International Journal of Applied Research 2020; 6(6): 415-421

ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 5.2
IJAR 2020; 6(6): 415-421
www.allresearchjournal.com
Received: 17-04-2020
Accepted: 22-05-2020

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Internet of things: A review of Architecture and its use to manage waste efficiently in smart cities

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Abstract
Internet of things (IoT) integrates many technologies and is bringing about a paradigm change in the way of living across the world. With the fifth generation of modern wireless communication, it is rapidly gaining popularity enabling numerous and diverse applications. Assorted and heterogenous devices and soft wares can be connected to form one single logical architecture. A smart world with energy saving, pollution control as well as smart transportation, industries, cities, home are a reality made possible by IoT technology. Despite some benefits, traditional management of waste which often involves manual collection, followed by disposal or recycling through a defined process, also involves a significant number of errors of judgement e.g., bins may get overfilled or remain underfilled. Waste pickup trucks collect waste on schedule regardless of bin fill status. Unoptimized routes can waste fuel and pollute. Bringing together garbage at the central location further complicates sorting and recycling. Without appropriate technologies and tools, waste management is laborious and inefficient. This paper aims to provide an insight into this trending technology and explore its application in making of a smart city by smart garbage disposal. This paper includes an overview of the technology, the importance of maintaining biodiversity, and the use of IoT in smart waste management to safeguard urban biodiversity.

Keywords: Internet, Architecture, Fog and Edge Computing, Biodiversity, Waste, Smart City, Infrastructure, Smart Device

Introduction
The Internet has become omnipresent in today's existence and is influencing human life touching every aspect. IoT solutions are increasingly becoming a regular part of day-to-day life. We are getting used to having things work for us with connected devices everywhere. We are on the brink of an era with pervasive encompassing connectivity where a huge variety of devices will connect on the internet. A smart phone that responds to voice commands, a door that selectively opens biometrically, and the numerous other instantaneous results are the fascinating tasks that can be accomplished by IOT. Between the human requests/commands and they being fulfilled lies an invisible and large infrastructure involving interactions between multiple elements. The IoT devices usage is rapidly increasing day by day as these devices not only offer comfort but sometimes perform certain tasks better than humans. Fig 1 shows the trend of popularity of IoT devices and by year 2020 we will have 50 billion devices on the internet [1]. The number of devices linked on the internet is predicted to triple to over 29 billion in 2030 from around 10 billion in 2020. China is forecasted to have around 5 billion devices, the highest and emits noxious gases that are bad for people's health and the environment. It is concerning that ineffective waste management practices may pose threats to both environmental quality and human health. Another reason the local annual trash generation is a cause for serious concern because it is predicted to increase exponentially in future as a consequence of expanding populations, rising living standards and rapid urbanization [3]. It is time for a decisive action to exercise stringent measures to control the waste production and disposal in an environmentally responsible manner, so as to minimize any negative effects on nature and indeed on human health and diminished human efforts considerably bringing in convenience and remote operations. The tremendous growth in the volume of waste generated presents new difficulties for waste management [2]. IoT has numerous applications in transport systems, home automation, environment monitoring, energy conservation, social life, entertainment, education, fitness and health care.

IoT technology has significantly enhanced the quality of life. When dealing with a huge amount of trash, more time, energy, and money will be needed to properly dispose of it. Because of a lack of personnel and infrastructure dedicated to waste management, trash is often dumped in open pits, on vacant land, and even in rivers in many urban and rural regions. When trash is left out in the open, it eventually turns to a solid, becomes a waste heap, There is an urgent need to meticulously manage the different categories of wastes including organic waste, industrial waste, hospital waste, nuclear and electronic waste, commercial waste, green waste, and recyclable waste [4, 5]. The objectives of this paper are as follows:

- Understanding the basic Architectures of IoT.
- The effect of Waste in Cities and it impact on biodiversity.
- Highlight the application of IoT in smart waste management.

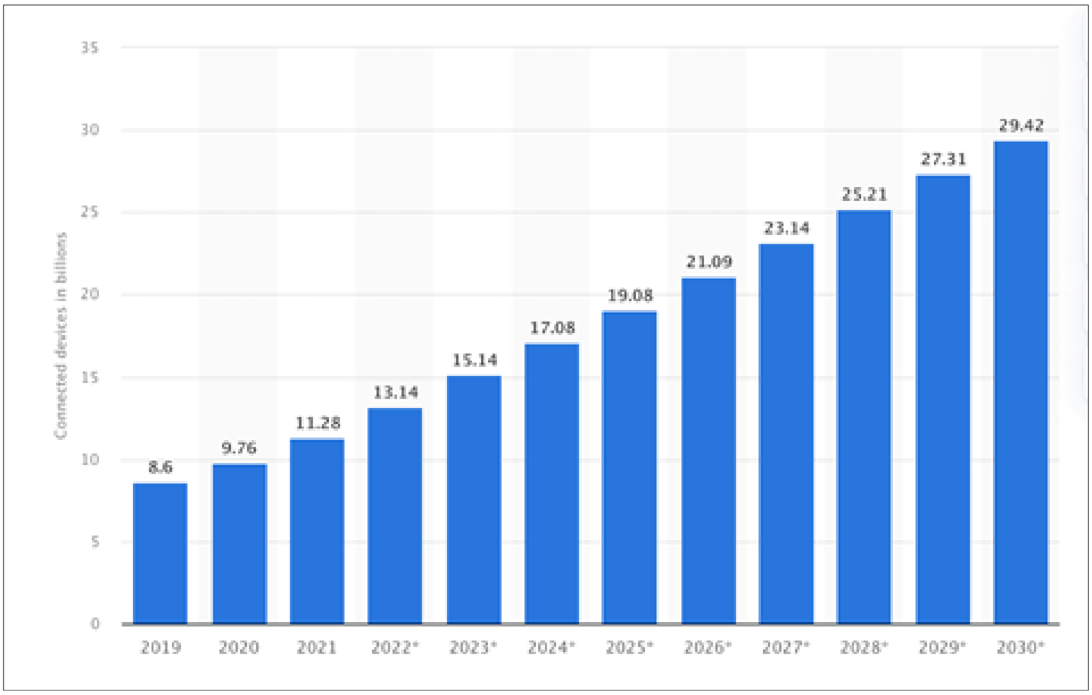

Fig 1: Number of IoT connected devices worldwide 2019, with forecasts to 2030

Architecture of IoT: Building Blocks and Layers

Strictly speaking there exists no agreed upon, by all, a single IoT Architecture. The number of layers and complexity varies and depends on the environment where it's to be deployed and /or the business task it is expected to perform. Irrespective of the number of layers and use cases, the main blocks to build any IoT structure [6] is the same and these are, Fig. 2.

1. Smart devices
2. Gateways & Networks to enable connection of low power devices with the internet.
3. IoT platform called the middleware providing analytical capabilities with supercomputing powers and huge data storage capacities.
4. Applications to allow end users utilize all the advantages and benefits from IoT.

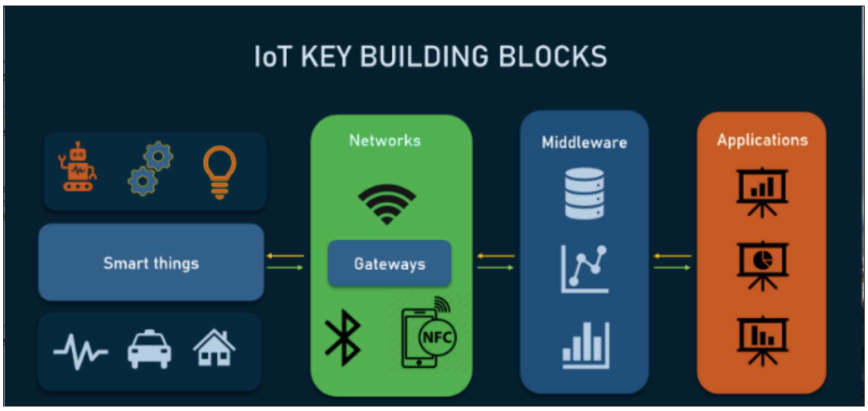

Fig 2: Key Blocks of IoT

The backbone of any IoT system is made up of these above mentioned 4 essential elements. A multilayered and effective architecture is subsequently built upon these. Intel, IBM and CISCO introduced a reference Architecture in 2014 comprising of seven layers. Two architectures have found popularity though many have been proposed by researchers. Three layer [7] architecture is the basic one and is shown in Fig 3. These three layers are as follows:

- Perception Layer: Comprises of sensors and primarily collects the information from the surroundings. It identifies smart objects in the vicinity and/or works on some available physical parameters.
- Network Layer: This layer lays procedures to help connect with the servers, network devices and other smart objects.
- Application Layer: Defines the applications for deploying internet of things and provides the user with specific services be it in their homes, cities, or world.

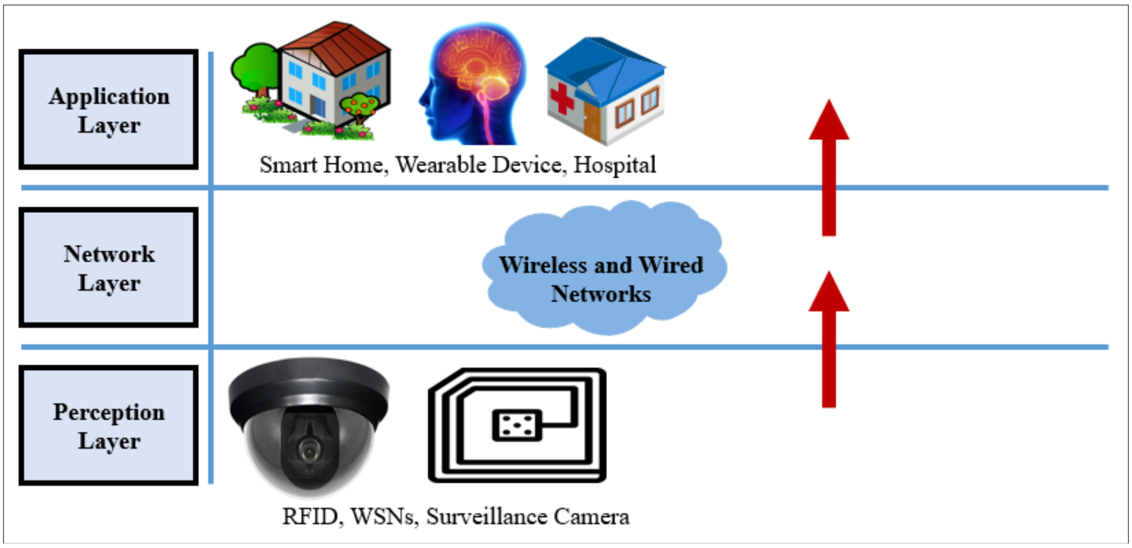

Fig 3: The Three Layer Architecture of IoT

Though the three layer Architecture has the basic structure of IoT but is inadequate for research purposes as it does not contain the finer aspects of this technology. That is also the reason behind numerous existing architectures proposed. Five-layer Architecture includes two additional layers, the business and processing layers, Fig 4. The Application and the Perception layers have the same role as in the 3-layer Architecture. The functions of the additional layers are as follows.

- Transport Layer uses networks such as NFC, RFID, Bluetooth, LAN and 3G to transmit the sensor data to the Processing layer from the Perceptron layer and vice versa.
- The Processing Layer stores and processes after analyzing large quantities of data that is sent up from the transport layer. It is also called as the middle layer and it provides and manages myriad services to the layers below it.
- Business layer supervises and regulates the entire IOT system which includes user privacy, profit models, business and applications.

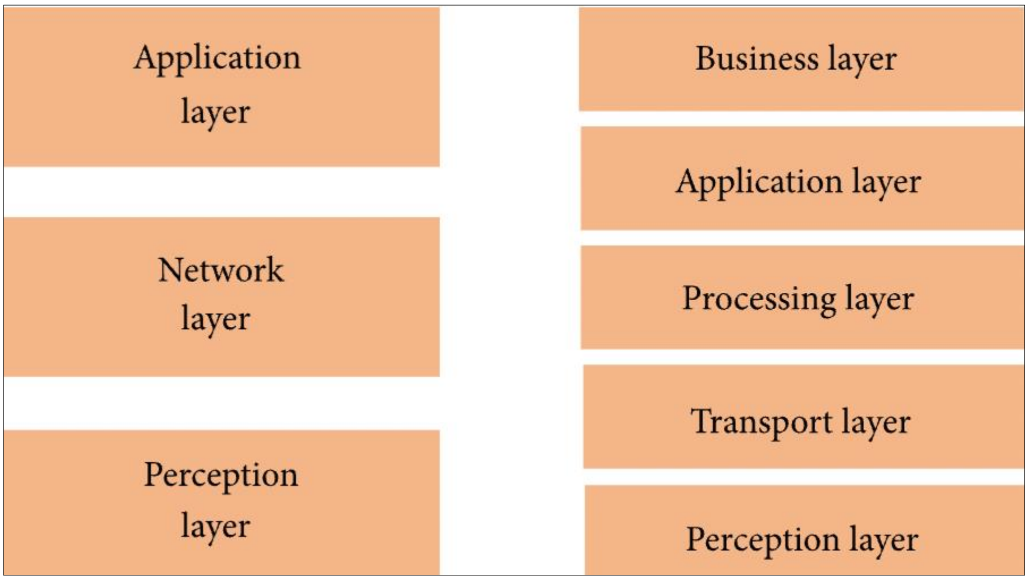

Fig 4: IoT 3-Layer Vs 5-Layer Architectures

Recently the trend is moving to another kind of layered IoT Architecture and that is the Fog Computing. In this the network gateways and sensors partially do analytics and data processing. In addition, it inserts a security layer between the transport and physical layer. The additional layers provide the following functionalities:

- Temporary Storage: Proffers functionalities such as data storage, distribution and replication

- Preprocessing: Performs Analytics, processing, and filtering for the Sensor data
- Monitoring: Monitors services. Responses, resources and Filtering
- Security Layer: Ensure data privacy and integrity using encryption mechanisms.

Preprocessing and monitoring are accomplished on the edge just before the data is sent to the cloud. Then terms edge computing (more penetrative) and fog computing (refers to smart sensors and smart gateways) are often used interchangeably. Table 1 summarizes the seven layers involved in the IoT, popularly called as the Fog Architecture of the smart IoT, their functions and threats.

Table 1: Fog Architecture of SMART IoT

Name of the layer	Functions	Threats	
Perceptron Layer	Hosting smart things	1. Eavesdropping 2. Replay Attack 3. Timing Attack	Essential Components
Connectivity/Transport layer	Transferring data from the physical layer to the cloud and vice versa via networks and gateways	Man-in-the-Middle Attack, Storage Attack, Exploit Attack	
Processing Layer	Accumulates and manages all data streams employing IoT platforms	DoS Attack, Malicious Insider Attack	
Application Layer	Delivers solutions like reporting and analytics to end users	Cross site scripting, malicious Code Attack	
Edge Layer/Fog Computing Layer	Collects new information and data preprocessing is done close to the edge, typically on gateways		Extra Components
Business Layer	For businesses to make decisions based on the data		
Security Layer	Encompasses all other layers		

Waste: The Bane of modern civilization in Smart Cities

The large amounts of municipal solid garbage that are produced annually around the globe pose a problem for urban regions in terms of management. The term "smart city" refers to a community that has adopted sustainable development practices and has also included cutting-edge technological infrastructure. The rising pace of garbage produced its collection and subsequent disposal are a grave cause of concern in light of the increasing rate at which waste is being produced in response to rising urbanization and industrialization. The threat is amplified by environmental challenges and hazards of contamination through leaching, etc. One of the most pressing problems in environmental management is the proper disposal of trash. The Internet of Things (IoT) is emerging as a promising approach to efficient garbage management in smart cities [8] From garbage creation to its ultimate disposal (incineration, landfill, or recycling), waste management encompasses many steps.

Smart Cities being most coveted globally, to provide inhabitants with a good living and world-class services, have attracted residents from their villages and hometowns. This mass movement has led to an explosion in growth and expansion of Smart Cities. It has significantly given rise to a multitude of issues. Effectively controlling the waste produced, whether it be medical, environmental, industrial or human waste is becoming important. One of the main problems brought on by the world's constantly expanding population is the rise in waste generation, as a result of human activities. Such waste may contain material goods, leftover food, human waste, trash from obsolete items, industrial waste, etc. If this enormous amount of waste is not judiciously disposed off, it can endanger the residents. Furthermore, certain essentials get thrown away to waste after their initially intended usage, and assuming we refrain from recycling them, the price of these items may rise gradually owing to their shortage of availability, and this would have a negative effect on the economy. We need to figure out how to guarantee reliable and effective waste disposal with minimal expenditure and least processing time. This will help boost not only the economy but also manage the shortage of essential items like for the paper industry, footwear industry, stationery items, tire manufacturing, remouldable plastic industry, and so on by recycling reusable waste. If not properly managed, these wastes pose a serious threat to the environment as a whole. Therefore, waste management is a crucial issue that needs to be given top priority [9]. In the priority list of Waste Management, preventing generation of waste is viewed as the most desirable goal [10]. Material reuse, recycling, and waste to energy conversion, are next in the priority, followed by the issue of actual disposal of the garbage. The goal of waste management by smart garbage disposal is to get rid of it most appropriately, and also to monitor and manage end to end operations involved like the collection from its source, transportation, processing, and recycling of the wastes into new materials or depositing it in the landfill for incineration, [11].

Urban biodiversity is the diversity of living species, phenotypic variation, habitat types and ecological systems that may be found within and around human populations in a metropolis, including all plants, animals, fungi, and microorganisms and their communities and environments. Species can be found anywhere from the outskirts of town to the heart of a major city, as environmental remnants such as dwindling native plant populations are a component of the ecosystem. Biogeographic and anthropogenic factors affect urban biodiversity, with the latter dominating. Protecting biodiversity is critical for the harmonious equilibrium of the planet, so as to ensure a long-term development and well-being of humans and indeed for all life Biodiversity safeguards, manages and maintains the health and quality of both soil and water. It helps to reduce our vulnerability to natural disasters like floods and fires. Loss of biodiversity has a negative influence on human health and food and energy security, and it may disrupt ecosystem function. Cities are massive centers for ecosystem services and biodiversity has significant environmental impact, in terms of: providing fresh oxygenated air, food and medicines, raw materials such as timber, fuel and fiber, purification of air and water, pollution abatement, controlling the quality of soil, controlling the quality of water, noise reduction, and microclimate adjustment, regulating climate by the cooling effect in the presence of vegetation, controlling the occurrence of flash floods, providing remediation of polluted land and water bodies, providing for carbon sequestration, providing inspirational avenues both aesthetic and artistic, providing protected natural home for birds, bees and butterflies, providing spiritual inspiration, providing for recreation, relaxation and psychological well-being, providing education and knowledge, creation of a sense of space based on culture and history, providing for ecotourism, and climate change mitigation and adaptation, to name a few. Biodiversity boosts city resilience.

City wildlife resources are by far undervalued. Urban wetland ecosystems abandoned factory sites, roadside greenery, vacant property, abandoned lands, ruins, allocated garden space, and cemeteries are being recognized as potential repositories of urban biodiversity, along with cultivated herbs, shrubs and trees in gardens within city greenbelts**,** residential societies and villas, botanical gardens, and individual balconies. These are often becoming dumping ground for waste if not monitored. Cities house a remarkable amount of species richness. As many as 70% of urban species are local or endemic. Urbanization however threatens loss of both habitat and city species, and it indicates ecological health. City biodiversity as a resource, delivers ecosystem services that would otherwise have to be paid for and end up raising the city's ecological footprint. Maintaining biodiversity despite urbanization is a global challenge. [12]. Waste accumulation has become a barrier to people's health and hygiene in the urban areas and is a matter of grave concern. It's about time to devise strategies to deal with organic waste while smart cities are being built. Smart waste management practices refer to those that make use of technology to effectively manage waste. Protecting the environment and improving public health are two of the many benefits of effective waste management. It might be challenging to sort garbage from various origins into biodegradable and non-biodegradable components.

Using IoT for efficient Waste management in Smart Cities

A Smart city certainty needs smart trash management and it's an essential part of its ecosystem. More than two thirds of the population in the world is predicted to be in urban areas by the end of 2030. Waste management and disposal is going to be one of the most critical challenge the smart cities will face. Trash disposal expenses are on the rise and all initiatives of smart city are investing in innovations in the waste disposal and management sector. IoT is playing a vital role in supplementing smart city through management by real time monitoring.

The current practices of waste management include the following

- Prevention: Studies for achieving this mainly focus on waste legislation, enhancing awareness amongst people [13].
- End strategy: These include suitable and on time waste collection [14], appropriate landfill, incineration, waste separation (both at origin and destination) [15, 16]. These primarily focus on recovering utility that may be remaining in the waste.
- Environmental restoration: These concentrate on restoring the damages caused by the waste leaks into the surrounding environs [17].

The prevention techniques are the most economical and are also most effective. The environment restoration techniques are least efficacious and most expensive.

Waste management is the need of the hour, and a lot of research has been in progress for the past many years. The new buzz word around waste management is the IoT enabled techniques for efficiently managing waste especially as the concept of smart cities is getting popular. IoT enabled sensors are envisaged to help smart cities in reducing the overloaded bins while optimizing waste accumulation, Fig.5.

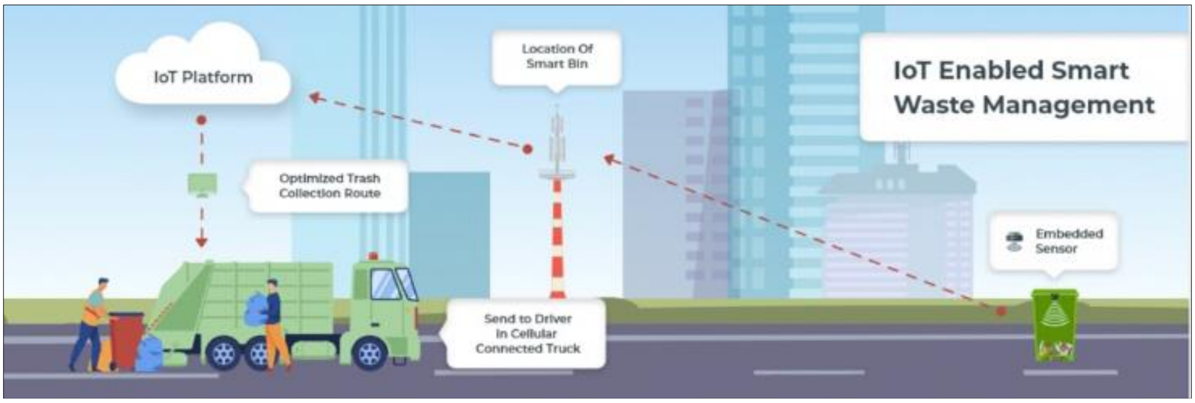

Fig 5: IoT enabled smart waste management.

IoT has the potential to substantially bring down the operational expenses around the waste collection processes. The research/studies around the waste management techniques enabled by IOT can be categorized into the following four main classes:

1. Sensor-based Technologies and Data Acquisition Development [18, 19].
2. Data transmission infrastructure and Communication Technology Development [20, 21, 22].
3. Field Experiments to test the IoT systems' effectiveness and capabilities [23]
4. Route Optimization: Truck scheduling with routing for collection of waste. [24, 25]

IoT builds smartness into Trash Bins

More efficient waste collection is made possible using smart bins/dumpsters. A sensor is small but can help in a big way. Proximity based and ultrasonic sensors can evaluate segregation levels, guide drivers of collection trucks to full bins. Weight sensors can be deployed to help track levels in large sized trash bins. In other words, the cutting-edge technologies help report dumpsters filled to capacity enabling the trash management authorities to take it up on priority basis and resolve urgent requirements. Truck drivers too can choose efficient and quicker route, avoiding congestions using the IoT aided infrastructure. Essentially smart trash bins collect data such as fill levels, temperature, location etc. and relays these to the trash management companies for a quick, systematic, smooth, and precise action.

IoT helps Optimize Routes

The loads of trash in the waste collecting bins are not constant. They vary depending on seasons, week or day. The smart bin, one which has a IoT enabled sensor, constantly monitors the real time fill levels and communicates the information to the management team. Based on these inputs, the best routes for collection/clean-up can be determined using IoT solutions. Regions can be prioritized depending on which need immediate clean up avoiding dumpsters that have space. This makes for a very optimized and efficient model saving both manpower and fuel.

IoT ensures Diligent Tash Pickups

The smart dumpsters ensure reducing the misses in pick-ups. The sensors detect and communicate the dumpster fill levels and the process is completely automated. This enables the inbuilt IoT system to schedule streamlined pickups from the desired locations and to a great extent avoid trash overflows.

IoT provides Streamlined Analysis of Data

With the help of smart gadgets installed in the bins, it becomes immediately apparent when and how often trash cans have reached their full capacity. Location of the optimal route is also easy to chart with these smart devices. These inputs make practical tasks more fruitful and streamlined for the management companies. The sophisticated tool and technology assists in early detection and correction of underlying snags. Most of these can be mitigated considerably with IoT.

IoT assists Effective Recycling

The burgeoning of consumer electronic goods and devices is perturbing as these are eventually ending up in landfills. This is causing deep concern as these include not only valuable components but also hazardous compounds. A wearing out smartphone s battery has a high risk of leaking its lithium into the underground water and these toxins are injurious to health. At the same time precious metals like gold can be reclaimed from such devices and it’s much easier than mining. IoT makes it possible to empower businesses to recycle e-waste and extricate finite and rare resources along with managing their primary task of sanitation.

Future of Waste Management with IoT

As of today, interconnected IoT devices are managing most urban operations the world over and the network is rapidly growing. This is taking care of the carbon footprint and enhancing human experiences. More support is sought from private and public sectors to boost the efficiency of waste management with IoT. Various state agencies need to engage and collaborate, and innovations, regulations and incentives need to be intensified. These will enable the IoT applications help build a more sustainable and better future for the smart cities. The traditional ways of waste management are causing damage to marine life, contaminating air, water and soil and increasing pollution. The smart waste management is the way to healthy living on Planet Earth. The cutting edge IoT technology is promising and is envisaged to increase efficiency and reduce costs.

Despite being fully aware of its negative impacts on the environment, using traditional fossil fuels as a source of energy is an integral part of our everyday life. Identifying a renewable and sustainable source of energy has become imperative. The utilization of waste that gets generated to obtain a source of energy, would be an efficient and cost effective method of attaining a circular economy.

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