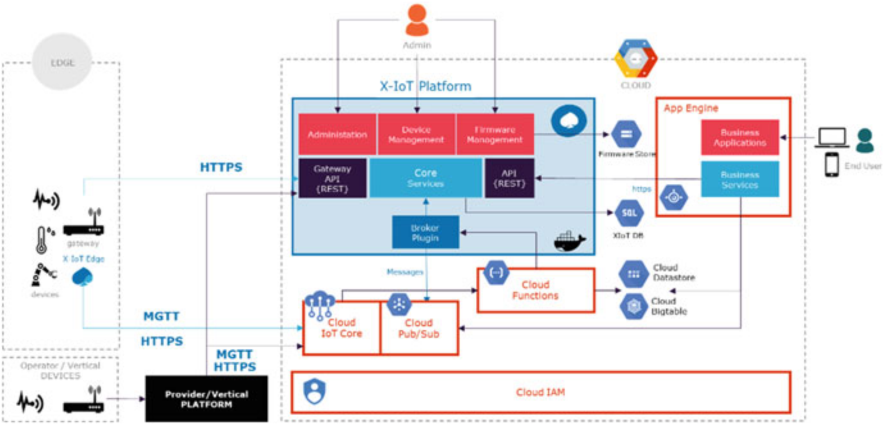


Fig. 14.13 Google cloud architecture (source: Capgemini)

14.4 Conclusion and Outlook

In this chapter, we have described how IoT, together with the related data and AI and analytics technologies to interpret it, plays a crucial role in smart cities. We have also argued that an integrated platform that brings the sheer variety of protocols under one roof is essential for the implementation of smart city solutions. Such an open platform makes it possible to connect diverse devices, or to be more specific, smart city components, with each other. Furthermore, the platform needs to ensure that the data generated by all these disparate devices can be collected and analyzed in real time and transformed into usable insights. For the entire solution to remain elastic and scalable, the use of the cloud is indispensable.

The next steps in terms of technical development might consist of the design of more detailed architectures geared towards specific smart city areas, since there is a lack of flexible and robust reference models in this space [21]. Testing the emerging system thinking models in more smart city contexts and refining the list of design variables that can be used to generate desirable smart city outcomes [12] are likely to attract both academic and practitioner interest. Structuring and synergistically combining as well as collecting and categorizing open data and reusable service components for smart cities, within and across city and governmental entity boundaries, are also areas for fruitful future exploration. There is still much to do here including finding answers to the questions of which open data covers which business capabilities, in which combination, and how, and how to design repositories and marketplaces for reusable service components [13, 16, 44]. Understanding how cities can build scalable and consistent data openness and data orchestration capabilities is also an important area for future research [40]. Last, but not least, future research should investigate ways to transcend the limitations of existing AI tools in complex, dynamic, and nondeterministic smart city environments, such as self-structuring, self-configuring, and self-learning AI technology [47].

References

1. Rifkin J (2011) The third industrial revolution: How lateral power is transforming energy, the economy, and the world. St. Martin's Press, New York, NY
2. Horizon2020 (2020) European Commission. https://ec.europa.eu/programmes/horizon2020/en
3. Smart Cities (2020) European Commission. https://ec.europa.eu/info/eu-regional-and-urban-development/topics/cities-and-urban-development/city-initiatives/smart-cities_en
4. The UNECE–ITU Smart Sustainable Cities Indicators (2015) United Nations Economic and Social Council, Geneva, Switzerland
5. Kirimtat A, Krejcar O, Kertesz A, Tasgetiren MF (2020) Future trends and current state of smart city concepts: a survey. IEEE Access 8:86448–86467
6. Lai CS, Jia Y, Dong Z, Wang D, Tao Y, Lai QH, Wong RTK, Zobaa AF, Wu R, Lai LL (2020) A review of technical standards for smart cities. Clean Technol 2:290–310
7. Street smart: Putting the citizen at the center of smart city initiatives (2020) Capgemini Research Institute
8. Iqbal A, Olariu S (2021) A survey of enabling technologies for smart communities. Smart Cities 4:54–77
9. Ahad MA, Paiva S, Tripathi G, Feroz N (2020) Enabling technologies and sustainable smart cities. Sustain Cities Soc 61:102301
10. Hanania P-A, Carsaniga G (2020) Sweet home, smart city. Capgemini
11. Internet of Things – XIoT Platform (2020) Capgemini
12. Noori N, de Jong M, Janssen M, Schraven D, Hoppe T (2021) Input-output modeling for smart city development. J Urban Technol 28:1–22
13. Raghavan S, Simon BYL, Lee YL, Tan WL, Kee KK (2020) Data integration for smart cities: opportunities and challenges. Computational Science and Technology, pp. 393–403

14. Daissaoui A, Boulmakoul A, Karim L, Lbath A (2020) IoT and big data analytics for smart buildings: a survey. Procedia Comput Sci 170:161–168
15. Allam Z, Dhunny ZA (2019) On big data, artificial intelligence and smart cities. Cities 89:80–91
16. Neves FT, de Castro Neto M, Aparicio M (2020) The impacts of open data initiatives on smart cities: a framework for evaluation and monitoring. Cities 106:102860
17. Sarker MNI, Khatun MN, Alam GM, Islam MS (2020) Big data driven smart city: Way to smart city governance. In Proceedings of the 2020 International Conference on Computing and Information Technology (ICCIT), pp. 1–8
18. Ben Rjab A, Mellouli S (2019) Artificial intelligence in smart cities: systematic literature network analysis. In Proceedings of the 12th International Conference on Theory and Practice of Electronic Governance, pp. 259–269
19. Souza JTD, Francisco ACD, Piekarski CM, Prado GFD (2019) Data mining and machine learning to promote smart cities: a systematic review from 2000 to 2018. Sustainability 11:1077
20. Bhattacharya S, Somayaji SRK, Gadekallu TR, Alazab M, Maddikunta PKR (2020) A review on deep learning for future smart cities. Internet Technol Lett 187
21. Hajjaji Y, Boulila W, Farah IR, Romdhani I, Hussain A (2021) Big data and IoT-based applications in smart environments: a systematic review. Comput Sci Rev 39:100318
22. Westraadt L, Calitz A (2020) A modelling framework for integrated smart city planning and management. Sustain Cities Soc 63:102444
23. Mohammadi M, Al-Fuqaha A (2018) Enabling cognitive smart cities using big data and machine learning: approaches and challenges. IEEE Commun Mag 56:94–101
24. Ismagilova E, Hughes L, Rana NP, Dwivedi YK (2020) Security, privacy and risks within smart cities: Literature review and development of a smart city interaction framework. Inf Syst Front:1–22
25. Lom M, Pribyl O (2021) Smart city model based on systems theory. Int J Inf Manag 56:102092
26. Cisco Global Cloud Index (2016) Forecast and methodology, 2015–2020. Cisco
27. AI & data engineering: True intelligence depends on data at scale (2019) Capgemini
28. Dutta S (2019) How to design a modern data and AI platform. Capgemini
29. Dijon, première smart city de France? (2018) Le Monde, March 14
30. How Dijon is becoming France's leading smart city (2021) Consultancy.eu
31. Dijon metropole launches a unique smart city project in France (2019) Capgemini
32. About the traffic agent (2021). www.trafikkagenten.no
33. Smart cities 2.0: Ep 4: Singapore (2017) ChannelNewsAsia, March 25
34. Tengah (2021) Singapore Housing and Development Board. https://www.hdb.gov.sg/
35. Chennai all set to get smart parking system (2019) The Hindu, October 16
36. 10 examples of how open data helps create sustainable smart cities (2021). https://www.smartcitieslibrary.com/
37. 40 Brilliant Open Data Projects Preparing Smart Cities for 2018 (2017). Carto.com
38. 10 Examples of How Open Data Helps Create Smart Cities (2017). Geographica.com
39. Mak HWL, Lam YF (2021) Comparative assessments and insights of data openness of 50 smart cities in air quality aspects. Sustain Cities Soc 69:102868
40. Gupta A, Panagiotopoulos P, Bowen F (2020) An orchestration approach to smart city data ecosystems. Technol Forecast Soc Chang 153:119929
41. Paskaleva K, Evans J, Martin C, Linjordet T, Yang D, Karvonen A (2017) Data governance in the sustainable smart city. Informatics 4:41
42. Hefnawy A, Elhariri T, Bouras A, Cherifi C, Robert J, Kubler S, Främling K (2016) Lifecycle management in the smart city context: Smart parking use-case. In IFIP International Conference on Product Lifecycle Management, pp. 631–641
43. Cyber resilience and the UK's evolving Smart City ecosystem (2020) Roke Manor Research Ltd.
44. Cirillo F, Gómez D, Diez L, Maestro IE, Gilbert TBJ, Akhavan R (2020) Smart city IoT services creation through large-scale collaboration. IEEE Internet Things J 7:5267–5275

45. The AI-powered enterprise: Unlocking the potential of AI at scale (2020) Capgemini Research Institute
46. Intelligent asset monitoring (2017) Capgemini
47. Alahakoon D, Nawaratne R, Xu Y, De Silva D, Sivarajah U, Gupta B (2020) Self-building artificial intelligence and machine learning to empower big data analytics in smart cities. Inf Syst Front:1–20