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Smart Infrastructure

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ABSTRACT

Smart infrastructure refers to the integration of advanced technology, data analytics, and connectivity into various components of physical infrastructure to improve efficiency, resilience, and sustainability. It consists of a system capable of monitoring, measuring, analyzing, communicating, and acting based on data collected from specific sensors. These data are utilized to enhance the efficiency, safety, and sustainability of both the infrastructures and the entire city. Smart infrastructure systems can monitor, analyze, and act based on collected data. This information can then be used to make better decisions about how to allocate resources, maintain assets, and respond to disruptions. Smart infrastructure will revolutionize how infrastructure is delivered, managed, and automatically controlled. This paper explores the essential components and key benefits of smart infrastructure.

KEYWORDS: *smart technologies, smart cities, smart infrastructure.*

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INTRODUCTION

Global urbanization is occurring on a massive scale. According to the UN, more than half of the world's population live in urban areas, with numbers expected to rise to up to 60% by 2030. Urbanization and globalization have had a profound impact on recent city development. Cities are the major economic engine for a nation. At their core, they are places where people congregate, travel, and find work. How cities are designed affects economic interactions in the most important regions of a country. A smart city is one that utilizes self-managing autonomic technologies to identify its functions and promote prosperity and sustainability. Buildings, infrastructures, and entire smart cities require intelligent management to perform optimally [1,2].

We are increasingly hearing the term "smart" associated with different things such as smart cities, smart buildings, smart environment, smart economy, smart transportation, smart people, etc. as typically shown in Figure 1 [3]. The main idea behind the term "smart" is a strict and continuous interconnection among infrastructure and vehicles. No matter what path each city takes in choosing what will make it Smart, they will all have one thing in common: infrastructure. Infrastructure consist of core systems and services that enhance the country's productivity by supporting growth and prosperity based on the interconnection of various equipment over the network platform. The infrastructure in smart cities should be geared towards being sustainable and eco-friendly.

Smart infrastructure is the outcome of connecting physical infrastructure such as water, transportation, and so on with digital infrastructure which provides improved information to enable better decision making that is faster and less expensive. It is a core aspect of the new digital world. It stands at the intersection of sustainability, operational efficiency, and economic viability. It is a relatively new concept, but it is rapidly developing and gaining traction around the world. The concept extends beyond individual buildings to encompass larger-scale infrastructure systems like transportation networks, utilities, communication systems, and more. Smart infrastructure has grown from concept to reality thanks to several capabilities employed by architects,

engineers, constructors, and facility managers. Over the past decade, inexpensive sensors, image capture, always-on wireless connections, advanced 3D visualization, Geographic Information System (GIS) technology, and Building Information Modeling (BIM) have enabled planners, designers, builders, and facility owners to create an intelligent nervous system for our infrastructure [4].

WHAT IS SMART INFRASTRUCTURE?

Technological advancements now embrace not only individual components but entire cities and infrastructures. This leads us to the concept of smart infrastructure, which refers to technologically advanced systems capable not only of collecting and analyzing data but also making decisions with minimal human intervention. Smart infrastructure is the use of digital technologies to improve the efficiency, sustainability, and resilience of physical infrastructure.

Smart infrastructure may be regarded as the use of sensors and smart grid technologies to enhance essential urban systems, including water and energy networks, streets, and buildings, facilitating intelligent management and improved services. It encompasses buildings, roads, bridges, energy distribution networks, and resources with advanced technology, enabling the collection and real-time sharing of data. As shown in Figure 2, smart infrastructure consists of physical and digital infrastructures [5], which constitute the basic infrastructures (platforms) of a smart city. Smart-physical infrastructure plays a decisive role in creating smart cities, so that it is impossible to achieve the goals of the smart city without them. The components of smart-physical infrastructure are shown in Figure 3 [3]. The components of smart-digital infrastructure include smart grids, smart data, sensors, and smart communications, as shown in Figure 4 [3]. The capability for richer live by integrating physical and digital infrastructures for the citizens of a smart city is centered on what people consider to be the next generation of information society. In addition to two basic infrastructures for any smart city, we also have smart-society infrastructure. Smart people, smart government, smart economy, and smart lifestyles are considered as domains of smart-society infrastructure, as illustrated in Figure 5 [3].

At its core, smart infrastructure involves the deployment of sensors, IoT devices, and data analytics tools across infrastructure systems. Supporting these smart infrastructures are software, applications, and a BIM IoT platform. IoT is generally defined as a technology that develops a network for devices to establish a connection and communication among them. Many regions have been using IoT solution to develop an actual smart city infrastructure. IoT-powered solutions can implement smart lighting to save energy consumption, enhance energy management systems, improve public security with smart monitoring, create smart parking systems, etc.

COMPONENTS OF SMART INFRASTRUTURE

Smart infrastructure includes the use of sensors and smart grid technologies to facilitate smart infrastructure, such as water and energy networks, streets, buildings, and so forth. The characteristics of the smart city include physical infrastructure, connectivity, access control, authentication, availability, interoperability, heterogeneity, scalability, handling big data, resident involvement, and mobility. A smart infrastructure encompasses several other equally smart elements such as [6]:

- *Smart Buildings*: Buildings account for more than 50% of smart-city services. Smart buildings are characterized by highly advanced technology that enables the automation of many internal processes, such as heating, ventilation, lighting, and security. They integrate various physical systems, increasing energy efficiency, reducing waste, and optimizing resource use.
- *Smart Mobility:* This focuses on the mobility of all users of the city, whether citizens or visitors. It reduces congestion and promotes greener, more economical, and faster transport options. Most smart mobility systems use big data collected from various mobility models to optimize traffic conditions.
- *Smart Energy:* Energy means the most important infrastructure for living anywhere on the earth. Humans need fuel, lighting, air conditioning to live on. Smart energy management relies on sensors, advanced meters, renewable energy sources, digital controls, and analytical tools to automate, monitor, and optimize energy distribution and usage. These systems balance the needs of stakeholders—consumers, producers, and suppliers—and optimize the network's operation and use.
- *Smart Water:* Water-scarcity problems have become more pronounced in recent decades and the availability of clean water has become the most important prerequisite for continued urbanization. Smart water management system uses technology to save water, reduce costs, and improve the reliability and transparency of water distribution. The system analyzes real-time flow

and pressure data to detect anomalies (such as leaks). Users simultaneously receive real-time updates on the network's status and other relevant information that aids in water and cost savings.

- *Smart Waste Management:* Waste materials, garbage, and sewage are all synonymous words for unpleasant or unwanted and polluting substances from human activities. Waste can be gas, liquid, or solid. Smart water management systems can classify waste types directly at the source and develop methods to optimize recycling and recovery. The main benefits include increased collection efficiency, proper separation, and the reuse and recycling of waste.

APPLICATIONS OF SMART INFRASTRUTURE

Smart infrastructure can be regarded as a cyber-physical system that integrates all its components through technology tools to analyze data and meet efficiency, sustainability, productivity, and safety goals. Some applications of smart infrastructure are depicted in Figure 6 [7]. Smart infrastructure can be applied to a wide range of sectors, including include the following [3,8-10]:

- *Smart Cities*: Smart infrastructure provides the inspiration for all of the key themes associated with a smart city, as well as good quality, good economy, good living, good governance, and good atmosphere. Cities are the places of living, work, and recreation for the inhabitants and their users. A smart city is a framework for developing, deploying, and promoting sustainable development strategies to solve growing urbanization concerns. By definition a smart city is equipped with smart infrastructure that provides improved quality of life with sustainable environment through smart built solutions. Smart city development is a great initiative for urban development that enhances the lives of citizens and also provides a great boost to public services. Governments have started many campaigns to develop smart city infrastructure and public services. Smart city infrastructure includes utility right of way, fiber optics communications, wireless radios, street lights, traffic control devices, cameras, street furniture and a variety of sensors. Other areas where smart cities can help improve the overall quality of life include smart housing and smart administration. Figure 7 illustrates the concept of smart city [11].
- *Smart Buildings*: Smart buildings use sensors and automation to control energy consumption, improve indoor air quality, and enhance occupant comfort. They are leveraging network infrastructure in new ways, delivering data and power to desktops, lighting, building operations, security systems, and more. Figure 8 shows some smart buildings [6].
- *Transportation:* Access to public transportation has increased in tomorrow's cities. In transportation, smart infrastructure involves the deployment of intelligent transportation systems (ITS) that use sensors, cameras, and communication networks to monitor traffic flow, manage congestion, and improve safety. Smart traffic management systems use sensors and software to optimize traffic flow and reduce congestion. This can help to reduce congestion and improve air quality. The traffic system is a very crucial factor in smart city development and for public services, as traffic management should be in an efficient manner to avoid any inconvenience. With IoT solutions, powered sensors can collect data on traffic conditions and operate traffic lights based on traffic conditions. Figure 9 shows a typical traffic system [1].
- *Smart Surveillance:* Smart surveillance is done to increase community security by detecting, preventing, or controlling anomalies/crime or social and health crises. It is implemented by systems based on imaging and control tools. The security of citizens is an important factor in developing a smart city and better public services infrastructure. Several cases of robbery, theft, etc. can be prevented with IoT-powered solutions. Smart cameras can be implemented within the city that keeps 24/7 eyes on the city to prevent any inconvenience. Affordable cameras are everywhere in surveillance and data collection. These cameras record video and recognize and track objects.
- *Energy:* Sustainable energy, clean energy, green energy, renewable energy, low carbon energy, zero energy, and smart energy are concepts that human beings have pursued to overcome energy problems. Smart grids use sensors and communication technologies to improve the efficiency and reliability of electricity delivery. Smart grid technologies use sensors to monitor the electricity grid and adjust the flow of electricity to meet demand. This can help to reduce energy consumption and improve reliability. In utilities and energy management, smart infrastructure utilizes sensors and IoT devices to monitor water, electricity, and gas distribution networks.
- *Building Information Modeling:* Smart infrastructure, built on a foundation on BIM, IoT

sensors, imagery, and GIS, has changed many parts of our lives. BIM combines geometric data and design properties for a wide range of building and infrastructure projects. It entails producing a 3D model of a building, roadway, utility, or other project type with detailed data on design, construction, maintenance, and operation. BIM models, when combined with GIS technology, include this data, allowing project managers to monitor site safety in real time. This technology combination with the support of GIS software prevents accidents, saves lives, and creates a safer workplace by providing a bird's-eye view of threats.

- *Manufacturing:* The US economy relies on communications-enabled infrastructure and manufacturing for its fundamental operations as a society. Today's infrastructure and manufacturing rely on communication and sensing networks for the transfer of actionable information using technology to make critical decisions. Smart connected manufacturing develops advances in measurement science that enable US manufacturers to use disparate data and advanced communications technologies to build knowledge and make better decisions to improve the quality, reliability, interoperability, and efficiency of connected smart manufacturing systems. In manufacturing, humans stand side by side with robots in the workplace.

BENEFITS

Smart infrastructures offer enormous advantages in managing cities and meeting the needs of their inhabitants. They can help to make infrastructure systems more resilient to disruptions caused by extreme weather events, cyber attacks, and other threats. They incorporate elements of resilience and sustainability. Smart infrastructure will allow owners and operators to get more out of what they already have – increasing capacity, efficiency, reliability and resilience. Other benefits include the following [6,9]:

- *Sustainability*: The need for sustainable and resilient infrastructure has never been greater. Smart infrastructure is a sustainable infrastructure development. It can help to reduce greenhouse gas emissions and other environmental impacts. Smart city development not only involves the enhancement of present scenarios but also needs to think about the future. Sustainability plays an important role in enhancing public services and environmental conditions. Smart infrastructures and their intelligent components ensure the sustainable use of all managed resources. This helps, for example, in efficient waste, water, or energy management.
- *Reliability:* This involves reducing system downtime and unforeseen problems, allowing organizations to continue providing services with maximum reliability.
- *Optimal Decision-Making*: Smart aspects of infrastructures collect data and information, supporting and enhancing the subsequent decision-making process.
- *Time and Cost Savings*: BIM models and IoT sensor data, along with GIS integration, can save money. Smart infrastructure can help to reduce the costs of operating and maintaining infrastructure. Intelligent systems enable organizations to optimize resources, thus saving time and costs. An example in this regard is the control of electrical consumption, which provides economic and environmental benefits simultaneously.
- *Environmental Monitoring:* There are many situations of bad environmental conditions, like bad air quality, outbreaks of diseases, bad sewage conditions, etc., that directly affect public health and also interrupt the establishment of smart city infrastructure. With IoT solutions, it is possible to monitor air quality in real-time to take any action during adverse conditions, allow prevention before the spreading of diseases. Connected surveillance systems (cameras), emergency alert systems, or AI-enabled real-time crime monitoring systems assist with emergency management and emergency service.
- *Efficient Waste Management*: Smart infrastructure can help to reduce waste and improve the performance of infrastructure systems. Local teams utilize IoT enabled smart waste bins with IoT sensors to provide fill level information to local staff, and notify local staff when it is time for a pick-up, and smart waste management systems can utilize more sustainable ways to reduce pick-up routes and trucks while cutting the environmental impacts of fuel (oil) and increasing sanitation.
- *Quality of Life:* Creating a sense of national belonging by emphasizing cultural and religious backgrounds along with cultivation to achieve collective aspirations improves the quality of life. Smart cities and campuses illustrate the benefits of integrating data, hardware, and communication systems with infrastructure to society. Innovative technologies like IoT sensors, BIM, and reality capture, combined with GIS, improve public

services and quality of life, enhance accessibility, and reduce stress.

Some benefits of smart infrastructure are depicted in Figure 10 [5].

CHALLENGES

Our cities and communities are changing faster than ever before. Many people are struggling to respond to concurrent disruptions — increases in cost of development and inflation, fast or negative growth, aging infrastructure, labor force issues, a changing climate, and the digitalization of everything. This trend in urbanization goes together with unique challenges, such as increasing costs of living, lack of adequate and affordable housing, environmental and infrastructure issues. Other challenges include the following [11]:

- *Security:* Establishing security and managing it for the lives of citizens is necessary for all times. However, it is more important to prevent the occurrence of crises and accidents and to provide safety and security for the citizens. Citizens are more likely to be involved in their own affairs and less likely to contribute to security. Therefore, planning is necessary to manage and control the effects of sensitive disasters on people's lives.
- *Safety:* Infrastructure and construction safety is crucial. The integration of IoT sensors, cameras, and BIM models, enhanced by GIS, provides a complete project site view. BIM models, when combined with GIS technology, allow project managers to monitor site safety in real time. The system can quickly indicate equipment failures and safety violations. Technologies, sensors, and all the smart aspects of infrastructures enhance user safety by avoiding human errors, predicting natural disasters, and planning responses to unforeseen events.
- *Pollution:* Water pollution, noise, parasite, and air pollution with harmful substances are among the pollutions that are caused by human activity and endanger the environment. Some of the pollutants such as fires, floods, and storms are created by nature and are temporary in nature. Governments are actively pursuing pollution control programs, especially carbon pollutants, for pollution control.
- *Human Capital:* Smart cities are human centered and ICT enabled. Being human centered in cities means planning all the facilities and services for humans, and these are the people who use them with their work and creativity. People in cities face many challenges to meet their needs. They are not the last consumers, but the main contributors to the change process. People live in cities alongside others and share common and sometimes conflicting interests that need to be addressed through interaction and so they need to be educated.
- *Smart Culture*: Cities are microcultural communities with acceptable standards in health, educational, and social infrastructure that support innovation, creativity, and economic development. Culture is one of the economic components of the smart-society infrastructure. Culturally embedded urban heritage is called smart culture, which utilizes information and communication technology and focuses on enhancing the capability of cities. Smart culture can significantly boost a city's economic growth.
- *Smart Housing:* Housing in smart cities should be affordable while also ensuring safety and security for its residents. Open and green spaces, public services, community areas, jobs as well as social facilities raise the housing standard in a smart city and enhance the quality of life in any given neighborhood.
- *Social Inclusion:* Individuals' lifestyles are directly related to the social inclusion of individuals and the opportunity that society offers to improve the social participation of individuals and groups. Social inclusion improves the ability and dignity of deprived people based on their identity. One of the powerful tools for social inclusion is the expansion and inclusion of mass media provided by the smart-digital infrastructure.
- *Education:* Citizens of smart cities must have the skills needed to use the most of the facilities and available services offered in the cities. Mastering these skills requires training and educational services in all areas of services provided. The demographic range of cities and the presence of middle-aged and elderly people away from technology necessitate the need for digital education in urban planning.
- *Public Participation:* Public participation in urban decision making improves governments ability to identify and act on citizens preferences. Public participation means engaging people in governance through the involvement of city stakeholders (people, communities, universities, officials, organizations, businesses, etc.), in a wide range of public administration activities such as health, safety, housing, economy, and education that supports the smart process. These activities cover the needs of individuals and urban communities such as neighborhoods, families,

immigrants, tourists, social organizations, the media, etc. Urban planners seek to establish a two-way relationship with the community to enrich life through long-term public participation in the planning, development, and implementation of infrastructure systems. The presence of the necessary infrastructure such as city hall services, transparency based on information and open data technologies, democratic requirements, and participatory decision making are key requirements for engaging citizens in smart governance.

- *Smart Governance:* Smart infrastructures are inefficient without smart governance. Governance means how organizations or nations are managed, while government is a group of people who formally control a nation. Therefore, those in charge of the country management should apply the highest level of management and related systems that this implementation requires smart-society infrastructure. Smart-society infrastructure focuses on the creation of new forms of social organization such as e-government, e-governance, and telecommunication services for mediated communication, citizenry engagement in decision making, and distance services and its use in decision making.

CONCLUSION

Smart cities are the vision of the new decade as cities all over the world innovate for the future. The purpose of smart cities is to leverage technology to improve the quality of life, promote economic prosperity, and innovate for environmental sustainability. Cities are working towards these goals though creating smart infrastructures. These infrastructures are necessary for a city to be able to leverage technology and smart solutions, thereby improving the day-to-day of its citizens. They collects data, process information, and take appropriate action completely autonomously, without human intervention. Many American cities are introducing new technology driven smart infrastructures [12].

As cities and businesses become increasingly interconnected and reliant on data, smart infrastructure will play an increasingly important role in ensuring the efficient, sustainable, and resilient operation. Smart infrastructure will allow owners and operators to get more out of what they already have, increasing capacity, efficiency, and resilience, and improving services. It brings better performance at lower cost. As IoT technology progresses, the opportunity for innovation in urban planning and administration grows. Cities will become more resilient, and able to respond to changes and crises with remarkable speed. Industry, organizations, and professionals need to be ready to adjust in order to take advantage of the emerging opportunities. Change is inevitable. Now is the time for the infrastructure industry to choose: to be smart. More information on smart infrastructure is available from the books in [13-18] and a related journal: *Smart Cities*.

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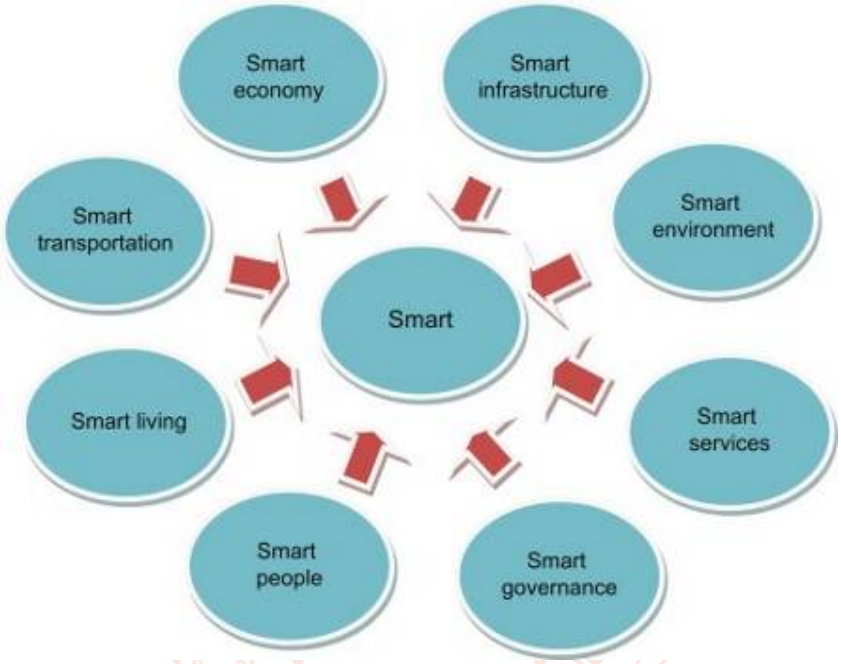

Figure 1 Smart everything [3].

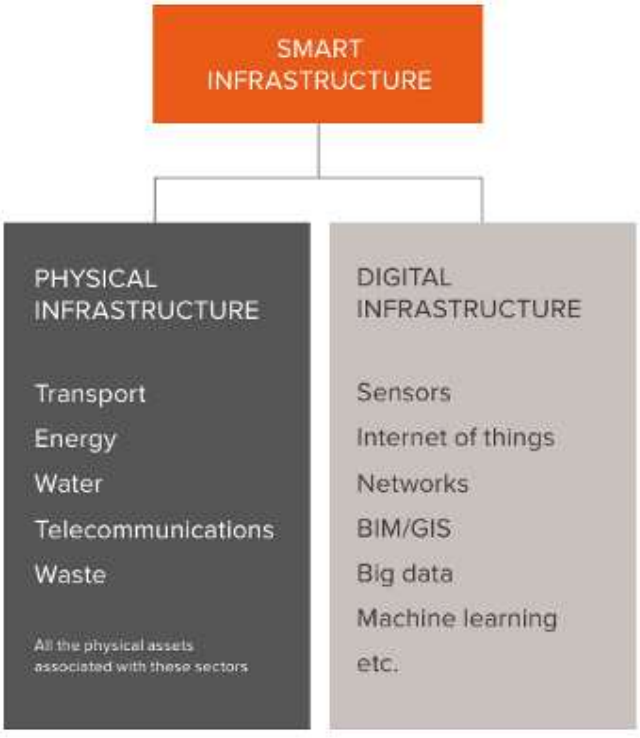

Figure 2 Smart infrastructure consists of physical and digital infrastructures [5].

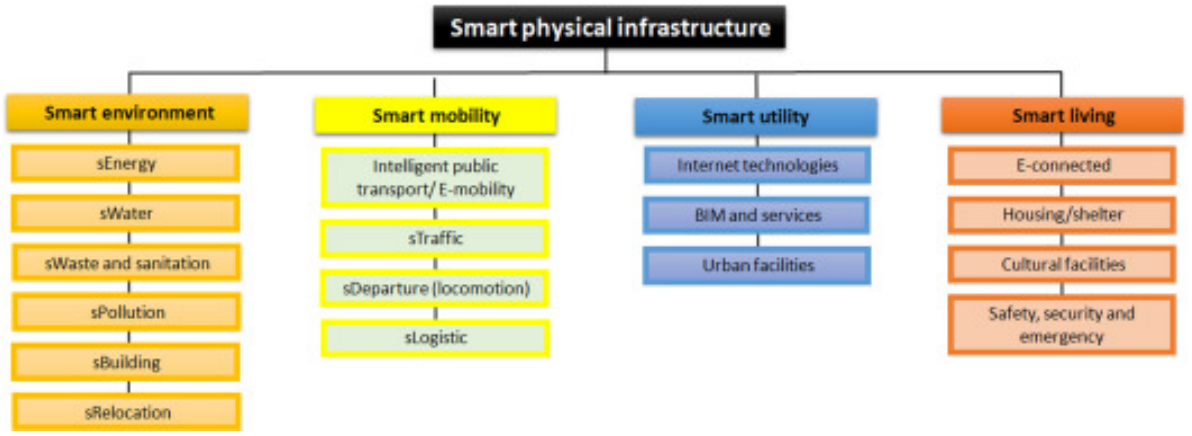

Figure 3 Components of smart-physical infrastructure [3].

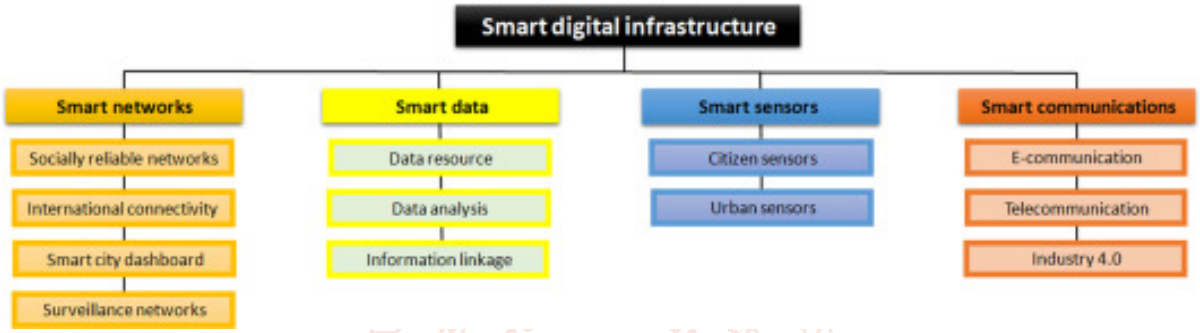

Figure 4 Components of smart-digital infrastructure [3].

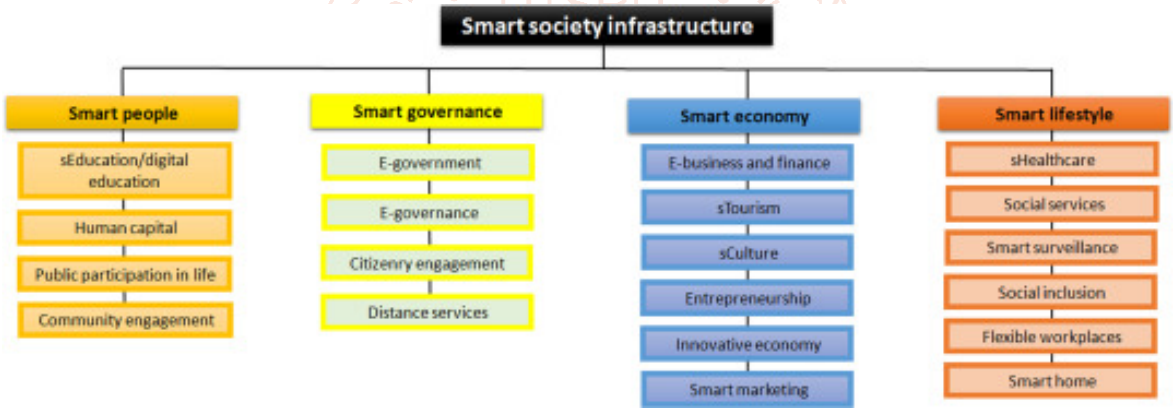

Figure 5 Components of smart-society infrastructure [3].

Figure 6 Some applications of smart infrastructure [7].

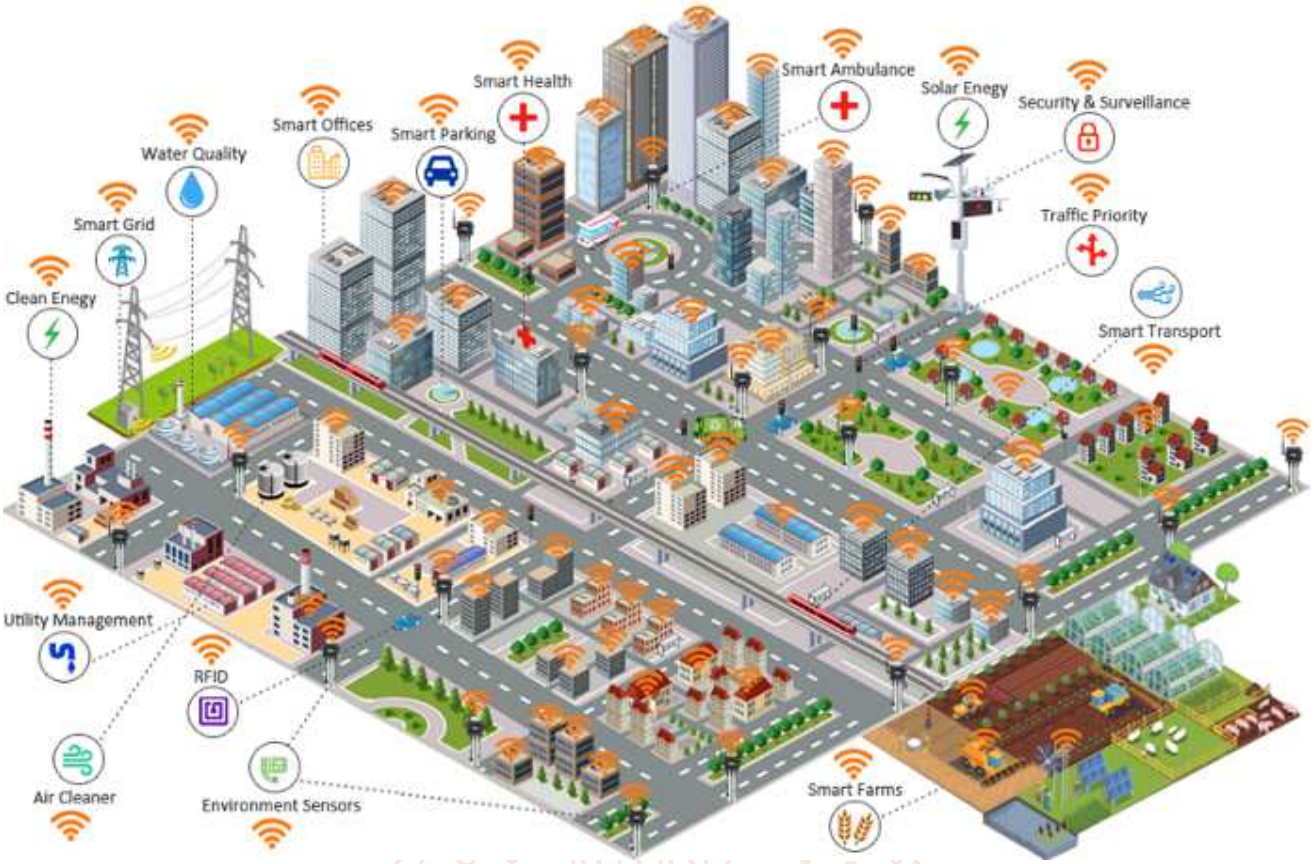

Figure 7 The concept of smart city [11].

Figure 8 Some smart buildings [6].

Figure 9 Typical traffic system [1].

Figure 10 Some benefits of smart infrastructure [5].