Science and Technology Parks: A Futuristic Approach

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ABSTRACT Most of the existing science and technology parks resort to various conventional ways to attract different stakeholders to the park. Some of these traditional measures include business support, workspaces, laboratories, networking events, accommodation, and essential commodities. Besides, with rampantly changing multidisciplinary technologies and increased data-oriented business models, the classic science and technology park value-creation strategies may not be instrumental in the near future. Hence, we foresee that future science and a technology parks should be fully integrated, sustainable, and innovative living science cities. Where park tenants can actively interact and contribute to emerging technologies. Therefore, this paper carries out an in-depth study of world's best practices in smart cities and science and technology parks, their characteristics, and value-added contributions that excite the prospective tenants. Developing on the detailed survey, we propose a unique feature of ''Autonomous Systems as a Service'' to bestow a futuristic look to the science and technology parks. It is envisaged that autonomous systems will not only provide value-added services to the park tenants but will also provide an infrastructure for testing new technologies within park premises. Furthermore, this study evaluates security and privacy challenges associated with autonomous systems and data-oriented services and recommends appropriate security measures. The role of universities in the success of a science and technology park is also delineated. Finally, the components deemed essential for the attainment of science and technology parks' objectives are highlighted.

INDEX TERMS Science and technology parks, autonomous systems, value creation, future technologies, security and privacy, security of autonomous systems, data as a service, smart cities.

I. INTRODUCTION

The idea of a Science and Technology Park (STP) dates back to 1953 when the world's first science park was opened at Stanford University, United States [1]. A science park is also termed as a technology park or a research park. The primary objective of Stanford's technology park was to provide a pleasant environment for collaboration between various stakeholders such as startups, research and development (R&D) companies, venture capital firms, and Stanford University's research brainpower. This technology park stimulated regional economic growth, thus transforming regional development policies. Similarly, other countries

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also followed, and in the 1960s and 70s, this phenomenon extended to England and Japan. In the 1980s, France, Germany, Sweden, Finland, Belgium, and some Southeast Asian countries also laid the foundations of such technological parks [2]. Correspondingly, Sydney Science Park (SSP) [3], [4] is a multi-billion-dollar greenfield development project that aspires to be a world-class facility clustering together leading innovators in the industry, education, and business. The vision for SSP is to be a fully integrated, innovation-based community that will include high-quality lifestyle opportunities. SSP aims to promote a culture of innovation, creativity, and entrepreneurship to benefit the whole region.

However, there may be a question that why do we need STPs? It is proffered that the sharing of knowledge and

resources is deemed essential to promote innovation and technological development. However, there are high communication costs associated with the transmission of knowledge to distance. Whereas technology parks and incubators support firms to transmit technical knowledge that is complex, uncertain, and in the noncodified form [5], [6]. Similarly, STPs and incubators fully articulate knowledge flows among the actors of a regional innovation system [7], [8]. If we look at the academic aspect of the science parks, the universities see the STPs and incubators as a means to conduct productive research and commercialize their technologies. The educational institutions also visualize an environment where they can improve corporate innovation capacity by converting academic knowledge and local R&D into commercial products or processes [9].

Hence, in the last decade or so, there has been an exponential rise in entrepreneurial activity at the universities, which has further stimulated activities such as patenting, licensing, research joint ventures with private companies, and the creation of spinoff companies. In this context, the universities resort to licensing for the commercialization of university-based Intellectual Property (IP). Correspondingly, universities are increasingly emphasizing the creation of new companies as a mechanism for commercialization [10]. Moreover, universities also facilitate technology diffusion by establishing technology transfer centers through the licensing of a university-based technology to an existing firm or a new venture [11].

Accordingly, there has been a rise of "Innovation Districts" in the world [12]. Innovation districts can be termed as a mash up of entrepreneurs and educational institutions, start-ups and schools, to foster mixed-use development and technological innovations. For example, David Johnston Research and Technology (R+T) Park [13], is Canada's largest innovation district. This innovation district aims at creation of state-of-the-art (SoTA) technology by incubating and helping companies in innovation, harnessing appropriate talent, and entering into a world-class ecosystem of startups. The main attractions of R+T park include: 1) A strong collaboration with University of Waterloo that is known for prolific industry partnerships to solve real-world problems. 2) The co-location of R+T park and University of Waterloo gives the residents of research and technology park an edge to be closer to the one of the world's best human resource in the form of over sixty thousand students. 3) Availability of an Accelerator Centre that offers comprehensive corporate innovation program to facilitate creation of spinoffs, develop out of the box solutions to customer problems, and fast validation of proposed solutions.

However, the desired impact of a STP may vary as per the types of tenants it accommodates. For example, the needs of a startup may differ from that of an established firm, academic research institution, or a service provider [14]. Besides, with rapidly changing multidisciplinary technologies, an increase in data-oriented business models, and resulting concerns over users' privacy, the classic STP business models may

not be very useful. Hence, it is envisioned that a STP should be a fully integrated, sustainable, innovative living science city. Where park tenants can actively interact and contribute to the future technologies with minimal impact to other citizens' privacy. Accordingly, an ideal science park should create value for all types of tenants with a futuristic approach. Therefore, there is a need to derive new value-creation strategies for STPs by evaluating world's best practices in technology parks and smart cities to attract tenants and promote technological innovation. Moreover, research is also required to explore new technologies that would give STPs a futuristic look. Subsequently, the proposed innovative systems should be carefully assessed to ensure the security and privacy of users' data in a living science city environment.

A. RELATED WORK

Existing literature on STPs is somewhat shallow, focusing on particular matters and therefore not comprehensive. For instance, researchers in [15] only evaluated the impact of science parks on local firms to validate policy effectiveness. Similarly, another study exclusively analyzed the economic impact of science parks [16]. In the same way, [17] examined the contributions of science parks to multiple stakeholders considering various contingencies. On the other hand, authors in [18] reviewed the current state of knowledge on science park contributions and proposed ways to enhance this knowledge. Also, some studies either focused on the general aspects of science parks [19] or concentrated on business incubation mechanisms [20]. Likewise, [21] mapped businesses' performance and their prospects of survival against contributions of STPs. Correspondingly, certain studies explored just a particular aspect of science parks such as entrepreneurship and incubators [22], effects of STP policies on the creation of spinoff firms [23], generalized benefits of parks and incubators [24], and the impact of science parks on different types of firms [8], [24].

Correspondingly, [25] proposed a performance management framework for science parks to demonstrate results and seek improvements. Similarly, [26], [27] analyzed the role of STPs in the United Kingdom (UK) in nurturing scientific activity and cooperation between various stakeholders. Likewise, [28] studied the effects of research centers and universities on organizations' growth, innovativeness, and overall R&D investments in the science parks. Hence, there is a lack of literature that emphasizes the value-creation strategies in STPs. Moreover, given the scope of existing literature, authors in [29] proposed that more research be done on the development of science parks. To address this, we see an opportunity in the ideation and definition of SSP to visualize SSP as an autonomous living city. Hence, this paper is relevant to researchers, policymakers, and stakeholders interested in establishing, investing in or joining a STP to make value-added contributions or gain from state-of-the-art technological development. Resultantly, this study aims to provide a holistic view of a STP as an autonomous living city

with a futuristic approach. The significant contributions of this research include:

1) Presents a comprehensive review of the world's best practices in STPs and smart cities and their value-added contributions in attracting prospective tenants.
2) Introduces numerous Autonomous Systems as a Service frameworks for STPs to not only act as the game-changing business models but also serve as a testbed for park residents to test and evaluate new technologies.
3) Proffers an analysis of security and privacy risks associated with autonomous systems and data-oriented services.
4) Recommends appropriate security and privacy measures to secure autonomous systems at various layers of the network architecture. The data security and privacy measures are further supplemented by a consolidated data strategy and viable technical controls to achieve desired cyber protection.
5) Stipulates the role of universities/HEIs (Higher Education Institutions) in the success of the STP.
6) Establishes a list of components/entities that should form part of the STP to help attain most of its goals/objectives.

B. ORGANIZATION OF THE PAPER

The rest of the paper is organized as follows: Section II covers some basic concepts related to STPs. At the same time, Section III illustrates numerous value-creation techniques and proposes ingenious application scenarios of ASaaS for STPs. Whereas Section IV highlights threats to data security and privacy in autonomous systems and related defensive measures. In addition, Section V delineates universities' role in STPs, and Section VI highlights some essential components of STPs. Finally, future challenges and conclusions are emphasized in Section VII, and Section VIII respectively.

II. STP - BASIC CONCEPTS

Before we dwell upon the benefits and objectives of STPs, it is imperative to differentiate between a smart city and a STP. Both smart cities and STPs are considered the hub of technological innovation that offers high-class livability and a quality lifestyle. However, it is perceived that a smart city is just an application of technology with the vision of providing futuristic, safe, and interactive environment for living [30]. In comparison, a STP is believed to be a property-based initiative close to HEIs [31], that fosters innovation by increasing R&D activities, extending cooperation among firms [32], facilitating knowledge transfer, and promoting the transfer-of-technology (ToT). Moreover, STPs also provide infrastructure, business support, and allied services to support the growth of startups and young firms [33]. In general, the vision of STPs is to bolster the knowledge-based economy and contribute towards local and regional economic growth [34]. Since the distinction between STP and a smart city is now

TABLE 1. Benefits of a science and technology park.

Benefits	Applicable to (Stakeholders)
Planned knowledge sharing	Startups, technology-based young firms
Unplanned knowledge transfer or data sharing	Startups, universities, technology-based firms
Collaboration	Universities, startups, technology-based young firms, industrial R&D
Proximity of universities	Startups, technology-based young firms
Proximity of research institutes or specialized laboratories	Startups, technology-based young firms, industrial R&D
Complex innovation, high number of patents and licenses	Startups, technology-based young firms, industrial R&D, mature science-based firms
Adjacency to same sector firms	All concerned
Closeness of markets and customers	Commercially oriented firms, mature science-based firms
Livability of the site	All tenants
Reputation and prestige (image building)	Startups, technology-based young firms, mature science-based firms
Cost effectiveness (accommodation, and services)	Startups, technology-based young firms
Increased social networking	All tenants
Diverse and high standard services	All tenants
Availability of skilled manpower	Startups, technology-based young firms, science park management
Economic growth	All tenants

clear, it is important to illustrate the fundamental benefits of STPs.

A. BENEFITS OF A STP

Some of the perceived benefits expected out of STPs with respect to various stakeholders are shown in Table.1. It is evident that to harbor a knowledge-based economy, a meticulously planned and efficiently managed STP

accrues knowledge sharing between startups and other technology-based young firms. Another significant contribution of a science park with a pristine location is increased collaboration between co-located organizations, technology-based young firms, industrial R&D centers, and universities. Hence, multiple-stakeholders residing, working, and collaborating in the shared space also benefit from unplanned data sharing. It is also believed that proximity to universities' research brain in the STP is productive for all the stakeholders. Correspondingly, if we consider other factors such as proximity to HEIs' research centers, closeness to same sector firms, availability of specialized labs and testing facilities, a well-equipped and prepared STP stimulates innovation [15]. Which subsequently results in a high number of patents and IP [35].

Furthermore, a well-reputed science park boosts the tenants' image (all stakeholders) [36]. It also attracts customers to various state-of-the-art products developed by commercially oriented or science-based firms. Moreover, as discussed earlier, a well-managed STP usually offers high livability conditions for its prospective tenants [37]. Additionally, a STP developed with a futuristic approach provides various high-tech services to its users, thus attracting a large number of national and international companies with promising growth potential [38]. Therefore, a user-oriented specialized STP supplied with a high standard lifestyle, essential commodities, public spaces, and high tech research facilities promotes social networking [39] and attracts a skilled workforce [40], [41]. Finally, the utmost benefit of a STP to any region is increased economic activity based on research and accelerated development of new technologies [21]. Undoubtedly, the above-quoted benefits are attainable; however, a STP should carefully set its objectives to achieve desired goals.

B. OBJECTIVES OF A STP
Keeping in view the desired benefits of STPs discussed in the previous section, some of the elementary objectives (shown in Fig.1) that a science park must pursuit include:

1) Reduce the gap between universities and the industry.
2) Increase networking and collaboration between park tenants by facilitating accessibility [42].
3) Augment knowledge sharing [43].
4) Ease ToT between various stakeholders.
5) Enhance regional technological developments.
6) Promote innovation and boost regional economic development.
7) Increase innovation efficiency [44].
8) Help educational institutions/startups showcase their technologies to secure funds for future developments [45].
9) Accelerate technological development by localizing technology-based firms at one location [29].
10) Facilitate regional progress by establishing a localized mechanism for shared resources and knowledge development [46].

11) Support product development life cycle through all stages, i.e., (a) concept development, (b) design and engineering, (c) prototyping, and testing, and (d) launch stage [47].
12) Make the science park a living science city by planning, designing, developing, and deploying value-added autonomous tech services for the park tenants.
13) Provide a conducive environment and infrastructure for the testing and evaluation of new technologies.
14) Promote and support local industry, and the R&D sector, by developing autonomous systems locally.
15) Provide excellent and cost-effective services (including accommodation, dining, workspace, business support, leisure, networking venues, etc.)

III. VALUE CREATION FOR THE STP TENANTS
It is envisioned that the progressive firms and other industry representatives residing in the science park facilitate achieving most of the park objectives. Hence, a STP should endeavor to offer unique value-added services to attract progressive tenants. Correspondingly, researchers in [18] emphasize that the science parks should have the means to make alluring contributions to all the stakeholders. Also, there should be exceptional reasons why the industry, startups, entrepreneurs, and Venture Capitalists (VCs) come to the STPs. Therefore, to form a consensus on the essential attributes that a science park should have, we analyzed some of the world's best practices in various science parks around the globe, including the Netherlands and Sweden [15], [48]. It is observed that the critical attributes of a science park (that the park tenants perceive to be attracted to) are business support, park management's commitment and expertise, proximity to universities and other firms, and high tech infrastructure. According to "Triple Helix Theory" [49], integration of industry, academia, and other sectors is a common trait of successful STPs. There are other contributing factors/attributes as well, which are highlighted in the following paragraphs.

Considering the importance of business support, science parks usually support the new firms initially during the park's planning stages and later during provisioning of desired services. Correspondingly, during the science park planning stages, the business support aims to attract quality firms, startups, and entrepreneurs. Moreover, park management selects/prioritizes the prospective tenants based on their knowledge intensity, innovativeness and by mapping their technical profile to the on-site HEI's research activities. The park management can also offer business support to the tenants in the form of consultation related to marketing, finance, IP, copyrights, and government regulations. Furthermore, financial support to the firms may be provided through public and private VC organizations and seed capital providers.

Subsequently, the activities and services that fall under business support once the science park is operational may include the university-led incubation and development programs. The incubators advise and assist the firms through
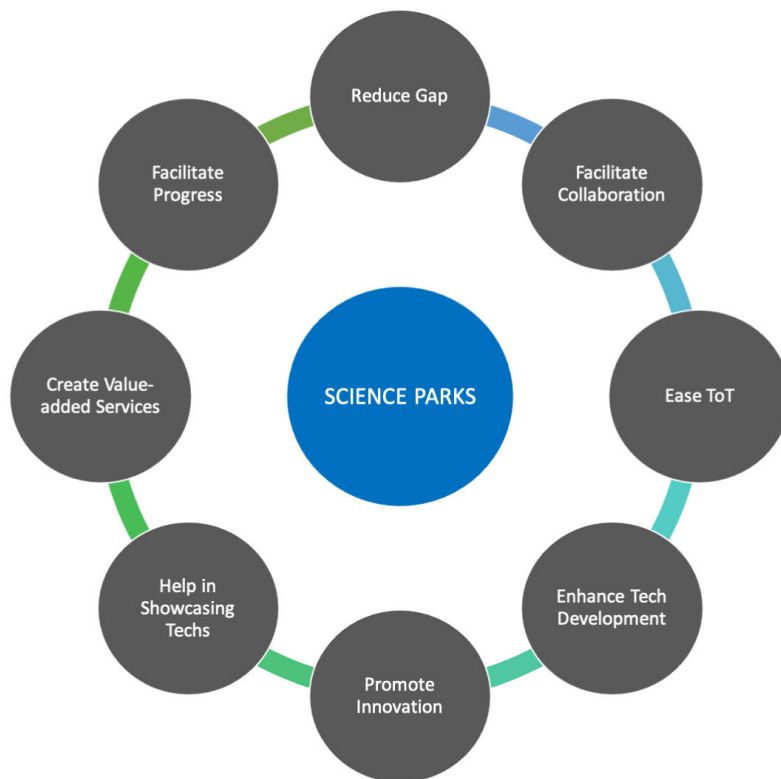
FIGURE 1. Objectives of a science and technology park.

kick-start programs in the initial period (a few months) of their establishment. The assistance can be external consultancy, access to lawyers, marketing experts, business coaches, and technical facilities. Correspondingly, young firms or startups are also interested in various training activities offered by the park management. These may include specialized workshops, symposiums, or demonstrations. The new businesses are also interested in multiple entrepreneurship programs offered during their respective preincubation, incubation, and post-incubation period. These programs also help the startups develop/refine their business ideas and reduce the investors' risks.

Another critical attribute is industrial R&D that increases collaboration and stimulates innovation. Then is the establishment of laboratories, which facilitates testing and experimentation. Similarly, proximity to universities and co-located firms /startups results in more complex innovation and a high number of patents. Thus the enterprises prefer to locate on-park premises to establish connections with the universities and associated research centers [50]. Moreover, an affordable and high-tech workplace as per business's needs, including green environmentally sound spaces, always attracts potential tenants.

In addition, information sharing between park tenants is also believed to enhance innovation, increase collaboration among the stakeholders, and boost technological development. It is also observed that the STP tenants are interested in the social events organized by the park management or other

stakeholders. These events are taken as networking opportunities to increase personal interaction, knowledge transfer, and seek professional partnerships. The social events may include academic conferences, seminars, and roadshows. In the context of social events, the provision of facilities such as conference rooms, exhibition halls, auditoriums, and theatres by the science park management is considered an essential element in attracting enterprises and industry leaders to the park premises. Moreover, the availability of a resilient, sustainable, and highly livable environment is also a contributing factor to attract people from various walks of life to the park. Likewise, park tenants also expect the availability of essential services such as restaurants, bars, banks, ATMs, supermarkets, and post offices.

Moreover, prestigious locations are in high demand by startups and high-tech companies to showcase their ideas and technologies. A science park's site should also be in closer proximity to an international airport to facilitate cargo and human resource transfer/travel. Similarly, accessibility is another contributing factor to attract firms to the science park. Where accessibility refers to the access to support services and technical knowledge provided by the network of neighboring/co-located firms [51]. Moreover, a clearly defined business plan by the STP for valuable knowledge sharing and service provisioning is also seen positively by the park tenants [21]. Researchers have also identified that the tech firms chose to stay on-site in a well-established science park to build up their prestige [52], [53]. Finally,

the science park management's commitment, expertise, and services offered also play a vital role in the success of a STP.

A. CASE STUDY OF SINGAPORE - THE SMARTEST CITY OF THE FUTURE

The previous section highlighted the importance of business support, proximity to universities, and other critical attributes that mostly contribute to a STP's success. However, in this section, we analyze various factors that make a city highly futuristic and boost its livability by improving its residents' quality of life. The same attributes can be inherited by the STPs to transform into high-tech living science cities and attract prospective tenants. For this purpose, because of developed IT infrastructure, strong government support, effective IP laws, and innovation-friendly environment, we selected Singapore as a case study [54]–[56]. The Singapore government endeavors to make Singapore the smartest city in the world by 2025. In this regard, Singapore is developing and implementing future technologies in eight highly technical and specialized areas.

The first on the list is the use of autonomous cars. Singapore has implemented autonomous taxis since 2015, and to further promulgate the use of driver-less cars, the National University of Singapore (NUS) has developed and implemented the concept of self-propelled golf buggies. Similarly, Nanyang Technological University (NTU) is working on driver-less city buses and aims to bring them on the roads by 2022. Secondly, the Singapore Government is using drones to enhance the local policing capability to monitor crowds. The specialized police drones are equipped with powerful sirens, blue and red police lights, and a searchlight almost ten times more potent than a standard car headlight. Besides, the police are also making use of autonomous ground bots (rovers) for remote surveillance. The rover is equipped with cameras and sensors and is fully independent. However, it can be programmed with pre-planned routes for navigation. Moreover, to raise the living standard and quality of life of its people, the Singapore Government has paid due attention to smart homes. These houses have been equipped to automate the daily routine of the residents. In this context, the house lighting, Heating Ventilation and Air Conditioning (HVAC), infotainment, energy, and security settings can be customized as per the user's preferences. For example, the smart home can be configured to switch off extra lights, raise curtains, reduce security level, start the coffee machine, and regulate shower temperature under the good morning settings as per user-preferred timings. Similarly, the settings can be configured to prepare for bedtime. Correspondingly, robotic vacuums and smart house assistance are common elements in Singapore households.

Furthermore, to ensure citizens' security on the roads, the Singapore Government is developing smart lamp posts (street lights). These lamp posts are equipped with numerous sensors to monitor environmental changes, respond to high sounds like car crashes, and screams for help. Also, plans have been made to install smart radars and facial recognition systems to detect unusual traffic and unlawful citizens. Another technological landmark achievement of Singapore is the ubiquitous use of robots. It is estimated that there are around four hundred and eighty-eight robots per ten thousand people in Singapore. The robots have been employed in shopping malls where people can interact with them by asking questions. These robots can also sing, rap, wink, crack jokes, and perform cleaning duties. They are also being used in restaurants to collect and return trays and used crockery from the dining tables.

A more official version of the robots is being used as robocops at airports. These robocops act as auxiliary police and perform various security duties. Another breed of robots is being employed in pharmacies to assist its human counterparts in delivering medicines. Other than these, there are numerous personal, social, and service robots, e.g., a robot-coach that advises and demonstrates physical exercises to the senior citizens. Another monumental step by the Singapore Government is the amalgamation with Virtual Reality (VR). Subsequently, different VR applications have been developed and put into use, e.g., intelligent interactive mirrors have been deployed to help kids with learning disabilities to practice various tasks such as tracking a train or finding the way to a particular restaurant. Similarly, equal attention has been given to Augmented Reality (AR) applications used by various enterprises to attract customers to their products and try them virtually. Lastly, the Singapore Government is in the process of deploying a three-dimensional (3D) city model to provide a testing ground to students, researchers, citizens, and government officials for various learning, planning, and professional activities.

B. AUTONOMOUS SYSTEMS AS A SERVICE

Keeping in view the discussion on park attributes and cutting edge technologies in the preceding sections, we propose a unique feature of Autonomous Systems as a Service (ASaaS). In this business model, numerous autonomous systems and smart applications provide unparalleled services to the park tenants. One of the reasons we are interested in ASaaS is that these are economical besides other value-added services. They also reduce the associated risks to human lives [57] in the provision of various services and increase the quality of life. However, before these autonomous systems are discussed, it is imperative to understand an autonomous system's basic concepts and requirements in a STP setting.

1) AUTONOMOUS SYSTEM DEFINITION

The history of autonomous systems dates back to 1964 when Leonard Scheer from APL Adaptive Machines Group developed and demonstrated sensors and actuators supported autonomous rover system. The rover could navigate, identify an electrical outlet, and plug in to recharge its batteries without any human intervention. Hence, an autonomous system can be defined as a system that can change/modify its behavior when subjected to unexpected events during
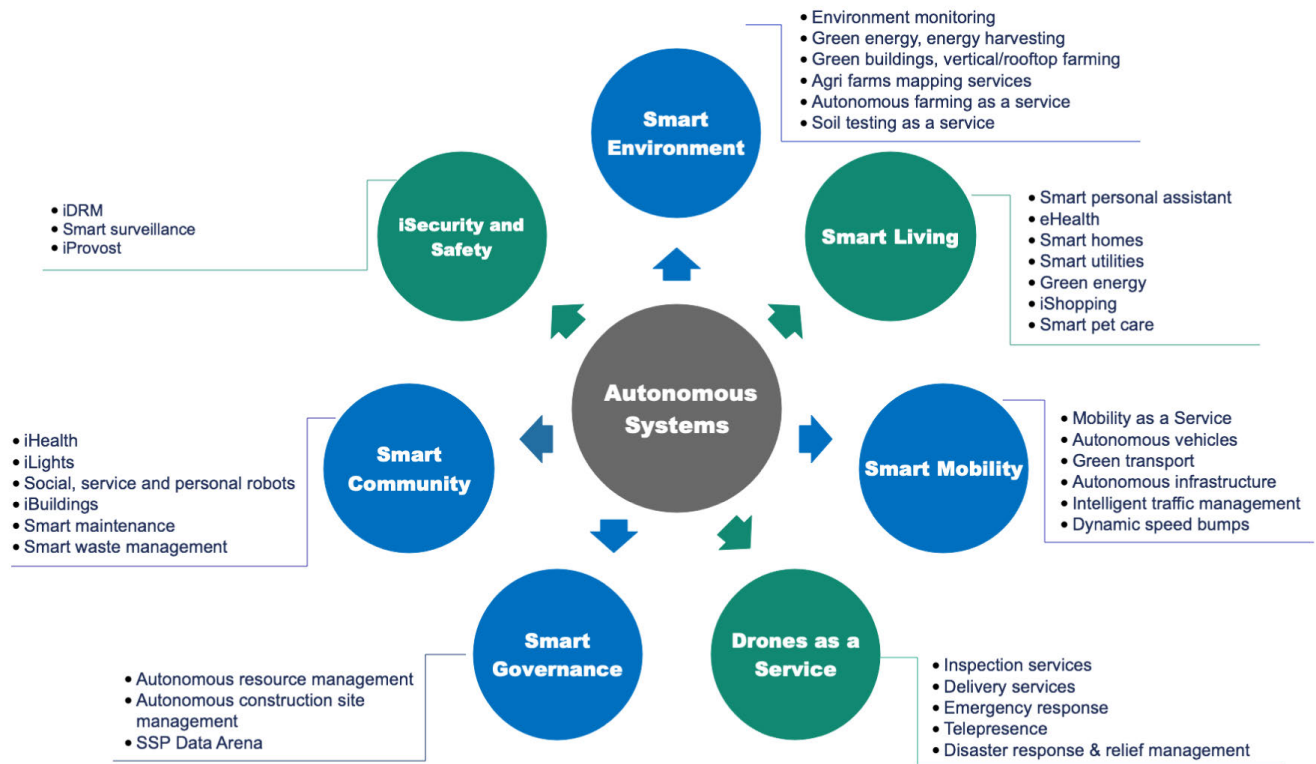
FIGURE 2. Autonomous systems in science and technology parks.

operation [57]. However, once we talk about ASaaS in a science park, a particular system must meet some essential requirements.

2) REQUIREMENTS FOR AN AUTONOMOUS SYSTEM IN A STP

(a) An autonomous system should be designed and developed based on open systems and standards-based approaches for compatibility with other technologies.

(b) It should interact with users through a well-designed mobile application (app).

(c) In addition to default settings, the system should have the capability of being personalized by remembering user's preferences so that his experience is always familiar and easy.

(d) It must conform to respective country's legislative, regulatory, and standards frameworks, e.g., Section 95 of Australian Government's Privacy Act 1988 [58], outlines the guidelines issued by National Health and Medical Research Council (NHMRC) concerning handling/processing of personal health information.

(e) Ensure security and privacy of users' data at all stages of STP operation.

(f) It should be self-sustained (including operation and maintenance).

(g) To reduce the carbon footprint and support renewable energy technologies, the system should focus on using

solar energy, energy harvesting mechanism, or other green energy technologies.

(h) To create a unified or collated picture of the ASaaS to the park tenants, all the autonomous systems should be able to integrate.

(i) It should support open communications protocols/standards.

(j) The system should have minimal operation and maintenance requirements (including infrastructure, human resources, power, spares, scheduled servicing, etc.)

(k) Availability of any simulation technology or a lab setup related to a particular/multiple autonomous systems will help the researchers and industry partners test and further improve respective technology/system.

C. PROPOSED AUTONOMOUS SYSTEMS FOR A STP
Fig.2 gives an overview of the autonomous systems that we have conceived for STPs. The design details, features, and the services offered by respective systems to the STP tenants are illustrated in following paragraphs.

1) SMART AND GREEN ENVIRONMENT
According to [15] a vibrant and green landscaped public area indicates the level of environmental quality. Correspondingly, potential tenants of the science park value a clean and healthy environment for quality living. Hence, we propose an autonomous environment monitoring system

that is self-sustainable in monitoring and maintaining healthy air and water quality levels. Such an approach is also expected to ensure high flora and fauna standards in the STPs. The factors that contribute to achieving the desired outcomes through autonomous smart and green environment system may include:

- Monitoring of air pollution (including vehicle emission control), and water quality.
- Monitoring of soil quality to assist in the growth of vegetation in the area.
- Soil moisture testing to facilitate smart irrigation.
- Smart weather monitoring; Weather sensors can be integrated with intelligent street lights. These sensors can monitor and analyze the effects of global warming and propose remedial measures.
- Smart tree monitoring: Smart tree sensors enable efficient monitoring of tree states. This not only ensures a cost-effective optimal tree growth and cheaper maintenance but also helps in early detection of diseases.
- A green environment is not possible without green energy such as solar or wind power. Hence, the due focus should be given to renewable energy sources in a STP.
- Correspondingly, to promulgate green environment, researchers in [59] highlight the importance of sustainable, intelligent buildings. It is believed that the availability of smart and green buildings is one of the main attractions to lure potential tenants to the STPs. The main features of intelligent buildings include indoor environment control, water, and energy efficiency, eco-friendly construction, roof-top/vertical gardens, durable and sustainable design, waste reduction and management, smart surveillance and intrusion detection system, disaster response, high tech ICT services, dynamic and spacious workspaces, and last but not the least charging stations for electric/hybrid vehicles.
- Similarly, since the onset of the fourth revolution in agriculture triggered by the advancement in ICT, especially Internet of Things (IoT) technologies, there has been an increased focus on smart/autonomous farming [60]. Smart farms not only ensure food sustainability but also make efficient use of the available space. Today, numerous robotic machines can autonomously perform various farming/agriculture operations, including weeding, harvesting, plowing, fertilizing, and irrigation. In addition, autonomous drones have been developed to calculate biomass development and fertilization status of the crops [60]. The drones also provide visual information to the farmers concerning various plant diseases. Similarly, advancement in IoT technologies can be beneficial in cattle, horses, ducks, swans, or other domestic animals/wildlife management. Correspondingly, we propose a business model of Autonomous Farming as a Service in the subsequent paras.

a: AUTONOMOUS FARMING AS A SERVICE

To patronage the concept of a STP as a self-sustainable autonomous greenfield project, there may be one to two-acre size farms to grow different crops, vegetables, and fruits to sustain park tenants. Hence, to effectively and efficiently realize agriculture (Agri) farms' development and autonomous management in STPs, we propose Autonomous Farming as a Service (aFaaS). The proposed system aspires to tackle conventional agriculture problems such as high machinery costs, safety risks concerning massive machines, shortage of skilled labor, the slower value of trade-ins, long working hours, wastage of products, and materials during seeding, fertilizing, spraying, harvesting, picking, sorting, and irrigation. Moreover, it is difficult for farmers to detect and identify crop/plant diseases in time for effective treatment without losses in crop yields in traditional settings. Furthermore, the human workforce's safety and health concerns due to accidents while working with heavy machinery and pesticides is also a matter of grave concern.

Hence, the concept of precision agriculture/farming involves farm management with the support of various technologies. The primary objective is to improve crop production and environmental quality. Thus, to address above mentioned problems, assist farmers in optimizing every acre of their operation, and achieve high productivity with reduced cost effect, aFaaS utilizes advancements in agricultural technologies, especially the autonomous systems [61]–[63]. Before illustrating aFaaS business model shown in Fig.3, it is highlighted that all the autonomous vehicles, robots, and agricultural machines have some common traits. They all are equipped with a navigation system and multiple layers of safety equipment, sensors, and tools to detect obstacles (tree line, water bodies, power lines, rocks, etc.), perform self-diagnostics and generate an alarm in the case of any error/faults to notify owners. The sensing and safety equipment includes LiDAR (Light Detection and Ranging) to create a 3D map of the area, SONAR (Sound Navigation and Ranging), visual cameras, and IR sensors to detect obstacles, kill switches for emergency stop, environmental sensors to monitor temperature, humidity, soil moisture, wind speed and GPS for navigation [64].

Moreover, before the autonomous agricultural machinery is put into operation, the farmer creates the path plan by entering the boundary and permanent obstacles information for each field/farm on the field's satellite image using aFaaS user app. To cater to people who are not comfortable with computers and technology, they can follow the "Drive and Learn" approach. In which, the farmer can map the field/farm by driving in the farm. After that, with the help of LiDAR and other sensing equipment, the field/farm boundary and obstacles are automatically mapped through the aFaaS app. The autonomous robots/machines can then move on the prescribed route using GPS. Moreover, the farmer can set various parameters for a particular agriculture operation, e.g., in the case of seeding, he can set the seed density, the pattern of

laying, and the distance between each seed location through aFaaS app.

Another key highlight of aFaaS is that it does not employ exiting large-scale agricultural machineries such as tractors, harvesters, and sprayers. Instead, based on the concept of Mobile Agricultural Robot Swarms (MARS) [65] and swarm farms [66], aFaaS employs swarms of small agricultural robots with a modular design. These robots can be customized for a particular task. Moreover, the robots are carried and managed through a mobile Robots Transport and Coordination Unit (RTCU). The RTCU acts as a transporter for the robots and can also store supplies, e.g., seeds, fertilizers, water, pesticides, spare tools, batteries, etc. RTCU also functions as a Real-time Kinematic (RTK) base station to ensure robots' positional accuracy.

On the other hand, the robots can operate around the clock with satellite navigation and data management through aFaaS and STP Data Arena (being illustrated later in Section-III-C8). At the same time, the farm owners have permanent access to their data. As shown in Fig.3, the autonomous robots can perform numerous agricultural/farming tasks [67] including soil sampling and testing, seeding, planting, spraying, weeding, crop protection and inspection, watering, harvesting, fruit picking, sorting, materials handling, pruning, and grass cutting/mowing. It can also be seen that aFaaS may employ a combination of aerial and ground robots as per the requirements of the tasks. Although some of the agricultural/farming operations can be achieved by both platforms, yet there are some distinctions.

Ground-based autonomous robots varying in shapes and sizes such as a crawler, caterpillar [68], [69] and the most simplistic wheeled platforms are the common types. As compared to their aerial counterparts, ground robots can be equipped with more sensors and actuators without considering their weight. The sensors may include GPS, LiDAR (considered better than Radars), SONAR, visual cameras, kill switches, and weather sensors. Moreover, the autonomous robots designed for picking fruits may have different types of end-effectors, e.g., electric gripper, pneumatic gripper, suction cups [70], gecko gripper, origami flower gripper, fruit picker, trash fingers [71] and other robotic tools, depending upon the shape and size of the fruit, bins, or nature of the task. Similarly, to compensate for the terrain-specific limitations of wheeled robots, spherical robots can also be used in all-terrain types for exploration [72], surveillance [73], and measuring soil temperature and moisture for precise agriculture [74]. Hence, some of the tasks that can be performed explicitly by ground-based autonomous agricultural robots include:

1) Seeding and planting: Ground-based robots controlled by RTCU can be employed in a swarm for seeding or planting crops/saplings.
2) Weeding: It involves using computer vision and machine learning (ML) to detect weed in cereal crops such as wheat, rice, maize, oat, barley, rye, and millet. The weed can be controlled by two methods. The

first one is precision spraying, in which the robots accurately spray herbicides at the exact location of the weed to prevent any overlapping or overflow of the pesticides. However, chemically removing the weed has other associated hazards affecting actual crops and adjacent soil. Hence, to manually remove the weed in an old-fashioned way without any labor and in less time, autonomous robots can be equipped with a plucking tool. It is also visualized that the robots can autonomously navigate different field configurations and run unstoppable for long hours [75].

3) Precision spraying: Use of pesticides is necessary to prevent crop losses and improve yield. Conventionally, farmers use traditional sprayers to apply pesticides. These sprayers distribute them uniformly over the entire field. Subsequently, due to toxicity, pesticides have a significant impact on the environment and people's health. Therefore, there is a need for accurate delivery of defoliants in the correct amount using a fleet of autonomous robots to reduce the impact on humans and the environment [76].
4) Soil moisture and temperature sensing: Ground robots equipped with the right tools are the most suitable for checking soil moisture and temperature, especially once crops/plants grow up and it is not easy to access soil from the top.
5) Precision irrigation. Based on soil moisture and soil temperature readings, the ground-based robots can be utilized for precise watering of the crops/plants. Such a controlled irrigation mechanism will help in conserving water, especially in dry or drought-hit areas.
6) Measurement of water stress: An autonomous ground-based robot equipped with a micro-thermal and hyperspectral camera can measure water stress in a farm/field. Water stress can arise due to excess water (in case of floods) or water deficit (during drought) and affect crop productivity. Therefore, measurement of water stress level in a field is essential to ensure precise watering of the crops/plants.
7) Measurement of Leaf Area Index (LAI): Robots on the ground are suitable to measure LAI. Where LAI is the ratio of leaf surface to the unit ground area, which reflects the essential ecological characteristics by quantifying the amount of foliage in the plant canopy [77].
8) Autonomous ground robots are also useful for grass cutting/mowing without any human intervention.

In comparison with ground-based robots, aerial platforms can be employed for:

1) Pest and disease control: Pests and diseases can be detected in crops/plants by applying computer vision techniques on RGB (Red Green Blue) and 3D images of the crops/plants [78], [79]. Moreover, the same can also be done by taking samples from the fields/orchards and analyzing them in the laboratory. Correspondingly, the correct amount of fertilizers can be calculated and applied to the crops [80], [81] with precision and
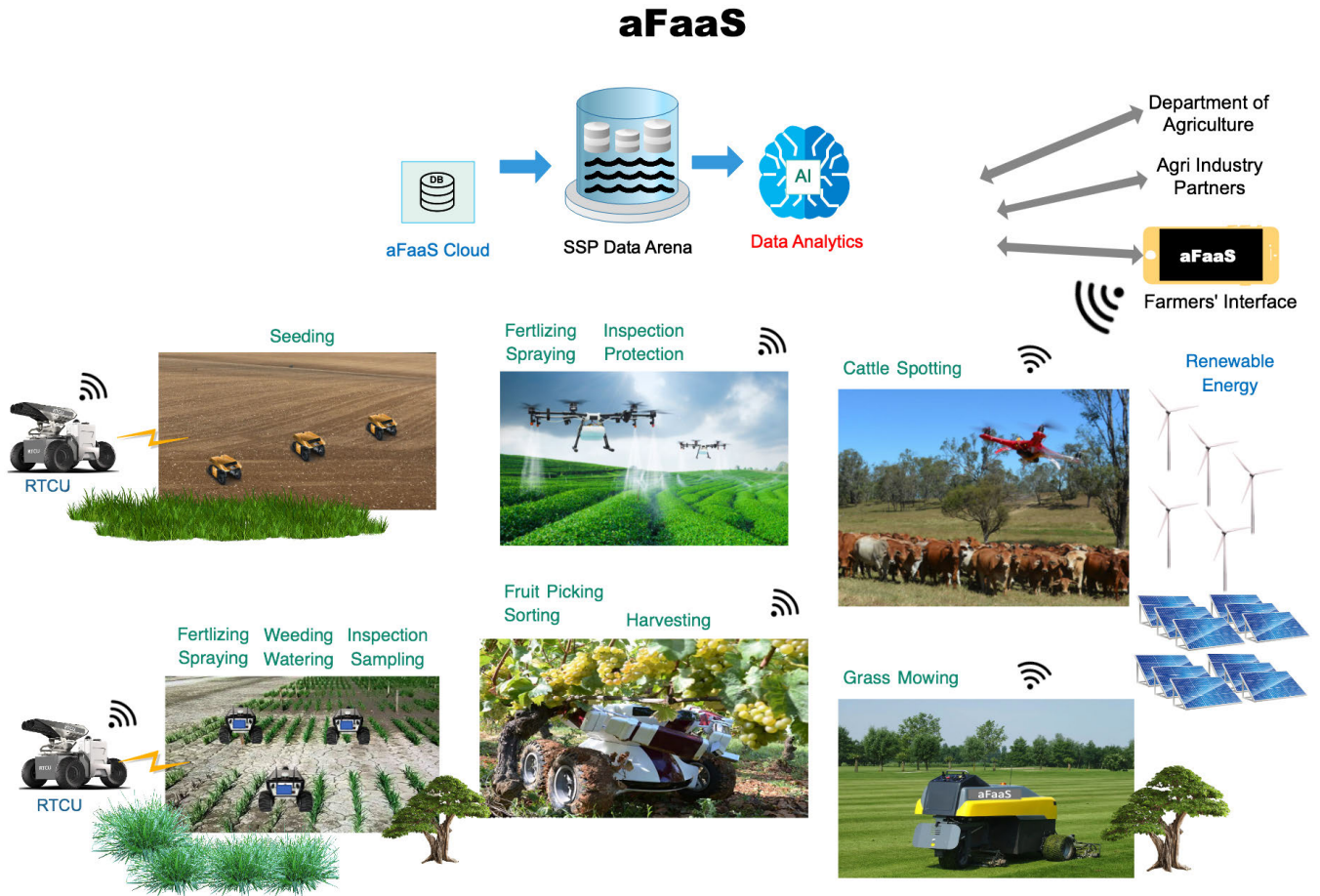
FIGURE 3. Autonomous farming as a service.

economy of effort using robots. There are, however, different parameters that need to be optimized for the effective and efficient delivery of fertilizers. These parameters include the operational height and velocity of the Unmanned Aerial Vehicles (UAVs) and the volume of fertilizer delivered as per different heights and types of plants.

2) Yield Prediction: UAVs can also collect RGB and Normalized Difference Vegetation Index (NDVI) data from the crop/plants. The collected data can then be analyzed to predict crop yield using deep Convolution Neural Networks (CNN) [82].

3) Distributed environmental monitoring and assistance in crop pollination: Micro aerial robots to the likes of RoboBees [83] may be employed to monitor environmental parameters. They can also assist in the pollination of plants as well as crops in the STP.

4) Crop inspection and protection: Appropriately equipped autonomous drones can inspect the crops and plants. The drones provide high-resolution images that can be used to check crops, detect diseases, and find unseeded rows or bare soil in the field [84]. Similarly, UAVs can also protect crops and fruit trees from birds.

5) Cattle spotting: Australia is home to world's largest cattle stations. E.g., Anna Creek has an area of around twenty-four thousand square kilometers, followed by three other stations with an area of more than fifteen thousand square kilometers [85]. Therefore, cattle in such large areas can only be tracked and monitored by using aerial platforms.

b: AGRI FARMS MAPPING SERVICE

Mapping of agricultural and forestry land provides means to estimate current production and environmental states. It also helps in monitoring progress over time. The information on production and ecological conditions can be used in site-specific farming to tailor specific crop and soil treatments for each field [86], [87]. Keeping in view the advancements in 3D mapping technologies and their benefits for the farmers, a STP may offer Agri farms mapping service. There are two ways to create a 3D map of a field: using ground-based robots and, secondly, by utilizing aerial technologies.

Correspondingly, satellite imagery and the images obtained from manned aircraft are used to map land all over the world. However, satellite and aircraft sensory data's spatial resolution is of low quality compared to a UAV.

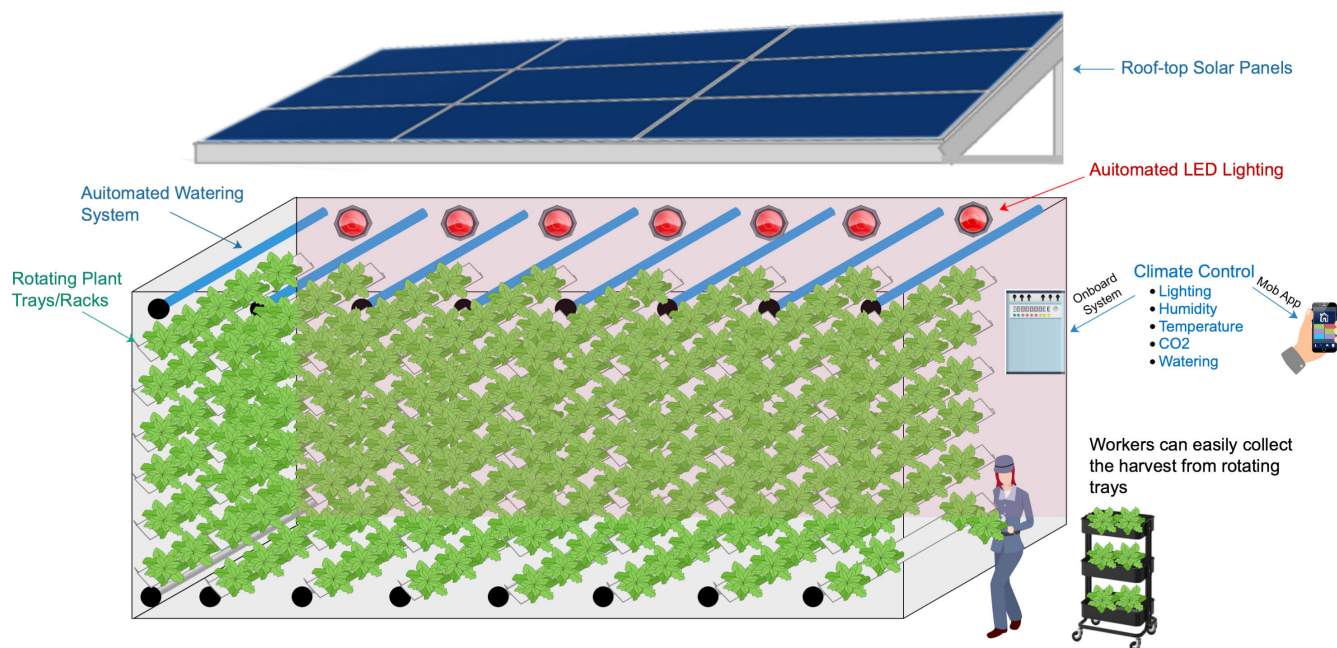**Shipping Container-based Autonomous Farm**

FIGURE 4. Autonomous vertical farm.

However, some limitations may affect the quality of images or operation of UAVs. E.g., the presence of clouds, the extended data delivery times, the need for special permissions, and the cost effect. Subsequently, the low spatial resolution sensory data may underestimate productivity and environmental factors and result in insufficient treatment coverage [88]. Besides, with the advancements in vertical take-off and landing technologies, UAVs like quadcopters are among the best alternatives. These UAVs are economical, efficient, can carry multiple sensors, and do not have many restrictions on the usage [89].

UAVs equipped with multi-spatial sensors, including LiDAR, RGB, thermal, and hyperspectral imaging, can be used to map green farms. Similarly, LiDAR mapping data can then be used to evaluate the impact of agricultural production methods [90]. In addition to large-scale farms, LiDAR mapping and monitoring [91] can also be applied to orchards and wineries. Moreover, the mapped data can also estimate crop volume/canopy and related biomass for precise delivery of nitrogen (N), which is the primary source of nutrients for crops/plants. Similarly, ground-based mobile robots equipped with a stereo camera, location sensor, and inertial measurement unit [92] can create 3D terrain maps using Simultaneous Localization and Mapping (SLAM) algorithm for precise agriculture [93]. We believe that the above-discussed mapping technologies can also be used to create a 3D map of a STP for the urban archaeology project.

c: SOIL TESTING AS A SERVICE (STAAS)

Soil plays an integral part in keeping the environment healthy by regulating N use and carbon flow. Similarly, soils help in mitigating greenhouse gasses [94]. However, crop health may be threatened by soil-borne diseases. Numerous factors influence soil-borne diseases such as block selection, crop rotation, varieties, nutrition, irrigation, and fumigation [95]. Therefore, healthy soil is essential for the environment and high yields in Agri farms. Hence, to facilitate commercial and household farmers, the STP must offer STaaS, in which autonomous robots collect soil samples from the prescribed location. The soil samples are then analyzed and profiled for the microbial population using Next Generation DNA Sequencing (NGS). STaaS may also provide agronomic insights from soil data using AI-driven analytics. The test results will help farmers understand their soils and decide on the type and amount of nutrients, fertilizers, and water to be used in the farms.

There might be a question of what advantages we get by using autonomous robots for agricultural tasks. Rather people are a bit pessimistic about giving autonomy to the machines. Subsequently, they see it as a safety risk in case of a hardware/ software failure and a threat to human jobs. However, in reality, autonomous technologies are paving the way to create and grow new industries. Similarly, jobs requiring skills related to servicing, managing, observing, and optimizing autonomous systems' performance are emerging. Moreover, the demand for competent data engineers and analysts is also on the rise.

Some other benefits of using robots in the agriculture/farming sector are:

1) Robots can perform dangerous and high precision monotone tasks.
2) Autonomous robots can be more efficient in performing Agri tasks because they better understand the situation based on sensor data and access to online databases and forecasts.
3) Robots mostly operate on batteries or solar energy; hence they contribute to a greener future with less carbon footprint and noise pollution.
4) Robots will optimize the use of resources, including water, energy, time, and skilled workforce. Thus, increasing the yields of the farms.
5) Save farm workers from various risks/hazards including:
   - Exposure to pesticides.
   - long working hours.
   - Injuries from heavy machinery.
   - Exposure to heat and ultraviolet (UV) rays.
   - Organic dust toxic syndrome that is caused by inhaling dust from moldy material, thus causing an inflammatory reaction in the lungs.
   - Exposure to excessive noise from machines.
   - Risk of accidents caused by fatigue, wild weather, and equipment failure.
   - Stress of health-related claims and huge costs of medicines.

However, at the same time, there are particular challenges associated with using robots in farming. For instance, unlike industrial, the agricultural environment is not controlled. Hence, natural calamities like rain, storms, flood, fire, and earthquakes affect the operations. Therefore, agriculture requires more versatile and robust robots. Moreover, despite high economic and environmental benefits, the adoption of autonomous Agri technologies is very slow [96]. This lag can be attributed to knowledge gaps in farmers around the world. Besides, precision farming has not been adopted in an umbrella deployment. Instead, some specific tasks are automated to meet the farmers' needs. Correspondingly, the existing robotic technology in precision agriculture is limited to vehicle guidance and auto-steer systems. The reason is that the economic benefits are easily achievable without requiring the integration of additional components or decision support systems [96]. However, it is envisaged that aFaaS offered by the futuristic STPs will pave the way for better understanding and complete transformation of traditional agriculture/ farming operations with autonomous technologies.

d: AUTONOMOUS VERTICAL FARMS

To avoid uncertainties emerging from natural calamities and global warming, a more refined variant of smart farms is autonomous vertical farming. The concept of vertical farms is not new. In 2010, Kono Designs created an urban farm in a nine-story office building (Pasona Headquarters) in Tokyo, Japan. In addition to providing green space, this farm also allows its employees to grow and harvest their food at work [97]. Vertical farming is expected to be the best option to meet future food production requirements in the backdrop of the rapidly increasing global population, shrinking agricultural lands, and adverse effects of global warming [98]. Hence, vertical farming's primary objective is to yield maximum harvest with economical use of resources and zero waste in a minimum possible space. E.g., as shown in Fig.4, a small autonomous farm can even fit into a standard shipping container [99]. The farm is equipped with various sensors and actuators to automate the processes without any human intervention. The smart environment provides a crop with a perfect climate, including light, temperature, humidity, nutrients, and water every day. On the contrary, it is impossible in the natural environment.

One of the significant benefits of growing plants in such a concealed/controlled environment is that there is no need for any pesticides or herbicides. Hence, there is no danger of passing any contamination to humans. The automated farm in the shipping container is designed in a way that one container can accommodate hundreds of trays. At the same time, the dimensions of the trays can be adjusted as per the size of the plant/crop. Therefore, each vertical farm can be individually climate controlled, allowing for a perfect environment for each crop at every stage of its life. Moreover, the sensors-based watering system ensures that water and nutrients are distributed as per requirement, and the excess water is also recycled. It has been tested and proven that autonomous vertical farms yield quality products in terms of size, taste, and nutrient value and ensure the efficient and economical use of resources [100], [101].

2) SMART LIVING

Besides dynamic workspaces, smart living is an equal fascination for present and future park tenants. The desired services in this regard include:

(a) **Smart Homes:** Houses with an intelligent security system, smart lighting, and HVAC (energy-saving mode when the house is empty) are no more out of reach. Hence, STP's management must provide intelligent homes equipped with high-tech gadgets/technologies to its tenants. Similarly, the availability of intelligent appliances such as a smart refrigerator with inventory notifications and smart vehicle diagnostics (fuel, battery, tire pressure, coolant, engine oil) is also vital. Correspondingly, an intelligent home application (app) must allow the residents to configure different ambient settings such as "bedtime" mode. In this mode, the unnecessary lights (as per user's preferences) are switched off, the security system is armed, and non-required appliances are put into idle mode. In the same way in the "Good Morning" mode, the security lights and nonessential security equipment are switched off, and necessary appliances such as coffee machine, toaster, and oven are warmed up.

(b) **Smart Personal Assistant:** This feature allows providing services to a tenant as per his personal preferences. E.g., the tenant gets an alert for wake-up as per daily traffic, road and weather conditions, office time, meetings schedule, or if the vehicle requires refueling. He may also be notified when there is a restaurant deal on his favorite dish, or he gets an alert for his favorite movie show in the cinema. Similarly, a resident may be suggested to attend a social/professional networking event in the science park based on his professional/personal interests, research area, skills, etc.

(c) **eHealth:** Remote healthcare is considered a basic need in the current pandemics era. The remote health monitoring devices comprising sensing and actuating systems keep track of an individual's vital physiological signs and inform the medical personnel immediately upon any medical emergency. In this context, a portable, lightweight on-body sensing device can monitor a person's vitals, including heart rate, ECG, blood pressure, and blood sugar. It can also keep track of and inform the patient at the time of his usual medication. The data or any alarm generated by these devices instantly notifies the medical center for emergency response [102], [103].

(d) **Smart Utilities:** For efficient usage of home utilities such as water, gas, and electricity, smart metering can be offered as a service (SMaaS). Hence, the residents can be informed about the utilities' usage in real-time. This service can be provided in the form of a smart metering app embedded in the science park user dashboard (main app). The smart metering app will assist the users in efficient and economical use of the utilities based on peak and off-peak hours [104]. Moreover, data collected through smart meters help the service providers detect any leakages, line losses, or faults at the earliest than the manual metering services [105]. Likewise, smart metering also reduces the cost of manual meter reading, and the continuous information flow helps the distributors understand demand patterns and supply forecasts. Hence, the utility companies can reduce operational costs and pass some of this financial relief onto the consumers.

(e) **iShopping:** Although world's first VR-based shopping app was launched in May 2016 to enhance customers' shopping experience [106]. However, in a post-pandemic (COVID-19) environment, online shopping has increased enormously [107]. For example, in South Australia, online shopping has seen an increase of sixty-four percent (Year Over Year (YOY)) in November 2020 [108]. No wonder businesses worldwide have started using immersive VR environments to provide an interactive in-store equivalent shopping experience to the customers without leaving their homes [109]. Hence, today people can shop for clothes by trying them virtually using mobile VR and AR apps. Moreover, they can also buy products, e.g., furniture, by virtually decorating their house/room space. Therefore, we foresee STPs offering a VR/AR-based shopping services to the park tenants in both online and in-store environments. The objective should be to make the life of the park tenants productive and easy. Some other features of the perceived VR/AR-based shopping environment in the STPs may include; display of product's key features, e.g., for food products, it may show its origin, date of the package, user rating, taste, seed or seedless, nutritional information, special offers, and comparative prices at other stores.

(f) **Smart Pet Grooming:** In today's busy life, it is challenging and stressful for people working in offices for long hours to take care of their pets at home. Hence, to facilitate researchers, developers, and other tenants at STPs, a smart pet monitoring, and grooming system is recommended. Such a system should have the capability to monitor the pet's whereabouts, interact and play with it like humans, take it for a walk (in case of dogs), conduct scheduled or emergency visits to the vet, and feed the pets at times prescribed by the owner. This interactive assistance in the absence of a human owner is expected to keep the pets stress-free and happy and keep them refrained from destructive activities while home alone.

Correspondingly, there has been a significant advancement in computing, sensing, and actuating communications technologies and automobiles. However, at the same time, an increase in population has given rise to the number of cars on the roads, thus creating a stressful negative impact on the environment, human safety, and transportation systems [110]. Hence, to increase drivers' and driving safety, efficient time management, and optimum resource utilization, some of the leading tech companies, car manufacturers, and governments have started investing in autonomous cars. The greater interest in autonomous car technologies is to launch personal and fully commercialized autonomous car fleets to improve traffic safety.

3) MOBILITY AS A SERVICE (MAAS)

Keeping abreast with world trends and future requirements, the modern STPs should aim to provide autonomous MaaS for park tenants and visitors. More importantly, the science parks must serve as a testing ground for new autonomous transport infrastructure and related technologies by providing a rare real-life greenfield city environment. In this regard, the primary prerequisite is autonomous intelligence, which must permeate the system, from recharging, to maintenance, garaging, parcel handling, scheduling, and user interaction. Correspondingly, some other desired constituents of MaaS are:

(a) **Autonomous Vehicles:** The fundamental elements for the autonomous vehicles comprise: state of the art smart vehicle technologies (hardware and software), fully autonomous control, fail-safe navigation
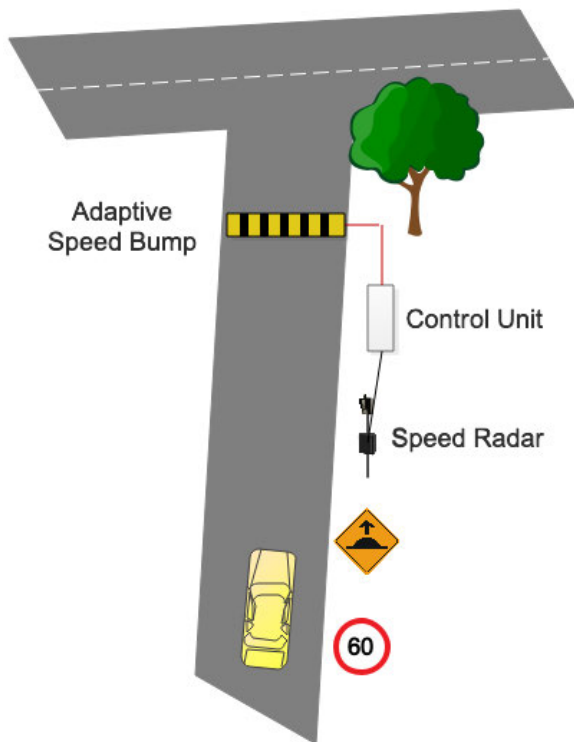
FIGURE 5. Adaptive road bump.

to make efficient use of parking space and keep cars safe from thefts, accidents, and other sabotage activities. To make the vertical car park more economical and eco-friendly, it can be operated just on solar power with sufficient battery backup to sustain through prolonged bad weather days. In addition to the autonomous vertical car parks, the autonomous cars' navigation system should be able to communicate with the smart parking systems so that the car is taken directly to the empty car space at/near the desired destination. Moreover, to make the recharging of driver-less cars more autonomous, the roads in the future STPs may be equipped with dynamic wireless charging lanes [115], [116].

Besides, when we talk about autonomous infrastructure, the discussion is not complete if smart concrete in constructing self-healing roads, pavements, and other architectures is not highlighted. Smart concrete is an upcoming technology that can extend respective infrastructure's life by autonomously repairing the cracks [117]. The mechanism behind smart concrete is a super absorbent polymer that is mixed with the concrete during the construction stage. Over the period, when cracks develop in the concrete architecture and water enters these cracks, the polymer absorbs the water and produces concrete-like material that fills in the gaps. Scientists believe that cracks of even a few microns can be fixed to prevent significant damage. Similarly, using Phase Change Materials (PCM) like Butyl Stearate (BS), concrete's thermal properties can be enhanced [118]. As a result, the ambient temperature in a concrete building can be maintained as per the comfort level of humans by preventing temperature fluctuations.

system [111], integrated health monitoring system to monitor passengers' health such as heart rate and blood pressure, emergency response to inform concerned authorities regarding a safety or health emergency event, simple user interaction using Natural Language Processing (NLP) or other Artificial Intelligence (AI) technology to communicate with normal as well as passengers with a disability. Similarly, self-charging capability is also an essential requirement. Hence, once in low power, the autonomous car should automatically park itself at a prescribed charging station and get a recharge.

(b) **Green Transport:** In a bid to contain the impact of global warming, the STPs should advocate the use of green transport within park premises. Green transport may include electric or solar vehicles. Moreover, in addition to autonomous, green cars, smart personal transportation such as self-driving scooters [112], can be used to commute in various areas of the park.

(c) **Autonomous Infrastructure:** Operation of autonomous vehicles cannot be completed without autonomous/smart infrastructure. E.g., A driver-less vehicle once approaches a charging station to recharge its batteries; the charging station should have the provision of wireless charging to prevent any human involvement. Similarly, there can be an autonomous car wash and autonomous vertical parking system [113], [114]

(d) **Intelligent Traffic Management:** One of the rudiments of a successful MaaS system is perceived to be the intelligent traffic management system. The primary element of this system is the traffic signal operation. According to [119], modern traffic-actuated signals ensure traffic flow in minimum possible phases. Where a phase consists of a set of nonconflicting movements. E.g., the existing traffic signal system in Australia uses an inductive loop detector to adjust the duration of the signal lights, i.e., red or green, by detecting the number of vehicles waiting or moving through an intersection. However, inductive loop detectors are not considered very effective as compared to infrared (IR) or video radar detectors. Moreover, there is a minimum time for which green light is to be displayed for a particular approach/lane even if there is no vehicle waiting. Hence, considering STP, a testing ground for various autonomous technologies, it is recommended that a dynamic/intelligent traffic management system be employed to regulate the traffic based on real-time traffic conditions in each lane. These conditions may include traffic density and speed of heavy and light
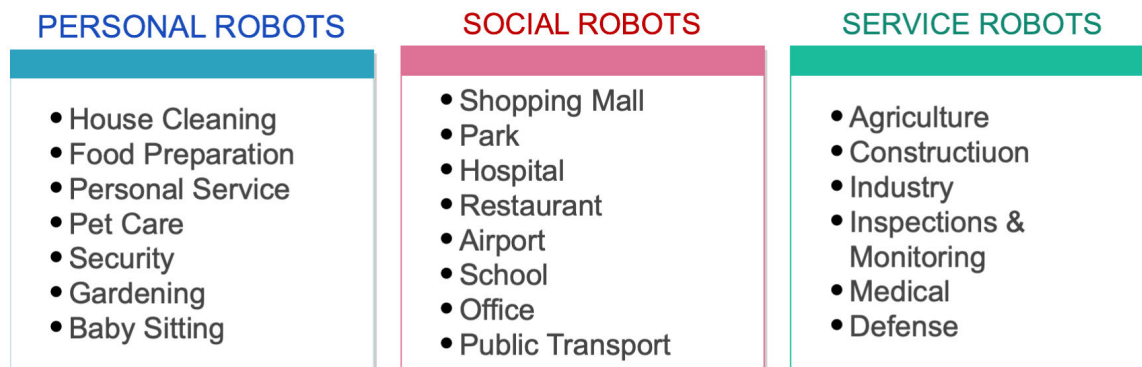
PERSONAL ROBOTS	SOCIAL ROBOTS	SERVICE ROBOTS
• House Cleaning • Food Preparation • Personal Service • Pet Care • Security • Gardening • Baby Sitting	• Shopping Mall • Park • Hospital • Restaurant • Airport • School • Office • Public Transport	• Agriculture • Constructiuon • Industry • Inspections & Monitoring • Medical • Defense

FIGURE 6. Use cases of robots in a smart community.

vehicles, the emergency vehicle, if any, and the type of road, i.e., a lateral, highway, or a local street.

This idea is not unrealistic, as many researchers have proposed various solutions in this regard. For instance, [120] uses real-time data about vehicle volume and waiting time in each lane to determine traffic light sequence and length of green light. Similarly, researchers in [121] used IR sensors to manipulate traffic signals based on traffic density. Also, [122] proposed a monitoring system using street video cameras in parallel to the traffic light system to determine different street cases (e.g., empty, normal, crowded) in varying weather conditions. Other than intelligent traffic signals, we foresee testing of dynamic/adaptive speed bumps on the streets of STPs. As shown in Fig.5, an adaptive speed bump system may comprise a speed bump sign, speed radar, a control system with an actuator to control the operation of the speed bump, and the bump itself. The speed bump remains in de-active mode, i.e., parallel to the road during peak hours, once most vehicles are moving within the prescribed speed limit. However, when the radar unit detects an incoming car driving over the speed limit during off-peak hours, it alerts the control unit, which activates the speed bump from a safe distance from the approaching vehicle to slow it down. Moreover, to add more security, license plate recognition can also be performed to slow down specific vehicles [123].

4) SMART COMMUNITY

(a) **iHealth:** Intelligent health services at community level aim at improving medical emergency response, managing patients Electronic Health Record (EHR), analysis of community medical data, predict community transfer diseases, propose precautions, and make efficient use of resources. In addition, data collected from community (local council) medical center may be shared with state's health department for analysis and provision of specialized medical services like an

air ambulance, special medical consultancy, emergency response, and health alerts.

(b) **Use of Personal, Social, and Service Robots:** To foster an ingenious view of STPs, we propose the use of personal, social, and service robots. These robots will improve the livability in the STPs by autonomously performing various tasks and making the processes more cost-effective, risk-free, reliable [124], and productive. Although using a personal robot is quite intuitive, one may get confused in differentiating between a social and a service robot. A service robot is designed and developed to interact with humans as living human machines. Therefore, social robots should be realistic, and they should communicate, and cooperate with humans as naturally and intelligently as possible [125]. Whereas a service robot is used to automate specific or several tasks, where human interaction may not be necessary, e.g., industrial and medical robots [126]. Some use cases of these robots are shown in Fig.6. As per a case study on personal robots, people desire that a personal robot should clean the house, prepare food, do laundry, serve people, care for pets, look after kids, and ensure the security of the house [127]. On the contrary, social robots can be used in shopping malls, parks, hospitals, restaurants, airports, schools, offices, and public transport to interact with humans and also for security-related tasks. Whereas service robots can be used to assist in agriculture, construction, industry, inspection and monitoring, medical, and defense-related tasks [126].

Moreover, every day, numerous incidents globally involve Hazardous Materials (HAZMAT) such as chemical spills, leaks, fires, and the intentional release of toxic substances. These incidents not only adversely affect human health but also ecosystems and the environment. Therefore, the most vulnerable are the emergency services personnel. E.g., in South Australia alone, there had been one thousand four hundred and twenty-one incidents involving HAZMAT, fire, transport, sabotage, etc., between 2001 and 2018 [128].

FIGURE 7. Intelligent street light (iLight).

Besides, it is a fact that human rescue workers become a scarce resource in disaster scenarios. Therefore, [129] proposes that a single rescue worker should supervise a multitude of autonomous robots equipped with appropriate sensors and tools in ideal circumstances. These intelligent machines can assist in inspecting incident sites from a safe distance, analyzing the type of HAZMAT, damage assessment, rubble clearance, and search for survivors. However, there are numerous challenges in using autonomous rescue robots as a service. [130]. Firstly, existing rescue robots cannot operate autonomously in a harsh environment. Where

harsh environments are perceived as unknown, unstructured, dynamic, cluttered, hazardous, and limited in resources (such as the availability of communications, GPS, and visibility) [131], [132]. Hence, machine decision-making capabilities in rescue robot technologies need further research. It is also difficult to decide whether a fully autonomous or semi-autonomous (teleoperated by a human supervisor) system would be better as a general-purpose rescue robot. Another critical challenge for rescue robots is the mapping or construction of a path profile.

(c) **iLighting (Smart Street Lights):** To augment environmental monitoring, surveillance, security, information dissemination, emergency response, and public service, the use of intelligent street lights can never be overemphasized. An intelligent street light is an autonomous element of the overall smart community. As shown in Fig.7, the iLight is solar-powered and equipped with numerous sensors and equipment such as a WiFi transceiver module, temperature, humidity, CO_2, smoke, and noise sensors, surveillance camera with image processing capability, motion sensor, emergency telephone, digital street sign, digital info screen, a speaker and a microphone, an electric vehicle (EV) charging port, and a power socket for general use (mobile charging). The highlight of the iLight is that the surveillance camera with the requisite image processing capability can detect and generate alerts for any security or emergency incident such as street crime, street fight, bullying, road accident, flash flooding, or a prescribed health emergency. Upon receiving an alert, the STP management can always monitor the real-time situation and generate an appropriate response.

(d) **ibuildings:** The intelligent buildings are mostly equipped with sensing and control infrastructure for efficient HVAC and lighting management. Some other technologies may include energy generation, storage, and distribution. Smart buildings maximize efficiency and productivity. Hence, the essential features envisaged in an ibuilding include safety and security, network connectivity, functional spaces, IoT enabled environment (HVAC, lighting), layered security (integrated access control, fixed network camera, network dome camera, multi-factor authentication locks, intrusion detection), safety (HAZMAT, fire, gas, and sabotage detection), and efficient water and energy management.

(e) **Smart Maintenance:** It implies using sensors and other surveillance means to autonomously monitor and initiate a complaint to the council/park management for maintenance issues along with evidence in the form of pictures, videos, or sensor data.

(f) **Smart Waste Management:** Waste management is an integral part of a green environment. However, in the existing scenario, most of the counties resort to manual/predefined waste collection, irrespective of the
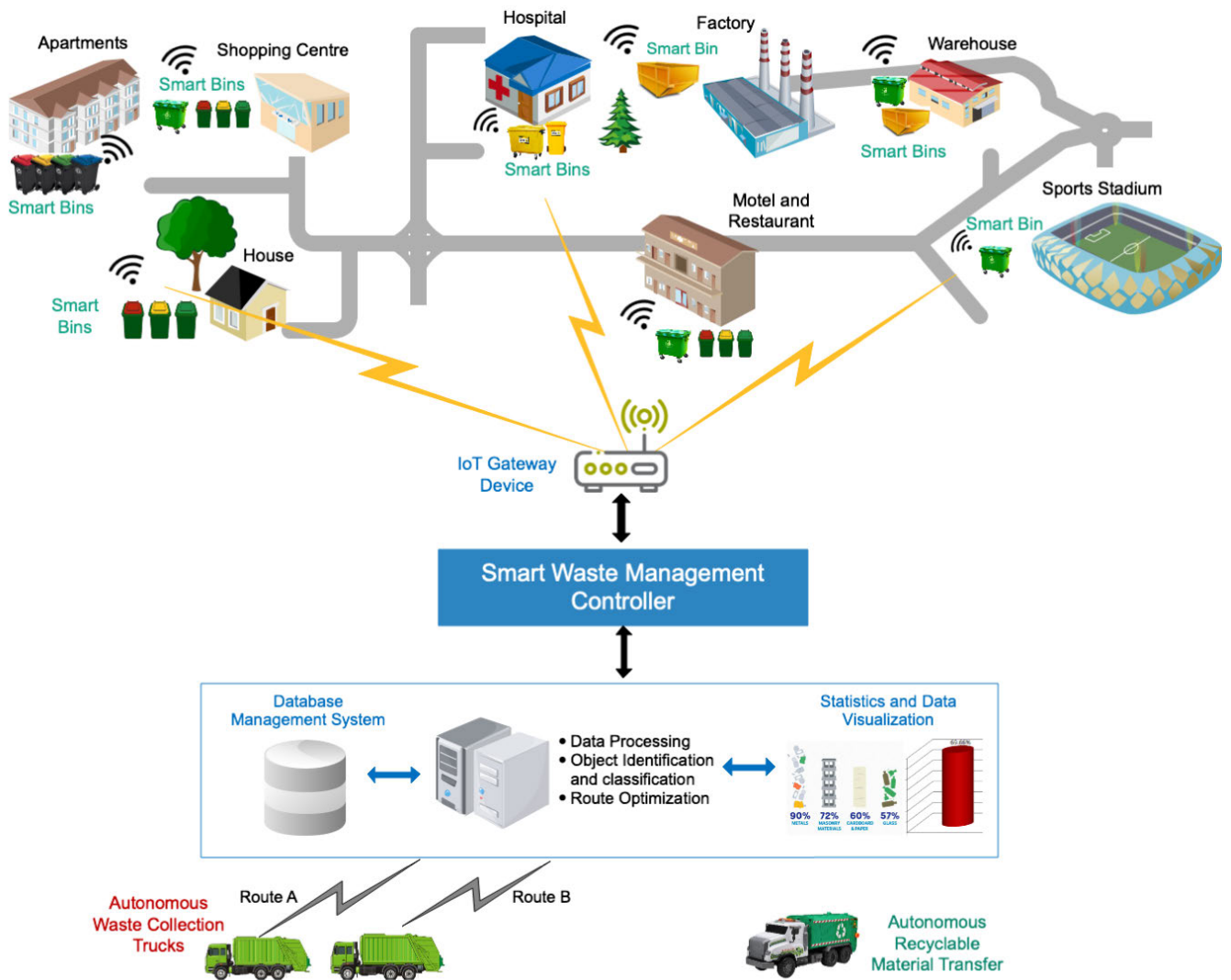
FIGURE 8. Waste management system architecture.

fact that what percentage of a waste bin is full. This may infer extra costs in terms of fuel and waste collection vehicles. Moreover, if there is a waste bin with rotting and fast decaying food items such as fish waste, meat, and fruits, then if the bin has to wait to be emptied as per respective council's schedule, it may affect the environment. Although there are different color codes for the bins for the segregation of waste items at the source in Australia, e.g., a Red-lidded container is for nonrecyclable household rubbish and is collected weekly. The yellow-lidded bin is for recyclable items collected fortnightly, and the green-lidded bin is for garden cuttings and is also collected fortnightly. Nevertheless, it has been observed that people may not follow the color codes and throw unwanted items in different bins, such as batteries, toxic materials, medical waste, and fast decaying food items, including fruits and meat products.

Hence, we recommend using digital technologies to; reduce costs and resource consumption, identify objects in the waste for faster response, overall improved performance, and social well-being with increased engagement. In this context, the smart waste management system architecture is shown in Fig.8. All the waste bins placed at various locations are intelligent bins equipped with IoT sensors that continuously monitor the volume [133], [134] and the type of objects in the waste. As soon as a bin is ninety percent full, or a rotting, fast decaying, or a toxic thing is thrown in the bin, an alert message is generated containing the location of the bin, time, volume, and type of the waste to the waste management controller (located at STP waste management office). The controller automatically compiles the data from all the waste collection points in the STP. After processing the received data, the waste management app generates

the dynamic route and schedule for daily waste collection. Any impromptu task of waste collection on an urgent basis is also automatically added to the specific waste collection vehicle route. Keeping in view the use of autonomous vehicles in the STP, it is presumed that the complete waste collection process is autonomous, comprising smart bins, driver-less vehicles, and intelligent app. The waste management system is envisaged to perform necessary data processing to dynamically create waste collection routes and schedules and propose an appropriate recycling plan. However, the only foreseeable challenge in successfully implementing the smart waste management system is the effective classification of objects in the waste. Although many solutions have been proposed in this regard, [135]–[138], yet considerable research is required to develop a real-world product.

5) INTELLIGENT SAFETY AND SECURITY SYSTEM
The vision of a STP as a living science city cannot be accomplished unless an autonomous security and safety system is deployed to intelligently protect against conventional security threats and reduce the impact of natural calamities and man-made disasters. An autonomous and intelligent security and safety system has the following necessary attributes.

(a) A wide network of surveillance cameras with image processing capabilities for real-time incident detection, face recognition, alarm generation, immediate response, and follow-up monitoring based on the analysis of live video/surveillance cameras feed. The surveillance system based on CCTV cameras can be supplemented by incorporating drones and robots in the security and monitoring mechanism.

(b) Use of iProvost (robotic police) for surveillance, incident detection, and initial response. The robots equipped with armor protection, cameras, acoustic sensors, speakers, searchlights, sirens, and blue and red flashing lights can be deployed at all public places, including parks, shopping malls, sports grounds, science park residential and commercial areas, car parks, bus/train stations, public libraries, etc. The robots should be able to operate autonomously on the predefined routes, generate an alarm, and preserve any onsite evidence (video, pictures, handheld objects, etc.). The essentials of an iProvost's job profile include detection of road-rage, street fights/crimes, bullying at public places, carjacking, illegal travel on bus and train without a ticket, shoplifting, etc. The robots can also identify criminals using facial recognition and help find family/guardians of lost kids or senior citizens.

(c) Safety of science park against natural/man-made disasters based on environmental monitoring and issuance of related warnings and precautionary/remedial measures. The sensors may include seismic sensors, fire/smoke detectors, and an automated flood warning system.

6) DRONES AS A SERVICE (DAAS)
In today's dynamic and eventful world, the requirement of speedy response to various social service requests has been made easy by drone technologies. Nonetheless, most of the current drone applications are centered around a service-based business model. However, as per the existing regulatory frameworks e.g., drone policy outlined by Civil Aviation Safety Authority (CASA) Australia [139], limited commercial use of drones or Remotely Piloted Aircraft (RPA) is allowed under strict standing operating conditions for micro and small excluded category RPA. Small excluded category RPA involving drones weighing no more than 25 Kilograms is only applicable to private landowners. Some of the other conditions that restrict an all-out commercial use of drone technology include no flying within 5.5 Km of an airport with a control tower. The drone should not go beyond 120 m from the operator. No drones should be flown in an area with emergency operations underway. Hence, the above discussion concludes that the future STPs should seek some leverage from the respective government in the commercial use of drones within the park premises. Thereby, the STPs may use drones to inspect industrial equipment or construction sites, surveillance and security services, cargo delivery, land surveying, and farming operations. It is also proposed that a STP should workout a customized drone use policy as a test case for the provision of various autonomous drone-based services and try new business models in a realistic urban environment under centralized control. To deliberate further on the concept of DaaS, some of the proposed applications, as shown in Fig.9 are illustrated in succeeding paragraphs:

(a) **Inspection and Surveying Services:** Inspection/observation service may include rooftop condition assessment, land surveying, construction site monitoring, gas/water pipe leakage detection and assessment, and other HAZMAT leakage detection or monitoring.

(b) **Emergency Response:** It can include different scenarios, e.g., in the case of a traffic accident, drone-based service may be used for first responder damage assessment, evidence gathering for insurance purposes, and road/traffic assessment to regulate traffic on alternate routes. Concerning health emergency response, park residents may sign up with the STP health emergency response service indicating desired medicines or medical equipment. Therefore, once the affected person or his nominated close contact triggers an alarm for immediate requirement of a specific medication or medical equipment such as EpiPen, inhaler, defibrillator, insulin, Ventolin, anti spider/snake venom, etc., a drone is dispatched to make the delivery.

(c) **Disaster Response and Relief Management:** Disaster response and management is a critical task that requires speedy situational awareness for a targeted and effective response. E.g., in case of natural/man-made disasters, including bushfire, earthquake, flood, or severe storms, autonomous drones can be used to assess the extent of damage caused by the calamity, monitor
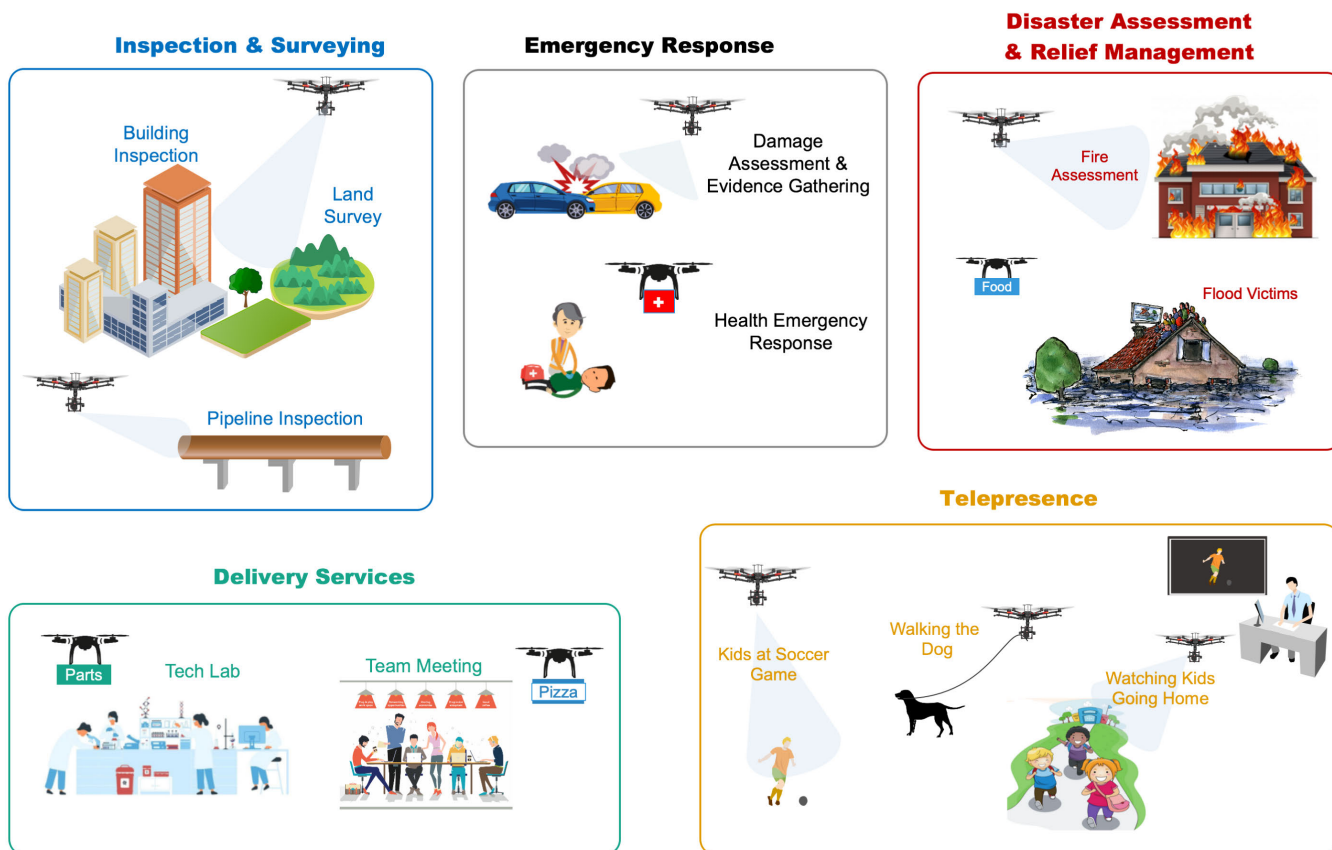
DRONES as a Service (DaaS)

FIGURE 9. Drones as a service (DaaS) use cases.

rescue and relief efforts, and also provide food and necessary supplies to the affectees. There are drone technologies that can assist in fire fighting efforts in areas inaccessible to humans. Correspondingly, drones can provide early warning of flash floods by visual surveillance of waterways and reservoirs.

(d) **Delivery Services:** It is perceived that most stakeholders tend to engage in time constraint activities in the science park environment. They may require some essential equipment, IT parts, tools, small packages, or food and grocery items on an urgent basis. Hence, the drone delivery service's on-demand nature will allow shipments to be sent as soon as they are ready rather than waiting for the following day's shipping run. The drones can thus ensure swift fulfillment of time-critical scheduled as well as spontaneous deliveries. In this regard, users may be charged an extra amount depending upon the urgency/priority of delivery.

(e) **Telepresence:** Another compelling use case of DaaS business model is telepresence. This service can assist STP residents in supervising various tasks remotely. E.g., Walking kids home from school if their nanny is

not available that day. The kids' parents can view the real-time video footage of the drone to see their kids going home. Similarly, if a person is busy at work and wants to check on his kid at a soccer game remotely, the DaaS app will provide him the opportunity to request such a service by entering the date, time, and location of the event. Correspondingly, a drone can also be hired to search and locate a lost pet.

(f) **Research Support:** Research scientists, startups, and other parties can book a drone flight to test a new sensing technology or a flight control mechanism. Similarly, university students can also hire standard drones to test various intelligent applications.

(g) **Challenges:** Like other autonomous systems, DaaS business model also has associated challenges. E.g., A bad weather environment, including thunderstorms or strong winds, may disrupt drone flights, especially for the small RPAs. Similarly, in a large drone fleet, it would be an arduous task to monitor and manage drone flight paths, scheduled and spontaneous task assignments, and prioritizing the jobs based on user-specific response time. Besides, the urban
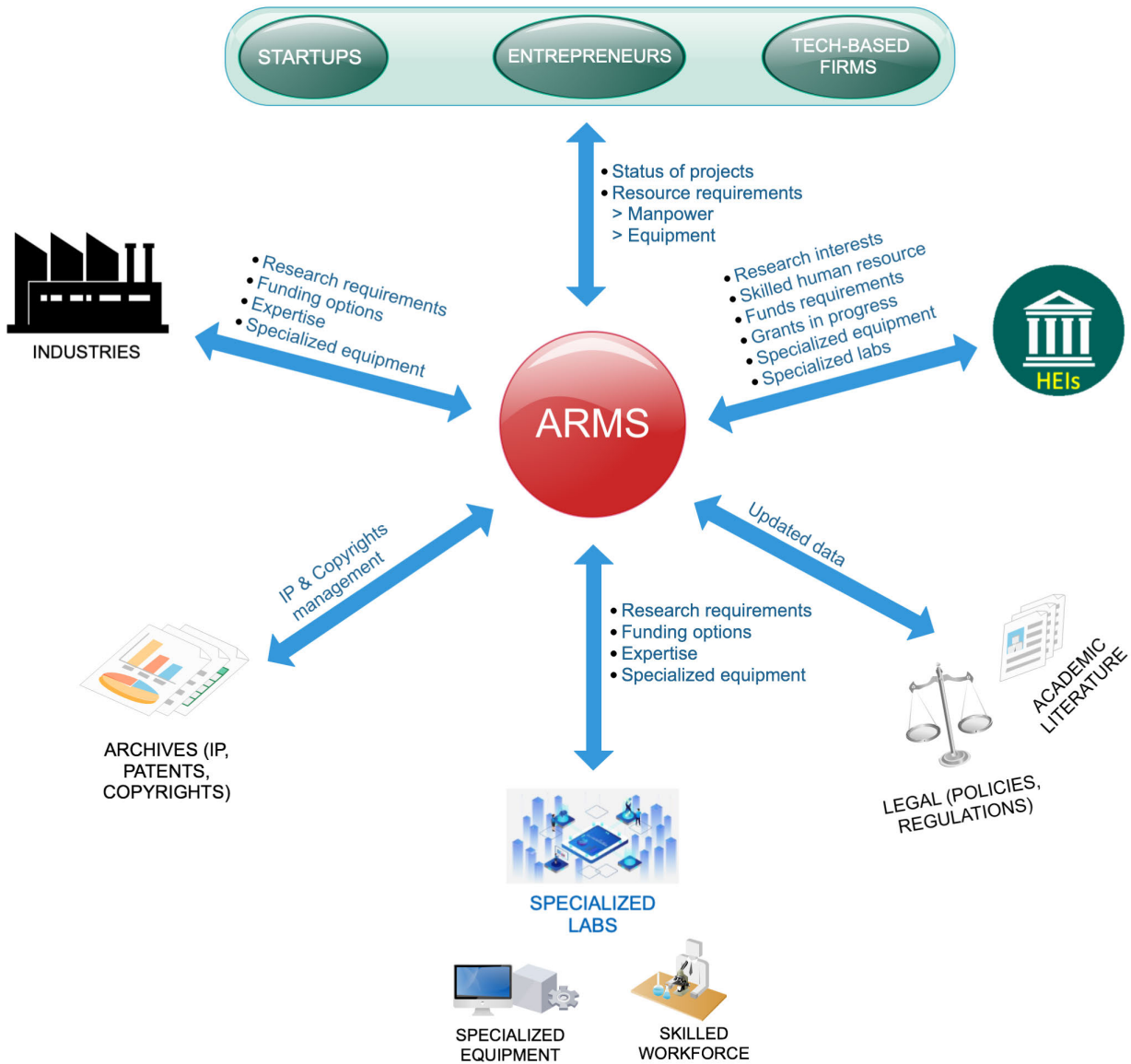
FIGURE 10. Autonomous resource management system (ARMS).

environment and integral obstacles may adversely affect drone flight paths. Likewise, transitioning from fully outdoor to semi-indoor operation may affect the performance of on-board GPS. Hence, an improved drone localization algorithm needs to be developed to provide cm-level accuracy in the absence of GPS service. Correspondingly, there is a need to create a flight management system with the capability of flight schedule, flight path mapping and analysis, data analytics for proactive/predictive maintenance, and drone abstraction that involves working with multiple drone providers.

7) SMART GOVERNANCE AND MANAGEMENT

(a) **Autonomous Resource Management System (ARMS):** It refers to monitoring and managing all types of resources in the STPs. E.g., as shown in Fig.10, to facilitate research, innovation, and collaboration between various stakeholders, we introduce ARMS. The suggested system will monitor the status of all the projects undertaken by startups, tech-based firms, and entrepreneurs. It keeps a record of organizations' resource requirements, including equipment and a skilled workforce. Similarly, it will connect with the industry partners to track their R&D needs, funding
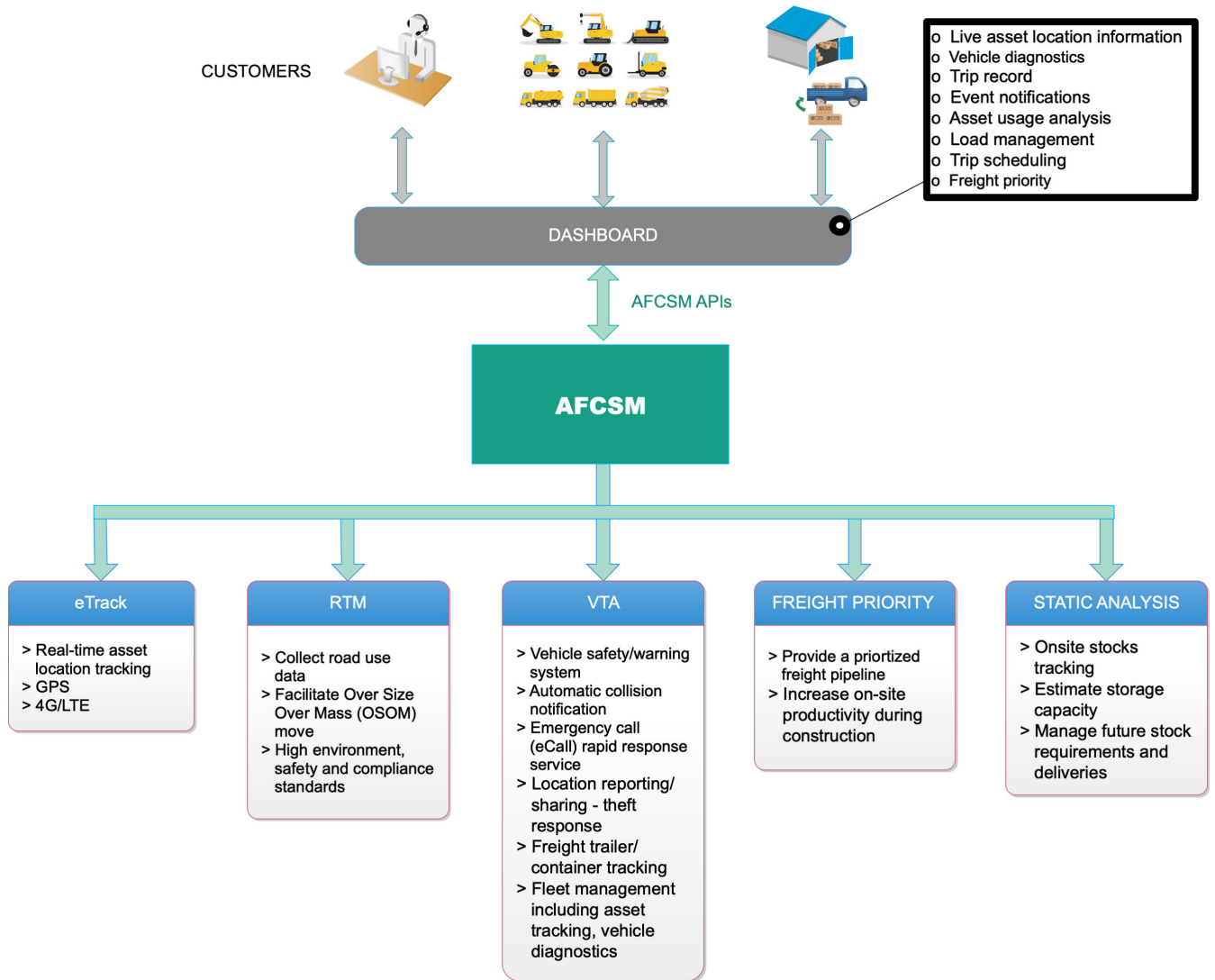
FIGURE 11. Autonomous fleet and construction site management.

options, and expertise/specialized equipment on the inventory. In the same way, the ARMS will monitor and maintain data on HEIs' research interests, skilled human resources, the requirement of funds, grants in progress, specialized equipment, and laboratories. HEIs' incubation capabilities will also be monitored along with data on academic literature, government policies, and regulations. Correspondingly, the system will maintain and manage the availability of equipment and skilled workforce at specialized laboratories. Hence, when an organization requires some equipment or a skilled workforce, ARMS can provide the desired information and do the requisite coordination. Moreover, if an organization requires HEIs' support for a research project, then ARMS can facilitate the submission of Expression of Interests (EoIs). Besides, ARMS

will also provide updates on patents and innovative technologies to all stakeholders in the STP.

(b) **Smart IP and Copyrights Management:** IP and copyrights management is a critical affair in academics and the tech world. Hence, it is proposed that ARMS being connected to all the stakeholders can easily monitor and detect any IP and copyrights violation not only within the STP but also with any other organization globally (based on resources available on the internet).

(c) **Autonomous Fleet and Construction Site Management:** Most of the time, construction sites present a scene of the hustle and bustle with heavy machinery moving in and out of the site. Due to the involvement of heavy trucks, giant construction machines, and massive construction materials, the safety and management of men and material is an arduous task. However, today
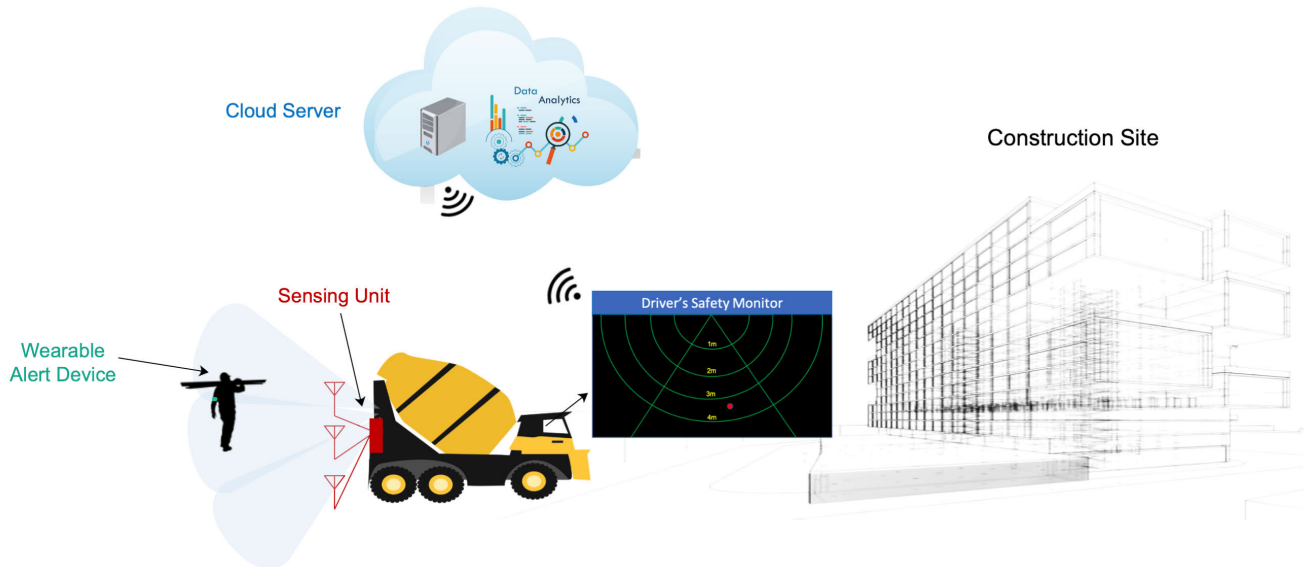
SAFE@WORK

FIGURE 12. Safe@Work system.

autonomous hardware and software-based applications have made the job easy. For instance, researchers in [140] introduced the concept of Smart Construction Objects SCO) to enable a safer, greener, efficient, and cost-effective construction system. SCOs are the construction resources or materials that can be made autonomous and smart by harnessing them with requisite capabilities such as sensing, actuating, networking, computing, and data processing. Subsequently, the ability of SCOs to interact/talk to each other results in increased awareness and more autonomous decision-making without human intervention. E.g., a smart tower crane can communicate with a smart steel column to find its weight and potential safety hazards before lifting it. Hence, SCOs provide decision-making information to human decision-makers and make rule-based decisions autonomously themselves. Therefore, construction companies can now remotely manage the fleet of heavy vehicles, do load balancing, estimate future stock requirements, and carry out trip planning [141].

In this regard, we propose an Autonomous Construction Fleet and Site Management (AFCSM) service. As shown in Fig.11, AFCSM comprises various applications. For instance, eTrack provides GPS-based real-time asset location information via 4G/LTE. Similarly, the Road Traffic Management (RTM) app collects road usage data from vehicles through onboard sensing devices. RTM thus facilitates the movement of large vehicles by monitoring vehicle loads and road

conditions. It can also ensure compliance with environmental and safety standards by generating an alarm in case of any violation.

Correspondingly, vehicle telemetrics plays a vital role in managing a large fleet of vehicles [142]. Hence, the Vehicle Telemetrics Application (VTA) continuously performs vehicles' diagnostics and generates early warnings. It can also initiate collision and breakdown notifications. Subsequently, an emergency call is automatically made for a rapid response in case of an accident. VTA may also report/share the location of the vehicle in case of a theft. Also, to assist the organizations in fleet management, VTA can perform vehicle diagnostics to optimize maintenance and fuel consumption and ensure driver and vehicle safety.

AFCSM offers another compelling feature of freight priority in which the customer organizations can prioritize delivery of the freight/construction material as per their schedule or to meet an urgent requirement. The customers registered with AFCSM can access a range of information about their fleet and construction sites. The users can see live asset location, asset trip record (including history, routes, and load), vehicle safety, and breakdown event notifications. The AFCSM dashboard may also show information about an organization's assets being used on-site, the available space, and the upcoming scheduled deliveries. Thus facilitating the customers in the efficient management of their stocks. We believe that AFCSM will improve fleet management, reduce maintenance costs, safety risks,
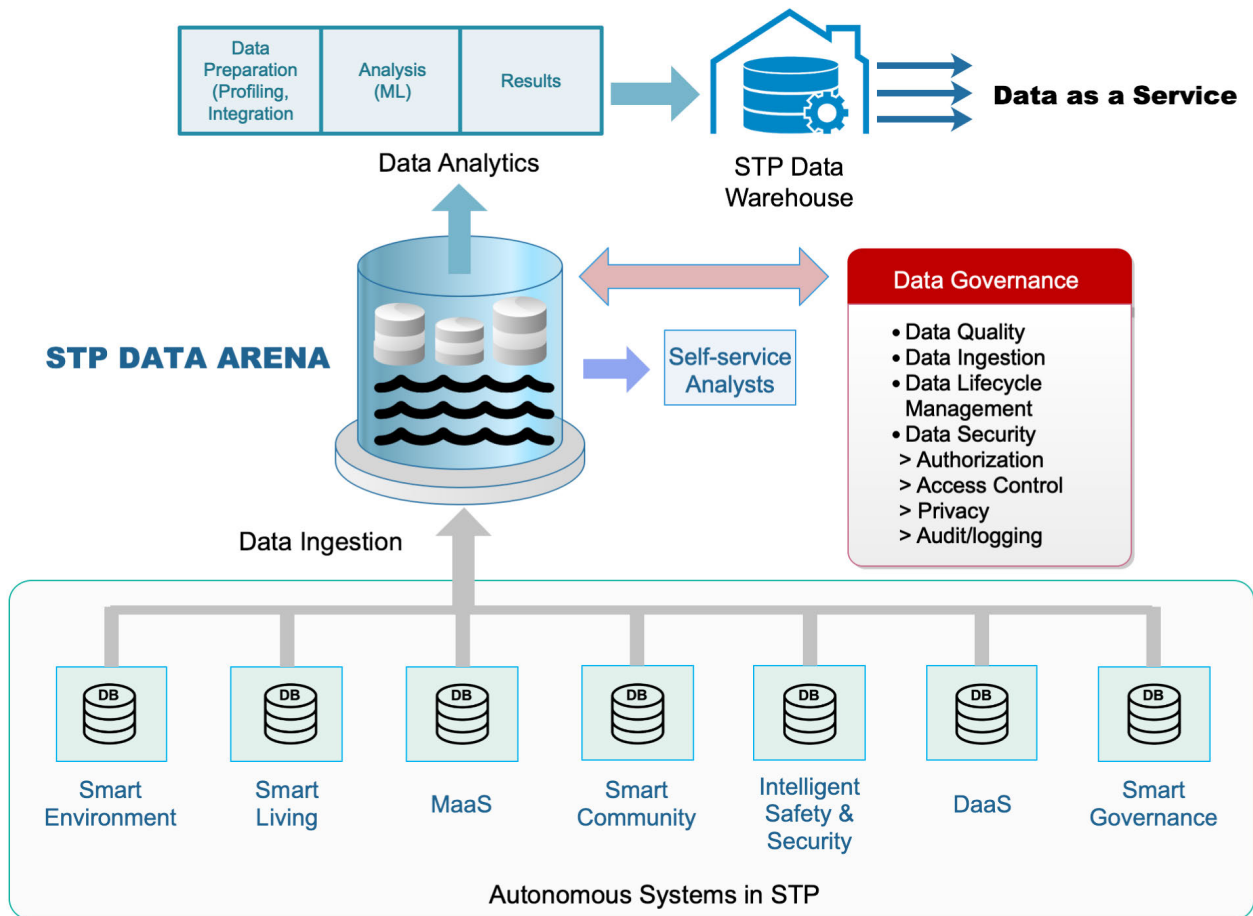
FIGURE 13. STP Data Arena business model.

and liabilities. AFCSM can also make use of geofencing to monitor fleet activity and identify abnormal driver behavior. In addition, by real-time asset tracking, AFCSM will facilitate road safety and infrastructure management, e.g., once a heavy vehicle, such as a prime mover, is entering a narrow road, other personal and commercial vehicles are shifted to alternate routes.

(d) **Autonomous System for Workers' Safety:** It is not surprising that construction sites and other industries involving heavy machinery and vehicles are full of potential hazards. Especially during summer, due to long working hours and temperatures exceeding forty degrees Celsius, the construction workers may lose focus on their surroundings. Hence, distracted workers working at dangerous heights or moving around heavy machinery and equipment along with unaware drivers are prone to life-threatening risks. As a result, the risk of injury in a construction site due to collision with site vehicles, falling from heights, and run-over by plant machinery is significant. As per Safe Work Australia [143], there have been 158 deaths at work in 2020. And the top industries in these work-related deaths include transport/warehouse, agriculture, and

construction. Hence, we propose an intelligent safety service named ''Safe@Work''. Based on the solution proposed in [144], [145], Safe@Work system may consist of three main components. First is the sensing unit that is installed to the rear of the vehicles or heavy machinery. It comprises three 868 MHz Radio Frequency (RF) transceivers, three directional antennas, three 40 kHz ultrasonic sensors, a processor, and a monitoring app. The second component is the alert device (a wearable device) that consists of a radio transceiver, an RF wake-up sensor, and an alarm/vibrator actuator. Whereas the third component includes a cloud server and safety monitoring, and data analytics dashboard.

As shown in Fig.12, to prevent vehicle backover accidents, the sensing unit installed at the back of the vehicles or heavy machinery starts functioning as soon as the vehicle is put into reverse gear. Hence, when a worker wearing the alert device enters the sensing unit's coverage area, the alert device is powered up by the RF wake-up sensor. Otherwise, the alert device remains in power save (idle) mode. Soon after the alert device is activated, it sends an acknowledg-

ment (ack) message to the sensing unit along with its unique identity (ID). All the three RF transceivers in the sensing unit receive the ack message with varying Received Signal Strength Indicator (RSSI) values. The processor analyzes the RSSI values and accordingly instructs the respective ultrasonic sensor to measure the worker's distance in the direction of the highest RSSI value. If the measured distance is within the prescribed dangerous zone, e.g., four meters, then as a warning, an alarm/vibrator activation signal is sent to the worker's alert device. Moreover, the worker's location with respect to the vehicle (based on distance and angle) is also shown on the driver's monitoring app. Similarly, sensing units can be installed at various hazardous locations within a STP to alert the workers and prevent any untoward incident. These locations may include big dug-outs, deep pits, unprotected rooftops, freshly laid concrete or charcoal area, HAZMAT, or a busy work zone involving heavy machinery.

8) STP DATA ARENA

Based on the concept of "Data Lakes," we propose STP Data Arena, a data as a service business model that aims to overcome organizational boundaries and system complexities involved in data sharing. Illustrating a data lake, James Dixon in [146] referred to it as a large body of water in a natural state which requires further cleansing and processing to be useful. On the contrary, this paper proffers STP Data Arena to be a more refined and user-ready application. As shown in Fig.13, raw data from each autonomous system database (DB) is extracted and moved to STP Data Arena. The raw data may include any type or size of data, e.g., sensors data, user interaction logs, images or video libraries, structured or semi-structured data (JSON, Avro, Parquet, etc.), and snapshots of autonomous systems' DB. The data ingestion can be done through Apache Sqoop that bulk loads (pull) relational data to Hadoop Distributed File System (HDFS) [147]. HDFS is a distributed file system designed to store big data and stream those data sets at high bandwidth to user applications [148], [149]. Similarly, to ingest batched or streaming data into the STP Data Arena, scalable message ques (Kafka [150]) and data stream engines such as Samza [151], or Spark streaming [152] can be used. However, as data is stored in Data Arena in the original format, the inconsistent and incomplete data pose a problem of data integration for the data scientists [153]. Therefore, data scientists must carefully prepare the data, including data profiling and integration, before the analytical results are extracted.

However, HDFS is believed to have numerous system administration challenges related to data replication, adding nodes, creating directories and partitions, performance, workload management, data (re-)distribution, etc. [154]. Furthermore, HDFS has minimal core security tools, thus often requiring add-ons. Moreover, disaster recovery is another significant problem. Nonetheless Snowflake [155] resolves above-mentioned problems. Snowflake data cloud eliminates

storage management concerns by ousting the need to set up and manage nodes, define file systems or directories, and implement and revise data distribution policies. Besides, Snowflake provides data replication, backup, and disaster recovery as an integral part of managed services. In addition, Snowflake employs end-to-end encryption to ensure user data security at rest and in transit [156].

The ultimate objective here is to drive value from the raw data by exploring and transforming original data and training statistical models to be used in various services/applications. E.g., based on data uploaded by the DaaS system, the data scientists can extract the peak time for various drone-based services such as the type of deliveries, i.e., food or packages, the kind of drone used, i.e., delivery or inspection. Hence, a careful analysis can reveal users' preferences for drone services at a particular time of day, peak hours for each type of drone service, users' food choices, most popular restaurants, etc. The processed data/results will help the DaaS management optimize drone scheduling and flight paths as per peak hours of various drone services. Similarly, the restaurants can prepare the popular food items in appropriate quantity at peak hours to reduce delivery time for their customers.

Similarly, analysis of data ingested by the smart living system may infer the STP tenants' usage pattern of various appliances/utilities in a smart home. Hence, the manufacturers can use the processed data to improve predictive maintenance or optimize various utilities' load/availability. In the same way, data available from real-time autonomous systems can help stakeholders in statistical analysis, customized marketing campaigns, or improved services. Moreover, by collecting data in STP Data Arena, different sources' data can be correlated without crossing system or organizational boundaries. E.g., the data generated by various research centers can be correlated with the industry's technological challenges. This will help the analysts or STP management in understanding whether the current research at the science park is aligned with real-world challenges or not. In addition, STP Data Arena infrastructure should be accessible to nontechnical users, i.e., self-service analytics or enterprise applications. Furthermore, to prevent the storage of garbage data in the data arena, there is a need for a data governance process to control what goes into the data arena and how it is shared. Correspondingly, a well-placed governance model will ensure data quality, security, privacy, and accountability.

9) ADDITIONAL SERVICES

In addition to ASaaS, this research also proposes a couple of unconventional services and 3D modeling and printing as a supporting service to facilitate STP tenants.

a: TECH THINK TANK AS A SERVICE (3TAAS)

Augmenting the support provided to the new firms and businesses in the form of incubators and business support by the STP management, we propose 3TaaS, a think tank as a service. The 3TaaS is supposed to be a technology research policy institute comprising representatives from academia,
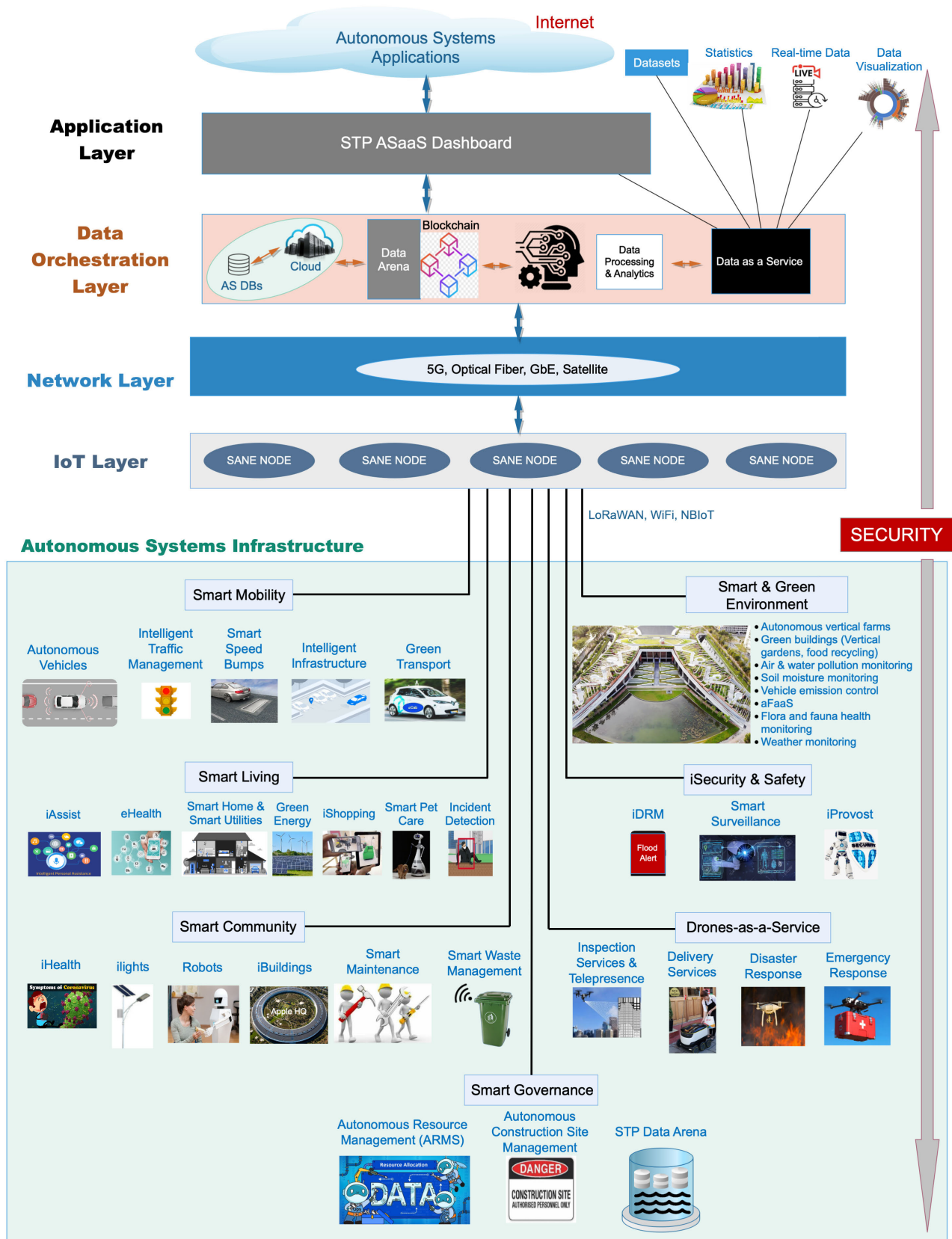
FIGURE 14. Autonomous systems as a service (ASaaS) - network architecture.

industry, research centers, and enterprises. The think tank will analyze the industry's overall technology needs, future technologies, and current orientation of research in the STP to advocate new research ideas. Such an arrangement is expected to promote innovation and make the respective STP a leader in developing new technologies while solving real-world industry/tech problems.

b: 3D URBAN ARCHAEOLOGY

According to Archaeological Institute of America [157], archaeology is the scientific excavation and study of ancient human material remains. Similarly, urban archaeology is defined as the application of archaeological methods to the study of cities and the process of urbanization [158], [159]. Based on the concept of urban archaeology, we propose a 3D STP Archaeology Service, i.e., time-lagged history of the STP evolution/development. The main features of this service are:

- It allows for evaluation of past design decisions that may affect future investments in a STP.
- It provides a rich source of data to improve future designs by identifying mistakes in the past projects.
- Provides macro and micro-level views of a STP site development on a timeline.
- It is a chronology of the complete development process of every building on the site.
- Contains a record of the development process, including pictures, materials used, workforce employed, supervisors, builders, and architects on the job.
- It will assist in auditability, transparency of processes, future reference, and assessment of compliance with regulations/standards.

c: 3D MODELLING, SCANNING AND PRINTING LABORATORY

Today, there is a multitude of diverse 3D printing technologies that can manufacture objects using a vast array of materials. These materials range from thermoplastics and polymers to metal, and micro-fluids, which are capable of fulfilling most engineering and design needs [160]. Hence, a 3D modeling, scanning, and printing laboratory is recommended in STPs to facilitate researchers and startups in the swift design and manufacturing of essential components or product parts.

D. INTEGRATION OF AUTONOMOUS SYSTEMS

Advances in Sensors and Actuators Network Environment (SANE) have provided an opportunity to integrate multiple autonomous systems. As shown in Fig.14, different autonomous systems may have a wholly distinct or shared infrastructure. E.g., At some locations in a STP, especially the areas with road network, the smart environment system may rely on the sensors installed on iLights. Similarly, the iSecurity and Safety system or DaaS may depend on the information received from personal, social, and service robots for search and rescue or an emergency response operation.

The data generated by autonomous systems' sensors and other devices such as surveillance cameras, robots, intelligent traffic management, iBuildings, or iLights is received or routed by multi-protocol gateway devices installed in SANE nodes available throughout the STPs at strategic locations. The end-devices and sensing equipment mostly communicate with the gateway devices using LoRaWAN, WiFi, or NBIoT technologies. Whereas the back-haul communication to link IoT layer with data orchestration layer primarily supports 5G, optical fiber, Gigabit Ethernet (GbE), or satellite technologies. Besides, the data orchestration layer comprises the autonomous systems' DBs, STP Data Arena, data processing, and analytics infrastructure, and requisite data services. Moreover, the data orchestration layer further feeds the data to the application layer that comprises an STP ASaaS dashboard. The dashboard provides an interface to the autonomous systems applications and offers essential statistics and selected real-time data streams.

In addition, there are certain aspects that may drive the methodology of integrating different systems:

- Autonomous systems' relationships, networks and security, may dictate how data is exchanged between different systems [161]- [164].
- STP autonomous systems' dashboard be designed to better support the end-users by providing understandable, flexible and trustworthy services [165].
- Efficient coordination is essential between multiple systems with different objectives. And the same can be provided via a centralized or distributed approach [166].
- Ethics, regulations, and standards should be complied with for ethical, reliable, and safe performance of autonomous systems [167]- [169].

1) KEVIN - A STP TENANT's CASE STUDY

To better understand the potential of ASaaS, let us visualize a day in the life of Kevin, an entrepreneur, and an STP tenant. Today, he has an important presentation to a VC at 4 pm. But before that, he has to collect and assemble a prototype of his new IoT device by 9 am. So that he can include some actual results about device's operation in his presentation. Kevin lives in an autonomous smart home that intelligently and independently controls all the functions in the house. E.g., at night, all the lights and the HVAC vents are switched off in the unoccupied rooms. The smart home controller "iAssist" regulates all the operations as per Kevin's habits and personal preferences. Correspondingly, over the period, the iAssist learns that Kevin likes to run the ceiling fan at medium speed in his room if the ambient temperature is less than or equal to twenty degrees Celsius. Hence, the iAssist keeps the air conditioner switched off. Moreover, iAssist ensures that Kevin wakes up at the right time to reach his workplace in time. In this regard, iAssist accesses data from the STP Data Arena to estimate the expected travel time based on current weather and traffic conditions. Unfortunately, due to yesterday evening's storm, there are a few road blockades. Hence, based on real-time traffic data extracted from the STP

Data Arena, iAssist predicts that it will take fifteen minutes more than the usual travel time. Thus, it sets Kevin's alarm clock to trigger at 7:15 am instead of 7:30 am every day.

Accordingly, the iAssist switches on the HVAC in the ensuite at 7:10 am to regulate the temperature to twenty degrees Celsius, and the light in the room is switched on as the alarm is set off. To conserve energy, all the lights are also controlled through motion sensors. Hence, the light in the ensuite switches on as Kevin walks in. Usually, Kevin takes thirty minutes to get ready and reach the kitchen for breakfast. Therefore, keeping an eye on the shower, iAssist switches on the coffee machine at 7:41 am so that when Kevin comes to the kitchen at 7:46 am, the coffee is ready at Kevin's desired temperature. As soon as Kevin gets his bread out of the toaster, iAssist orders an autonomous cab for 8 am so that Kevin reaches his office by 8:15 am with sufficient time to collect and assemble his IoT device. iAssist also alerts Kevin to take his routine medicines and vitamins after breakfast. However, just two minutes before the arrival of the autonomous cab, Kevin realizes that he had to buy a new lounger for his living room today as it was the last day of the sale. But his 4 pm meeting leaves him no time to visit the furniture outlet. Hence, he immediately opens up the iShopping app on the STP ASaaS dashboard, visually performs a final inspection of the lounger for his living room, and places an order for delivery at 6:30 pm.

Once Kevin leaves for work, his wife Sophia prepares for her ''Chef@Home'' a home-cooked food delivery business. Because of the on-park autonomous vertical farms, it is pretty easy for Sofia to organize her daily cooking and preparation of orders. She receives fresh produce and groceries every morning through an autonomous cab. In contrast, all the packaging and consumables are delivered from suppliers in the city by delivery drones. Sofia mostly provides food at lunchtime to STP offices, and in the evening, the great bulk of her food is delivered to people's homes using DaaS. She does not even need to know the customers' personal details. All that is required is customers' location code from their phone when they place the order, and the system takes care of the rest. However, in the midst of her work, Sofia realized that today her eight-year-old daughter Bella's school would close early, but she cannot leave her work due to an urgent order. Although the school is in the near vicinity, and she believes that Bella can quickly get home. However, still as a worried mother, she requests a telepresence drone using her STP app by entering the school location and her daughter's STP digital ID. Now, she can easily monitor her daughter walking to the home via live streaming through the DaaS system.

On the other hand, en-route to his office, Kevin realized that the autonomous cab had taken a diversion from the usual route. Upon checking the real-time 3D map of STP, Kevin finds out a small accident on the other road a few minutes before. As a result, the nearby iLighting system detected and escalated the incident so that all the traffic is autonomously diverted to the alternate routes shown on the map. As soon as Kevin glances away from his smartphone,

suddenly, a cyclist brushes past the side of the car. Although it is just a minor scratch, however still to record the incident and fulfill insurance formalities within three minutes of the incident; an inspection drone arrives and takes the mishap's visual evidence. Moreover, the cyclist also got a minor scuff mark on his leg and was immediately provided medical aid through an emergency response drone. Despite a couple of untoward events, Kevin reaches his office well in time to work on the IoT device. But there is one discrepancy, a part supposed to come with the device is missing. Kevin immediately logs into the DaaS's parcel tracking and location system, which tracks the parcels through RFID tags. He finds that the package was incorrectly addressed and delivered to another company on the other side of the park in error. It is 10 am, and the DaaS system has already identified the mistake and arranged for the parcel to be collected and delivered to the correct address. Finally, Kevin gets the part, and he starts working on his presentation to finish it by 3 pm. By then, Kevin realizes that it is difficult for him to go for a late lunch to his favorite restaurant, with the meeting starting in an hour. So he places an order for office delivery.

Kevin has a severe peanut allergy. Even small quantities of peanuts can lead to anaphylactic shock, which can be life-threatening. Therefore, he always carries an EpiPen as a precaution. However, due to the scheduled meeting in mind, he forgot to bring the EpiPen today. To his bad luck, the restaurant uses breadcrumbs from a new supplier and is less careful about peanut contamination. Therefore, after a few bites of his favourite chicken schnitzel, he starts feeling the allergic reaction. He searches his bag for his EpiPen and is alarmed to find it is not there. Fortunately, he has subscribed to the STP's EpiPen Service and quickly uses the app on his phone to trigger an alarm. The system immediately dispatches a drone with an EpiPen to Kevin's location. The EpiPen arrives in three minutes, and Kevin gets a lifesaving dose of Epinephrine. It took ten minutes for Kevin to recover from the allergy attack, but he finally got better. Later, at 4 pm, he made a successful presentation to the VC. However, during the presentation, the VC team was a bit skeptical about the idea's IP rights. However, Kevin directed the team to verify the new concept's IP and copyrights from the ARMS app available on the STP ASaaS dashboard. Once validated, VC bought the pitch and showed interest in funding the project. After the rewarding meeting, Kevin left his office at 5:15 pm in an autonomous cab to his home.

On the way home, Kevin was thinking of spending a good evening with his family. Suddenly, it came like a shock to him that today is his anniversary. Just like most of the good husbands, he had forgotten the critical day. Now it was too late to go to the mall and buy a gift. Thanks to the STP autonomous technologies, Kevin opened the iShopping app and, using his wife's full body picture, selected a beautiful dress for her and placed the order for the dress to be delivered to his home at 6 pm. Once Kevin reached home, luckily, his wife had taken their daughter to the swimming class. So Kevin received the dress and the delivery of the lounger
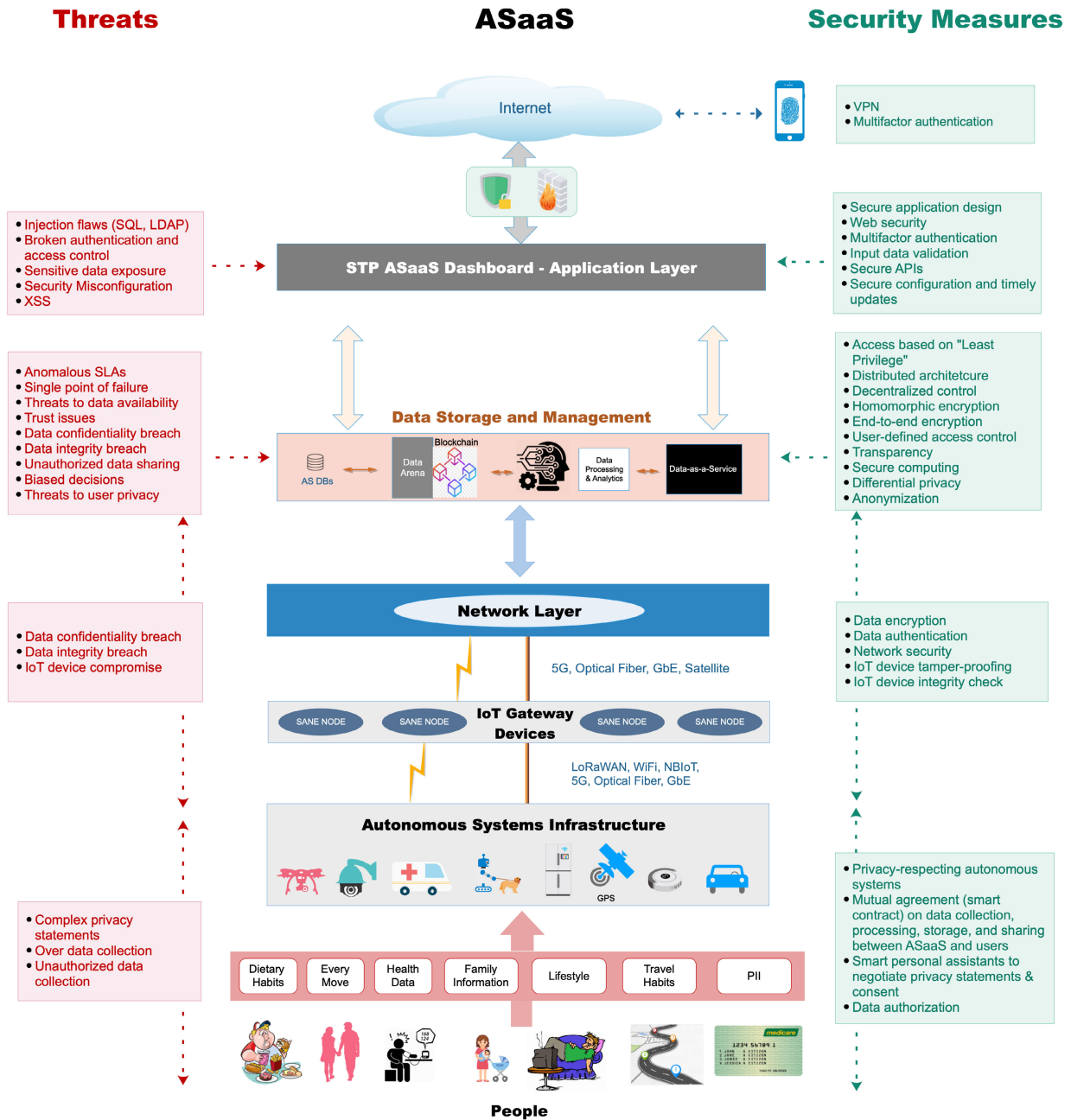
Threats　　　　**ASaaS**　　　　**Security Measures**

FIGURE 15. Autonomous systems' security evaluation.

at 6 pm and 6:30 pm, respectively. Moreover, as a surprise for his wife, he made a dinner booking using the STP ASaaS app, and while selecting the food items, he was proposed dishes based on his allergies. Once they left for dinner, the smart home activated its security apparatus, switched off all unwanted lights and HVAC vents, and the personal robot started taking care of their pet dog. Using the STP ASaaS app, Kevin could always watch the personal robot's video stream to check on their pet and monitor their house. Thanks to the autonomous systems, Kevin survived another day.

IV. DATA SECURITY AND PRIVACY IN AUTONOMOUS SYSTEMS

A. THREATS TO AUTONOMOUS SYSTEMS

AI-based autonomous systems process every type of user/environmental data for intelligent decision-making. Hence, they are a potential threat to user data security and privacy [170]. Similarly, the pervasive use of Online Social Networks (OSN) and smart devices has led to the collection and processing of users' data by different OSN platforms, smart city control center, or various other smart city

components such as Intelligent Transportation Systems (ITS), e-governance, health, and emergency response, smart homes, etc. In return, these entities provide various services to the users and third parties based on personal choices, interests, and current location. However, the point of concern here is that most OSNs and smart city systems have centralized control over users' data. Hence, they risk a single point of failure in case of a cyber-attack, or other technical malfunctions [171]. Moreover, this arrangement also has trust issues, as the users have to trust the entity that is handling their data. Hence, data owners have no control over their data assets [172] as they do not know where their data is stored, what is happening to it, who has access to it and is there any unauthorized disclosure to the third parties [173].

Before we further explore data security and privacy, it is essential to illustrate security and privacy terminologies. In this regard, data security is referred to as confidentiality of data, i.e., data protection from unauthorized disclosure. Whereas data privacy does not have a universal definition, it may differ from person to person according to individual preferences [172]. According to [174], when the confidentiality property of a system is breached, i.e., unauthorized users get access to confidential data, then the privacy breach also occurs if the disclosed data contains someone's personal information. Similarly, [175] describes privacy as "the claim of individuals, groups, or institutions to determine for themselves when, how, and to what extent information about them is communicated to others." Another definition [176] interprets privacy as "an individual's ability to exercise control over the collection, use, and dissemination of his/her Personally Identifiable Information (PII)." Where PII is any piece of information that distinguishes or helps to trace a person's identity, such as his name, social security number, insurance policy number, biometric records, etc.

Hence, privacy issues arise with the collection, processing, and disclosure of PII. Moreover, researchers in [177] claim that privacy is difficult to achieve in today's environment of intensive surveillance and monitoring technologies, including CCTV, RFID, IoT, data mining and profiling, ubiquitous computing, and ambient intelligence. Further, delineating threats to IoT-based Agri tech, [178] classify the threat models into five main categories, including attacks against privacy, authentication, confidentiality, availability, and integrity properties.

Correspondingly, as shown in Fig.15, autonomous systems collect varying information about people. E.g., health information, smart home data, food choices, travel habits, research interests, personal skills, financial data, etc. According to [179], personal information is collected by two methods, i.e., surveillance and interrogation. Surveillance refers to the automatic collection of data by autonomous systems, e.g., autonomous cars collecting information about routes taken, time-stamped locations, distance, and destinations. Also, smart surveillance systems watch every move of people. Whereas in interrogation, systems actively ask the users for specific data. E.g., the iHealth system asking a user for

existing health conditions and medications for data analytics or timely emergency response. Now the collection of information through surveillance and interrogation can be controlled to some extent by system designers by conforming to the privacy statement or privacy policies. However, there may be challenges for fully autonomous systems. These systems may start collecting new information that was not supposed to be collected, E.g., autonomous cars start recording people's private conversations during a ride.

Similarly, another activity during which user data may be subjected to security and privacy breaches is information processing. It involves the use or transformation of collected data. Data can be used or processed in many ways. Such as data aggregation, which refers to studying different pieces of data about an individual to predict his future behavior accurately. E.g., aggregating users' travel data consisting of travel time, destinations, distance travel, and waypoints to predict his future destination or travel distance. Similarly, an iHealth system may predict an individual's estimated life span based on his health history, medications, and lifestyle (eating and exercise habits). Such a piece of information may affect users' insurance policies/claims. Hence, a scenario where an autonomous system has more information about a person than the person knows himself is termed as "Inverse Privacy" [180]. In addition to data aggregation, identification [179] is another data processing action in which a person is uniquely identified based on his real-world ID. E.g., if autonomous cars and smart surveillance systems start identifying and proactively recording data about all the people moving around. In such a case, people will not have any privacy of their movement, location, and usual activities.

Sequel to data collection and processing, data storage, and management is another critical function that may affect data security and privacy. As shown in Fig.15 all the data collected and processed by autonomous systems in STP is stored in the respective autonomous system DB and also in STP Data Arena. The most significant requirement at this stage is that personal data should be protected against security breaches while it is kept in a traditional DB or a data lake. Hence, there is a need for secure autonomous systems. However, due to the complex nature of autonomous systems, and high-connectivity, they are vulnerable to hacking, and other cyber threats [181]. In addition, often due to service level agreements (SLA), the developers of autonomous systems have remote access to the deployed systems for troubleshooting or other maintenance tasks. Hence, it is highly probable that they have full access to respective autonomous system components, including user data, which may be a severe security and privacy threat. Therefore, service-level access should be carefully assessed and authorized.

Similarly, data sharing between different autonomous systems should also be carefully planned and executed. Security and privacy of data must be ensured by design, and authorizations should be granted based on the principle of "Least Privilege" [182] i.e., people, systems, and processes should

have access to only those resources (networks, systems, and files) that are absolutely necessary to perform their assigned function. E.g., DaaS may have access to the MaaS system to coordinate hand over and delivery of packages in case of inclement weather. Or DaaS may access data of aFaaS to spot and monitor livestock. Similarly, DaaS can access iSecurity and Safety system for various search, rescue and relief efforts. Hence, DaaS may have many different levels of privilege with other autonomous systems on mutual trust. However, every system/organization must ensure that each trust relationship is granted minimal privileges to perform a particular task.

B. DATA SECURITY AND PRIVACY MEASURES

Security of any system is derived by some policy and regulatory controls. Subsequently, in the case of an IT system, the technical controls are designed and developed to comply with respective organization's or country's policies/regulations. According to Australian Privacy Principles (APP) [183], every individual has the right to decide how his personal (that identifies his identity) and sensitive information (personal opinion, choices, biometrics, etc.) is handled. Hence, any organization covered under the Australian Privacy Act 1988 (including all the amendments) [58], is bound to manage users' personal information in a transparent way with a clearly expressed privacy policy. Correspondingly, every user has the right to know that: what kind of personal details the respective entity collects and holds, how the entity collects and stores that information, and the purposes for which the entity collects, maintains, uses, and discloses personal information. Moreover, the act also directs that users' sensitive information must have a higher level of privacy protection than other data.

Therefore, concerned parties must take reasonable steps to ensure confidentiality, integrity, and availability of personal data. Also, in some cases, personal information/data should be destroyed or de-identified. In the same way, [170] emphasizes that protecting user privacy is the first line of defense against various cyber-attacks that exploit users' private data obtained through security breaches. These threats include online discrimination, phishing, identity theft, cyber scams, cyberstalking, cyberbullying, etc. Therefore, to preserve the privacy of user data, in addition to a transparent privacy policy statement, the respective organization/system should also hold confidentiality and integrity properties. In other words, any organization/system handling users' personal data must employ both regulatory and technical controls to ensure data privacy. Subsequently, we propose a data strategy and some technical controls to ensure the security and privacy of STP users and tenants.

1) DATA STRATEGY

STPs must advocate compliance to regulatory frameworks so that system designers and developers are bound to design and develop privacy-preserving autonomous systems. E.g., given the Australian Privacy Act 1988, and European Union General Data Protection Regulation (EU GDPR) [184], the autonomous systems should:

(a) Collect and process personal data only with the consent of the data owner.
(b) Preserve user privacy by design.
(c) Gather, process, and use personal data/information under the instructions based on a mutual contract between the user and respective organization/entity.
(d) Give data owner the right to access the information concerning the processing of his data, i.e., which third parties have access to what information and how they use it.
(e) Erase users' personal data immediately once it is no longer needed.
(f) Be transparent such that individuals know about the collection and use of their data.
(g) Make unbiased and fully autonomous decisions without any special considerations from the vendors or system manufacturers (additional regulation required).

2) TECHNICAL CONTROLS

Concerning technical controls, usually access to data is controlled through data encryption, authentication, and authorization measures [174]. Similarly, there are defined strategies to achieve privacy-by-design in autonomous systems [185]. Hence, the technical controls for security and privacy proposed in this study revolve around the following guidelines:

(a) Selected/particular data to be collected by the devices/autonomous systems and anonymization and pseudonymization techniques to hide the users' real identity.
(b) Data is to be secured at rest and in transit, in combination with network traffic hiding techniques such as TOR [186].
(c) Personal data must be stored and processed in a distributed manner, i.e., data from multiple sources about the same person should be stored and processed separately. So that if one DB or system is compromised, a complete profile of the affected users cannot be made.
(d) Use of privacy-preserving data aggregation techniques such as k-anonymity [187], differential-privacy [188]. In this context, Lu *et al.* [189] proposed a lightweight privacy-preserving data aggregation solution for IoT applications, which can be applied in Agri tech. The proposed solution combines three cryptographic techniques: homomorphic Paillier encryption, the Chinese Remainder Theorem, and a one-way hash chain. These three techniques are used to encrypt sensor data, calculate the mean and variance of aggregated IoT data, and provide lightweight authentication among IoT devices.
(e) While using any system, the users should be informed in a transparent way about the information being collected and processed, how it is collected, and its purpose. Data owners should also be informed about the

ways their data is protected. In addition, the users must know that with which third parties their information is shared. Similarly, users must be clear about their data access rights and how to exercise them.

(f) Users should control their data so that they can update their privacy settings, regulate access to their data assets, and delete data that is not required for any of the services the user is availing.

(g) Privacy policies based on legal requirements should be enforced using various access control measures.

(h) There should be an accountability of compliance to privacy policies using logging, auditing, or other techniques.

Correspondingly, Fig.15 portrays the complete picture of autonomous systems threats and requisite security measures. For better understanding, follow the diagram from left to right and bottom to top. The security threats are shown in the red box at each layer, and related security measures are shown in green boxes on the opposite (right) side. It can be seen that autonomous systems collect different types of user data varying from dietary habits to PII, such as medicare ID, citizenship number, driving license number, passport number, biometrics, etc. However, the autonomous systems should be so designed that they should consider privacy norms [190] while collecting information about users to optimize respective service levels. Moreover, most of the systems in the real-world present complex privacy statements at the time of signup. Therefore, it is recommended that there should be a smart personal assistant [191] that should negotiate the policy statements and related consents on behalf of the user. Similarly, to enforce compliance to a mutual agreement between an autonomous system and a user, a blockchain-based smart contract can be used. As blockchain works on the network consensus principle, no individual system can modify the contract terms. Moreover, data can only be collected as per authorizations defined by the data owner.

The data sensed and collected by autonomous systems infrastructure is further transported to the data orchestration layer through various communications protocols. The communications protocols may include WiFi, 5G, Optical Fiber, GbE, satellite communications, or LP-WAN technologies such as LoRaWAN, and NB-IoT. Nonetheless, to counter protocol-specific vulnerabilities that may pose a threat to data confidentiality and integrity during transit, it is recommended that the source devices should encrypt the data. Similarly, an additional user/data authentication mechanism should also be employed to ensure data integrity. It is also preferred that autonomous systems such as DaaS, MaaS, aFaaS, smart homes, and iHealth mostly comprise particular types of IoT devices. And these devices, usually operating independently in a trustless environment, are vulnerable to various threats, such as physical compromise, hacking, and code modification [192]. Hence, the security of IoT devices is of utmost importance. Therefore, it is proposed that all the devices/equipment part of an autonomous system that operates directly in the public place must be tamper-proofed.

Also, there should be some mechanism to verify the integrity of IoT devices on a regular basis.

It is evident from Fig.15 that most of the vulnerabilities emerge at the data orchestration layer, where data is stored, processed, managed, and shared with various stakeholders. Hence, to prevent various attacks, different defense strategies are proposed. Firstly, to prevent unauthorized access to data in the garb of SLAs, access to system resources should be regulated based on the principle of "Least Privilege." In the same way, to avoid a single point of failure, threats to data availability, and trust issues, STPs can leverage blockchain-based privacy and integrity-preserving data sharing framework [173] that provides a distributed environment with decentralized control. It also empowers data owners to authorize access and control the time of access to their data. The data owners are given an incentive for sharing their data. This incentive is important to bolster maximum participation of people by residing and working in a data-enabled living science city offering numerous autonomous services that rely on users' data for intelligent decision-making. Correspondingly, there have been work on various blockchain-based solutions for Agri tech including Blockchain-based privacy-preserving data analytics [193], blockchain-based distributed key management solution [194], blockchain-based access control solution [195], blockchain-based reputation and trust solution [196], blockchain-based authentication and identification solution [197], and blockchain-based secure SDN to prevent false data injection [198].

Furthermore, entrusting users with more control over their data, end-to-end encryption can be used to ensure data security as it is collected and transmitted by the autonomous systems and stored in the local DB, followed by collection and storage in the STP Data Arena. However, it is not easy to perform different data analytics functions over encrypted data. Even homomorphic encryption schemes provide limited computable functions. On the contrary autonomous systems need to perform complex tasks over data such as reasoning, planning, inferring, or learning. Hence, an alternative to encryption may be trusted computing, which has been quite successful for private multi-party learning [199].

In addition, transparency is also considered essential for both user privacy [200] and autonomous systems [201]. In the context of privacy, transparency is that data owners know how a particular system collects, processes, stores, and share their data. Whereas, for autonomous systems, transparency fosters trust between humans and respective systems by allowing humans to better understand the operation of autonomous systems and their decisions. However, it is comparatively difficult to assess transparency for autonomous systems than traditional software applications where mostly public disclosure of the code is enough [202]. Therefore, a new research area has emerged to ensure fair computations and fair machine learning so that the autonomous systems make unbiased decisions [203]. Another challenge is the balance between transparency and privacy in autonomous systems. Since transparency involves knowing the current state of
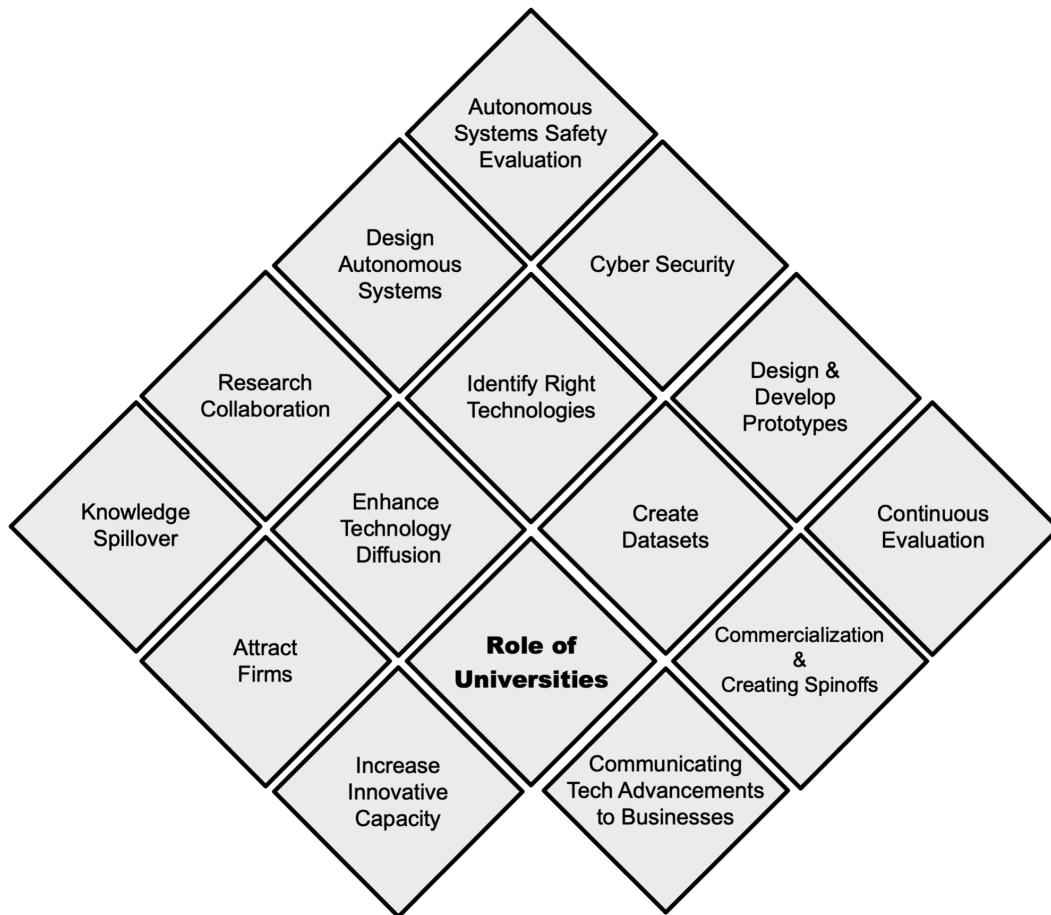
FIGURE 16. Role of universities.

reasoning of an autonomous system and related data sets, this would be acceptable unless the current state of reasoning and related data sets does not disclose PII [201]. Hence, to preserve users' privacy by preventing disclosure of PII, it is recommended that differential privacy based blockchain solutions be considered [204], [205].

Besides, there are numerous security threats to web applications [206]. Some of the most pronounced attacks at the application layer and related security measures are illustrated in the following paragraphs:

- **Injection Flaws:** Web applications are vulnerable to Structured Query Language (SQL), noSQL, and Lightweight Directory Access Protocol (LDAP) injection flaws. These attacks enable the attacker to execute some specific commands or have unauthorized access to data by sending malicious data as a query to the interpreter. Such attacks can be avoided by carefully verifying the input data.
- **Broken Authentication and Access Control:** Attackers can compromise passwords, keys, session tokens, or have unauthorized access to users' accounts and sensitive data. Similarly, attackers can modify access rights due to incorrect implementation of application functions related to authentication, access control, and session

management. However, these threats can be prevented by prioritizing security during the design and development of web applications. Subsequently, the application developers should employ multifactor authentication schemes, and effective access control techniques such as role-based or geo-location-based access control [207], [208] to regulate unauthorized access to the applications and sensitive data.

- **Sensitive Data Exposure:** Most of the time, application developers do not pay much heed to the security aspects [192]. As a result, many web applications and APIs do not adequately protect sensitive data such as financial, healthcare, and PII. Hence, attackers may modify or steal such unprotected sensitive data and conduct identity theft, web extortion, credit card fraud, or other attacks. However, sensitive data can be protected with sufficient authentication and access control measures, as mentioned in the previous paragraph.
- **Security Misconfiguration:** This is the most common security vulnerability in web applications. It involves insecure default configurations, incomplete or ad-hoc configurations, open cloud storage, misconfigured HTTP headers, and verbose error messages containing sensitive information. Therefore, it is recommended that

all applications be securely configured with the compulsion of changing default security parameters such as usernames and passwords. Moreover, there must be timely security updates in case of any security breach or discovery of a zero-day attack.

- **Cross-Site Scripting (XSS):** A successful occurrence of XSS attack enables an attacker to execute malicious chunks of JavaScript in victim's browser. As a result, the attacker can redirect the victim to a malicious website, hijack the current session or deface the affected website. Such attacks can be prevented by making sure that any dynamic content coming from the back-end data store cannot be used to inject JavaScript on a web page [209].

V. ROLE OF UNIVERSITIES IN A STP

Universities are the epic center of academic research, innovation, and generation of new ideas. According to [210], universities are a kind of "factory" generating new patentable products. Moreover, authors in [211], [212] assert that universities in a STP cause knowledge spillovers that benefit various stakeholders and promote the creation and exchange of technological knowledge. As a result of this knowledge sharing, the firms or startups at STP have the opportunity to improve their innovative capacity. Hence, universities attract private-sector organizations and other nonprofit technology research groups. However, universities require ways and means to turn academic research into innovative commercial products [9]. For this purpose, STPs should endeavor to provide the desired platform to the universities and private-sector research centers to play their part. In this context, STPs must try to enhance universities' role with an increased cooperation/collaboration with industry.

As shown in Fig.16 during the planning and design phase of a STP, universities can employ higher degree research students and respective staff members to conceive and prepare initial designs of different autonomous systems. The vital aspect here is identifying the right technologies and related products to sustain a particular autonomous system for the next 10-15 years, with an up-gradation option to cater to futuristic changes. Similarly, HEIs can help create data sets that would be required for various intelligent systems for training purposes. Moreover, keeping in view the research potential and availability of specialized equipment, HEIs can even develop numerous systems as part of the ASaaS business model. E.g., a university equipped with cutting-edge robotics technologies may develop prototypes of some personal, service, and social robots. These prototypes can be employed in universities' campuses for further testing and optimization. Similarly, universities can design and develop prototypes of iLighting systems and use them in local council areas to gather environmental data and provide various services to the users. Subsequently, universities can collaborate with manufacturers/vendors for the ToT and commercial level development of new technologies/products.

Another critical aspect that seeks the attention of HEIs is the evaluation of safety aspects related to autonomous systems. Here, the point of concern is uncontrolled or biased actions [203] by autonomous systems due to hardware or software bug threatening human lives. Similarly, research scientists from HEIs or specialized research centers can play their part in the research and development of security solutions against cyber threats at all stages of STPs' development, i.e., planning, design, development, and operation. Universities are also expected to build up a research collaboration with industry to stimulate patenting, licensing, and development of new technologies and products. Correspondingly, universities are increasingly emphasizing the creation of new startups/companies as a mechanism for commercialization [10] of newly developed technologies and products. E.g., University of Technology Sydney (UTS's) "Startups" [213] and "Techcelerator" [214] programs aim at helping young entrepreneurs to promote their ideas, develop prototypes, and survive successfully through their infancy stages. These programs provide all necessary support to the students in terms of collaboration spaces, mentorship, profile-building, community-building, and enhancing prototyping and market-testing skills. Therefore, it is certain that if facilities like UTS's Startups, and Techcelerator are available in STPs, many young firms can benefit from them. Moreover, universities are the best platform to communicate technological advancements identified through R&D to the business community and industry partners. This will also help in better understanding and propagation of innovative ideas. Thus increasing the chances of getting R&D grants. It is also foreseen that HEIs can facilitate technology diffusion by providing technical consultancy and establishing technology transfer centers through the licensing of university-based technologies to existing firms or new ventures [11]. Similarly, academic and specialized research centers can promote the development of new technologies by providing specialized equipment and labs for testing and evaluation. In the same way, HEIs should continuously carry out an appraisal of technologies employed in STPs to identify vulnerabilities and suggest improvements.

VI. COMPONENTS OF A STP

Based on our discussion on STP's objectives in Section II-A and ASaaS in Section III, it is envisaged that components shown in Table.2 should form part of a STP to support attainment of most of its goals/objectives. As discussed in Section V universities and other HEIs are essential for the success of STPs. They are the source of knowledge spillover and also facilitate R&D collaboration with the industry. Moreover, HEIs can also support new startups and young entrepreneurs in the early stages of their establishment. Similarly, private-sector or even government-sponsored R&D centers located inside STPs can collaborate with HEIs and industries to solve future problems. In addition to R&D cooperation, technical consultancy services to tech-based startups in any form, i.e., technical advice or skilled resource, are necessary for new prototypes or product development. Correspondingly, new startups, entrepreneurs, and tech-based

TABLE 2. Components of a science and technology park.

Component	Rationale
Universities and other HEIs	Knowledge spillover, R&D collaboration
R&D centers	Collaborate with HEIs and industry to solve future challenges
Startup incubators	Mentorship of entrepreneurs
Technical consultancy services	Assistance in product/prototype development
Startups/Entrepreneurs	Solve social & industry problems, develop new technologies
Industry representatives	Collaboration with academic and R&D centers
Financial institutions	Assist STP tenants
Representatives of government regulatory bodies (Finance, law, customs, cyber security, research and innovation, ICT, IP etc.)	Guide and ensure compliance to government rules
Park management	Govern and resolve all the issues of the park
Business support	Guide and assist park tenants
ICT service providers	Provision of ICT services
Security Operations Center (SOC)	Cyber security
Roads and Maritime Services (RMS) representatives	Implement traffic laws
Disaster Recovery and Management (DRM) services	Disaster management
Basic commodities (restaurants, parks, shops, hospital, cinemas, professional gaming zones)	Improve livability of STP
Libraries, auditoriums, and community centers	Assist in knowledge sharing
Specialized laboratories	Assist in testing of new technologies
Equipment, spares, tools, and warehouses	Assist in prototype and product development
Workspace (Private spaces, shared public workspaces and conference rooms)	Improve collaboration
Accommodation	Improve livability
Autonomous systems	Value-added services

firms are some of the cardinal components of a STP that boost technological advancements. Likewise, representatives from industries such as manufacturing, agriculture, robotics, and construction should also be located in the park to coordinate and drive industry-focused research.

Another critical element is the provision of business support by STP management to the tenants. This support can be in the form of consultation related to marketing, finance, IP, copyrights, and government regulations. Furthermore, public and private VC organizations and seed capital providers with a presence in STP may provide financial support to the firms/startups. Subsequently, government agents from various regulatory bodies, e.g., finance, law, customs, cybersecurity, ICT, research and innovation, and IP, should be there in the STP to ensure compliance with government policies/regulations. Similarly, the presence of a suitably composed onsite park management is vital to govern and resolve all the issues related to maintenance, tenant registration and accommodation, event management, dispute resolution, supply chain management, disaster management, and security of park infrastructure. Other than park management, ICT service providers are also one of the core elements of a STP. ICT service providers must be involved in all the planning and development stages so that ICT services are available to the park developers, management, and tenants from the initial phases of their settlement in the park. Subsequently, after the start of ICT operations in the STP, a Security Operations Center (SOCS) is a crucial entity. SOC is a centralized function within the STP that employs people, processes, and technology to continuously monitor and improve security posture. Its primary objective is to prevent, detect, analyze, and respond to cybersecurity incidents [215]. On the other hand, to ensure road safety and regulate the MaaS system, Roads and Transport Services' (RTS) availability in the park is of fundamental importance.

Moreover, the adverse effects of global warming in the form of floods, storms, bush fires, and cyclones are on the rise than ever before. Hence, in coordination with respective government agencies, the STP management should prepare a comprehensive Disaster Recovery and Management (DRM) plan. And equip STP with the necessary equipment and allied resources. Similarly, to provide a high standard of living to the tenants, park management must arrange essential commodities such as grocery stores, restaurants, motels, parks, sports centers, gyms, hospitals, cinemas, professional gaming zones, etc. Likewise, to facilitate knowledge sharing and networking/collaboration between onsite firms/companies/HEIs, there should be libraries, auditoriums, and community centers at the STP. Park management may coordinate and arrange different social events, academic conferences, workshops, or seminars to build networking and collaboration opportunities between various stakeholders. In the same way, keeping in view the scope of R&D, the park management, in coordination with HEIs, and industry partners, should ensure the availability of necessary equipment, spares, and tools to meet demands in the minimum possible time. Also, to further enhance the STP's livability, cutting-edge smart homes/units at economical rates should be provided to the park tenants. Correspondingly, to make STP a rare attraction for all the stakeholders with an innovative

look, different autonomous systems should be employed to provide value-added services to the tenants.

VII. FUTURE CHALLENGES

Though we believe that ASaaS business model for STPs has more merits than the demerits. However, there are some significant challenges concerning autonomous systems that must be given due consideration during the design and development stages and while integrating different systems.

(a) It is a daunting task to ensure open-sourcing of autonomous systems and their compliance with international standards once a myriad of technologies and systems operate in a STP.

(b) Moreover, it is also an open challenge to control fully autonomous systems' biasedness or malicious action if they are compromised or malfunction. Similarly, it is currently difficult to assess the transparency of fully autonomous systems.

(c) Furthermore, it is also challenging to draw a balance between transparency and privacy in autonomous systems. Correspondingly, the governments should update their data security and privacy regulations by including some clauses on autonomous systems' unbiased decision making and transparency.

(d) Concerning the ASaaS user interface, we envision that the autonomous systems should intuitively interact with the users, which can be achieved using NLP supporting multiple languages, including French, English, Chinese, Hindi, Urdu, etc.). The users must find the interface familiar and straightforward where they can interact using voice and text commands. It is also essential that the user interface for each user should support customized settings as per the services subscribed by the respective user. Similarly, the STP tenants and other users should have a simple way, e.g., a slider to control the priority of their jobs for each service. The cost and the estimated time for the desired service can then be calculated and displayed in real-time on the user interface.

(e) If we look at system-specific merits and challenges, firstly, the autonomous waste management system requires considerable research for accurate identification and classification of objects. So that fast decaying items should be collected and disposed off immediately.

(f) The DaaS's on-demand nature allows shipments to be sent as soon as they are ready rather than waiting for the following day's shipping run. Thus DaaS supports the rapid fulfillment of time-critical deliveries. Moreover, data gathered both actively and passively can enhance the DaaS delivery system's capability to track shipments accurately. However, inclement weather can affect the drones' operation. Therefore, graded priority on jobs can help the system make intelligent decisions about responding to such events. Correspondingly, ground-based autonomous vehicles can be a suitable

alternative to drones in inclement weather. Besides, the autonomous cars carrying more sensors are also suited to continuous mapping functions to update the real-time 3D map of STP. We also believe that a subscription to the DaaS health emergency service will save loved ones' lives.

(g) Concerning the STP Data Arena, a considerable effort is required to develop a privacy-preserving data analytics framework that must protect users against data privacy and security threats. Likewise, if we look at aFaaS, it has a lot of potentials. However, in addition to establishing model autonomous Agri farms in STPs, farmers worldwide need to be educated on Agri technologies' use-cases and benefits. Hence, there is a need to address farmers' concerns/misconceptions over safety, security, and loss of jobs due to autonomous robots.

(h) Another critical issue for autonomous systems is the availability of suitable datasets. Correspondingly, The datasets for cyber security are equally important in intrusion detection. Actually, most and recent intrusion detection systems are tested with KDD 1999, NSL-KDD, CICIDS2017, and Bot-IoT [178]. However, these datasets are not designed for IoT-based Agri tech scenarios. Hence, there is a requirement of developing new datasets for IoT-based agriculture environment to build network security and other service models.

(i) For blockchain supported IoT-based Agri tech solutions, the critical area to explore is validation of IoT devices' integrity. This is also termed as an ''Oracle Problem'' for blockchain applications, where ensuring integrity of data input to the blockchain is an open challenge. Similarly, security of blockchain applications and smart contracts require considerable efforts in addition to conventional security measures.

VIII. CONCLUSION

STPs are considered to be the epitome of innovation and growth of a technology-based economy. However, for a STP to be successful, it should have the means to attract technology-based companies, related businesses, and industries. Therefore, to impart a futuristic look to STPs, we introduced the concept of autonomous systems as a service. We believe that the autonomous systems-based business model will increase the liveability in the STPs and provide a playground for the testing and evaluation of new technologies in a controlled environment. On the contrary, entrepreneurs and tech-based firms cannot reasonably evaluate new products and technologies without impacting the general population's safety and privacy.

However, autonomous Agri technologies need to be more robust and intelligent to operate effectively in a world of ever-increasing natural calamities, like bush fires, flash floods, storms, and earthquakes. We also anticipate reducing the operational costs and increase the serviceability of the

autonomous systems. It can be achieved by ensuring that the autonomous systems must perform self-diagnostics to monitor the health of their equipment, devices/components, and schedule replacements and maintenance accordingly.

This study also appraised threats to data security and privacy in autonomous systems and proposed requisite security measures. Subsequently, we observe that ensuring the security of multidimensional data acquisition, storage, and processing systems against perilous cyber threats is an appalling task that requires careful planning, risk assessment, and a defense-in-depth approach. This research also specified many components that may contribute to attaining the overall objectives of a STP. Finally, numerous challenges concerning autonomous systems were emphasized to facilitate practical implementation of the proposed ASaaS business model in near future.

REFERENCES

[1] (2020). *Stanford Research Park*. Accessed: Oct. 25, 2021. [Online]. Available: https://stanfordresearchpark.com/about

[2] Y. Zhang, "The science park phenomenon: Development, evolution and typology," *Int. J. Entrepreneurship Innov. Manage.*, vol. 5, nos. 1–2, pp. 138–154, Feb. 2005.

[3] (2021). *Sydney Science Park*. Accessed: Oct. 10, 2021. [Online]. Available: https://www.celestino.net.au/sydneysciencepark/residential

[4] S. Judy. (2021). *Sydney Science Park Tests Smart Waters*. Accessed: Oct. 10, 2021. [Online]. Available: https://www.governmentnews.com.au/sydney-science-park-tests-smart-waters/

[5] D. B. Audretsch and M. P. Feldman, "R&D spillovers and the geography of innovation and production," *Amer. Econ. Rev.*, vol. 86, no. 3, pp. 630–640, Mar. 1996. [Online]. Available: http://www.jstor.org/stable/2118216

[6] M. Polanyi. (1966). *The Tacit Dimension*. [Online]. Available: https://books.google.com.au/books?hl=en&lr=&id=zfsb-eZHPy0C&oi=fnd&pg=PR6&dq=The+Tacit+Dimension,+Reissue&ots=HffCQCAqdP&sig=rkCIuUONNA61V-cisvW2yaahh6U#v=onepage&q&f=false

[7] Z. J. Acs, L. Anselin, and A. Varga, "Patents and innovation counts as measures of regional production of new knowledge," *Res. Policy*, vol. 31, no. 7, pp. 1069–1085, Sep. 2002. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0048733301001846

[8] I. Díez-Vial and M. Fernández-Olmos, "Knowledge spillovers in science and technology parks: How can firms benefit most?" *J. Technol. Transf.*, vol. 40, no. 1, pp. 70–84, Feb. 2015.

[9] D. Massey and D. Wield, *High-Tech Fantasies: Science Parks in Society, Science and Space*. Evanston, IL, USA: Routledge, Sep. 2003.

[10] J.-J. Degroof and E. B. Roberts, "Overcoming weak entrepreneurial infrastructures for academic spin-off ventures," *J. Technol. Transf.*, vol. 29, no. 3/4, pp. 327–352, Aug. 2004.

[11] D. S. Siegel, M. Wright, and A. Lockett, "The rise of entrepreneurial activity at universities: Organizational and societal implications," *Ind. Corporate Change*, vol. 16, no. 4, pp. 489–504, Jul. 2007, doi: 10.1093/icc/dtm015.

[12] K. Bruce and W. Julie. (2021). *The Rise of Innovation Districts*. Accessed: Nov. 27, 2021. [Online]. Available: https://www.brookings.edu/essay/rise-of-innovation-districts/

[13] (2021). *David Johnston Research+Technology Park*. Accessed: Nov. 26, 2021. [Online]. Available: https://rtpark.uwaterloo.ca

[14] F. Ubeda, M. Ortiz-de-Urbina-Criado, and E.-M. Mora-Valentín, "Do firms located in science and technology parks enhance innovation performance? The effect of absorptive capacity," *J. Technol. Transf.*, vol. 44, no. 1, pp. 21–48, Feb. 2019.

[15] W. K. B. Ng, R. Junker, R. Appel-Meulenbroek, M. Cloodt, and T. Arentze, "Perceived benefits of science park attributes among park tenants in The Netherlands," *J. Technol. Transf.*, vol. 45, no. 4, pp. 1196–1227, Aug. 2020.

[16] A. Albahari, S. Pérez-Canto, and P. Landoni. (Sep. 2010). Science and technology parks impacts on tenant organisations: A review of literature. MPRA. [Online]. Available: https://mpra.ub.uni-muenchen.de/id/eprint/41914

[17] K.-F. Huang, C.-M.-J. Yu, and D.-H. Seetoo, "Firm innovation in policy-driven parks and spontaneous clusters: The smaller firm the better?" *J. Technol. Transf.*, vol. 37, no. 5, pp. 715–731, Oct. 2012.

[18] L. Lecluyse, M. Knockaert, and A. Spithoven, "The contribution of science parks: A literature review and future research agenda," *J. Technol. Transf.*, vol. 44, no. 2, pp. 559–595, Dec. 2019.

[19] K. G. Hobbs, A. N. Link, and J. T. Scott, "Science and technology parks: An annotated and analytical literature review," *J. Technol. Transf.*, vol. 42, no. 4, pp. 957–976, Aug. 2017.

[20] C. P. Eveleens, F. J. van Rijnsoever, and E. M. M. I. Niesten, "How network-based incubation helps start-up performance: A systematic review against the background of management theories," *J. Technol. Transf.*, vol. 42, no. 3, pp. 676–713, Jun. 2017.

[21] S. Mian, W. Lamine, and A. Fayolle, "Technology business incubation: An overview of the state of knowledge," *Technovation*, vols. 50–51, pp. 1–12, May 2016. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0166497216000183

[22] M. McAdam, K. Miller, and R. McAdam, "Situated regional university incubation: A multi-level stakeholder perspective," *Technovation*, vols. 50–51, pp. 69–78, Apr. 2016. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0166497215000632

[23] A. Lockett, D. Siegel, M. Wright, and M. D. Ensley, "The creation of spin-off firms at public research institutions: Managerial and policy implications," *Res. Policy*, vol. 34, no. 7, pp. 981–993, Sep. 2005. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0048733305001113

[24] Á. R. Vásquez-Urriago, A. Barge-Gil, A. M. Rico, and E. Paraskevopoulou, "The impact of science and technology parks on firms' product innovation: Empirical evidence from Spain," *J. Evol. Econ.*, vol. 24, no. 4, pp. 835–873, Sep. 2014.

[25] J. Ribeiro, A. Higuchi, M. Bronzo, R. Veiga, and A. de Faria, "A framework for the strategic management of science & technology parks," *J. Technol. Manage. Innov.*, vol. 11, no. 4, pp. 80–90, Dec. 2016.

[26] D. Minguillo, R. Tijssen, and M. Thelwall, "Do science parks promote research and technology? A scientometric analysis of the U.K.," *Scientometrics*, vol. 102, no. 1, pp. 701–725, Jan. 2015.

[27] D. Minguillo and M. Thelwall, "Which are the best innovation support infrastructures for universities? Evidence from R&D output and commercial activities," *Scientometrics*, vol. 102, no. 1, pp. 1057–1081, Jan. 2015.

[28] F. Lamperti, R. Mavilia, and S. Castellini, "The role of science parks: A puzzle of growth, innovation and R&D investments," *J. Technol. Transf.*, vol. 42, no. 1, pp. 158–183, Feb. 2017.

[29] E.-M. Mora-Valentín, M. Ortiz-de-Urbina-Criado, and J.-J. Nájera-Sánchez, "Mapping the conceptual structure of science and technology parks," *J. Technol. Transf.*, vol. 43, no. 5, pp. 1410–1435, Oct. 2018.

[30] R. E. Hall, B. Bowerman, J. Braverman, J. Taylor, H. Todosow, and U. Von Wimmersperg, "The vision of a smart city," in *Proc. 2nd Int. Life Extension Technol. Workshop*, Paris, France, Sep. 2000, pp. 1–7. [Online]. Available: https://www.osti.gov/biblio/773961

[31] J. Henneberry, "Science parks: A property-based initiative for urban regeneration," *Local Economy: J. Local Economy Policy Unit*, vol. 6, no. 4, pp. 326–335, Feb. 1992, doi: 10.1080/02690949208726117.

[32] J. Phillimore, "Beyond the linear view of innovation in science park evaluation an analysis of western Australian technology park," *Technovation*, vol. 19, no. 11, pp. 673–680, Nov. 1999. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0166497299000620

[33] Y. L. Bakouros, D. C. Mardas, and N. C. Varsakelis, "Science park, a high tech fantasy: An analysis of the science parks of Greece," *Technovation*, vol. 22, no. 2, pp. 123–128, Feb. 2002. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0166497200000870

[34] M. van Geenhuizen, "Science parks' diversity and broadened roles: New concepts and grounds for evaluation," in *Proc. 14th Triple Helix Int. Conf.*, Heidelberg, Germany, 2016, pp. 1–8.

[35] H. Romijn and M. Albu, "Innovation, networking and proximity: Lessons from small high technology firms in the U.K.," *Regional Stud.*, vol. 36, no. 1, pp. 81–86, Feb. 2002, doi: 10.1080/00343400120099889.

[36] K.-Y.-A. Chan, L. A. G. Oerlemans, and M. W. Pretorius, "Knowledge exchange behaviors of science park firms: The innovation hub case," in *Proc. Portland Int. Conf. Manage. Eng. Technol. (PICMET)*, Portland, OR, USA, Aug. 2009, pp. 964–1006.

[37] P. Westhead and S. Batstone, "Perceived benefits of a managed science park location," *Entrepreneurship Regional Develop.*, vol. 11, no. 2, pp. 129–154, Apr. 1999, doi: 10.1080/089856299283236.

[38] F. Cheng, F. van Oort, S. Geertman, and P. Hooimeijer, "Science parks and the co-location of high-tech small- and medium-sized firms in China's Shenzhen," *Urban Stud.*, vol. 51, no. 5, pp. 1073–1089, Jun. 2014, doi: 10.1177/0042098013493020.

[39] Ö. Koçak and Ö. Can, "Determinants of inter-firm networks among tenants of science technology parks," *Ind. Corporate Change*, vol. 23, no. 2, pp. 467–492, Apr. 2014.

[40] Y. Zou and W. Zhao, "Anatomy of Tsinghua university science park in China: Institutional evolution and assessment," *J. Technol. Transf.*, vol. 39, no. 5, pp. 663–674, Oct. 2014.

[41] T. Ratinho and E. Henriques, "The role of science parks and business incubators in converging countries: Evidence from Portugal," *Technovation*, vol. 30, no. 4, pp. 278–290, Apr. 2010. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0166497209001382

[42] J. Edler and L. Georghiou, "Public procurement and innovation—Resurrecting the demand side," *Res. Policy*, vol. 36, no. 7, pp. 949–963, Sep. 2007. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0048733307000741

[43] M. Ferrara, F. Lamperti, and R. Mavilia, "Looking for best performers: A pilot study towards the evaluation of science parks," *Scientometrics*, vol. 106, no. 2, pp. 717–750, Dec. 2016. [Online]. Available: https://link.springer.com/content/pdf/10.1007/s11192-015-1804-2.pdf

[44] B. Bigliardi, A. I. Dormio, A. Nosella, and G. Petroni, "Assessing science parks' performances: Directions from selected Italian case studies," *Technovation*, vol. 26, no. 4, pp. 489–505, Apr. 2006. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0166497205000039

[45] I. Diez-Vial and A. Montoro-Sanchez, "Research evolution in science parks and incubators: Foundations and new trends," *Scientometrics*, vol. 110, no. 3, pp. 1243–1272, Jan. 2017.

[46] D.-S. Oh, F. Phillips, S. Park, and E. Lee, "Innovation ecosystems: A critical examination," *Technovation*, vol. 54, pp. 1–6, Aug. 2016. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0166497216300062

[47] E. Dahan and J. R. Hauser, *Product Development: Managing a Dispersed Process*. Newbury Park, CA, USA: Sage, Sep. 2002.

[48] A. Albahari, M. Klofsten, and J. C. Rubio-Romero, "Science and technology parks: A study of value creation for park tenants," *J. Technol. Transf.*, vol. 44, no. 4, pp. 1256–1272, Aug. 2019.

[49] H. Etzkowitz and L. Leydesdorff, "The Triple Helix–University-industry-government relations: A laboratory for knowledge based economic development," *EASST Rev.*, vol. 14, no. 1, pp. 14–19, Jan. 1995.

[50] P. Westhead and S. Batstone, "Independent technology-based firms: The perceived benefits of a science park location," *Urban Stud.*, vol. 35, no. 12, pp. 2197–2219, Dec. 1998, doi: 10.1080/0042098983845.

[51] Y. K. Tang, "The influence of networking on the internationalization of SMEs: Evidence from internationalized Chinese firms," *Int. Small Bus. J., Researching Entrepreneurship*, vol. 29, no. 4, pp. 374–398, May 2011.

[52] R. Ferguson and C. Olofsson, "Science parks and the development of NTBFs—Location, survival and growth," *J. Technol. Transf.*, vol. 29, no. 1, pp. 5–17, Jan. 2004.

[53] E. Salvador, "Are science parks and incubators good 'brand names' for spin-offs? The case study of Turin," *J. Technol. Transf.*, vol. 36, no. 2, pp. 203–232, Apr. 2011.

[54] S. L. Hoe, "Defining a smart nation: The case of Singapore," *J. Inf., Commun. Ethics Soc.*, vol. 14, no. 4, pp. 323–333, Nov. 2016.

[55] M. Cavada, M. R. Tight, and C. D. Rogers, *A Smart City Case Study of Singapore-Is Singapore Truly Smart?* L. Anthopoulos, Ed. London, U.K.: Elsevier, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780128161692000146

[56] (2020). *Singapore: Smartest City in the World. Robots and Technology of the Future Today*. Accessed: Sep. 25, 2021. [Online]. Available: https://youtu.be/SPbqsCqEwfs

[57] D. P. Watson and D. H. Scheidt, "Autonomous systems," *Johns Hopkins APL Tech. Dig.*, vol. 26, no. 4, pp. 368–376, 2005.

[58] (2021). *Privacy Act 1988*. Accessed: Nov. 10, 2021. [Online]. Available: https://www.legislation.gov.au/Details/C2021C00024

[59] Q. Zhao, L. Xia, and Z. Jiang, "Project report: New generation intelligent building platform techniques," *Energy Informat.*, vol. 1, no. 1, pp. 1–5, Dec. 2018.

[60] A. Walter, R. Finger, R. Huber, and N. Buchmann, "Opinion: Smart farming is key to developing sustainable agriculture," *Proc. Nat. Acad. Sci. USA*, vol. 114, no. 24, pp. 6148–6150, Jun. 2017. [Online]. Available: https://www.pnas.org/content/114/24/6148

[61] I. Husti, "Possibilities of using robots in agriculture," *Hung. Agricult. Eng.*, vol. 35, pp. 59–67, Sep. 2019.

[62] A. Rask-Andersen, "Organic dust toxic syndrome among farmers," *Occupational Environ. Med.*, vol. 46, no. 4, pp. 233–238, Apr. 1989. [Online]. Available: https://oem.bmj.com/content/46/4/233

[63] J.-H. Han, C.-H. Park, J. H. Kwon, J. Lee, T. S. Kim, and Y. Y. Jang, "Performance evaluation of autonomous driving control algorithm for a crawler-type agricultural vehicle based on low-cost multi-sensor fusion positioning," *Appl. Sci.*, vol. 10, no. 13, p. 4667, Jul. 2020. [Online]. Available: https://www.mdpi.com/2076-3417/10/13/4667

[64] Kondinin-Group. (2017). *Autonomous Tractors: The Rise of the Robots*. Accessed: Nov. 27, 2021. [Online]. Available: https://www.farmingahead.com.au/digital_assets/eee4d8df-ebd0-4e93-a472-39a985d78f47/Research-Report-Autonomous-tractors-88.pdf

[65] FENDT. (2017). *MARS: Robot System for Planting and Accurate Documentation*. Accessed: Nov. 8, 2021. [Online]. Available: https://www.fendt.com/int/fendt-mars

[66] D. Ball, P. Ross, A. English, T. Patten, B. Upcroft, R. Fitch, S. Sukkarieh, G. Wyeth, and P. Corke, "Robotics for sustainable broad-acre agriculture," in *Proc. 9th Int. Conf. Field Service Robot.*, L. Mejias, P. Corke, and J. Roberts, Eds. Manhattan, NY, USA: Springer, 2015, pp. 439–453.

[67] J. J. Roldán, J. del Cerro, D. Garzón-Ramos, P. Garcia-Aunon, M. Garzón, J. de León, and A. Barrientos, *Robots in Agriculture: State of Art and Practical Experiences*. Rijeka, Croatia: InTech, 2018.

[68] A. P. Chatzimichali, I. P. Georgilas, and V. D. Tourassis, "Design of an advanced prototype robot for white asparagus harvesting," in *Proc. IEEE/ASME Int. Conf. Adv. Intell. Mechatronics*, Singapore, Jul. 2009, pp. 887–892.

[69] A. A. Aljanobi, S. A. Al-hamed, and S. A. Al-Suhaibani, "A setup of mobile robotic unit for fruit harvesting," in *Proc. 19th Int. Workshop Robot. Alpe-Adria-Danube Region (RAAD)*, Budapest, Hungary, Jun. 2010, pp. 105–108.

[70] B. Catherine. (2016). *Different End Effectors on the Market*. Accessed: Nov. 9, 2021. [Online]. Available: https://blog.robotiq.com/bid/65660/Different-End-Effectors-on-the-Market

[71] O.-H. Alex. (2019). *10 Strange Robot End Effectors From the Future*. Accessed: Nov. 9, 2021. [Online]. Available: https://robodk.com/blog/strange-robot-end-effectors/

[72] Q. Zhan, Y. Cai, and Z. Liu, "Near-optimal trajectory planning of a spherical mobile robot for environment exploration," in *Proc. IEEE Conf. Robot., Autom. Mechatronics*, Chengdu, China, Sep. 2008, pp. 84–89.

[73] J. D. Hernández, D. Sanz, G. R. Rodríguez-Canosa, J. Barrientos, J. del Cerro, and A. Barrientos, "Sensorized robotic sphere for large exterior critical infrastructures supervision," *J. Appl. Remote Sens.*, vol. 7, no. 1, Aug. 2013, Art. no. 073522.

[74] J. D. Hernández, J. Barrientos, J. del Cerro, A. Barrientos, and D. Sanz, "Moisture measurement in crops using spherical robots," *Ind. Robot, Int. J.*, vol. 40, no. 1, pp. 59–66, Jan. 2013.

[75] E. Ackerman, "Bosch's giant robot can punch weeds to death," *IEEE Spectrum*, pp. 1–2, Nov. 2015. [Online]. Available: https://spectrum.ieee.org/automaton/robotics/industrial-robots/bosch-deepfield-robotics-weed-control

[76] P. Gonzalez-de-Santos, A. Ribeiro, C. Fernandez-Quintanilla, F. Lopez-Granados, M. Brandstoetter, S. Tomic, S. Pedrazzi, A. Peruzzi, G. Pajares, G. Kaplanis, M. Perez-Ruiz, C. Valero, J. del Cerro, M. Vieri, G. Rabatel, and B. Debilde, "Fleets of robots for environmentally-safe pest control in agriculture," *Precis. Agricult.*, vol. 18, no. 4, pp. 574–614, Aug. 2017.

[77] S.-B. Duan, Z.-L. Li, H. Wu, B.-H. Tang, L. Ma, E. Zhao, and C. Li, "Inversion of the PROSAIL model to estimate leaf area index of maize, potato, and sunflower fields from unmanned aerial vehicle hyperspectral data," *Int. J. Appl. Earth Observ. Geoinf.*, vol. 26, pp. 12–20, Feb. 2014. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0303243413000561

[78] Y. Li, C. Xia, and J. Lee, "Detection of small-sized insect pest in greenhouses based on multifractal analysis," *Optik-Int. J. Light Electron Opt.*, vol. 126, no. 19, pp. 2138–2143, Oct. 2015. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S003040261500409X

[79] C. Xia, L. Wang, B.-K. Chung, and J.-M. Lee, "*In situ* 3D segmentation of individual plant leaves using a RGB-D camera for agricultural automation," *Sensors*, vol. 15, no. 8, pp. 20463–20479, Aug. 2015. [Online]. Available: https://www.mdpi.com/1424-8220/15/8/20463

[80] M. H. Ko, B.-S. Ryuh, K. C. Kim, A. Suprem, and N. P. Mahalik, "Autonomous greenhouse mobile robot driving strategies from system integration perspective: Review and application," *IEEE/ASME Trans. Mechatronics*, vol. 20, no. 4, pp. 1705–1716, Sep. 2014.

[81] D. K. Giles, "Use of remotely piloted aircraft for pesticide applications: Issues and outlook," *Outlooks Pest Manage.*, vol. 27, no. 5, pp. 213–216, Oct. 2016.

[82] P. Nevavuori, N. Narra, and T. Lipping, "Crop yield prediction with deep convolutional neural networks," *Comput. Electron. Agricult.*, vol. 163, Aug. 2019, Art. no. 104859. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0168169919306842

[83] W. Robert. (2019). *RoboBees: Autonomous Flying Microrobots*. Accessed: Nov. 8, 2021. [Online]. Available: https://wyss.harvard.edu/technology/robobees-autonomous-flying-microrobots/

[84] T. T. Sankey, J. McVay, T. L. Swetnam, M. P. McClaran, P. Heilman, and M. Nichols, "UAV hyperspectral and LiDAR data and their fusion for arid and semi-arid land vegetation monitoring," *Remote Sens. Ecol. Conservation*, vol. 4, no. 1, pp. 20–33, Mar. 2018. [Online]. Available: https://zslpublications.onlinelibrary.wiley.com/doi/abs/10.1002/rse2.44

[85] Entegra. (2020). *Anna Creek—The Biggest Cattle Station in Australia*. Accessed: Nov. 8, 2021. [Online]. Available: https://www.entegra.com.au/anna-creek-the-biggest-cattle-station-in-australia/

[86] M. P. Christiansen, M. S. Laursen, R. N. Jørgensen, S. Skovsen, and R. Gislum, "Designing and testing a uav mapping system for agricultural field surveying," *Sensors*, vol. 17, no. 12, p. 2703, Nov. 2017.

[87] J. D. Rudd, G. T. Roberson, and J. J. Classen, "Application of satellite, unmanned aircraft system, and ground-based sensor data for precision agriculture: A review," in *Proc. ASABE Annu. Int. Meeting*. Washington, DC, USA: American Society of Agricultural and Biological Engineers, 2017, p. 1.

[88] A. Matese, P. Toscano, S. Di Gennaro, L. Genesio, F. Vaccari, J. Primicerio, C. Belli, A. Zaldei, R. Bianconi, and B. Gioli, "Intercomparison of UAV, aircraft and satellite remote sensing platforms for precision viticulture," *Remote Sens.*, vol. 7, no. 3, pp. 2971–2990, Mar. 2015.

[89] J. Torres-Sánchez, F. López-Granados, N. Serrano, O. Arquero, and J. M. Peña, "High-throughput 3-D monitoring of agricultural-tree plantations with unmanned aerial vehicle (UAV) technology," *PLoS ONE*, vol. 10, no. 6, Jun. 2015, Art. no. e0130479.

[90] T. Jensen, H. Karstoft, O. Green, and L. J. Munkholm, "Assessing the effect of the seedbed cultivator leveling tines on soil surface properties using laser range scanners," *Soil Tillage Res.*, vol. 167, pp. 54–60, Apr. 2017. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0167198716302331

[91] D. Andújar, A. Escolà, J. R. Rosell-Polo, R. Sanz, V. Rueda-Ayala, C. Fernández-Quintanilla, A. Ribeiro, and J. Dorado, "A LiDAR-based system to assess poplar biomass," *Gesunde Pflanzen*, vol. 68, no. 3, pp. 155–162, Sep. 2016.

[92] F. Rovira-Más, Q. Zhang, and J. F. Reid, "Stereo vision three-dimensional terrain maps for precision agriculture," *Comput. Electron. Agricult.*, vol. 60, no. 2, pp. 133–143, Mar. 2008. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S016816990700172X

[93] F. A. Cheein, G. Steiner, G. P. Paina, and R. Carelli, "Optimized EIF-SLAM algorithm for precision agriculture mapping based on stems detection," *Comput. Electron. Agricult.*, vol. 78, no. 2, pp. 195–207, Sep. 2011. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0168169911001542

[94] Better-Earth. (2021). *Our Mission*. Accessed: Nov. 9, 2021. [Online]. Available: https://www.betterearth.ag/about

[95] SoilWealth. (2018). *The Role of Soil DNA Testing in Managing the Risk of Soilborne Diseases—How is it Being Used and What Can it do?* Accessed: Nov. 10, 2021. [Online]. Available: https://www.soilwealth.com.au/resources/webinar-recordings/the-role-of-soil-dna-testing-in-managing-the-risk-of-soilborne-diseases-how-is-it-being-used-and-what-can-it-do/

[96] E. Pierpaoli, G. Carli, E. Pignatti, and M. Canavari, "Drivers of precision agriculture technologies adoption: A literature review," *Proc. Technol.*, vol. 8, pp. 61–69, Dec. 2013. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2212017313000728

[97] A. Kate. (2013). *Pasona Urban Farm by Kono Designs*. Accessed: Nov. 10, 2021. [Online]. Available: https://www.dezeen.com/2013/09/12/pasona-urban-farm-by-kono-designs/

[98] CGTN. (2019). *Vertical Farms: A New Solution to Food Security in Big Cities*. Accessed: Nov. 11, 2021. [Online]. Available: https://news.cgtn.com/news/2019-09-23/Vertical-farms-a-new-solution-to-food-security-in-big-cities-KdwRIHmAZG/index.html

[99] Cubicfarm Systems Corp. (2021). *A New Way to Feed Our World*. Accessed: Nov. 5, 2021. [Online]. Available: https://cubicfarms.com

[100] C. Banerjee and L. Adenaeuer, "Up, up and away! The economics of vertical farming," *J. Agricult. Stud.*, vol. 2, no. 1, pp. 40–60, Mar. 2014, doi: 10.5296/jas.v2i1.4526.

[101] (2020). *Feeding a Changing World With CubicFarms' Automated Vertical-Farming Technology*. Accessed: Nov. 11, 2021. [Online]. Available: https://www.youtube.com/watch?v=4PbaZE7Nfx0

[102] M. J. Deen, "Information and communications technologies for elderly ubiquitous healthcare in a smart home," *Pers. Ubiquitous Comput.*, vol. 19, nos. 3–4, pp. 573–599, 2015.

[103] (2020). *Use Fall Detection With Apple Watch*. Accessed: Nov. 11, 2021. [Online]. Available: https://support.apple.com/en-au/HT208944

[104] J. Lloret, J. Tomas, A. Canovas, and L. Parra, "An integrated IoT architecture for smart metering," *IEEE Commun. Mag.*, vol. 54, no. 12, pp. 50–57, Dec. 2016.

[105] H. March, Á.-F. Morote, A.-M. Rico, and D. Saurí, "Household smart water metering in spain: Insights from the experience of remote meter reading in Alicante," *Sustainability*, vol. 9, no. 4, p. 582, Apr. 2017.

[106] M. Sophie and J. Elizabeth. (2016). *World's First Virtual Reality Department Store*. Accessed: Nov. 5, 2021. [Online]. Available: https://www.ebayinc.com/stories/press-room/au/worlds-first-virtual-reality-department-store/

[107] N. Donthu and A. Gustafsson, "Effects of COVID-19 on business and research," *J. Bus. Res.*, vol. 117, pp. 284–289, Sep. 2020.

[108] (2020). *Key Insights From the 2020 eCommerce Update*. Accessed: Nov. 4, 2021. [Online]. Available: https://auspost.com.au/content/dam/auspost_corp/media/documents/inside-australian-online-shopping-update-dec2020.pdf

[109] M. Speicher, S. Cucerca, and A. Krüger, "VRShop: A mobile interactive virtual reality shopping environment combining the benefits of on-and offline shopping," *Proc. ACM Interact., Mobile, Wearable Ubiquitous Technol.*, vol. 1, no. 3, pp. 1–31, Sep. 2017, doi: 10.1145/3130967.

[110] R. Hussain and S. Zeadally, "Autonomous cars: Research results, issues, and future challenges," *IEEE Commun. Surveys Tuts.*, vol. 21, no. 2, pp. 1275–1313, 2nd Quart., 2019.

[111] M. Joerger and M. Spenko, "Towards navigation safety for autonomous cars," Inside GNSS, Nov. 2017. [Online]. Available: https://par.nsf.gov/biblio/10070277

[112] (2020). *These 'Self-Driving' Shared Scooters Will Automatically Return to Base After Each Use*. Accessed: Nov. 12, 2021. [Online]. Available: https://thenextweb.com/shift/2020/05/30/first-public-trial-of-self-driving-scooters-launches-in-the-us-syndication/

[113] D. S. Khudhur, A. E. Sa'ad-Aldeen, and L. MatterNasser, "Analysing the efficient use of solar energy in an automatic vertical rotary car parking system," *Proc. IOP Conf. Ser., Mater. Sci. Eng.*, vol. 745, no. 1, 2020, Art. no. 012077.

[114] C. Patel, M. Swami, P. Saxena, and S. Shah, "Rotary automated car parking system," *Int. J. Eng. Sci. Innov. Technol.*, vol. 4, no. 2, pp. 408–415, Mar. 2015.

[115] V. Cirimele, M. Diana, F. Bellotti, R. Berta, N. E. Sayed, A. Kobeissi, P. Guglielmi, R. Ruffo, M. Khalilian, A. La Ganga, J. Colussi, and A. D. Gloria, "The fabric ICT platform for managing wireless dynamic charging road lanes," *IEEE Trans. Veh. Technol.*, vol. 69, no. 3, pp. 2501–2512, Mar. 2020.

[116] J. He, H. Yang, T.-Q. Tang, and H.-J. Huang, "Optimal deployment of wireless charging lanes considering their adverse effect on road capacity," *Transp. Res. C, Emerg. Technol.*, vol. 111, pp. 171–184, Feb. 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0968090X19309155

[117] K. Van Tittelboom, J. Wang, M. Araújo, D. Snoeck, E. Gruyaert, B. Debbaut, H. Derluyn, V. Cnudde, E. Tsangouri, D. Van Hemelrijck, and N. De Belie, "Comparison of different approaches for self-healing concrete in a large-scale lab test," *Construct. Building Mater.*, vol. 107, pp. 125–137, Mar. 2016. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0950061815308576

[118] K. Cellat, F. Tezcan, G. Kardaş, and H. Paksoy, "Comprehensive investigation of butyl stearate as a multifunctional smart concrete additive for energy-efficient buildings," *Int. J. Energy Res.*, pp. 7146–7158, Aug. 2019. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/er.4740

[119] RTA-TC-106. (2010). *Traffic Signal Operation: New South Wales, Australia*. Accessed: Nov. 3, 2021. [Online]. Available: https://www.rms.nsw.gov.au/business-industry/partners-suppliers/documents/technical-manuals/rtatc106b.pdf

[120] B. Zhou, J. Cao, X. Zeng, and H. Wu, "Adaptive traffic light control in wireless sensor network-based intelligent transportation system," in *Proc. IEEE 72nd Veh. Technol. Conf.-Fall*, Ottawa, ON, Canada, Sep. 2010, pp. 1–5.

[121] P. Sinhmar, "Intelligent traffic light and density control using ir sensors and microcontroller," *Int. J. Adv. Technol. Eng. Res.*, vol. 2, no. 2, pp. 30–35, Mar. 2012.

[122] E. I. A. Kareem and A. Jantan, "An intelligent traffic light monitor system using an adaptive associative memory," *Int. J. Inf. Process. Manage.*, vol. 2, no. 2, pp. 23–39, Apr. 2011.

[123] C.-Y. Ho, H.-Y. Lin, and L.-T. Wu, "Intelligent speed bump system with dynamic license plate recognition," in *Proc. IEEE Int. Conf. Ind. Technol. (ICIT)*, Taipei, Taiwan, Mar. 2016, pp. 1669–1674.

[124] M.-H. Huang and R. T. Rust, "Artificial intelligence in service," *J. Service Res.*, vol. 21, no. 2, pp. 155–172, Feb. 2018, doi: 10.1177/1094670517752459.

[125] C. Breazeal, "Toward sociable robots," *Robot. Auton. Syst.*, vol. 42, nos. 3–4, pp. 167–175, Mar. 2003. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0921889002003731

[126] (2021). *Service Robots*. Accessed: Nov. 2, 2021. [Online]. Available: https://www.robotics.org/service-robots/what-are-professional-service-robots

[127] G. Bugmann and S. N. Copleston, "What can a personal robot do for you?" in *Towards Autonomous Robotic Systems*, R. Groß, L. Alboul, C. Melhuish, M. Witkowski, T. J. Prescott, and J. Penders, Eds. Sheffield, U.K.: Springer, 2011, pp. 360–371.

[128] S. Gaskin, S. Mehta, D. Pisaniello, L. Turczynowicz, S. Bruschi, and K. Mitchell, "Hazardous materials emergency incidents: Public health considerations and implications," *Austral. New Zealand J. Public Health*, vol. 44, no. 4, pp. 320–323, Jul. 2020. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1111/1753-6405.12981

[129] A. Birk and S. Carpin, "Rescue robotics—A crucial milestone on the road to autonomous systems," *Adv. Robot.*, vol. 20, no. 5, pp. 595–605, May 2006, doi: 10.1163/156855306776985577.

[130] C. Wang, L. Dong, D. Peng, and C. Pan, "Tactile sensors for advanced intelligent systems," *Adv. Intell. Syst.*, vol. 1, no. 8, Dec. 2019, Art. no. 1900090. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/aisy.201900090

[131] C. B. Wong, E. F. Yang, X. T. Yan, and D. B. Gu, "Autonomous robots for harsh environments: A holistic overview of current solutions and ongoing challenges," *Syst. Sci. Control Eng.*, vol. 6, no. 1, pp. 213–219, Jan. 2018, doi: 10.1080/21642583.2018.1477634.

[132] C. Wong, E. Yang, X.-T. Yan, and D. Gu, "An overview of robotics and autonomous systems for harsh environments," in *Proc. 23rd Int. Conf. Automat. Comput. (ICAC)*, Huddersfield, U.K., Sep. 2017, pp. 1–6.

[133] A. S. Wijaya, Z. Zainuddin, and M. Niswar, "Design a smart waste bin for smart waste management," in *Proc. 5th Int. Conf. Instrum., Control, Automat. (ICA)*, Yogyakarta, Indonesia, Aug. 2017, pp. 62–66.

[134] G. K. Shyam, S. S. Manvi, and P. Bharti, "Smart waste management using Internet-of-Things (IoT)," in *Proc. 2nd Int. Conf. Comput. Commun. Technol. (ICCCT)*, Chennai, India, Feb. 2017, pp. 199–203.

[135] Md. S. Islam, M. A. Hannan, H. Basri, A. Hussain, and M. Arebey, "Solid waste bin detection and classification using dynamic time warping and MLP classifier," *Waste Manage.*, vol. 34, pp. 281–290, Feb. 2014. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0956053X13005163

[136] P. Nowakowski and T. Pamula, "Application of deep learning object classifier to improve e-waste collection planning," *Waste Manage.*, vol. 109, pp. 1–9, May 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0956053X20302105

[137] M. Yang and G. Thung, "Classification of trash for recyclability status," CS229 Project Rep., Stanford, CA, USA, 2016.

[138] B. Chowdhury and M. U. Chowdhury, "RFID-based real-time smart waste management system," in *Proc. Australas. Telecommun. Netw. Appl. Conf.*, Christchurch, New Zealand, Dec. 2007, pp. 175–180.

[139] CASA. (2019). *Advisory Circular AC 101–01 V3.0, Remotely Piloted Aircraft Systems—Licensing and Operations*. Accessed: Nov. 3, 2021. [Online]. Available: https://www.casa.gov.au/sites/default/files/101c01.pdf

[140] Y. Niu, W. Lu, K. Chen, G. G. Huang, and C. Anumba, "Smart construction objects," *J. Comput. Civil Eng.*, vol. 30, no. 4, Jul. 2016, Art. no. 04015070, doi: 10.1061/%28ASCE%29CP.1943-5487.0000550.

[141] (2021). *V-DAQ*. Accessed: Nov. 5, 2021. [Online]. Available: https://www.v-daq.com.au

[142] H. Said, T. Nicoletti, and P. Perez-Hernandez, "Utilizing telematics data to support effective equipment fleet-management decisions: Utilization rate and hazard functions," *J. Comput. Civil Eng.*, vol. 30, no. 1, Jan. 2016, Art. no. 04014122.

[143] (2021). *Fatality Statistics*. Accessed: Nov. 7, 2021. [Online]. Available: https://www.safeworkaustralia.gov.au/data-and-research/work-related-fatalities/preliminary-work-related-fatalities

[144] R. Kanan, O. Elhassan, and R. Bensalem, "An IoT-based autonomous system for workers' safety in construction sites with real-time alarming, monitoring, and positioning strategies," *Autom. Construction*, vol. 88, pp. 73–86, Apr. 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0926580516303946

[145] R. Kanan, O. Elhassan, R. Bensalem, and A. Husein, "A wireless safety detection sensor system," in *Proc. IEEE SENSORS*, Orlando, FL, USA, Oct. 2016, pp. 1–3.

[146] D. James. (2010). *Pentaho, Hadoop, and Data Lakes*. Accessed: Nov. 7, 2021. [Online]. Available: https://jamesdixon.wordpress.com/2010/10/14/pentaho-hadoop-and-data-lakes/

[147] C. Mathis, "Data lakes," *Datenbank-Spektrum*, vol. 17, no. 3, pp. 289–293, Nov. 2017.

[148] K. Shvachko, H. Kuang, S. Radia, and R. Chansler, "The Hadoop distributed file system," in *Proc. IEEE 26th Symp. Mass Storage Syst. Technol. (MSST)*, Incline Village, NV, USA, May 2010, pp. 1–10.

[149] D. Borthakur, "The Hadoop distributed file system: Architecture and design," *Hadoop Project Website*, vol. 11, no. 2007, p. 21, Aug. 2007.

[150] Z. Wang, W. Dai, F. Wang, H. Deng, S. Wei, X. Zhang, and B. Liang, "Kafka and its using in high-throughput and reliable message distribution," in *Proc. 8th Int. Conf. Intell. Netw. Intell. Syst. (ICINIS)*, Tianjin, China, Nov. 2015, pp. 117–120.

[151] S. A. Noghabi, K. Paramasivam, Y. Pan, N. Ramesh, J. Bringhurst, I. Gupta, and H. R. Campbell, "Samza: Stateful scalable stream processing at Linkedin," *Proc. VLDB Endowment*, vol. 10, no. 12, pp. 1634–1645, Aug. 2017, doi: 10.14778/3137765.3137770.

[152] M. Zaharia, R. S. Xin, P. Wendell, T. Das, M. Armbrust, A. Dave, X. Meng, J. Rosen, S. Venkataraman, M. J. Franklin, A. Ghodsi, J. Gonzalez, S. Shenker, and I. Stoica, "Apache spark: A unified engine for big data processing," *Commun. ACM*, vol. 59, no. 11, pp. 56–65, Nov. 2016.

[153] X. L. Dong and D. Srivastava, "Big data integration," in *Proc. IEEE 29th Int. Conf. Data Eng. (ICDE)*, Brisbane, QLD, Australia, Apr. 2013, pp. 1245–1248.

[154] J. Jeffrey. (2019). *The Elephant in the Data Lake and Snowflake*. Accessed: Nov. 12, 2021. [Online]. Available: https://jeffreyjacobs.wordpress.com/2019/05/29/the-elephant-in-the-data-lake-and-snowflake/

[155] Snowflake. (2021). *Snowflake (the Data Cloud): Eliminate Data Silos and Run Your Workloads From a Single Platform*. Accessed: Nov. 12, 2021. [Online]. Available: https://www.snowflake.com

[156] Snowflake—Documnetation. (2021). *Data Encryption*. Accessed: Nov. 12, 2021. [Online]. Available: https://docs.snowflake.com/en/user-guide/security-encryption.html

[157] (2021). *Archaeological Institute of America, Glossary*. Accessed: Oct. 21, 2021. [Online]. Available: https://www.archaeological.org/programs/educators/introduction-to-archaeology/glossary/

[158] S. R. Pendery, "Urban archaeology," in *The Oxford Companion to Archaeology*. New York, NY, USA: Oxford Univ. Press, 1996.

[159] T. O'Keeffe, *Urban Archaeology*, C. Smith, Ed. Now York, NY, USA: Springer, 2014, doi: 10.1007/978-1-4419-0465-2_1422.

[160] D. Mitsouras and P. C. Liacouras, *3D Printing Technologies*, 1st ed. New York, NY, USA: Springer, 2017.

[161] X. Dimitropoulos and G. Riley, "Modeling autonomous-system relationships," in *Proc. 20th Workshop Princ. Adv. Distrib. Simulation (PADS)*, Singapore, 2006, pp. 143–149.

[162] L. Gao, "On inferring autonomous system relationships in the internet," *IEEE/ACM Trans. Netw.*, vol. 9, no. 6, pp. 733–745, Dec. 2001.

[163] M. Li, "Data routing across multiple autonomous network systems," U.S. Patent 2016 0 261 493A1, Sep. 8, 2016.

[164] V. Varadharajan, K. K. Karmakar, and U. Tupakula, "Securing communication in multiple autonomous system domains with software defined networking," in *Proc. IFIP/IEEE Symp. Integr. Netw. Service Manage. (IM)*, Lisbon, Portugal, May 2017, pp. 195–203.

[165] S. Stumpf, M. Burnett, V. Pipek, and W.-K. Wong, "End-user interactions with intelligent and autonomous systems," in *Proc. CHI Extended Abstr. Hum. Factors Comput. Syst.* Austin, TX, USA: Association for Computing Machinery, May 2012, pp. 2755–2758, doi: 10.1145/2212776.2212713.

[166] A. Abel and S. Sukkarieh, "The coordination of multiple autonomous systems using information theoretic political science voting models," in *Proc. IEEE/SMC Int. Conf. Syst. Syst. Eng. (SoSE)*, Los Angeles, CA, USA, Apr. 2006, p. 6.

[167] J. Bryson and A. Winfield, "Standardizing ethical design for artificial intelligence and autonomous systems," *Computer*, vol. 50, no. 5, pp. 116–119, May 2017.

[168] D. Danks and A. J. London, "Regulating autonomous systems: Beyond standards," *IEEE Intell. Syst.*, vol. 32, no. 1, pp. 88–91, Jan. 2017.

[169] A. F. Winfield, K. Michael, J. Pitt, and V. Evers, "Machine ethics: The design and governance of ethical AI and autonomous systems [scanning the issue]," *Proc. IEEE*, vol. 107, no. 3, pp. 509–517, Mar. 2019.

[170] J. M. Such, "Privacy and autonomous systems," in *Proc. 26th Int. Joint Conf. Artif. Intell. (IJCAI)*. Melbourne, VIC, Australia: King's College London, 2017, pp. 4761–4767.

[171] D. Puthal, S. Nepal, R. Ranjan, and J. Chen, "Threats to networking cloud and edge datacenters in the Internet of Things," *IEEE Cloud Comput.*, vol. 3, no. 3, pp. 64–71, May/Jun. 2016.

[172] A. Acquisti, L. Brandimarte, and G. Loewenstein, "Privacy and human behavior in the age of information," *Science*, vol. 347, no. 6221, pp. 509–514, Jan. 2015.

[173] I. Makhdoom, I. Zhou, M. Abolhasan, J. Lipman, and W. Ni, "PrivySharing: A blockchain-based framework for privacy-preserving and secure data sharing in smart cities," *Comput. Secur.*, vol. 88, Jan. 2020, Art. no. 101653. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S016740481930197X

[174] M. Stamp, *Information Security: Principles and Practice*. Hoboken, NJ, USA: Wiley, 2005.

[175] A. F. J. W. Westin and L. L. Review, "Privacy and freedom," *Washington Lee Law Rev.*, vol. 25, no. 1, p. 166, Jan. 1968.

[176] MITRE. (2014). *Privacy Engineering*. Accessed: Nov. 13, 2021. [Online]. Available: https://www.mitre.org/publications/systems-engineering-guide/enterprise-engineering/engineering-informationintensive-enterprises/privacy-systems-engineering

[177] A. Rouvroy and Y. Poullet, "The right to informational self-determination and the value of self-development: Reassessing the importance of privacy for democracy," in *Reinventing Data Protection?* Dordrecht, The Netherlands: Springer, 2009.

[178] M. A. Ferrag, L. Shu, X. Yang, A. Derhab, and L. Maglaras, "Security and privacy for green IoT-based agriculture: Review, blockchain solutions, and challenges," *IEEE Access*, vol. 8, pp. 32031–32053, 2020.

[179] D. J. Solove, "A taxonomy of privacy," *Univ. PA Law Rev.*, vol. 154, no. 3, pp. 477–564, Jan. 2006.

[180] Y. Gurevich, E. Hudis, and J. M. Wing, "Inverse privacy," *Commun. ACM*, vol. 59, no. 7, pp. 38–42, Jun. 2016, doi: 10.1145/2838730.

[181] A. Lima, F. Rocha, M. Völp, and P. Esteves-Veríssimo, "Towards safe and secure autonomous and cooperative vehicle ecosystems," in *Proc. 2nd ACM Workshop Cyber-Phys. Syst. Secur. Privacy (CPS-SPC)*. New York, NY, USA: Association for Computing Machinery, 2016, pp. 59–70, doi: 10.1145/2994487.2994489.

[182] G. Fisk, C. Ardi, N. Pickett, J. Heidemann, M. Fisk, and C. Papadopoulos, "Privacy principles for sharing cyber security data," in *Proc. IEEE Secur. Privacy Workshops*, San Jose, CA, USA, May 2015, pp. 193–197.

[183] OAIC. (2021). *Australian Privacy Principles Quick Reference*. Accessed: Nov. 13, 2021. [Online]. Available: https://www.oaic.gov.au/privacy/australian-privacy-principles/

[184] GDPR. (2018). *General Data Protection Regulation*. Accessed: Nov. 13, 2021. [Online]. Available: https://gdpr-info.eu/

[185] G. Danezis, J. Domingo-Ferrer, M. Hansen, J.-H. Hoepman, D. L. Metayer, R. Tirtea, and S. Schiffner, "Privacy and data protection by design-from policy to engineering," in *Proc. Eur. Union Agency Netw. Inf. Secur. (ENISA)*, Dec. 2014, pp. 1–79.

[186] R. Dingledine, N. Mathewson, and P. Syverson, "Tor: The second-generation onion router," Naval Res. Lab., Washington, DC, USA, Tech. Rep., 2004.

[187] L. Sweeney, "K-anonymity: A model for protecting privacy," *Int. J. Uncertainty, Fuzziness Knowl.-Based Syst.*, vol. 10, no. 5, pp. 557–570, May 2002, doi: 10.1142/S0218488502001648.

[188] M. U. Hassan, M. H. Rehmani, and J. Chen, "Differential privacy techniques for cyber physical systems: A survey," *IEEE Commun. Surveys Tuts.*, vol. 22, no. 1, pp. 746–789, 1st Quart., 2020.

[189] R. Lu, K. Heung, A. H. Lashkari, and A. A. Ghorbani, "A lightweight privacy-preserving data aggregation scheme for fog computing-enhanced IoT," *IEEE Access*, vol. 5, pp. 3302–3312, 2017.

[190] O. Kafaly, N. Ajmeri, and M. P. Singh, "Revani: Revising and verifying normative specifications for privacy," *IEEE Intell. Syst.*, vol. 31, no. 5, pp. 8–15, Sep. 2016.

[191] T. Baarslag, A. T. Alan, R. C. Gomer, I. Liccardi, H. Marreiros, E. H. Gerding, and M. C. Schraefel, "Negotiation as an interaction mechanism for deciding app permissions," in *Proc. CHI Conf. Extended Abstr. Hum. Factors Comput. Syst. (CHI EA)*. New York, NY, USA: Association for Computing Machinery, May 2016, pp. 2012–2019, doi: 10.1145/2851581.2892340.

[192] I. Makhdoom, M. Abolhasan, J. Lipman, R. P. Liu, and W. Ni, "Anatomy of threats to the Internet of Things," *IEEE Commun. Surveys Tuts.*, vol. 21, no. 2, pp. 1636–1675, 2nd Quart., 2018.

[193] M. Shen, X. Tang, L. Zhu, X. Du, and M. Guizani, "Privacy-preserving support vector machine training over blockchain-based encrypted IoT data in smart cities," *IEEE Internet Things J.*, vol. 6, no. 5, pp. 7702–7712, Oct. 2019.

[194] M. Ma, G. Shi, and F. Li, "Privacy-oriented blockchain-based distributed key management architecture for hierarchical access control in the IoT scenario," *IEEE Access*, vol. 7, pp. 34045–34059, 2019.

[195] O. Novo, "Blockchain meets IoT: An architecture for scalable access management in IoT," *IEEE Internet Things J.*, vol. 5, no. 2, pp. 1184–1195, Apr. 2018.

[196] V. Dedeoglu, R. Jurdak, G. D. Putra, A. Dorri, and S. S. Kanhere, "A trust architecture for blockchain in IoT," in *Proc. 16th EAI Int. Conf. Mobile Ubiquitous Syst., Comput., Netw. Services (MobiQuitous)*. New York, NY, USA: Association for Computing Machinery, Nov. 2019, pp. 190–199, doi: 10.1145/3360774.3360822.

[197] M. T. Hammi, B. Hammi, P. Bellot, and A. Serhrouchni, "Bubbles of trust: A decentralized blockchain-based authentication system for IoT," *Comput. Secur.*, vol. 78, pp. 126–142, Sep. 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0167404818300890

[198] A. Derhab, M. Guerroumi, A. Gumaei, L. Maglaras, M. A. Ferrag, M. Mukherjee, and F. A. Khan, "Blockchain and random subspace learning-based IDS for SDN-enabled industrial IoT security," *Sensors*, vol. 19, no. 14, p. 3119, Jul. 2019. [Online]. Available: https://www.mdpi.com/1424-8220/19/14/3119

[199] O. Ohrimenko, F. Schuster, C. Fournet, A. Mehta, S. Nowozin, K. Vaswani, and M. Costa, "Oblivious multi-party machine learning on trusted processors," in *Proc. 25th USENIX Secur. Symp.* Austin, TX, USA: USENIX Association, 2016, pp. 619–636. [Online]. Available: https://www.usenix.org/conference/usenixsecurity16/technical-sessions/presentation/ohrimenko

[200] D. K. Mulligan, "The enduring importance of transparency," *IEEE Secur. Privacy*, vol. 12, no. 3, pp. 61–65, May 2014.

[201] R. H. Wortham, A. Theodorou, and J. J. Bryson, "What does the robot think? Transparency as a fundamental design requirement for intelligent systems," in *Proc. Ethics Artif. Intell. Workshop (IJCAI)*, New York, NY, USA, 2016, pp. 1–6.

[202] O. Cathy, *How Big Data Increases Inequality and Threatens Democracy*. London, U.K.: Penguin, 2016.

[203] C. Dwork, M. Hardt, T. Pitassi, O. Reingold, and R. Zemel, "Fairness through awareness," in *Proc. 3rd Innov. Theor. Comput. Sci. Conf. (ITCS).* New York, NY, USA: Association for Computing Machinery, 2012, pp. 214–226, doi: 10.1145/2090236.2090255.

[204] K. Gai, Y. Wu, L. Zhu, Z. Zhang, and M. Qiu, "Differential privacy-based blockchain for industrial Internet-of-Things," *IEEE Trans. Ind. Informat.*, vol. 16, no. 6, pp. 4156–4165, Jun. 2020.

[205] C. Yin, J. Xi, R. Sun, and J. Wang, "Location privacy protection based on differential privacy strategy for big data in industrial Internet of Things," *IEEE Trans. Ind. Informat.*, vol. 14, no. 8, pp. 3628–3636, Aug. 2018.

[206] OWASP. (2020). *Top 10 Web Application Security Risks.* Accessed: Nov. 14, 2021. [Online]. Available: https://owasp.org/www-project-top-ten/

[207] J. Murphy. (2016). *Enhanced Security Controls for IBM Watson IoT Platform.* [Online]. Available: https://developer.ibm.com/iotplatform/2016/09/23/enhanced-security-controls-for-ibm-watson-iot-platform/

[208] F. Jazib, C. Pignataro, A. Jeff, and M. Monique. (2015). *Securing the Internet of Things: A Proposed Framework.* [Online]. Available: http://www.cisco.com/c/en/us/about/security-center/secure-iot-proposed-framework.html

[209] Hacksplaining. (2020). *Protecting Your Users Against Cross-Site Scripting.* Accessed: Nov. 14, 2021. [Online]. Available: https://www.hacksplaining.com/prevention/xss-stored

[210] E. L. Birch, "From science parks to innovation districts research facility development in legacy cities on the northeast corridor," PennIUR, Philadelphia, PA, USA, Tech. Rep. 008, Aug. 2015, vol. 37.

[211] I. Díez-Vial and Á. Montoro-Sánchez, "How knowledge links with universities may foster innovation: The case of a science park," *Technovation*, vols. 50–51, pp. 41–52, Apr. 2016. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0166497215000620

[212] A. Montoro-Sánchez, M. Ortiz-de-Urbina-Criado, and E. M. Mora-Valentín, "Effects of knowledge spillovers on innovation and collaboration in science and technology parks," *J. Knowl. Manage.*, vol. 15, no. 6, pp. 948–970, Oct. 2011.

[213] (2021). *UTS Startups.* Accessed: Nov. 15, 2021. [Online]. Available: https://www.uts.edu.au/current-students/opportunities/uts-startups

[214] (2021). *Techcelerator.* Accessed: Nov. 15, 2021. [Online]. Available: https://www.uts.edu.au/about/faculty-engineering-and-information-technology/research-faculty-engineering-and-it/funding/techcelerator

[215] McAfee. (2021). *What is a Security Operations Center (SOC)?* Accessed: Nov. 17, 2021. [Online]. Available: https://www.mcafee.com/enterprise/en-au/security-awareness/operations/what-is-soc.html

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