A STUDY OF CRITICAL ROLE OF SOFTWARE ENGINEERING IN DEVELOPMENT OF SMART CITIES, WITH SPECIAL EMPHASIS ON DIGITAL AND INFORMATION COMMUNICATION TECHNOLOGIES

A **Report**

Submitted in Partial Fulfilment of the Requirements for Award

of

POST DOCTORAL FELLOW

by

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MUKKA, KARNATAKA, INDIA

June 2021

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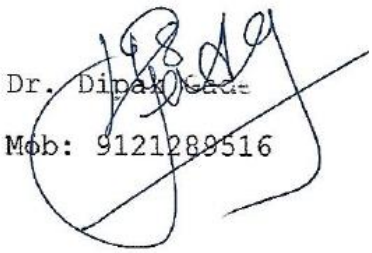
Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this Report is original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This Report is my own work and does not contain any outcome of work done in collaboration with others, except as specified in the text and Acknowledgements.



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Certificate

This is to certify that entitled **(A Study of Critical Role of Software Engineering in Development of Smart Cities, with Special Emphasis on Digital and Information Communication Technologies)** submitted by **DR. DIPAK S. GADE** to SRINIVAS UNIVERSITY for the award of the Post Doctoral Fellow is a Bonafede record of the research work carried out by him under my supervision and guidance. The content of the Report, in full or parts have not been submitted to any other institute or university for the award of any degree or diploma.

Supervisor: Dr. P.S. Aithal

Professor P.S. Aithal

Place : *Mukka*

Date : *30 / 06 / 2021*

Acknowledgements

Foremost, I would like to express my sincere gratitude to my Guide and Advisor honorable VC of Srinivas University Prof. P.S. Aithal for his continuous support and guidance during my PDF study and research. His constructive review of my research work only ensured maintaining high standard of my research outcome in form of published papers. It would have been impossible to complete this research without guidance of Aithal Sir.

I am grateful to various SMEs, Consultants, and Industrial Professionals working across the globe on Smart Cities Development Projects who directly and indirectly helped me in providing reference to their research work and patiently clarified my queries.

My sincere thanks also goes to Editorial and Review Team of Research Journals IJMTS and IJAEML of Srinivas Publications for reviewing my research papers and publishing them in their reputed journals.

Besides my Guide, I would like to thank Dr. Praveen BM, Director – Research and Innovation Council Srinivas University for encouraging me to enroll for PDF Course and contribute for this innovative research.

I also wanted to thank my PDF batchmates for sharing various research articles and important information on latest research areas on our official WhatsApp group, this always encouraged and widen my knowledge levels.

Last but not the least, my heartfelt thanks to my beloved wife Rohini and my sweet daughters Aastha and Aarya who managed the household activities truly independently, giving me complete time to focus on my research work.

- Dr. Dipak Gade

ABBREVIATIONS

AI	Artificial Intelligence
API	Application Programming Interface
BBM	Block-level Boundary Matching
CPS	Cyber Physical System
GPS	Global Positioning System
IT	Information Technology
ICT	Information and Communications Technology
IOT	Internet of Things
SME	Subject Matter Expert
SMArc	Semantic Middleware Architecture
SRDO	Surveillance Rate–Distortion Optimization

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1. INTRODUCTION

From last few decades there is tremendous growth and opportunities are seen in Software Engineering Field. In fact, evolution of Digital and Communications Technologies are now started playing an integral part in our day to day life. Whether it is travelling, entertainment, or the information sharing with one or many, locally or across geographies, has been become very simple, reliable, and fast. This digital evolution is expected to continue throughout this century and there are many things going to come in our way to offer more and more surprises. As of now the continuous growth in software engineering, how can remain unaffected the evolution of smart cities development. My research is focusing on the study of Software Engineering role in the evolution of smart cities across globe and specifically in India.

I am concentrating on digital and information communication technologies which has really dominated the development of smart cities. Though well focused and planned development efforts are already going on from last few decades for development of planned cities, however it is indeed visible from last 10 to 15 years that ongoing efforts are not enough and societies are now more demanding and looking for more robust technical solutions for real life problems from residence, infrastructure and commute perspective. I feel that this constant pressure and more demanding nature from societies and city residents to make the life easy and safe must have triggered the thought of digital technology compatible city, which is nothing but, in my opinion a Smart City.

It is not uncommon to expect that Smart City is nothing but one which provides smart services to its citizens to make their life more comfortable, safe and happy. It is also about connecting the city residents in reliable and safe way with the government digital governance platform where citizens can consume the services, can give their feedback and improve the services through mutual participation in ongoing basis. And this aim can't be possible without utilizing the advances happening in Software Engineering Technologies.

Smart City is different from traditionally well-developed cities and or the way cities were planned and grown. Smart City has brought new trend in setting up and development of cities and applying the governing policies, rules and regulations using technologies. This enables the citizens to freely access and use digitally available information, various apps providing various digital services related to the city such as various events info, shopping offers, tours and travels related info, tracking and locating address, online admissions to school and colleges etc. Thus, Smart City is a place where traditional information networks are replaced with digital services offering more flexibility, more efficient and more sustainable by making best use of available technologies such as digital and information communication technologies, to improve the overall operations and provide benefits to its residents. Smart City not only best utilizes the technology to make the citizens life better livable but also cares to reduce harmful impact on environment. Technologies such IOT, Bigdata, Geospatial Technology, Artificial Intelligence, Blockchain etc. are making long term impact in smart cities development and operation making them more efficient and more innovative and creative. No doubt that this is very important development and will be marked as

an important era of information and technology.

Fig.1 : Smart City Model

In figure 1 above, the typical model representing smart city concept is shown. As shown in the figure, the key ingredients of smart city are shown around the basic residence infrastructure of a city and presented as a collection of paradigms spread among different domains such as people, processes, governance, mobility, environment and better living facilities such as residence buildings, education institutes and medical facilities.

Smart City thus facilitates and responsible for lot of functionalities under one umbrella including traffic flow analysis and necessary optimization, incident monitoring and reporting, public transportation, utilities monitoring, carbon foot print measurement and monitoring, smart governance, smart power management, best optimized natural resource utilization, smart water management, smart waste management and so on. Please refer figure 2 which has listed down the essential capabilities of Smart City. The necessary capabilities of Smart City ensure liability for citizens and also offer economic opportunities for cities to attract and empower citizens of all age groups including senior citizens. Smart City technologies when used wisely and with planning can alter the city infrastructure and the ways the digital services are deployed. These technologies also offer good opportunity to accommodate expectation and desires from ageing communities and disabled communities. All the stakeholders of Smart City thus can ensure that offered services are inclusive.

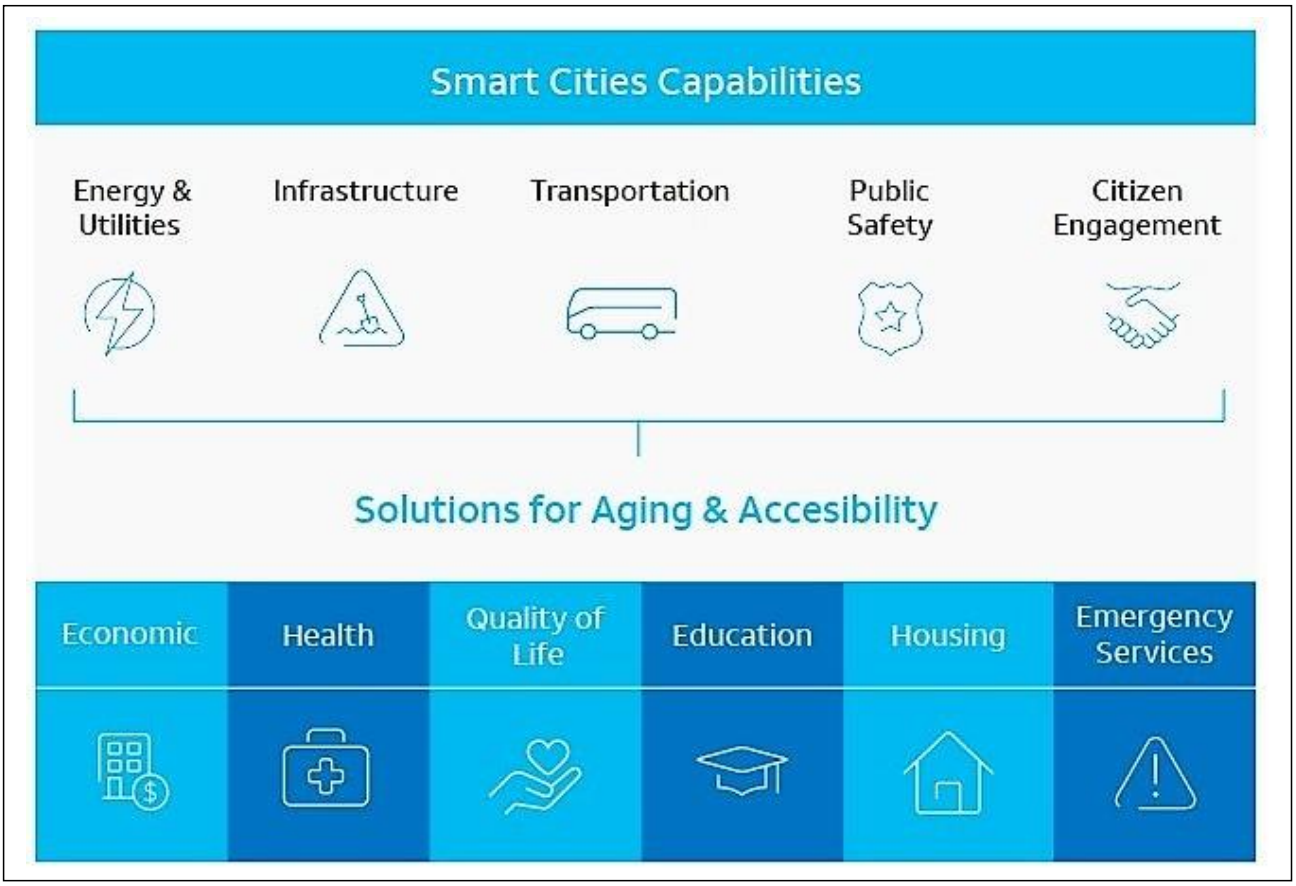

Fig. 2: Smart Cities Capabilities

Refer figure 3 below, which is presenting all the essential components of ICT which directly assist Smart City meeting and fulfilling its many of the objectives. Though the figure has only listed essential ICT Actors, the list in reality is very exhaustive and will continue to grow depending upon the ICT revolution and its implementation across multiple domains. The list is also going to accumulate the new elements in line with industry 4.0 generation. The smart ways of managing the things required acquiring the relevant data from various sensors, necessary data monitoring and analysis. The relevant data analytics from smart management of various services enables the city governance to make relevant improvements in infrastructure, super asset management and overall effective control on all the relevant resources. For this purpose, a smart city must include key components such as secure centralize server, safe way to access the data through mobile apps or simple secured websites and powerful hardware platforms to drive this IT Infrastructure. With such facilities the citizens can then freely and securely access the systems and subsequently required data, and this can happen in two ways where citizens can also upload and update the relevant information in real time. By enabling the relevant controls citizens can contribute in information sharing and can collectively fulfil the combine aim of smart city governance.

Fig. 3: Smart City ICT Components

The systematic definition of Smart City is “a city in which its social, business, and technological aspects are supported by Information and Communication Technologies to improve the experience of the citizen within the city. To achieve that, the city provides public and private services that operate in an integrated, affordable, and sustainable way.” Thus, the smart city's basic aim is to have an integrated as well as collaborated environment to facilitate interoperability, participation and enhancements among city’s sub-systems. Making City Smarter is an evolving and ongoing activity and it is necessary that the shared services must be integrated under unified technology infrastructure. A more sensible way to make this reality is with a well-thought of and designed, robust software platform providing the essential infrastructure for dealing with huge volumes of data, a wide variety of software devices, platforms and applications, interoperable systems, and other issues related to Smart City environments.

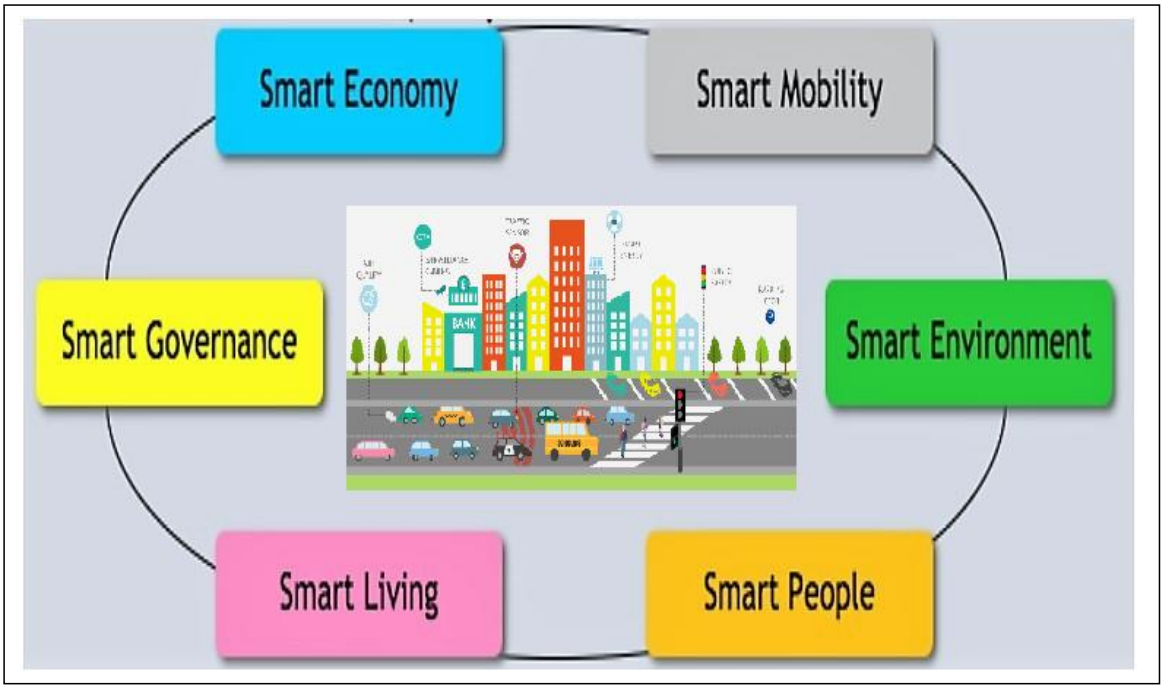

Fig. 4: Smart City Features

Refer figure 4 above which has shown the 6 essential features any smart city must have. The smart city is built on the smart combinations of enabling these features. For smart and sustainable growth of a city, it is important to promote a more efficient use of available resources, reliable data analysis, robust technical infrastructure, a competitive economy and continuous innovation. For better performance, smart city depends upon advancements in software engineering field and uses digital and information communication technologies to enhance quality of the offered services to make citizens lives better. All the stakeholders of Smart City including administration and management officials are provided with better technology driven ways to connect with each other and take rapid action as and when required. Continuous small steps are being taken towards the final goal, Smart City, by providing & continuously improving on the Smart Living aspect of it.

2. LITERATURE REVIEW

Smart City concept is now not new to the world. From last 10-15 years Smart City requirement came forward to address growing demands from city residents to have better and affordable services to make their life more enjoyable and livable. Current Smart City is a trend for many of the cities in the world. Many residents are moving to cities from villages in search of better employment and better life. This day by day increasing population is putting lot of load on city infrastructure and have raise lot of expectations from Smart City to address such challenges more effectively.

Worldwide scientists, research scholars, Industry SMEs have put lot of efforts in proposing and implementing various innovative solutions to address the real-life challenges faced in developing Smart Cities. Lot of good research papers, white papers, presentations, thesis and books are available online as well as in printed form elaborating in detail the Smart City concept, systematic steps in implementing and maintaining Smart City infrastructure and solutions based on advanced technologies to meet specific features and functionalities Smart City needs to fulfil. The use of Information Communication Technologies enables process automation, communication, and a mechanism to monitor, analyze and take appropriate actions in Smart City development, administration, management and maintenance. The available literature in this regard is necessary to review and analyze to understand latest technology trends in Smart City Development, operation, and maintenance.

Systematic Literature Review is a method to conduct deep literature reviews. There are three stages, the first stage is the introduction that includes the limit scope, determining the research question, the search process which involves the selection of literature sources and keywords, inclusion and exclusion criteria for sorting paper type and performed the data extraction form of papers selected to be explored further [16]. In this chapter, I am going to review selected papers/journal articles/reference books written on Smart City development and its maintenance. The aim of this review is to identify latest technology trends in Smart City development and collect more information on issues and challenges faced while developing Smart Cities and how Smart Cities can be made smarter. My constructive criticism and comments on already existing literature is expected to assist me in digging out more and more reliable information on Smart City and collect and quantify relevant data, ideas and concepts for carrying out further research and to reach to a dependable conclusion. Following is the partial list of reviewed papers which are reviewed for identifying certain keywords, technology trends, quantified data and data correlation.

[1] Thinking about smart cities by Amy Glasmeiera and Susan C. (2015)

In this paper, author went through the various definitions of Smart City and came forward with different perspective about Smart City keeping in mind the two essential attributes. These two essential attributes are: technology driven and living experience in urban places with new reality. Author has discussed about the various expectations from citizen about Smart City and elaborated their thoughts throwing light on following

- Better equipped infrastructure of Smart City for smarter Cities
- Are Smart City resident real beneficiary from Smart Cities?
- Can Smart City movement fulfil the better urban living expectation from its citizens

Authors feel that the Smart City Development process should be well thought of and conducted through collaborative research. While doing so following questions shall be answered

- The capabilities and constraints of technologies used in development of Smart Cities
- Application deployment conditions such as scale, market size, density and proximity and finally
- Applications marketability

Authors have also raised concerns stating that many of the smart cities will need to be developed from scratch considering the possibility that many of the people will move from rural areas to Urban for exploring better employment opportunities and better livable experience. In such cases it is extremely important to consider essential resources requirements such as water, transportation, waste management, electricity, housing, medical facilities, education facilities etc.

[2] Agatha: Predicting Daily Activities from Place Visit History for Activity-Aware Mobile Services in Smart Cities by Byoungjip Kim et al (2015)

For any Smart City to smartly function, many digital services are used such as city planning, transportation, administration, location mapping and so on. Number of

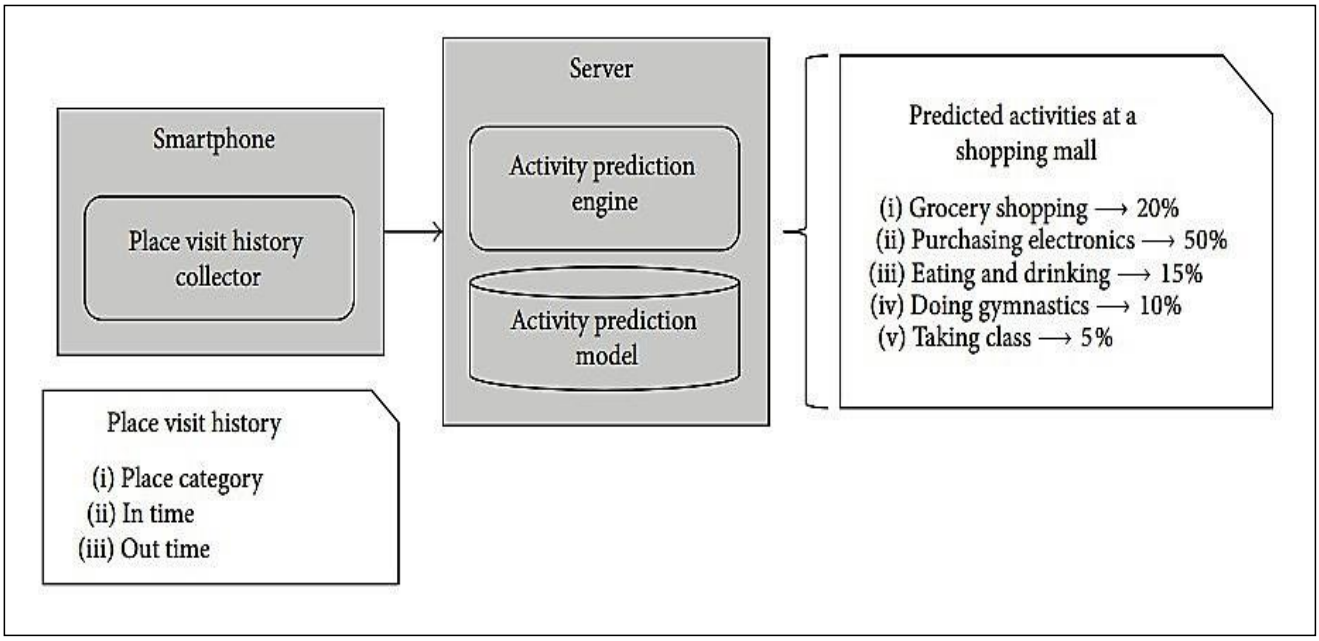

Fig.5: System Architecture for location based activity recognition

digital services are increasing day by day according to the larger requirements of Smart Cities. In this paper Authors have shared details of new digital service for citizens of Smart Cities that is place-history-based activity prediction system called as Agatha. This service will be mobile app based. While people moves around city the GPS enabled Smartphone installed with Agatha Service App will collect location coordinates of the place visited by the user, time stamp the event for In and

OUT information. This data will be then processed, and the system will extract the place visit history of the user and on that can predict the user's likely activities in and around city using machine learning techniques.

Refer Figure 5 which has shown the overall architecture of Agatha Service. Authors have claim that this new service of place-history-based activity prediction can be very useful for Mobile Advertising and for recommending the users specific other services and information such as best dining out nearby or entertainment event happening nearby or even information related to forth coming events in such places where user is expected to visit in nearby future.

[3] Analysis and assessment of a knowledge based smart city architecture providing service APIs by C. Badii et al (2017)

Smart City development faces many of the issues and challenges where one of the main challenges is related to collecting data generated from various services, analysing it and generating meaningful conclusion out of it. Also, Smart City service effectiveness depends upon its capability of collecting the relevant data and passing it to its stakeholders reliably and accurately. To meet this challenge, authors have proposed a robust solution for data aggregation and for Smart City API. This work was performed by the authors in the context of Sii-Mobility smart city project on developing the smart city architecture addressing huge data processing requirements

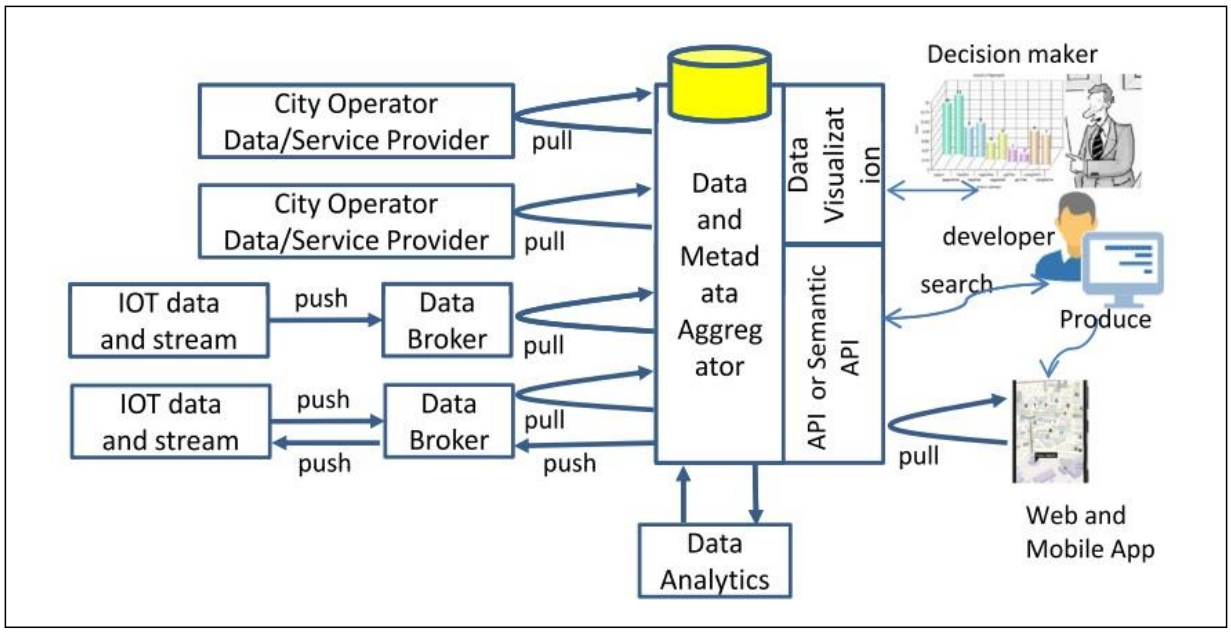

Fig.6: Smart City Architecture for data aggregation

The authors proposed solution by aggregating and re-conciliating all types of generated data including real time, static, openly available as well as private services data by using smart algorithms for enabling Smart City API sophisticated service delivery. Refer figure 6 above which has presented the proposed Smart City architecture for Services API.

[4] Smart Cities as Cyber-Physical Social Systems by Christos G. Cassandras (2016)

The Smart City network infrastructure consists of network of sensors and actuators

embedded throughout the throughout the urban terrain and Smart City services, interacting with smart phones, tablets and laptops. All these devices and or nodes are finally interacting with cloud services offered via internet. In this paper authors have correlated the smart city architecture with Cyber Physical Systems. Authors have successfully argued that the data collected and flowed through various network nodes in Smart City may involve data related to traffic signals information, traffic flow information, parking availability information, vehicles monitoring and location coordinates, water and air quality related information, emergency related information. Under such conditions data reliability, accuracy and availability of information is key requirement which demands a robust CPS infrastructure equipped with new software platforms adhering to strict standards of mobility, safety, security and data privacy. In this paper authors have discussed key characteristics of Smart City and discussed following lessons learned by viewing Smart City as CPS.

- Smart City CPS shall treat Smart City as close loop system and not just the architecture data collecting and distributing among various digital services
- Instead of numerous applications, implementing a user-friendly platform for accumulating and data distribution can have major impact
- Just technology alone cannot transform any city into Smart City. Participation and involvement of human beings in managing and running Smart Cities is more important and essential and hence in developing any CPS human being behaviour and role should also be considered.

[5] Algorhythmic governance: Regulating the 'heartbeat' of a city using the Internet of Things by Claudio Coletta and Rob Kitchin (2017)

In this Paper, authors have discussed how the IOT infrastructure with its associated network of sensors and actuators can be used to regulate, measure and monitor the polymorphic temporal rhythms of urban city life. Authors have developed a concept of 'algorhythmic governance' by employing rhythmanalysis in conjunction with Miyazaki's notion of 'algorhythm' and nascent work on algorithmic governance. Authors have also successfully demonstrated the concept of 'algorhythmic governance' through two case studies on Traffic Management System and Sound Monitoring and Modelling. Through this study and discussion authors analysis has revealed following

- Various distinct forms of algorhythmic governance
- Practical applications and working style of algorhythmic governance works in practice and
- How Smart City technologies perform, computationally rhythmanalysis and undertake rhythm-making that intervenes in space-time processes

[6] Simulation Game as a Reference to Smart City Management by David Wiselia et al (2017)

In this paper authors have proposed simulating the Smart City aspects such as related to Citizen, Environment, Traffic, Welfare, Economy, Technology etc. and its associated problems in game fashion to make Smart City stakeholders aware of and understand the problem-solving techniques and solutions in efficient manner. Authors have discussed in detail the influence on the stakeholders from

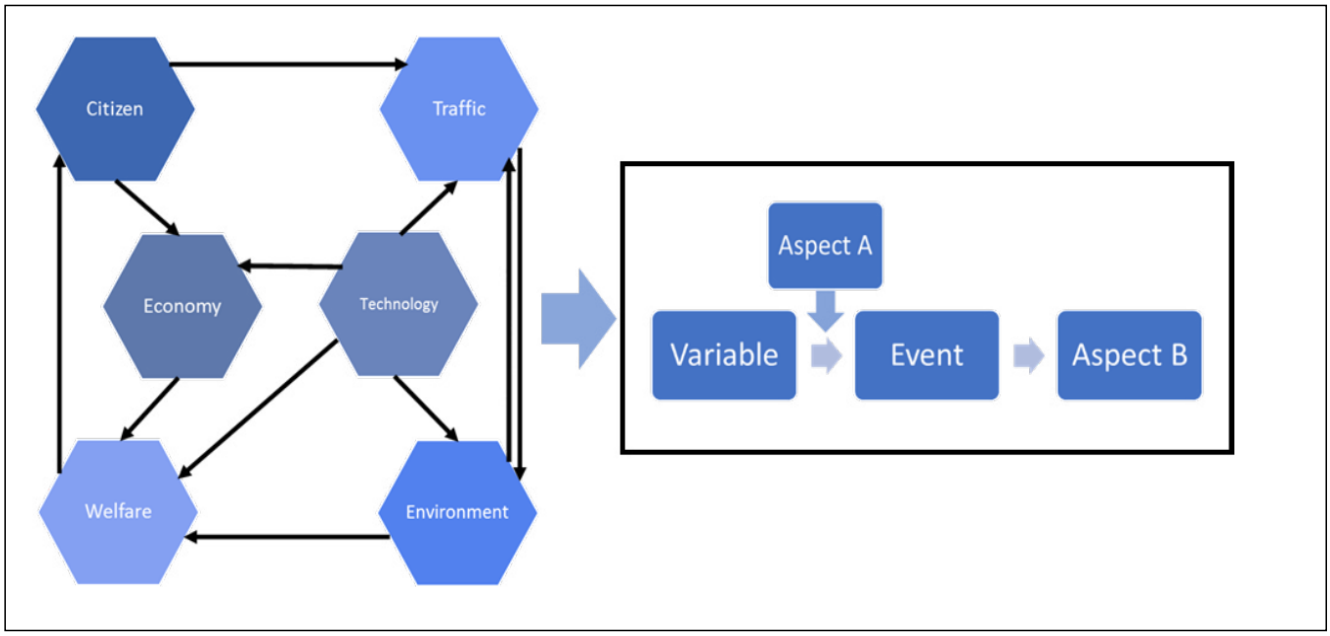

Fig.7: Smart City Aspects relation and mechanic

playing a game for City Management skills acquiring and better planning on what needs to be done first and in what order. Authors have claimed that by simulating real life practical problems associate in Smart City management and administration and providing relevant sandbox style of simulated solutions to tackle such problems can offer the game players i.e. Smart City stakeholders better skills, training and learning experience to handle similar kind of challenges in real life. Refer figure 7 where author have shown the Smart City aspects relation and the mechanic. It is clear from this diagram that any change in any node will affect the other nodes as well. Authors have successfully demonstrated how Smart City aspects can be simulated into game and it can positively influence the people playing this game to take appropriate actions for similar kind of situations in real life while managing the Smart Cities. Authors have concluded that simulation game can be used a successful teaching method by implementing problem and solutions of city management into a game and by allowing the player to solve it.

[7] Software Platforms for Smart Cities: Concepts, Requirements, Challenges, and a Unified Reference Architecture by Eduardo Felipe Zambom Santana et al (2017)

In this paper authors have surveyed the current research on software platforms for Smart Cities and tried to investigate the most relevant requirements to facilitate the development, integration, testing and deployment of Smart City Applications. Based on the analysis and investigations done to explore the highly reliable, effective and scalable Software Platform for efficient running of Software Applications/Services for Smart City, authors proposed a unified reference architecture supporting this prime objective. Refer Figure 8 which has shown the proposed reference architecture for the Software Platform for Smart City. The paper has provided all the relevant information to help software developers and Smart City stakeholders to handle the non-functional and functional requirements

to be fulfilled by software Platform for Smart Cities, classifying them into four categories: IoT, Big Data, Cyber-Physical Systems, and Cloud Computing.

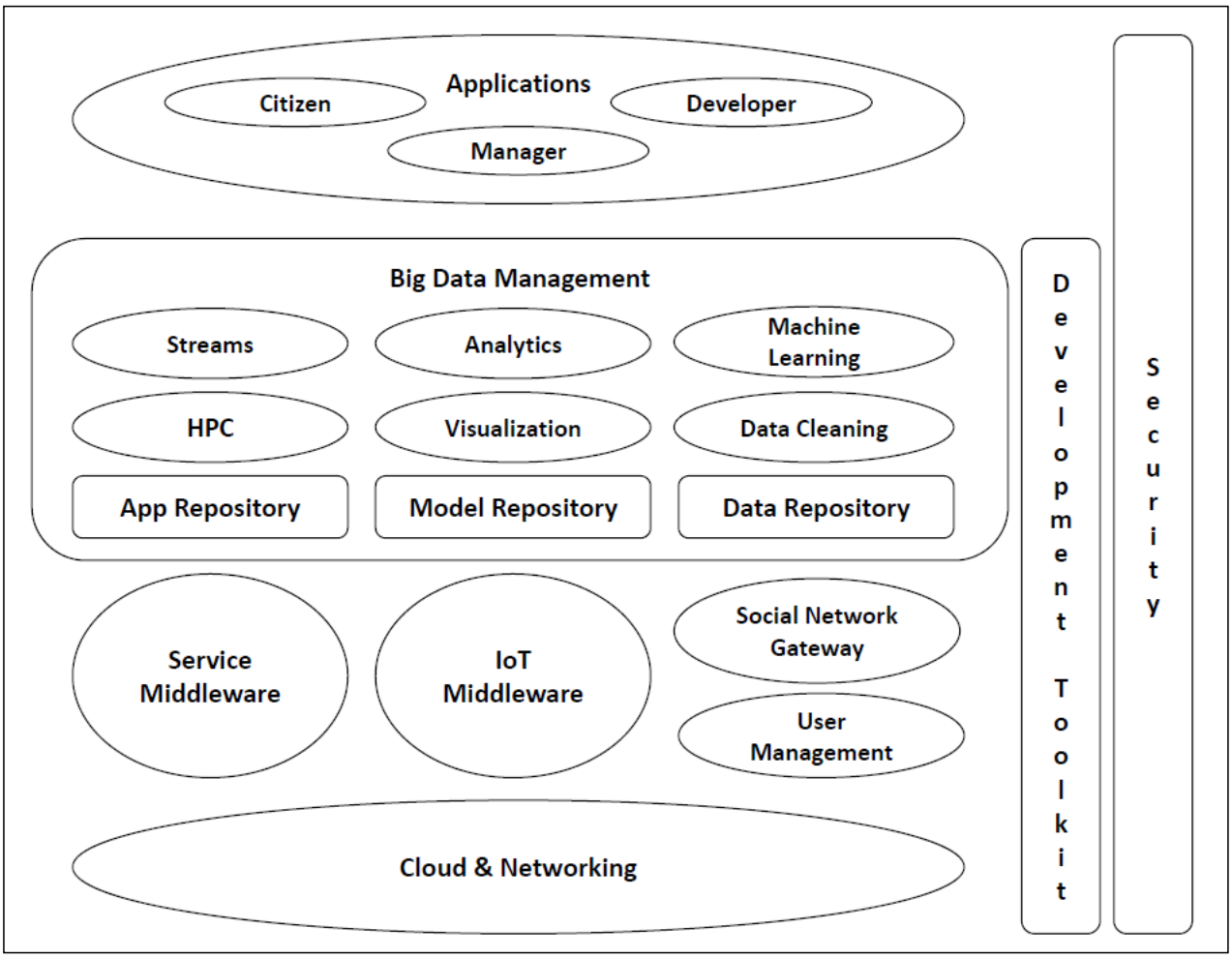

Fig.8: Unified reference architecture for Smart City

[8] SMArc: A Proposal for a Smart, Semantic Middleware Architecture Focused on Smart City Energy Management BY Jesús Rodríguez-Molina et al (2013)

In this paper authors have argued that among other various functionalities of Smart City, improved energy management is also one of the important functionalities to be analyzed, monitored, and fulfilled. To do so, authors feel that Smart Grid Energy management is the best suitable solution since it provides two-way information flow between consumer and provider and this mechanism can boost the energy management enhancement. However, authors also suggested that to use all the generated information effectively a middleware layer is also needed in the architecture which will be responsible for collection and distribution of data among various nodes. To meet this requirement, authors have proposed a Semantic Middleware Architecture named as SMArc. Please refer figure 9 which has depicted pictorial presentation of SMArc Middleware layer for Smart City architecture. The SMArc layer overall position has been depicted in the above figure. The SMArc layer basically takes care of any changes happens at lower layer of architecture and insulates applications from complex metering facilities.

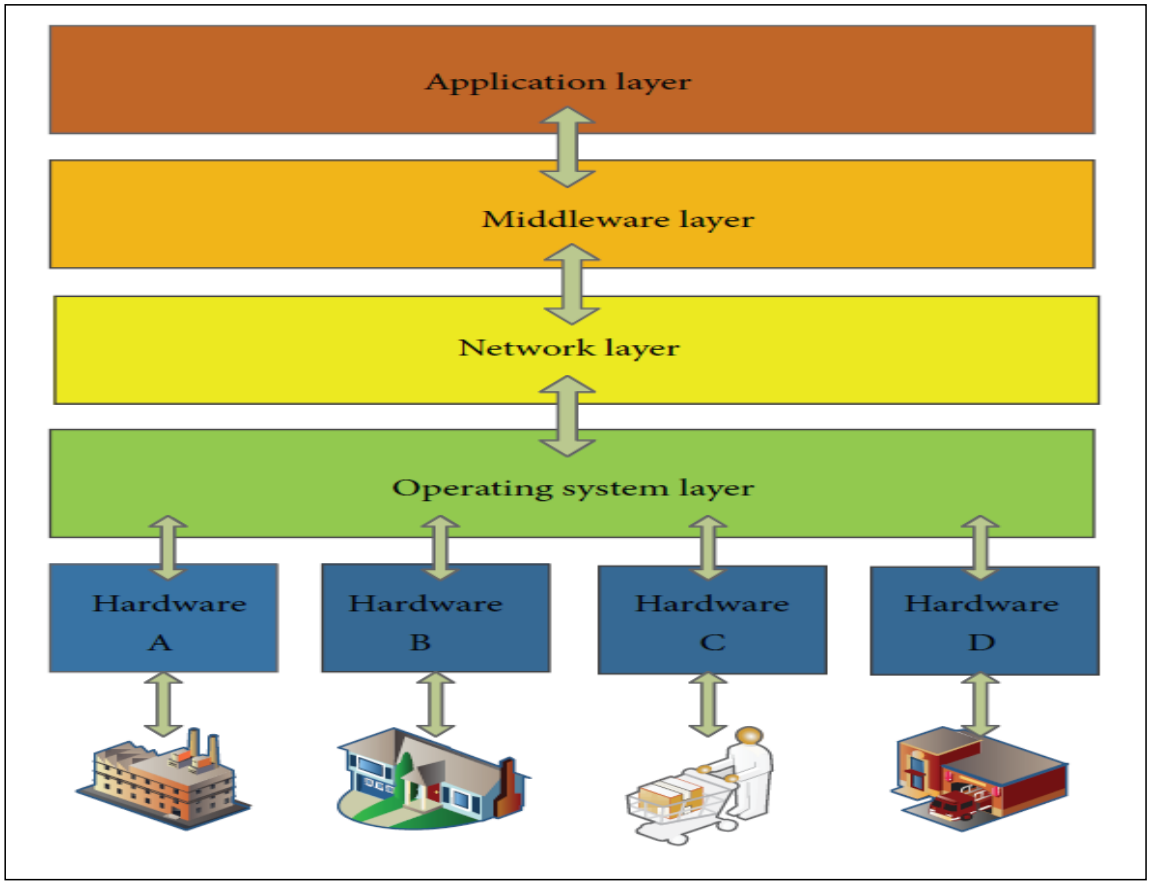

Fig.9: SMArc Middleware Layer for Smart City Architecture

Authors have also provided the computational and functional analyses to prove the successful functioning of SMArc. Authors have claimed that the SMArc layer can be easily integrated in a Smart Grid without need to be ported or adapted from other contexts.

[9] Securing Smart Cities Using Blockchain Technology by Kamanashis Biswas and Vallipuram Muthukkumarasamy (2016)

In this paper, authors have proposed a Blockchain technology-based security framework for Smart City Architecture to have a secure communication Platform. As the Smart City network is becoming more and more complicated where millions of IOT devices are supposed to be an integral part of Smart City architecture and going to generate huge messages for exchanging among various nodes, in such case safety and security aspects for data communication is an essential aspect to look after. The Blockchain Technology supports crypto currency as and is basically peer to peer distributed ledger technology which can record any kind of transactions such as contracts, agreements, sales etc. and it doesn't need any intermediary. The benefit of Blockchain Technology as security framework is that an attacker can't penetrate the system unless 51% of the system is compromised, which is as good as impractical. Also, such penetration attempts can catch the attention of security measures the moment first access layer is compromised. Thus, using Blockchain technology to secure the Smart City Architecture can offer high secured robust security framework which is practically secured to deal with any kind of virtual attack. Refer figure 10, which has represented the proposed security framework via four different layers i.e. Physical Layer, Communication Layer, Database Layer

and Interface Layer. Authors have claimed that using Blockchain based security framework can create a common platform which can enable secure data communication in a Smart City and can offer multiple advantages including better fault tolerance capability, improved scalability, faster and efficient operation, better reliability etc.

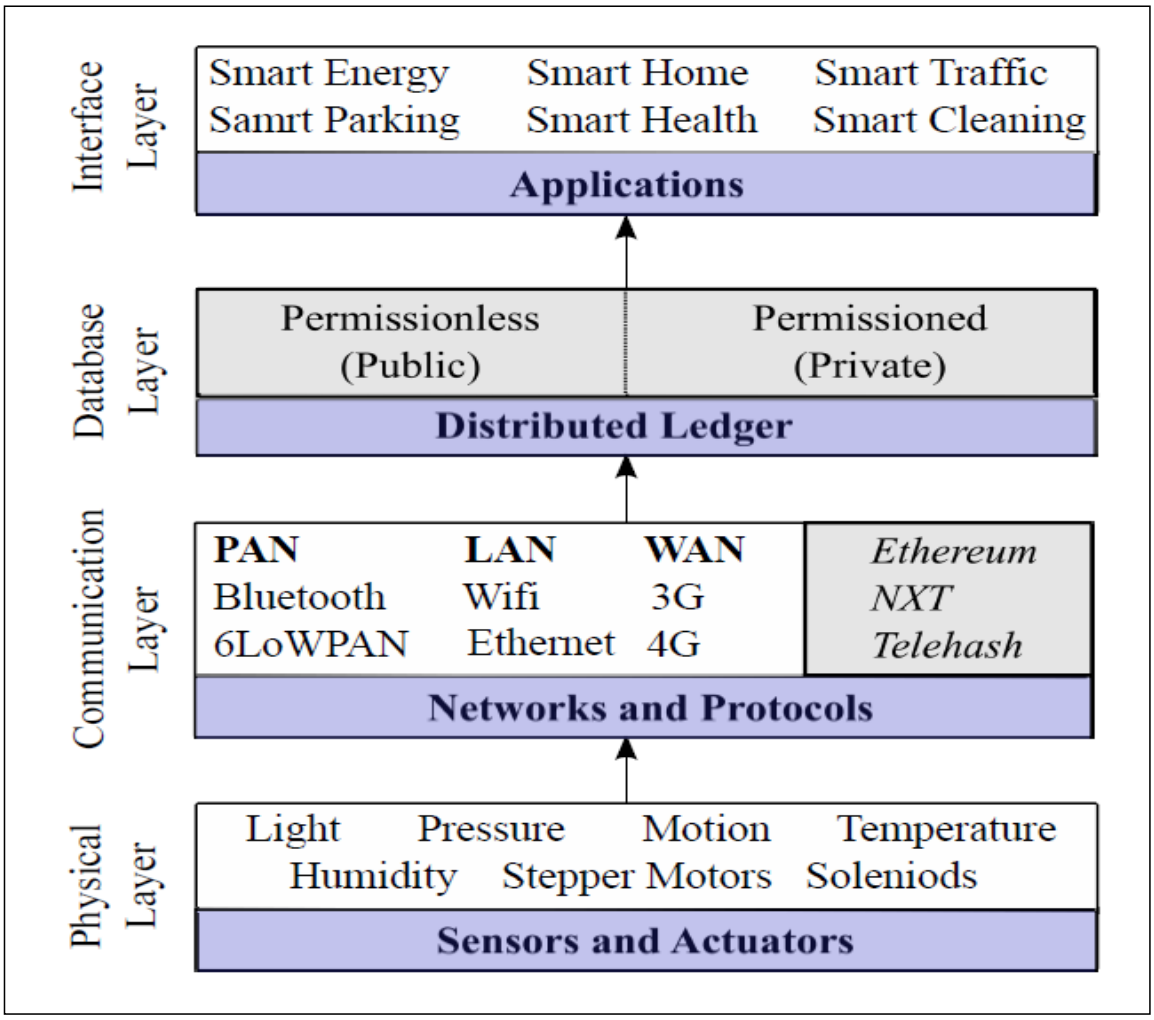

Fig.10: Blockchain Security Framework for Smart City Architecture

[10] Video big data in smart city: Background construction and optimization for surveillance video processing by Ling Tian et al (2018)

In this paper authors have proposed new scheme for Video Compression based on block-level boundary matching (BBM) algorithm to support long-term reference structure for efficient surveillance video coding. As the Smart City Architecture is going to use more and more IOT enabled sensors for better surveillance and city administration, it is obvious that huge amount of text and video data is going to get generated and needs to be processed in time bound manner. As video data is bulky, if it is not compressed while transmission from one place to other can seriously pose data processing and data loss challenges.

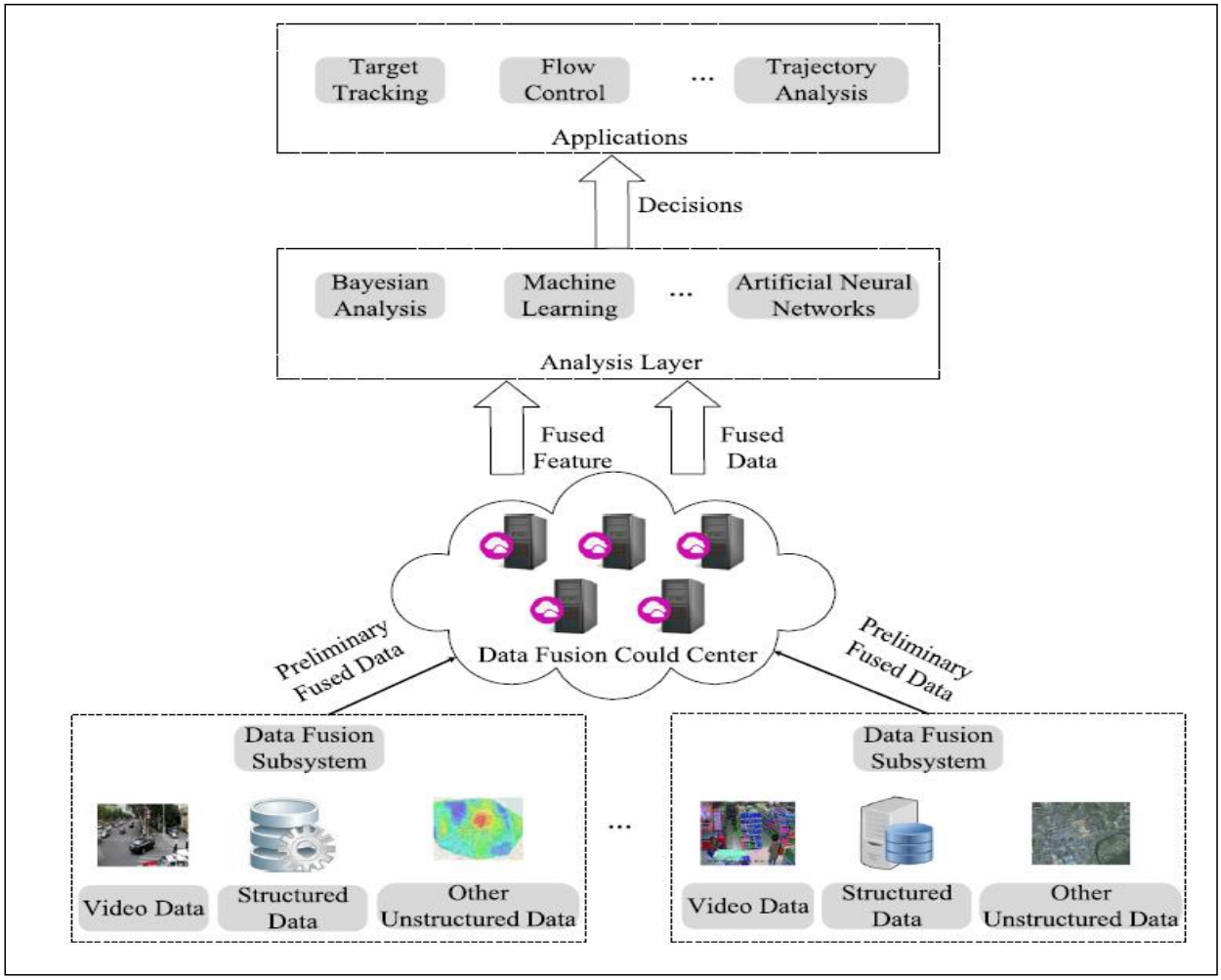

Fig.11: Video Data Fusion Architecture

To deal with such issues, authors feels that better compression technique for Video Data is an essential requirement rather than just necessity. Refer figure 11 where typical Video Data fusion architecture proposed by authors is shown. Authors have also developed a rate–distortion optimization for surveillance source (SRDO) algorithm to improve coding performance. Authors have further proposed to collaborate the BBM Video Compression technique with surveillance rate–distortion optimization algorithm (SRDO) for further improving the video compression performance. Authors have recommended using this newly developed BBM and SRDO algorithms in Video Compression for surveillance video data of Smart City and have also claimed that this technique would require less storage requirement for video data and can offer efficient video data processing for any video applications required in Smart City.

3. OBJECTIVES

The broad objectives of the proposed research are as follows.

- To study and analyze the existing technology trends in development of Smart Cities
- To review the available literature on Smart Cities development
- To understand the present challenges Smart Cities are facing and the constraints in development of Smart Cities
- To study and explore the emerging technologies used in development and sustenance of Smart Cities
- To analyze and study the impact of some of the digital technologies and ICT based solutions in development of Smart Cities
- To analyze and document solutions for some of the pain problem areas of Smart Cities

4. RESEARCH PLAN AND METHODOLOGY

In today's technology era of industry 4.0 generation, major technical challenges are getting solved through use of technologies such as connected devices, artificial intelligence, and data analytics. It will be very much interesting to see how such, and similar technologies have created any impact on development of Smart Cities. Through the proposed research I am focusing on analyzing and studying software engineering-based applications in development of smart cities with specific focus on digital technologies and Information communication technologies. It also aims to explore emerging technologies assisting in developing and managing Smart Cities. The research is going to be based on the qualitative methodology through a systematic study of existing literature as well as research data collected from interviews of well-known SMEs from Smart City Development domain.

The proposed research is carried out through following steps.

- Primary Data: Through Personal Interviews. Interact with the scientists and engineers from research institutes and SMEs from industries who are working on Smart City development projects throughout India and at International Level. Face to face meeting and or online meeting such as Webex or Skype were used to conduct the interviews of selected eminent scholars, Smart City Consultants and SMEs. The interview questions were formed aiming to understand following
    - ❖ The current pain areas in development of Smart Cities
    - ❖ Main challenges faced while developing Smart Cities
    - ❖ Latest Technologies used in addressing some of the main issues of Smart Cities
    - ❖ How the digital services are offered to Smart City citizens
    - ❖ How the stakeholder's communications and expectations are managed while developing Smart Cities
    - ❖ How the safety, security, reliability and data availability aspects are taken care of
    - ❖ What are the typical constraints in development of Smart Cities and how they are addressed?
    - ❖ What new technologies are being explored to address some of the main concerns Smart Cities are facing
    - ❖ Which are the main technologies from Software Engineering are mainly sought for Smart Cities

- Secondary Data: Study the available literature such as Online white papers, research papers, thesis from the similar area of research, journal articles, reference books related to the research topic.
- Data Analysis: Exploration and collection of the relevant data in database with respect to Smart Cities development and data analysis considering following

- ❖ Smart City Architectural Requirements
- ❖ Smart City Capacity Management
- ❖ Smart City Data management aspects
- ❖ Smart City Key Services
- ❖ Smart City Technology Trends
- ❖ Smart City Surveys and maintenance
- ❖ Smart City Sustenance
- ❖ Smart City Governance

The scope and limitations of proposed research work are as follows.

- The scope of proposed research work is to explore the technology trends and solutions in development of Smart Cities, revolving around Software Engineering based technologies alone and not any other technologies applicable to different engineering streams
- For this research, focus is limited to the emerging technologies from Digital and Information Communication Technologies for proposing solutions to some of the selected challenges faced while developing smart cities.
- Considering budget and infrastructure constraints, the POCs and prototyping of any software will be limited to software module or sub-module only and not for the entire system or subsystem.
- As such there is no constraint in exploring and surveying the existing smart cities from any geography however the physical meeting and face to face interactions with the selected scientists, scholars, consultants, industry SMEs will be limited to India geography only. For International resources interaction will be carried over Email/Telephone and or Skype online meetings only.

The proposed research is very important considering following some of the major benefits, it is expected to offer.

- The proposed research is expected to find out innovative solutions based of Software Engineering Technologies to some of the selected challenges faced while development and sustenance of Smart Cities
- The proposed research is expected to explore technology trends and impacts made by advancements in Digital and Information Communication Technologies on Smart City Development Projects. The generated artefacts and documentary evidences as an outcome of this research can really help the eminent scholars and research associates conducting research in development of Smart Cities
- The proposed research is expected to provide constructive criticism and improvement opportunities to enhance the overall efficiency, effectiveness and streamline the technology enabled activities undertaken across development of Smart Cities

The proposed research work is carried over period of one year, where the generating of primary and secondary research data, systematic review of existing literature forms an integral part of the research scope of work.

5. REFERENCES

Following is the partial list of the research articles/papers/books which are referred while preparing the synopsis.

1) Amy Glasmeiera and Susan Christopherson. (2015). Thinking about smart cities. Cambridge Journal of Regions, Economy and Society. 3–12.
2) Byoungjip Kim, Seungwoo Kang, Jin-Young Ha, and Junehwa Song. (2015). Agatha: Predicting Daily Activities from Place Visit History for Activity-Aware Mobile Services in Smart Cities. International Journal of Distributed Sensor Networks. 1-12.
3) C. Badii, P. Bellini, D. Cenni, A. Difino, P. Nesi, M. Paolucci. (2017). Analysis and assessment of a knowledge based smart city architecture providing service APIs. Future Generation Computer Systems. 75,14–29.
4) Christos G. Cassandras. (2016). Smart Cities as Cyber-Physical Social Systems. Science Direct Engineering. 2, 156–158.
5) Claudio Coletta and Rob Kitchin. (2017). Algorhythmic governance: Regulating the 'heartbeat' of a city using the Internet of Things. Big Data and Society- Sage Publications.1-16.
6) David Wiselia, Ryanarta Tanusetiawana, Fredy Purnomoa. (2017). Simulation Game as a Reference to Smart City Management. Proceedings of 2nd International Conference on Computer Science and Computational Intelligence. ScienceDirect. 468-475.
7) Eduardo Felipe Zambom Santana, Ana Paula Chaves, Marco Aurelio Gerosa, Fabio Kon, Dejan S. Milojicic. (2016). Software Platforms for Smart Cities: Concepts, Requirements, Challenges, and a Unified Reference Architecture. arXiv.1609.08089v3. 1-15.
8) Jesús Rodríguez-Molina, José-Fernán Martínez, Pedro Castillejo, Rubén de Diego. (2013). SMArc: A Proposal for a Smart, Semantic Middleware Architecture Focused on Smart City Energy Management. International Journal of Distributed Sensor Networks. 1-17.
9) Kamanashis Biswas, Vallipuram Muthukkumarasamy.(2016). Securing Smart Cities Using Blockchain Technology. Conference Proceedings of IEEE 14th International Conference on Smart City.1392-1393.
10) Ling Tian, Hongyu Wang, Yimin Zhou, Chengzong Peng. (2018). Video big data in smart city: Background construction and optimization for surveillance video processing. Future Generation Computer Systems. 86, 1371–1382.
11) Hoon Ko, Kitae Bae, Sang Heon Kim, and Kyung Jin An. (2014). A Study on the Security Algorithm for Contexts in Smart Cities. International Journal of Distributed Sensor Networks.1-8.
12) Kayalvizhi Sundarraj Chandrasekar, Bhishna Bajracharya, Daniel O'Hare. (2016). A comparative analysis of smart city initiatives by China and India - Lessons for India. ePublications Bond University, Proceedings of 9th International Urban Design Conference.1-18.

13) Liu Chaohua. (2014). The framework of smart city based on cloud computing. BTAIJ. 10(19), 11646-11648.
14) Liu, Xiufeng; Nielsen, Per Sieverts; Heller, Alfred; Gianniou, Panagiota. (2017). SciCloud: A Scientific Cloud and Management Platform for Smart City Data. 28th International Workshop on Database and Expert Systems Applications (DEXA). 27-31.
15) Luca Calderoni1, Dario Maio2 and Paolo Palmieri3. (2012). Location-aware Mobile Services for a Smart City:Design, Implementation and Deployment. Journal of Theoretical and Applied Electronic Commerce Research. 7, 74-87.
16) Meyliana, Hidayanto,A.N., Budiardjo.,E.K. (2015). The critical success factors for customer relationship management implementation: a systematic literature review. International J Business Information Systems. 1-3.
17) Narmeen Zakaria Bawany, Jawwad A. Shamsi. (2015). Smart City Architecture: Vision and Challenges. International Journal of Advanced Computer Science and Applications. 6, 246-255.
18) Qiannan Zhang, Tian Huang, Yongxin Zhu, and Meikang Qiu. (2013). A Case Study of Sensor Data Collection and Analysis in Smart City: Provenance in Smart Food Supply Chain. International Journal of Distributed Sensor Networks.1-12.
19) Radovan Novotný, Radek Kuchta and Jaroslav Kadlec. (2014). Smart City Concept, Applications and Services. Journal of Telecommunications System & Management. 3(2), 1-8.
20) Rodger Lea. (2017). Smart Cities: An Overview of the Technology Trends Driving Smart Cities. IEEE. 1-16.
21) Rumi Aijaz. (2016). Challenge of Making Smart Cities in India. Asie.Visions. IFRI.1-34.
22) Xiaolan Tang, Juhua Pu, Ke Cao, Yi Zhang and Zhang Xiong. (2012). Integrated Extensible Simulation Platform for Vehicular Sensor Networks in Smart Cities. International Journal of Distributed Sensor Networks. 8(12), 1-12.
23) YasuhirohaYa shi, Yu Fujimto, hideo ishii et al.(2018). Versatile Modeling Platform for Cooperative Energy Management Systems in Smart Cities. IEEE. 106(4), 94-612.
24) Zaheer Allam and Peter Newman. (2018). Redefining the Smart City: Culture, Metabolism and Governance. MDPI. 4-25.
25) Dr. Dipak Gade. (2019). Technology Trends and Digital Solutions for Smart Cities Development. International Journal of Advance and Innovative Research. 6(1), 29-37.
26) Dr. Dipak Gade. (2019). Introduction to Smart Cities and Selected Literature Review. International Journal of Advance and Innovative Research, 6 (2), 7-15.
27) Dr. Dipak Gade (2019). ICT Enabled Smart Parking System: Smartpark For Smart Cities. International Journal of Engineering and Advanced Technology. 8(5),1000-1006.

28) Dr. Dipak Gade. (2019). Reinventing the Waste Management through ICT and IOT driven Smart Solution. Scopus. Micro Electronics, Computing & Communication Systems. 1-15.
29) Dr. Dipak Gad.(2019). ICT based Smart Traffic Management System “iSMART” for Smart Cities. International Journal of Recent Technology and Engineering. 8(3), 1-9.

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APPENDIX -1: Published Papers - 01

Blockchain Technology: A driving force in Smart Cities Development

ABSTRACT

Smart Cities are well planned, designed, and established keeping in mind the growing need of citizens in search of better livelihood. Technology has played a big role in equipping Smart Cities to offer better facilities to its citizens in terms of better living comfort, better atmosphere, better surrounding, better medical facilities, and most importantly ease of doing business, office, and day to day activities. While doing so, IT Infrastructure and online transactions have influenced all the operational processes of Smart Cities and almost acting as its backbone. Obviously, any adverse impact on online transactions can create chaos in Smart City operations. To address this concern, a safe and reliable online transaction is a must. In this paper, we have discussed Blockchain Technology-based solutions for Smart Cities and their critical impact on Smart Cities Development. We particularly tried to address the concern of how Smart City online operational processes for various applications can be made reliable and safe by using Blockchain Technology and how this technology can benefit Smart Cities overall development. Based on the comprehensive research and detailed literature review, we proposed Blockchain Technology based secure framework for Smart Cities. We also identified various applications and process areas that can be highly benefited by using Blockchain Technology and can make these applications smarter and more reliable and fit for use for any Smart City.

Keywords: Blockchain, Smart City, Smart Contracts, Secure Framework, Distributed Ledger

1. INTRODUCTION:

Blockchain Technology is the most advanced, complex, and bit difficult to understand in the first place. It has gained significant popularity over the past few years and most businesses started using Blockchain technology in their business transactions. In a simple language Blockchain is nothing but Blocks of Chain. Now it is important to understand what these Blocks do and how they are connected in a Chain.

Blockchain Technology can be defined as a decentralized and distributed database of encrypted records. Blockchain is also referred to as Distributed Ledger Technology (DLT). Blockchain makes the history or record of any digital asset non-alterable and fully transparent by using cryptographic hashing and decentralization. Blockchain can be considered as the technology framework which allows the scalability of trust via technology for combining publicly available information with a system of control and checks in place to maintain integrity, data accuracy, and availability to create trust among users [1]. In a simplified manner, it can be explained as follows

- It is a data structure where each data block is linked with another data block in a chronological time-stamped order
- It is a transactional decentralized database which is an append-only, allowing full real-time access. It is not a replacement to the conventional databases
- In the data structure, every node maintains a copy of all the data transactions which are cryptographically secured and that happened in the past
- All the stored information on the ledger can be verified and audited at any time but cannot be edited under any circumstances
- The whole data structure is highly fault-tolerant and reliable since there are literally no chances of failure at any stage.

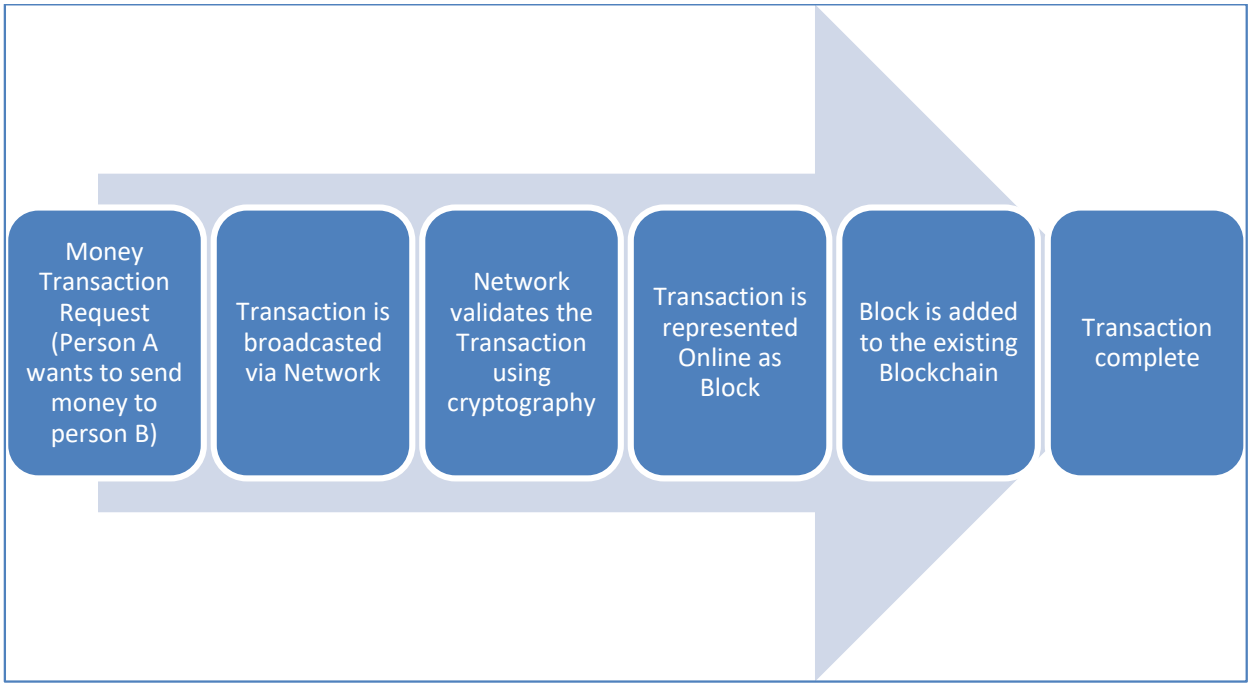

Fig. 1: Blockchain Six Steps Financial Transaction Process

The typical sequence of events that took place during the financial transaction using Blockchain Technology is represented in figure 1 above.
Blockchain Technology assures safe and reliable online transactions without the need for third-party intervention. This is advantageous over traditional online transaction system, making it more popular in conducting online business activities and that is why many online transactions in Smart Cities readily make use of Blockchain-based solutions.

2. PROBLEM STATEMENT:

Smart Cities are rapidly changing the concept of "better living" by offering a "smart living" facility. To do so, Smart Cities extensively relies on the deployment of information communication and digital technologies that facilitates storing online data records and online transactions in doing much administration, business and office activities sitting at the comfort of their home or from anywhere which allows one to connect to the internet. Just imagine, what will happen if the online transactions, fail to record transactions with the right data elements? Or if someone alters the recorded data of a transaction to commit fraud. Be it a financial transaction, land registrations, online insurance data, patient's medical history, or

student's academic transcripts, any alterations with such critical data record can permanently damage the stakeholder's reputation and may put them in huge financial loss which may be extremely difficult to recover. Also, such online data alterations or failed online transactions related to Smart Cities not only affects the individuals but also the organizations and administrations of whole Smart City.
If we ensure safe and reliable online transactions and storing and retrieving online records without any unwanted alterations, then any fraudulent activities or cyber fraud can be safely avoided. Blockchain Technology is a revolutionary and novel technology that facilitates a distributed ledger which can create immutable append-only databases with a unique identification number to trace the transactions made. This paper is exploring Blockchain Technology based solutions to address the above stated concerns of Smart Cities.

3. RESEARCH OBJECTIVES:

The main objective of this research is to study Blockchain Technology and propose the blockchain based secure framework which can be used in various applications of Smart Cities to conduct safe and reliable online transactions. The other objectives also involve analysing Blockchain Technology and identifying any limitations and constraints of Blockchain Technology in using with Smart Cities existing IT infrastructure and framework.

4. METHODOLOGY:

A systematic literature review is a backbone behind identifying various applications in Smart Cities where Blockchain Technology is either proposed or rigorously applied. We focused on research papers from reputed national and international journals which were mostly UGC-approved Research Journals, Scopus Indexed Journals, IEEE Journals, WOS Database Journals, reputed websites blogs, and or high impact factor multidisciplinary national/international journals. The relevant papers and research articles were identified through the online search by using specific keywords, titles, and or exploring the abstract. We also visited websites of reputed organizations that are conducting research on Smart Cities Technologies and or offering their services for setting up or operating and maintaining Smart Cities worldwide. An algorithm based on a combination of query and Boolean operator ("Smart City" AND "Blockchain Technology", "Smart Cit*" AND "Blockch*", with produced results refined based on Document Type such as "Journal Paper", "Book Chapter", "Blog", "Review Paper" and time coverage of mostly last 10 Years documents or articles") was employed to identify relevant Research Articles and or Journal Papers, Book Chapters and or websites blogs. Apart from this, we also interacted with industry professionals and researchers who are either prime stakeholders while delivering services for Smart Cities or conducting research on Blockchain Technology for Smart Cities Applications.

5. RELATED WORKS:

There are a lot of research papers available on Blockchain Technology elaborating its components, architecture, its various applications in different domains, and new focus areas where Blockchain Technology can be utilized. A systematic review of

most such papers can provide great details of technology trends, application domain areas, challenges, and limitations in the deployment of Blockchain Technology. In the present research paper, the literature review of some selected research papers, book chapters, online blogs, and white papers, is carried out, to understand Blockchain Technology details and its applications.

Blockchain Technology brought serious disruption and revolutionary change to the traditional business processes which basically depends upon centralised architecture and trusted third parties applications to carry out on line transactions, can operate in a decentralized manner with the help of blockchain technology with the same level of certainty [2]. Many times people think that Blockchain technology is only the basis of the crypto currency Bitcoin, but in reality it is not limited to that, Blockchain technology allows carrying out verifications and secure transactions on the internet and can be utilized as an excellent tool for management of Smart Cities [3]. Sun et al. in their paper[4], Blockchain-based sharing services: What blockchain technology can contribute to smart cities, have discussed the conceptual framework of Smart Cities based on three factors human, technology and organisation and using this triangle framework, also discussed the set of fundamental factors that makes a city smarter from a sharing economy perspective. The authors have highlighted various features of blockchain technology which can contribute to smart city development through sharing services. PWC Report [5] of year 2020 on Blockchain to make Cities Smarter has stressed that Blockchain Technology is an emerging tool for governments of many countries across the globe, to redefine the transaction framework for information exchange. The report provided elaborated information on the various urban challenges tackled through smart cities and how blockchain technology can transform the smart cities to make it more efficient and smarter. It has also highlighted that applications which has issues related to inefficiency, corruption, lack of transparency and data security can be very well based on Blockchain Technology for a positive impact. Blockchain Technology has started many and many applications across Smart Cities and Urban Management and Town Planning domain. Smart Cities are highly interconnected and complex technology-based cities which are intended to exchange information in real time and basically operates on digital infrastructure based on interconnected devices, machines and dispersed sensors [6]. Horst Treiblmaier and Abderahman Rejeb in their paper [7]: Blockchain as a Driver for Smart City Development: Application Fields and a Comprehensive Research Agenda, have discussed the Blockchain Technology concepts and its applications for Smart Cities. The authors identified and discussed nine application fields of Smart Cities such as energy, factory, healthcare, mobility, logistics and supply chains, home and education, e-voting, administration and services, which can be based on Blockchain Technology and can offer better services in making cities more smarter. Kamanashis Biswas and Vallipuram Muthukkumarasamy in their paper [8], Securing Smart Cities Using Blockchain Technology, have stated that Blockchain Technology using its distributed ledger form of storing and securing information can offer better solution to integrate and manage physical, social and business infrastructure of Smart Cities. They have proposed the Blockchain Technology based Security Framework making use of IOT components, Cloud Computing Platforms and

interconnected networks for Smart Cities. The authors have argued that Blockchain Technology based solutions are very safe and secure since if any attacker intentionally wanted to do any wrongdoings with such systems, then the attacker will have to compromise around fifty one percentage of system components to surpass the target network's hashing cryptographic power, thus it is logically and practically impossible to launch a successful attack against the Blockchain System. Carmen Rotuna and Alexandru Gheorghita in their paper [9]: Smart City Ecosystem Using Blockchain Technology have clarified that Blockchain Technology can be very useful in having Smart Cities systematically organised and more transparent in resource management. Authors have proposed a Smart City ecosystem model based on Self Sovereign Identity authentication and smart contracts between various entities, administration services and smart city residents. Authors have also confirmed that the results of their study can be a very good starting point for development of Blockchain based platform for communications and transactions in the public sector Blockchain Technology is also widely used for applications from other domains. Sara Rouhani et al [10], have specified in their research paper MediChainM: A Secure Decentralized Medical Data Asset Management System, that how a Blockchain technology can be successfully used to develop and implement a secure medical data asset management system. Nagothu Deeraj, Xu Ronghua et al [11], in their paper "A Microservice-enabled Architecture for Smart Surveillance using Blockchain Technology" have proposed a new architecture for Smart Surveillance Applications based on microservice using Blockchain Technology. Authors have clarified that traditional surveillance systems based on monolithic architecture to carry out lower level operations such as monitoring, and recording are typically not scalable to meet the extended requirements of advanced video streaming and safe data analytics and transactions of modern surveillance System. Authors have claimed that with their novel microservice architecture with Blockchain Technology a secure smart surveillance systems, using various independent microservices can not only isolate the video feed from different sectors but can also improves the system robustness and availability by decentralizing the operation using Blockchain Technology which can ultimately provide tamper proof robust data in the trustless network environment. It is not that deployment of Blockchain Technology do not pose any challenges with the existing Applications. In fact, if the design framework doesn't meet the IT Infrastructure requirement for running Blockchain, it is not possible to get full advantage of using Blockchain Technology. Shuling Li, in the research paper [12] has discussed the storage space requirements related challenges for the applications when applying blockchain technology to the IIoT infrastructure. To address this issue, author proposed a hierarchical blockchain storage structure where most of the old blocks of the blockchain are stored in the clouds, while the recently updated and or created data blocks are stored in the overlay network of the individual IIoT networks.

While Blockchain applications are being widely deployed in Smart Cities and Urban Management applications, there is enough room to fine tune and customized the Blockchain Technology components so that it can be used and deployed for other domains and services as well. based on various research papers survey and review it is confirmed that Blockchain Technology offers scalable and

robust solutions to suit requirements of wider applications but at the same time to take advantage of full capacity and potential of Blockchain Technology, a more robust and high performance IT infrastructure is also needed to run such applications. As Blockchain Technology becomes more mature, it is expected that their applications and solutions can be deployed in many more industries and domains.

6. BLOCKCHAIN TECHNOLOGY – DEEP DIVING:

Blockchain technology though complex, is always considered as safe and reliable since the goal of using Blockchain Technology is to increase transparency into digital trade transactions and eliminate the time spent on exchanging documents for verification. Implementing Blockchain Technology can reduce the bottlenecks in trade financing by facilitating a platform for all parties to observe the transfer of goods.

6.1 Main Elements of Blockchain Technology

The main technology elements for Blockchain are as follows.
(1) Distributed Network
(2) Cryptographic Algorithms
(3) Blockchain Protocols

(1) Distributed Network

In order to achieve outcome in a coordinated fashion, Blockchain uses distributed network where two nodes or more than two nodes work with each other. It should be noted that users of Blockchain are considered as peers or typically nodes who maintain their own copy of ledger. In distributed network architecture, transaction data is transmitted peer to peer. Note that faster transaction process makes the validation process also faster which directly results into faster transfer of digital assets.

(2) Cryptographic Algorithms

Cryptographic Algorithms used to encrypt Blockchain data. Everything stored in Blockchain is encrypted to ensure absolute data security. Cryptographic algorithms are complex mathematical algorithms, such algorithms, e.g. Secure Hashing Algorithm (SHA-256) are hard to detect and almost impossible to manipulate. All the transaction data is digitally signed by using Cryptographic algorithms.

(3) Blockchain Protocols

Blockchain Protocol is a set of rules and procedures used to manage Blockchain. Protocols are used to ensure that different aspect of the platform work as intended. Various protocols are used for various specific applications based on their suitability. Some of the protocols are open source protocols whereas some protocols are scalable private permissioned network. Following are popular protocols of Blockchain.

- Hyperledger: Opensource protocol managed by Linux foundation
- Quorum: Opensource Enterprise Blockchain Protocol
- Corda: Enterprise Protocol suitable for Banking and Finance Applications
- Enterprise Ethereum: Scalable private permissioned network

6.2 Blockchain Components

Blockchain consists of following 3 essential components [13], let us go through details of every component

(1) Blocks
(2) Nodes
(3) Miners

(1) Blocks

Blockchain consists of multiple blocks and the first block when created, it basically starts the chain. Each Block has following components.

- Data: This data is basically transactional data and it contains with in the block. Since Blockchain needs to be transparent, every action in the ledger requires easy view and verification. Each data transaction is given a unique alphanumeric identification number that shows their transactions in the form of data.
- Nonce: This is a 32-bit whole number which basically gets randomly generated when blocks get created. Nonce is also then generates a block header hash
- Hash: It is a block header hash which is basically 256-bit number attached with nonce. It always starts with number of zeroes

Note that the chain is started with creating first block, and nonce of that block creates the cryptographic hash. The block contains data which is permanently tied to nonce and hash and is considered signed. Note that this data subsequently cannot be edited and treated as good as recorded transaction.

(2) Nodes

As stated above, the whole Blockchain Technology relying upon decentralization mechanism. This ensures that no component of IT Infrastructure or Computer or any Organization can own the chain. Note that the blocks of Blockchain are connected via the nodes. Nodes are responsible for network functioning and are in form of any electronic device that maintains and have own copy of the Blockchain. Note that any newly mined block for the Blockchain that needed to be verified, trusted and updated, must be algorithmically approved in the network.

(3) Miners

Miners plays a very important role of creating new blocks in Blockchain. And, this process of creating new Blocks is called as mining. As we know that each Block has its unique id that is nonce, its own hash and also the hash of the previous block in the chain, it should be noted that this makes mining process not the easy one, this is very true specifically for large Blockchain. Since Nonce is 32-bit number and Hash is 256 Bits number, it is very difficult to find out right Hash-Nonce combination that must be mined, out of nearly 4 Billion combinations. This is the reason that through computer program and using right algorithms only it is possible to generate an accepted hash to identify correct nonce. When the right nonce is identified, then miners have said to get Golden Nonce and such block is then considered as approved and gets added to Blockchain. Now in case any change is required in the existing block of chain then it is extremely difficult since such change requires re-mining not to that alone block but to all the blocks which are added to the chain later after that block. That is why getting Golden Nonce

requires enormous amount of computing power and time and thus who receives it gets financially rewarded as well. Thus, manipulating Blockchain Technology is extremely difficult.

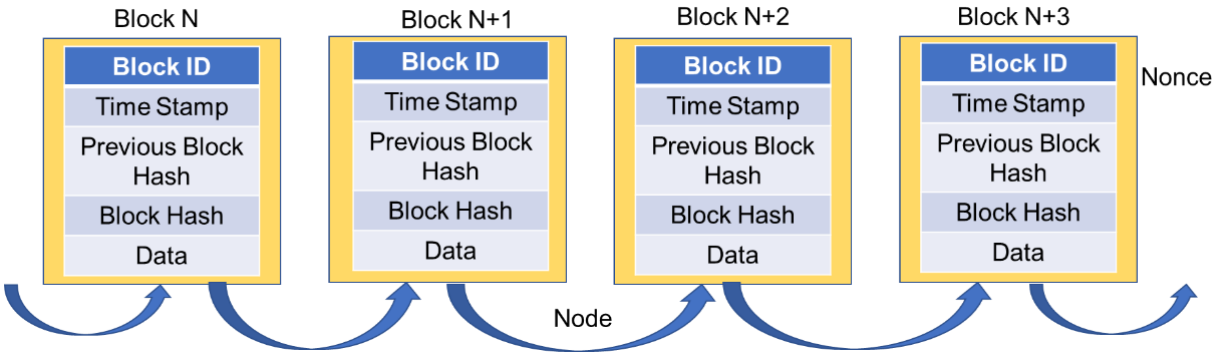

Fig. 2: Typical Blockchain Representation

Refer figure 2 which has represented the Blockchain and its components. The Blockchain has presented that digital currency is transferred from one person to other without involving third parties. Such transactions are safe, reliable and transparent. This is basically the power of using Blockchain technology.
Having explored the Blockchain Technology, its components and functioning, it is required to understand the attributes of Blockchain and its advantages to explore its full potential which makes this technology unique. Blockchain Technology has following basic attributes as stated by Table 1.

Table 1: Blockchain Technology Attributes

Sr. No.	Blockchain Attribute	Description
1.	Shared Ledger	It is a distributed system of records which is append only and can be shared across the business network. It can be considered as a robust system since it is as good as full proof and eliminates any chances of failure in the system.
2.	Consensus	It is an approval by all the stakeholders of Blockchain for a network verified committed transaction
3.	Provenance	All the available modification history of the record
4.	Immutability	Once the record is added to the shared ledger, it is neither editable nor tampered with. Only way available to alter the data is to add new valid record in the blockchain.
5.	Firmness	A valid completed transaction over Blockchain cannot be reverted.
6.	Smart Contracts	The Blockchain code executed by electronic nodes/computers are always in accordance with the contractual terms or an agreement. It cannot be just an auto executed code.

Blockchain technology offers numerous advantages to carry out safe and reliable online transaction. Refer figure 3 which has presented Blockchain Technology advantages which includes. but not limited to online transaction security through encryption, accidental and intentional alteration proof through immutation, safe and agreed alterations through consensus mechanism, programmable according to requirements, audit compatible because of transparent process and absolutely safe and reliable data transactions by having distributed ledger database.

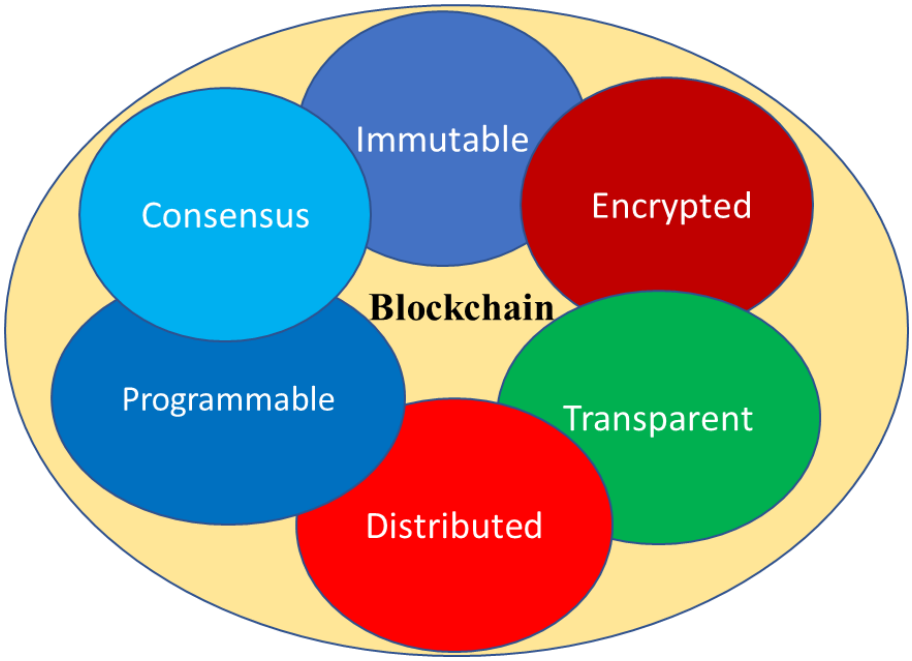

Fig. 3: Advantages of Blockchain Technology

7. BLOCKCHAIN DEVELOPMENT TOOLS:

Blockchain Technology is complex and needs specialised tools and training for development purpose. Refer Table-2 below, which has stated and described some of the top development tools for developing Blockchain Technology based Applications.

Table 2: Blockchain Development Tools

Sr. No.	Blockchain Dev. Tool	Description
1.	Solidity	It is object-oriented programming language, similar to Java and commonly used to develop smart contracts and Ethereum-based applications. It is the runtime environment in Ethereum.
2.	Geth	It is a software developed using Go Programming language which acts as the NODE for the Ethereum Blockchain. It is compatible with Linux and Windows Platform.

		It facilitates execution of smart contracts, token transfers between addresses and exploring of Block history.
3.	Remix	It is an open source compiler used for deploying, testing, and debugging of smart contracts. It connects to the Blockchain using Metamask. It is developed in Javascript and can be accessed using any modern browser. Remix is a Solidity IDE and use to write, debug, test and deploy smart contracts developed in Solidity. [14].
4.	Mist	It is developed by the creators of Ethereum, as an official Ethereum wallet and used for deploying smart contracts. It is considered as full node wallet. It used to store Ether tokens. One needs to download the entire Ethereum Blockchain to make use of Mist.
5.	Solium	It is a basically a vulnerability assessment tool used to check vulnerabilities in the code. It helps in fixing security related issues/potential threats, if any, in the code.
6.	Parity	Parity facilitates a secure way to interact with the blockchain. It is developed in Rust programming language. It allows access to basic wallet functions and can be straight integrated into a web browser.
7.	DApp Board	It is a web-based analytics service and acts as an analytical Ethereum blockchain explorer and as an analytical platform for Ethereum smart contracts. It monitors and analyse activities of smart contracts on the Ethereum blockchain.
8.	Truffle	It is a Smart Contract building and development tool suite that simplifies blockchain development to enable developers build decentralized applications quickly and easily. It allows network management of public and private networks and built-in smart contract compilation, linking and deployment
9.	Embark	It is a developer framework which enables one to create new smart contracts which can be then made available in the JS Code. It also helps in creating and deploying DApps. In case of Contract updating, Embark facilitates smart contract modification and related DApps.
10.	Blockchain Testnet	A Blockchain Testnet facilitates testing of DApps for any defects and errors before making them go live. Each Blockchain Application has

its unique Testnet. There are three types of Blockchain Testnet – GanacheCLI, Private Test, and Public Test. Blockchain Testnet facilitate cost effective testing.

8. BLOCKCHAIN BASED SECURE FRAMEWORK FOR SMART CITIES:

To be fully functional and for successful development, Smart Cities demands appropriate technological ecosystems. Smart Cities can become isolated in absence of such compatible technological ecosystem since they won't be able to communicate with each other due to different communication protocols [15]. With the literature review of various research papers, it is observed that Blockchain Technology started being widely deployed in Smart City Services, however the main issue observed is the development time and modifications required to suit the model to different services. Also interacting with the professionals dealing with such issues, one thing most of the professionals agreed for is to have some simple design architecture which can suit to most of the application areas and services of Smart Cities with minimum modifications. Keeping in mind this objective, we started developing modular architecture based on Blockchain Technology, which can be applied to any Services of Smart Cities with modifications to any specific module keeping rest of the architecture intact.

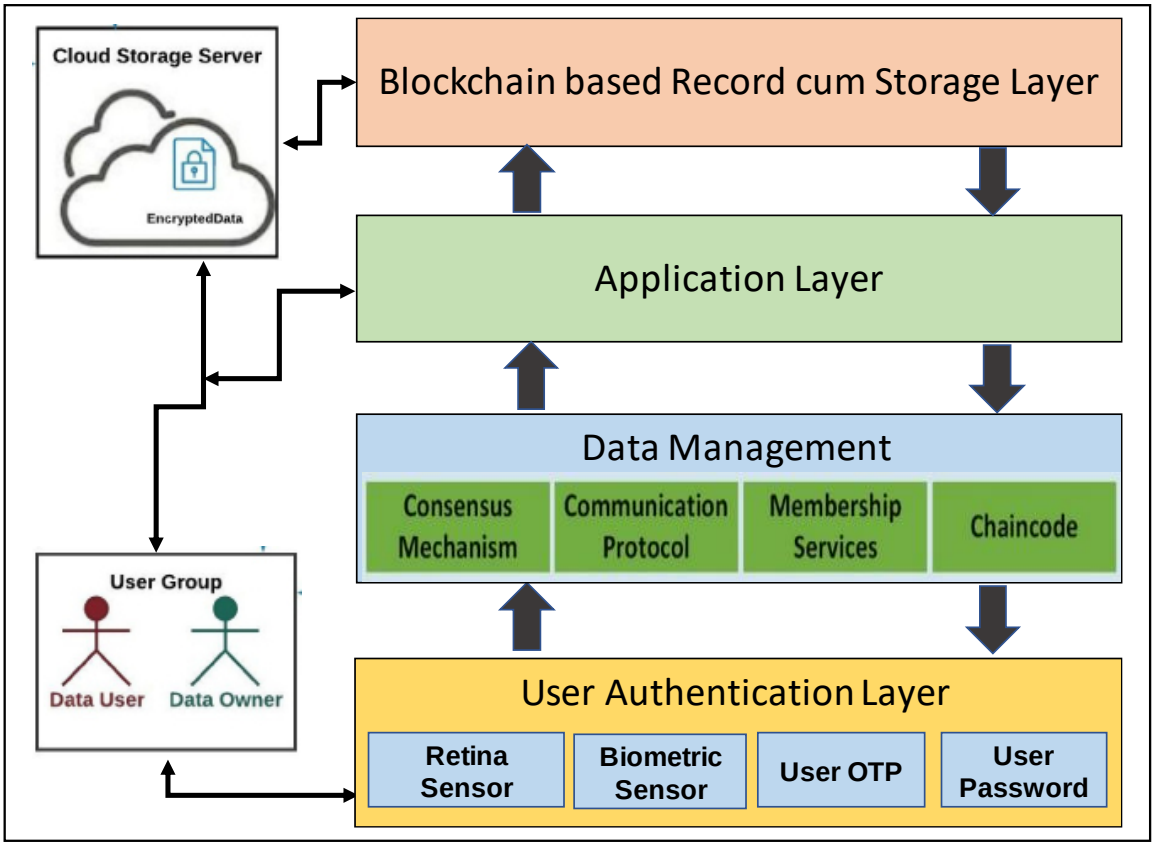

Fig. 4: Blockchain based generic Secure Architecture

The solution to deal such kind of requirement is to have design framework which can have application specific module separate from the common functionalities modules. Application Specific Module can deal with Application specific

functionality such as Application relevant dashboard, Application relevant Data process, algorithms implementations and relevant user actions processing. Whereas common functionalities can include processing of common User Dashboard, User Authentication, Communication Protocols with Cloud Server and backend database etc. Refer figure 4 which has presented a generic Security Framework based on Blockchain Technology for Smart City and Urban management domain. Note that this Security Framework is modular and has been developed keeping in mind its adaptability for any services of Smart Cities with minimum fine tuning and modifications. The proposed Secure Architecture is generic one and designed keeping in mind the flexibility to adapt to any specific Application for Smart City. As shown in figure 4, the Architecture is modular and contains 4 layers namely

(1) User Authentication Layer
(2) Data Management,
(3) Application Layer,
(4) Blockchain based Record cum Storage Layer.

Note that the Application based on this Secure Framework allows user interaction with the Application Service through an inbuilt authenticated mechanism. The Service can be hosted locally with on-premise Server or any cloud platform and the user can connect to the service with either dedicated Client Application or through a secure web browser over HTTPS. Let us briefly explore each layer of secure framework.

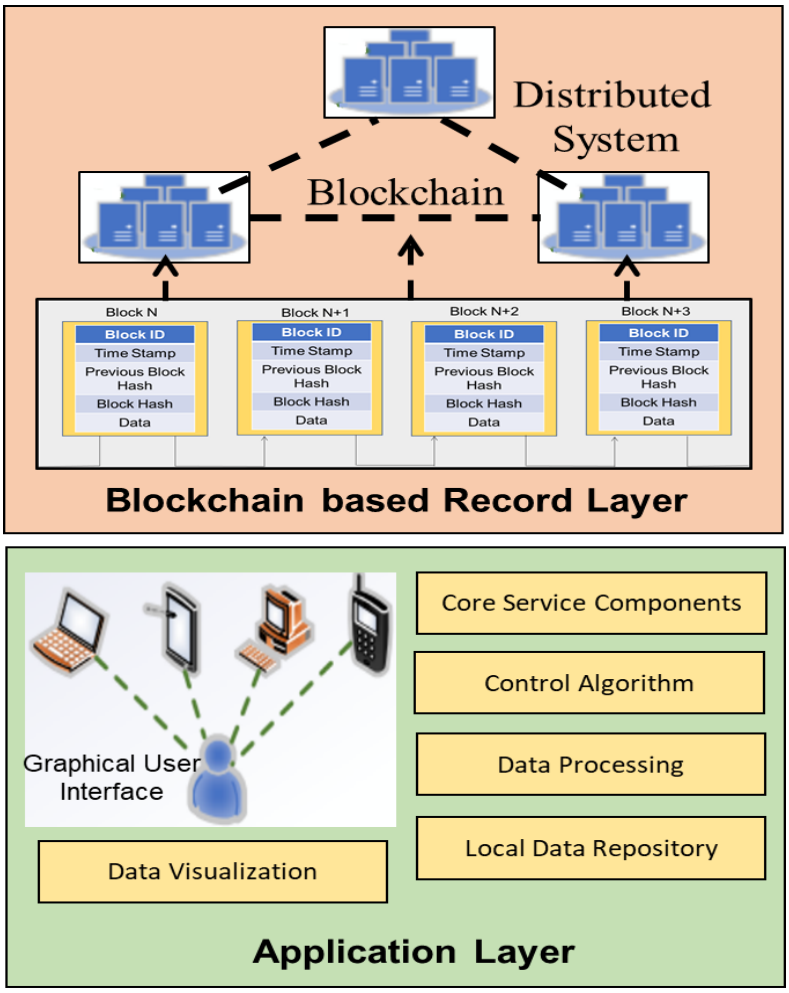

Fig. 5: Exploded view of Record Layer and Application Layer

(1) User Authentication Layer

This layer ensures only authenticated users are allowed to access the intended application. The user authentication can be carried out through various ways and means. i.e. by using biometric thumb impression sensors or by scanning eye retina through retina scanners. Also, an economical means of using one-time password sent over user registered mobile number and or by entering the registered password with the Application, User can get access of the application. Note that it is recommended to use two level authentication such as Biometric Thumb impression validation or Retina Scanning validation along with OTP or User Password. The Authentication mechanism and number of authentication levels can be user configurable. Note that User need to connect the sensors with the Laptop or Desktop installed with client application or through which the application is going to be accessed over web.

(2) Data Management Layer

This layer is responsible for data handling related activities. It sets the rules to allow the data alterations in accordance with agreed rules and regulations knows as consensus. This layer carries out data parsing for the user transacted data, data encryption and packaging cum arranging the data to generate the transaction block. It also maintains user cache data to faster transactions. Data management layer basically coordinates user actions between Application and Blockchain layer.

(3) Application Layer

This layer is like brain of Security Architecture. Application Layer basically segregates various activities as per the required services and also responsible for the underlying implementation technologies to connect each layer. This layer can be configurable to suit service level requirements for most of the application services offered by Smart Cities. Such applications can be Secure Online transactions, Online Insurance, Electronic Medical Record for Smart City residents, Smart City Governance Service, Smart Virtual Learning and performance evaluation, Smart Library Database, Smart Factory, Smart Public Transportation service and so on. Please refer figure 5 which has presented detailed view of Application Layer components. As required by the individual Service the Application layer components such as Data Processing using specific algorithms, User Dashboard, Service Data Repository, user interface for various kind of user privileges etc. can be configured. Application Layer interacts with Blockchain Layer to read write user transactions and application relevant data.

(4) Blockchain based record cum storage Layer

This layer is like a heart of the overall Secured Architecture Framework and key element with respect to safe and secure operation. It offers the capability to Application Service to securely store, read and write the encrypted data transactions, which are tamperproof and compliant to stringent cybersecurity requirements. Since the data is stored in distributed ledger form, it requires synchronising at regular interval and while updating the block record.

It should be noted that the secured architecture framework based on Blockchain Technology, can run and process thousands of data transactions safely over LAN and WAN environment and to utilize its full processing capability can need

powerful IT infrastructure including high speed Server and Client machines and Gigabit speed internet. Since Smart City services, already runs on powerful IT infrastructure, the proposed secure architecture framework can easily be deployed on the existing IT infrastructure of any Smart City.

9. USE OF BLOCKCHAIN TECHNOLOGY IN SMART CITIES DEVELOPMENT:

Having explored the Blockchain Technology, its components and functioning, let us see how Blockchain Technology is redefining Smart Cities development and facilitating wellbeing of Smart City residents. Smart City is a place where traditional information networks are replaced with digital services offering more flexibility, more efficient and more sustainable by making the best use of available technologies such as digital and information communication technologies, to improve the overall operations and provide benefits to its residents [15]. However, each Smart City may have specific set of requirements to fulfil and it may be different for a different Smart City. In absence of a standard framework, the technology infrastructure required by each Smart City may not be same and can be different to a significant extent. Such situations can impose certain challenges in development of Smart Cities. Under such scenario, Blockchain can play a vital role and can connect these technologies together [16]. Since, Blockchain Technology provides faster, secure and better experience in digital transactions, it can be used as an excellent tool to effectively remove corruption and inefficiency in managing and operating Smart Cities operations and digital transactions. This very advantage of Blockchain Technology makes Blockchain as preferred choice, in comparison with conventional less secure online services, while carrying out multiple services across Smart Cities operations and management. Smart cities worldwide are using Blockchain as the technology foundation to enhance urban living.

Fig. 6: Blockchain Applications Portfolio in Smart Cities

Dubai is on path of becoming global leader in the smart economy that is banking

heavily on Blockchain Technology as the first blockchain-powered government. Similarly, Moscow became the first city in applying Blockchain Technology in their e-voting system to eliminate voting fraud and corruption [17]. With the help of proposed Secured Architecture Framework, it is possible to build the application specific functionality over the application layer and use the overall model to suit the specific application service of Smart City. Please refer figure 6 which has presented some of the examples of such services [18-27].

9.1 Online Financial Transactions

Blockchain powered Applications being absolutely safe and secure while carrying out online digital transactions can be used to send and receive payments. Such solutions can be ideal for organisations with remotely operating employees. In similar way, Smart City based small traders and business owners can also apply Blockchain powered Applications to send and receive money in the most secured way, without need of paying any transaction fees to third parties and intermediaries.

9.2 Insurance

Insurance Industry transactions are known to be worst affected by online frauds and easy targets for cheating and carrying out fraudulent activities. Due to this Insurance business, though one time very flourishing business, today is considered risky and unstable. Blockchain applications, since offering highest security and safe online transactions, Smart City based Insurance Services are frequently using Blockchain Technology in managing and tracking digital identities with the help of cryptographic digital signatures in place of less secure conventional user authentication-based systems.

9.3 Supply Chain Management

Smart City Organizations can use Blockchain powered Smart Contracts for managing supply chain related operations across the city and a region effortlessly and securely. Such Supply Chain activities can be well applicable to right from the agriculture industry to automotive, or any logistics organisation where Blockchain based Applications can bring better transparency between producer and consumers.

9.4 Environment Management

One of the biggest challenges faced by Smart Cities to control Carbon footprint across the City and maintain a healthy environment. Due to technological advances, Smart Cities needs to manage a tremendous amount of generated electronic waste, and thereby increased Carbon Footprint. Blockchain Technology can assist Smart Cities in controlling the environment under check. Blockchain powered Applications can assist Smart Cities services in measuring and analysing the Carbon footprint from various sources and due to Blockchain Technology such environmental data records cannot be tampered with and can be treated as accurate sources of data for a better analysis and results.

9.5 Health Records

Smart Cities are determined to provide better health care facilities to its residents. While providing better healthcare facilities, one of the challenges faced by Smart City to maintain accurate health record of each stakeholder. Blockchain Applications can assist Smart City Services in maintaining accurate and tamperproof Medical Records of its users. Blockchain technology's use of decentralised ledger can facilitate the sharing of patients EMR data across hospitals and doctors seamlessly and accurately without worrying for any attempt to alter the medical record. This will also help in processing medical insurance claims from patients hassle-free.

9.6 Energy Trading Solutions

Blockchain based point to point energy trading solutions can offer better support to stakeholders to use and better manage energy sources such as Water driven, Solar powered, Wind Energy, and other alternative sustainable energy sources. While doing so, Blockchain Technology ensures eliminating middlemen and third parties and facilitates individuals to generate, maintain, procure, and trade energy. Since Blockchain Technology can also integrate with IoT based Sensors, the whole energy management process can be better controlled and analysed without any issue to the stakeholders.

9.7 Identity Management

Correctly managing and identifying Smart City residents due to ever increasing population of Smart City citizens is a big challenge for Smart Cities. Blockchain Technology facilitates an easy and safe mechanisms to store, verify and retrieve identities from the decentralised identity management solutions. Such Solutions not only assists in storing the identity data but also in preventing identity thefts and other such fraudulent activities.

9.8 Governance

For effective administration and governance of Smart Cities, effective and reliable solution is needed. Blockchain can assist Smart Cities in providing better governance by using Smart Contracts that can be deployed across a range of operation and activities. Blockchain Technologies can be deployed to make entire system smooth while conducting various activities right from conducting online transparent voting, maintaining city administration processes to automating Smart City Services, tangible and intangible Assets management, filing taxes, tracking ownership and so on.

10. CONCLUSIONS:

Blockchain Technology is complex and powerful technology and is going to shape the world with its enormous power of accuracy, assurance of safe transactions, and operating reliability. Due to such advantages, Blockchain applications are very effectively getting utilised in solving real life problems and challenges in Smart Cities Development. Blockchain powered Applications are finding their way across large sectors such as Insurance, Governance, Supply Chain Management

eHealth Records, and so on. Looking at the way Blockchain is slowly and steadily capturing a wide variety of application areas, there is no doubt that Blockchain has come to rule the world and is going to stay there for a longer time as the top preferred technology in digital transactions.

11. FUTURE WORK:

In the present paper, the secured architecture based on Blockchain Technology is proposed for various services of Smart Cities. Due to time and finance constraints, the architecture model could not be implemented and tested. However, looking at the enormous strengths of Blockchain Technology and its wide range of possible applications for maintaining and operating services with Smart Cities, in the future, I will go ahead and implement this framework and will also try to make the possible enhancements wherever possible. I also would like to evaluate the secure architecture based on its performance, operation speed, its flexibility to adapt to specific Service of Smart City, its cybersecurity compliance, and its limitations if any.

REFERENCES

[1] Yaga, Dylan., Mell, Peter., Roby, Nik., Scarfone, Karen. (2019). Blockchain Technology Overview. *NISTIR 8202*, 1-17.

[2] Casino, Fran (2019). A systematic literature review of blockchain-based applications: Current status, classification and open issues. *Elsevier, Telematics and Informatics*, 36, 55-81.

[3] Blockchain technology at the service of urban management. https://www.iberdrola.com/innovation/blockchain-for-smart-cities-urban-management. Accessed on 16/12/2020.

[4] Sun, J. et al. (2016). Blockchain-based sharing services: What blockchain technology can contribute to smart cities. *Financial Innovation*, 2(26), 1-9.

[5] Blockchain: The next innovation to make our cities smarter. http://ficci.in/spdocument/22934/Blockchain.pdf. Accessed on 16/12/2020.

[6] Aldoma, C. (2019). Blockchain and Smart Cities - Innovation & Technology Blog. https://www.e-zigurat.com/innovation-school/blog/blockchain-and-smart-cities/. Accessed on 16/12/2020.

[7] Treiblmaier, Horst., Rejeb, Abderahman., Strebinger, Andreas. (2020). Blockchain as a Driver for Smart City Development: Application Fields and a Comprehensive Research Agenda. MDPI, *Smart Cities*, 3(3), 853-872.

[8] Biswas, Kamanashis., Vallipuram M. (2016). Securing Smart Cities Using Blockchain Technology. Proceedings of IEEE 14th International Conference on Smart City, 1392-1393.

[9] Zamfiroiu, Alin., Rotuna, Carmen., et al. (2019). Smart City Ecosystem Using Blockchain Technology. *Informatica Economica*, 23(4), 41-50.

[10] Rouhani, Sara., Butterworth, Luka., et al. (2018). MediChain: A Secure Decentralized Medical Data, Asset Management System. Proceedings of IEEE International Conference on Internet of Things (iThings), 1-6.

[11] Nagothu, Deeraj., Xu, Ronghua., et al. (2018). A Microservice-enabled Architecture for Smart Surveillance using Blockchain Technology. Proceedings of IEEE International Smart Cities Conference (ISC2), 1-4.
[12] Shuling, Li. (2018). Application of Blockchain Technology in Smart City Infrastructure. Proceedings of IEEE International Conference on Smart Internet of Things (SmartIoT), 2761-2766.
[13] Gupta, Manav. (2020). Blockchain for dummies. 3rd IBM Limited Edition. John Wiley & Sons. *Taking a Look at How Blockchain Works*, 13-18.
[14] 10 Most Used Blockchain tools in 2020 For Blockchain Development. https://www.upgrad.com/blog/top-blockchain-tools/. Accessed on 16/12/2020.
[15] Gade, D. (2019). Introduction to Smart Cities and Selected Literature Review. *International Journal of Advance and Innovative Research*, 6(2), Part 4, 7-15.
[16] Gupta, Shekar. (2020). Using Blockchain in Smart Cities. https://meetingoftheminds.org/using-blockchain-in-smart-cities-29319. Accessed on 17/12/20.
[17] Sergio. (2018). 10 Ways Blockchain Is Revolutionizing Smart Cities. https://medium.com/smartcityworld/10-ways-blockchain-is-revolutionizing-smart-cities-595046ba05b1. Accessed on 18/12/20.
[18] Lopes, L. (2019). Blockchain's role in developing smart cities. https://theblockchainland.com/2019/03/05/blockchain-role-developing-smart-cities/. Accessed on 18/12/20.
[19] Wan, J., et al. (2019). A Blockchain Based Solution for Enhancing Security and Privacy in Smart Factory. *IEEE Transactions on Industrial Informatics*, 15(6), 3652-3660.
[20] Wang, Gang, et al. (2019). ChainSplitter: Towards Blockchain-based Industrial IoT Architecture for Supporting Hierarchical Storage, Proceeding of IEEE International Conference on Blockchain (Blockchain), 1-10.
[21] Zamfiroiu, Alin., Rotuna, Carmen., et al. (2019). Smart City Ecosystem Using Blockchain Technology. *Informatica Economica*, 23(4), 41-50.
[22] Zorzo, Avelino., Dorri, Ali., et al. (2018). SpeedyChain: A framework for decoupling data from blockchain for smart cities. Proceedings of 15th EAI International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services, 145-154.
[23] Z.Khan., et al. (2020). Securing Smart Cities through Blockchain Technology: Architecture, Requirements, and Challenges. *IEEE Network*, 34(1), 8-14.
[24] J. Xie., et al. (2019). A Survey of Blockchain Technology Applied to Smart Cities: Research Issues and Challenges. *IEEE Communications Surveys & Tutorials*, 21(3), 2794-2830.
[25] S. Christopher., Nam, Kichen., et al. (2019). Blockchain technology for smart city and smart tourism: latest trends and challenges. *Asia Pacific Journal of Tourism Research*, 1-15.
[26] S.Matteo., et al. (2017). CitySense: blockchain-oriented smart cities. Proceedings of the XP2017 Scientific Workshops, 1-5.
[27] Jo, Hoon., et al. (2019). Emerging Technologies for Sustainable Smart City Network Security: Issues, Challenges, and Countermeasures. *Journal of Information Processing Systems*, 15(4), 765-784.

Smart City Waste Management through ICT and IOT driven Solution

ABSTRACT

Purpose: *The growing population and mass relocation of citizens from urban and semi-urban areas to Smart Cities have resulted in exponential growth in Smart Cities and thereby certain challenges. One of the major challenges Smart Cities are facing is to control, manage and process waste generation on daily basis. Waste collection and processing at a wider scale is not an easy job. Growing population and resource constraints in waste management activities are the primary reasons which have made waste management a tough job. To deal with this challenging process, Smart Cities uses Smart Waste Management System. This paper has provided an overview of a typical Smart Waste Management system and a review of selected research papers on Smart Waste Management. We tried to identify areas of improvement with the existing Smart Waste Management Solutions and proposed an innovative solution called "iSmartWMS" for carrying out waste management specifically for Smart Cities. The paper has discussed in detail the architecture and building blocks of the proposed Smart Waste Management System, along with the details of software tools, sensors, and technologies proposed in iSmartWMS. The Paper has finally discussed results with respect to prototype implementation of iSmartWMS and also future plans to further improve the iSmartWMS smart waste management system.*

Design/Methodology/Approach: *iSmartWMS software prototype was built using IoT sensors and Cloud based Server running with custom software incorporating specialized algorithms and a graphical user interface. A model was simulated on a local machine network to check if the required goals can be met and if the proposed solution serves the purpose.*

Findings/Result: *The proof of concept prototype for iSmartWMS Solution is found working well at a limited scale. It is clear that it can very well serve the purpose of waste management solution if it is implemented as per specified architecture at wider scale considering large number of stakeholders.*

Originality/Value: *Using IoT Sensors for waste monitoring and through Cloud based Server software running with specialized algorithms, it is possible to automate waste management end to end activities. This paper has described in detail the proposed iSmartWMS software solution as a Smart Waste Management tool for Smart Cities.*

Paper Type: *Prototype and Simulation based Research*

Keywords: Solid Waste Management, Smart Waste Bin, IoT, Sensor Fusion, Image Processing, Data Analytics

1. INTRODUCTION:

Ever growing population causing a lot of issues and one of the biggest issues is increasing generated waste. Such waste can be food waste, material waste, waste from human beings, waste from useless stuff, waste from industries, etc. Such generated waste is hazardous for the overall environment if not managed

systematically. Hence waste management is a very important issue that requires high attention and resolution on priority.

Fig. 1: Unattended deposited waste in water, ground and on road [1]

The major contribution for waste generation is from human activities [1]. It should be noted that waste management's aim is not just disposing of the waste in the appropriate manner but also to control, collect, process, and recycle it. Waste management covers end-to-end activities involved such as monitoring the generated waste in City, from its source when citizens produce waste through waste collection, waste transportation, and depositing it to waste depo which can then be the landfill, incineration, and or recycled [2]. In Waste Management activities, prevention of waste is considered as the preferred option followed by reusing the material, recycling of the material, generating energy through waste, and finally waste disposal is considered as the least preferred alternative [3]. There are a variety of ways by which waste can be controlled, disposed of, processed, and recycled into useful stuff. Today waste management is also becoming challenging due to the enormous increase in the volume of generated waste. High volume generated waste requires larger manpower and larger efforts and increased cost in handling waste management activities. Refer to figure 1 which has shown high volume deposited waste in water and on the ground. In many cities and rural areas due to the absence of waste management staff and system in place, waste is regularly abandoned in open pit or on empty ground, or even in river water. Such openly accumulated waste subsequently becomes solid and converts into a waste heap and starts generating foul smell and toxic gases which are very dangerous to human health as well as hazardous to the environment.

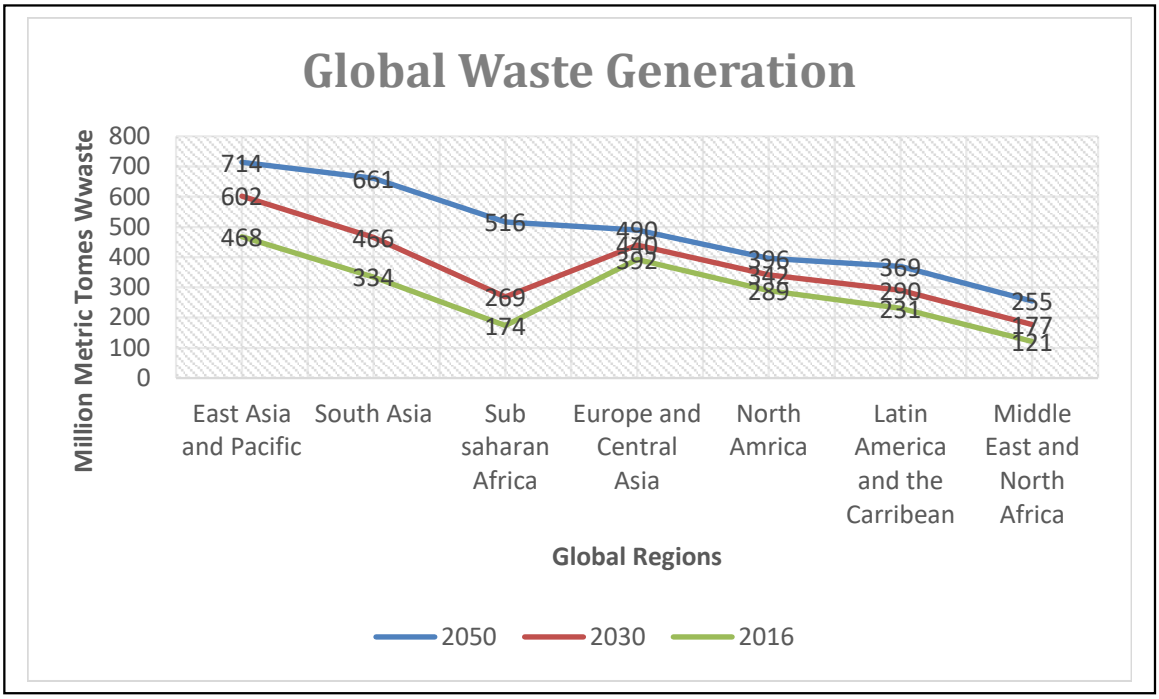

Fig. 2: Global Waste generation projection [4]

Refer to figure 2 which has shown the waste generation forecast in million metric tonnes for various regions across the globe for the period of 2016 to 2050, as per the statista.com projection. Due to growing populations and rapid urbanization, local annual waste generation is expected to jump to 3.4 billion tonnes over the next few decades, according to the World Bank Group. By 2050, it is estimated that around 714 million metric tonnes of waste will be generated alone in East Asia and the Pacific region [4]. It is scary to know that waste generation is going to increase exponentially over the period of time and is an alarming situation. We need to take the right action now. This is the time to control and dispose of the generated waste as effectively as possible so that the possible hazardous impact on the environment and human being health can be effectively reduced. Before further deep dive, let us understand what the different types of waste are [5] which need proper management.

(1) **Organic Waste**: It is the garbage derived from organic material.
(2) **Industrial Waste**: It is the residual solid waste generated from industrial production.
(3) **Hospital Waste**: It is the waste generating at hospitals and or medical clinics due to medical operations, patient tests, and treatments. This kind of waste can be dangerous to human beings and may cause to transmit diseases to people who come in contact with it.
(4) **Electronic Waste**: It is generated by the disposal of obsolete Electronics Products.
(5) **Nuclear Waste**: It is generated at Nuclear Plants during plants operation. Such kind of waste can be radioactive and is extremely dangerous for human

beings and the environment. Hence, it needs to be disposed of in strict safety guidelines

(6) **Commercial Waste**: It is generated by commercial establishments including shops, warehouses, appliances stores etc. Such kind of waste can be recycled entirely.

(7) **Green Waste**: This kind of waste gets generated due to trees. e.g. fallen leaves from trees, fallen fruits, from the pruning of trees, branches, trunks. Since it is mainly organic in nature, such kind of waste can be processed to produce fertilizers

(8) **Recyclable Waste**: It is typically the waste that gets generated at residences, organization premises. Such kind of waste can be reused after processing and after transformation to other useful stuff.

Traditional waste management often involves the manual collection of waste from waste bins and its manual disposal or recycling through a defined process [6]. Though this process helps, it involves a lot of human efforts and significant errors due to manually handled activities. Often these activities and efforts made are found inefficient specifically when the amount of generated waste is higher. Besides, it also creates other problems such as

- During waste collection, it is possible that some of the waste bins might be overfilled and some might be underfilled
- Overfilled waste bins can create toxic gases and foul smell and thus can create unhygienic conditions
- Waste collection from underfilled the waste bins can create inefficiency in the waste collection process
- Waste collection vehicles typically collect the waste in sequence irrespective of the waste fill status of the waste bins. These unoptimized routes can result in excessive fuel consumption and environmental pollution
- Combining collected waste at the central point, can complicate waste sorting and recycling operation
- Also due to not applying relevant tools and technologies, the waste management process becomes very difficult and inefficient.

2. PROBLEM STATEMENT:

Smart Cities are rapidly growing and globally set up by various countries for providing world-class services and enjoyable life to their residents. This has attracted many citizens to Smart Cities by leaving their existing cities and hometowns. This has resulted in exponential growth and expansion of Smart Cities at the same time multi-fold problems like an overload on Smart Cities to handle the growing population and to effectively control the waste produced by the huge population, let it be human beings made waste, industrial waste, environmental waste and or medical waste. If a large amount of generated waste is not handled correctly and efficiently, it can generate a hazardous situation and can cause danger to a great extent to the Smart City Residents. Also, a shortfall can be possible with some of the necessary items which go to waste after initial use, and if we do not recycle them, such items cost gets increases over time due to shortfall in supply and causes impacting the economy.

If we can find out a way to ensure safe and efficient waste management with low cost and low processing time, it will not only help to maintain healthy surroundings but also by recycling reusable waste, it can easily boost the economy and manage the shortfall of necessary items such as paper, footwear, stationery items, tyres, remouldable plastic and so on.

3. RESEARCH OBJECTIVES:

Research Area related to Waste Management Solutions is vast and time-consuming. With the available time constraints and limited infrastructure, research is carried out keeping in mind the following objectives

- Study the existing Waste Management Solutions of Smart Cities
- Identify deficiencies, limitations, and issues if any with the existing Waste Management Solutions deployed in various Smart Cities.
- Propose the IoT and ICT based solution to effectively carry out waste management specifically for Smart Cities
- Identify the improvement opportunities which can be carried out in future for the proposed Waste Management Solution.

4. METHODOLOGY:

While conducting the research and proposing a new solution for Waste Management, multiple methodologies and techniques were used by us. The main focus was on carrying out a time-bound existing literature review. For this purpose, we studied the relevant research papers, journal papers, white papers, conference papers, online blogs, and dedicated websites for Smart Waste Management. Specific keywords such as "Smart City", "Smart Waste Management" "Waste Handling", "Waste Generation", "Waste Recycling" were used while identifying relevant research papers and book chapters. The collected literature was then analysed considering the year it is published, proposed solutions for Smart Waste Management, notes on existing techniques while carrying out waste management across the globe, new considerations in new Smart Cities for waste management and also the operating cost, manpower and required infrastructure for doing the Smart Waste Management. We also went through the existing Interviews of Subject Matter Experts, researchers and industry professionals working in Smart Waste Management. Few Interviews were also taken of some well-known industrial professional enquiring their opinions and views on existing Waste Management techniques and suggestions for improvements in Smart Waste Management. Last we carried out certain experiments through simulations and prototypes to some extent to build a proof of concepts around the proposed solution (at lab level) to measure its efficiency and effective operations meeting the stated objectives.

5. RELATED WORKS :

Due to increasing population, urbanisation and industrial processing, a lot of waste is getting generated day by day. If this generated waste is not processed and managed properly then there are good chances of health hazards, environmental pollution, and contamination [7]. To avoid such issue well ahead of time, waste management is considered a priority task to address for the last few years.

Worldwide researchers, scientist and engineers are working on making improvements in existing Smart Waste Management Systems as well as identifying new features and functionalities to incorporate into the new Smart waste Management System being developed. Many research papers and significant reading material is available online on Smart Waste Management System. Let us review some of the existing research papers to get enough insights into this research topic.

Insung Hong et al, in their paper "IoT-Based Smart Garbage System for Efficient Food Waste Management" have proposed an IoT-based Smart Garbage System known as SGS for efficient food waste management [8]. In the SGS Pilot project, authors have used battery-based Smart garbage bins which can exchange information with each other using a wireless mesh network. The router and Server analyze the information exchanged by smart garbage bins and take appropriate actions with respect to food waste. To increase the lifetime of battery used in the SGS system, authors also supported two types of energy-efficient operations with Smart garbage bins, one is standalone operation mode and the second is cooperation-based operation mode. Authors have claimed that after using SGS on a pilot basis for a period of one year they found that the average amount of food waste decreased by almost 33%. Today there are a lot of systems that widely use and employ IoT-based sensors for data collection. I feel that the accuracy of collected data through IoT sensors becomes the backbone of such systems and hence it is of utmost importance to ensure that the sensors are working properly and are calibrated on regular basis.

María-Victoria Bueno-Delgado et al, in their paper "Optimal Path Planning for Selective Waste Collection in Smart Cities" have discussed the optimal planning algorithm [9]. Authors have claimed that this optimal planning algorithm with a suitable practical software platform, enables computation of optimal waste collection routes for Smart and sustainable cities. optimal planning algorithm which is executed in an open-source planning tool known as Net2Plan. Net2Plan is typically used for modelling and planning communication networks. Net2Plan along with Net2Plan-GIS library facilitates city layout input information to the algorithm including the positions of smart bins. The computed optimal waste collection paths minimize the number of trucks to be used for waste collection and thereby fuel consumption, this subsequently reduces the impact of CO2 emissions and acoustic damages. The authors have also discussed a practical case of the city of Cartagena (Spain) where the optimal path planning for plastic waste collection is addressed.

A smart network based on smart sensors which are capable of communicating with any authentic Server which can come within the range of communication is also becoming a convenient concept in view and need wide-area coverage for waste collection and management. This concept is well described by Yann Glouche et al [10], in their paper "A Smart Waste Management with Self-Describing objects". In this paper, the authors have discussed a solution based on RFID Tag which provides information about the waste bins. This information subsequently used to improve waste management by providing early automatic identification of waste at the bin level. Authors have claimed that the waste tracking using Smart Bins equipped with RFID-based Tags, doesn't require any other external information

system and this solution enables improvement in the selective sorting of Waste. Besides this RFID Tag helps to report back the waste contents of Smart Bin back to the recycling system.

On the other hand, it is always challenging to analyse the generated data systematically and a need to have a proper query mechanism to filter the right information so that one can easily know how much waste got generated, how much waste is processed, how much waste is recycled and so on. Zeki Oralhan et al, in their paper "Smart City Application: Internet of Things (IoT) Technologies Based Smart Waste Collection Using Data Mining Approach and Ant Colony Optimization", have discussed the design of garbage container integrated with sensors for measurement of temperature within the container, the ratio of Co2 within the container and fill level of the container [11]. The measured information from the container with the help of IoT Sensors then transmitted to the waste management Software System. The waste management software system then using a data mining approach forecasts when garbage containers can be completely filled and need replacement. Also, by using the ANT colony algorithm the software calculates the most efficient waste collection routes, and this route information is then passed on to waste collection trucks on the smart tablet. Authors have claimed that the developed system when implemented on a pilot basis in a city it offered around 30% of cost savings in waste collection. Also, this system helped in reducing garbage collection truck's oil costs, carbon emissions, traffic, and other negative environmental impacts.

Today based on the coverage areas, the municipality and Smart Cities Administration department arranges waste collection vehicles to collect the waste from various parts of cities and geographies. This manual collection of waste is considered a time-consuming and tedious job. Imagine how much time it can save if the whole process is automated. Considering the amount of time, it is taking up for waste collection ultimately there is a dire need for automated waste collection. Cicerone Laurentiu Popa et al [12], in their paper, "Smart City Platform Development for an Automated Waste Collection System", have discussed the development of a fully automated Smart waste collection System. Authors have claimed that such a system can be used to convert the automated waste collection system into a smart system and can be fit for use within Smart City Infrastructure. The authors have clarified that they used the Azure platform for the development of the proposed system. This Azure Platform facilitates real-time monitoring and communication with a central system. With the help of IoT-based Sensors, a Cloud Platform, and with data analytics, the Smart Waste management system could achieve fill status information of waste bins, route optimization for Vehicles used for Waste collection, Waste Bin status information, and so on.

6. WASTE MANAGEMENT CONCEPTS – DEEP DIVING:

Considering the significant negative impact due to inefficient waste management, in Smart Cities, waste management activity is given a top priority and often carried out in a controlled manner using the latest tools and technologies such as IoT, data analytics, Client Server, Image Processing, Smart Sensors, etc [13]. Such waste management often carried out right from controlled and efficient collection of waste, waste monitoring, and analysis, waste transportation, waste processing,

waste recycling, and finally environment-friendly waste disposal to ensure the minimum negative impact on the environment and Smart City residents. Such kind of waste management is often called Smart Waste Management.

6.1 Main Elements of Smart Waste Management

The main technology elements for Smart Waste Management are as follows.

(1) Automatic Alerts for Waste Bins filling Status
(2) Automated Waste Collection
(3) Landfill Modernization
(4) Energy Generation
(5) Environment Friendly Operation

Let us walk through some of the special features and advantages available with Smart Waste Management system.

(1) Automatic Alerts for Waste Bins filling Status

Using variety of Sensors along with Smart Trash bin it is possible to provide alerts and notifications when the waste bin needs to be serviced. This facilitates waste collection vehicles to be deployed to collect waste from only those containers which needs to be emptied.

(2) Automated Waste Collection

Using Autonomous Vehicles, equipped with Waste Collection Container and Robotic Arm for waste pickup and disposal in waste container, has made the waste collection process truly automatic in practical sense. This not only reduces the overall time required in waste collection but also the efforts and thus increases the overall process efficiency.

(3) Landfill Modernization

This is possible by modernizing the garbage dumps and highly engineered landfill operations complied with local and state level relevant regulations to reduce emission of methane gas and ensure adequate protection to human health and surrounding environment.

(4) Energy Generation

Waste may contain different materials such as agricultural leftovers, food, animal waste, etc. which can be suitably processed to produce biogas. With the help of Digesters, it can be possible to covert the biogas into energy. There are Thermal Converters available which helps to convert useless materials into useful stuff. Also, through proper processing of released gases by landfills it is possible to get the appropriate energy with the help of Bioreactors, Fuel cells and Microturbine Technology. Refer figure 3, which has presented typical stages in gas to energy transformation process.

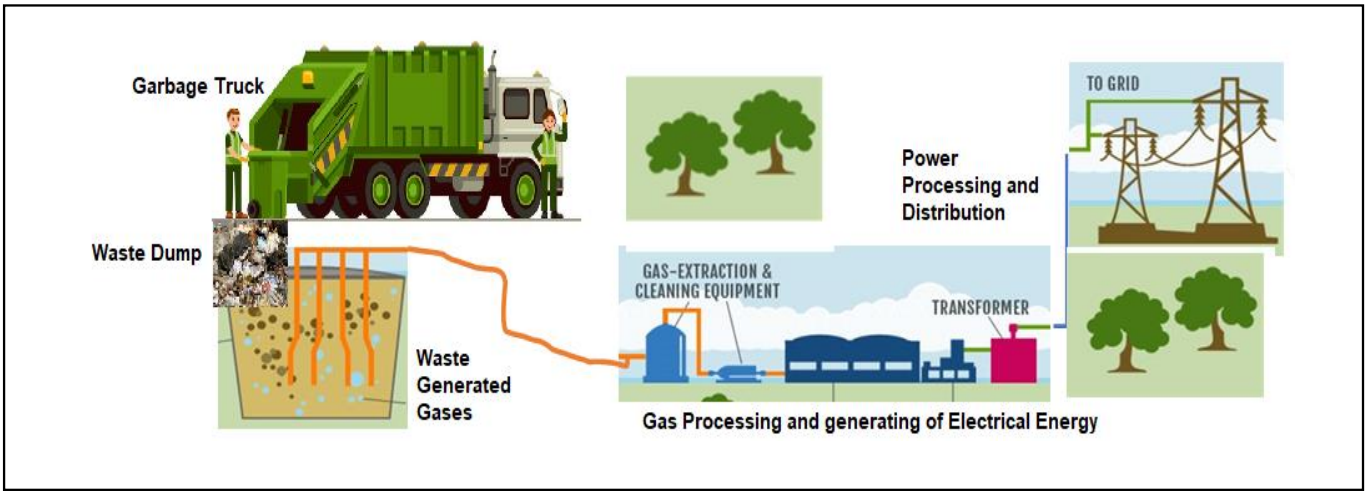

Fig. 3. Solid waste landfill gas-to-energy systems

(5) Environment Friendly Operation

By using the Waste Collection Vehicles running on Natural Gases instead of Petrol or Diesel, the overall transportation is quieter as well as cost effective. Also, timely collection of garbage from the waste bin ensure to avoid spreading of any harmful gases and foul smells in the environment. Besides, timely recycling of the waste also ensures avoiding any chances of depositing any harmful material in ground and or surrounding atmosphere. This whole operation finally helps in reducing the carbon footprint and overall negative impact on the environment.

Overall, Smart Waste Management System facilitates waste collection from waste bins only when required, efficient waste collection and transportation, automated process operations, optimized resource utilization and helps in maintaining the healthy environment.

7. SMART WASTE MANAGEMENT SYSTEM "ISMARTWMS":

Based on the key requirements to be addressed while dealing with waste management process and keeping in mind operation efficiency, a cloud based, IoT sensors driven smart solution called as iSmartWMS is proposed for managing end to end waste management process. iSmartWMS is based on secure end to encrypted communication and multi-tier Client Server communication architecture. Please refer figure 4 which has shown high level building blocks of iSmartWMS. Let us walk through the major components of iSmartWMS [14-28].

(1) Smart Trash Bin

Smart Trash Bins are more than a typical trash bin (also known as garbage bins or waste bins) used to store the waste. Users can deposit the waste from the bin opening conveniently. The trash can store wet and dry solid waste as usual. However, Smart Trash Bins also offer it's fill level information as well as servicing need information to external world. To do this, it employs variety of sensors capable of sensing the relevant things and connecting to the internet

network for communication purpose.

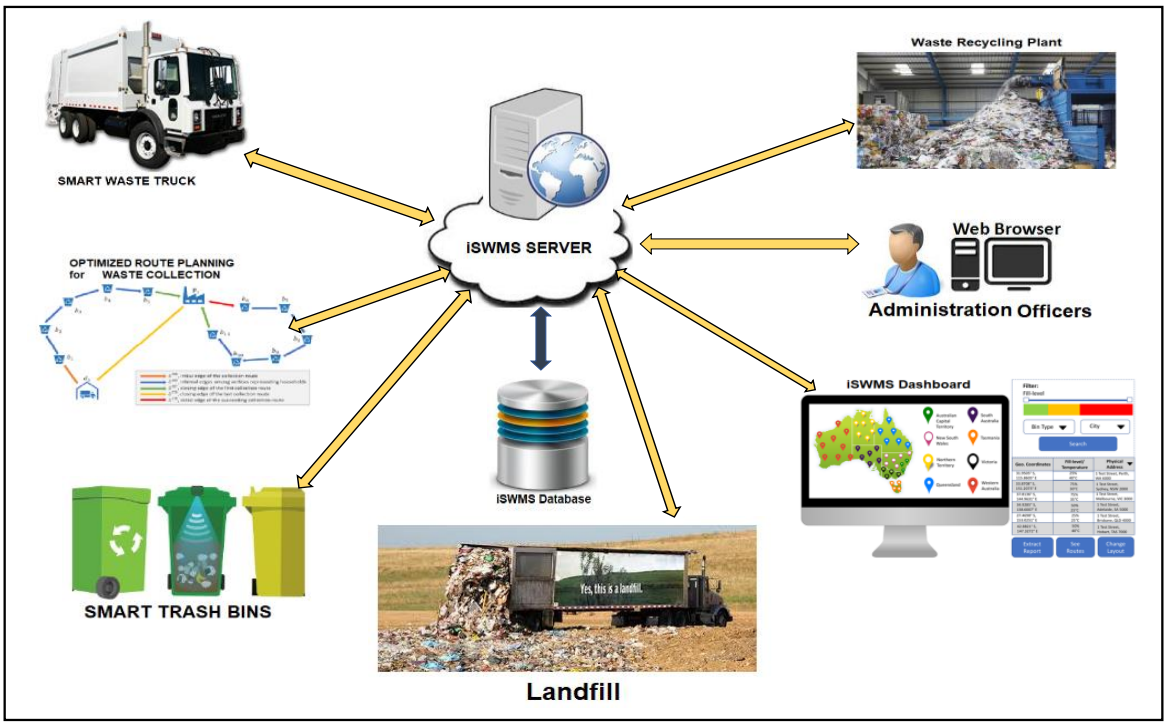

Fig. 4: High level block diagram of proposed iSmartWMS

The popular sensors used in Smart Trash Bin are as follows.

- **Ultrasonic Sensors**: These sensors measure fill-levels in trash bins via ultrasonic beams. Ultrasonic Sensors can easily set to measure distance from few cm to few hundred cm. Ultrasonic technology ensures top measurement accuracy. The information from sensors can be communicated using GSM Modems or IoT networks LORA / MQTT / COAP communication protocols. The communication can be encrypted for preventing misuse of information. For Sensor electronic circuit operation, long life replaceable batteries are connected, having typical lifespan of around 2 Years or more. Such sensors need to be light weight, compact, robust, water and shock resistant and supporting wide operational temperature range.
- **RFID TAG**: The RFID Sensors are very compact and can fit anywhere. The tags are passive contactless transponders which can be installed easily into most waste bins including metal bins and plastic bins However, in plastic bins they really perform well. RFID Tags doesn't need the line of sight for operation. These TAGS are configurable to operate in LF, HF and UHF Band and often fitted with some memory for data storage, read and write purpose. The TAGs can be read from around 5 to 6 ft distance. In addition to service verification and route management of waste vehicles, RFID Tags fitted with Trash bins helps in trash bins tracking, repairs of waste containers and work order management.
- **Load Cell**: Load cell are used to identify weight of the Trash Bins. Load Cells are attached below at the bottom of Trash Bins. Weight measurement may not accurately indicate fill level of trash bin, but in case the trash bin weight reaches to the specified limit of what Garbage Truck can pick up, then waste

collector vehicles can be deployed for evacuation of such trash bins. Load cells can be configured to measure weight from few kilograms to few thousand kilograms easily. Many Off the Shelf Load cells used in trash bins comes with IoT communication connectivity or with GSM Modems for communication with the external world. Such load cells are designed and manufactured to operate in harsh and wide operating temperature environment.

- **Image Sensors**: A network connected high resolution Camera mounted inside opening lid of trash bins in a protected IP Proof enclosure can be used to capture the trash bins images. By processing these images, it is possible to accurately know the fill status, various contents of trash bins and also the overall condition of trash bins. Image Sensors however are costly and needs special protection as well as special image processing algorithms for detecting the fill status information and condition of trash bin. The Image sensors typically find applications for trash bins which are bulky in size and storing the waste which is harmful for human beings. Some Image Sensors also provides Pan, Tilt and Zoom facility to have a closer look on the contents of bins remotely.
- **Temperature and Humidity Sensors**: For the trash bins storing industrial waste, needs bins servicing at regular intervals. Industrial waste is harmful, and the waste generates high temperature and causes high humidity inside trash bins over the short period of time. If not evacuated at right time such waste can impose danger to surrounding environment as well as to human beings. So, it is always necessary to detect the temperature and humidity conditions within trash bins at regular intervals. Low cost Electronic Sensors such as DHT11, DHT22 along with the controller and modem can provide the Trash bin inside temperature and humidity readings easily. However, since the sensors needs to be operated in the harsh environment, proper protection enclosure for electronic circuits is must while installing such sensors within trash bins.

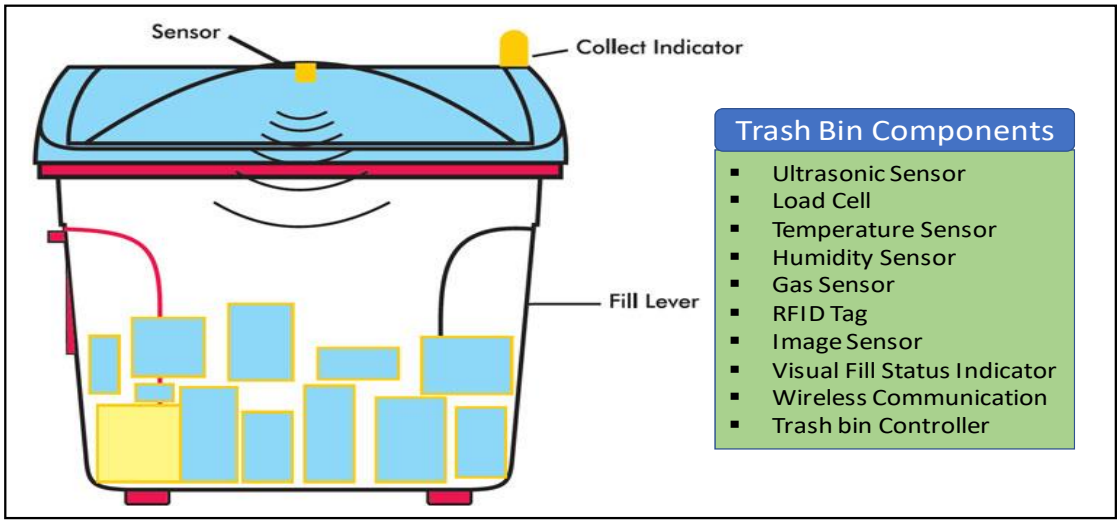

Fig. 5: Smart Trash Bin typical components

- **Gas Sensors**: When waste such as Hospital waste, Industrial waste from chemical industries are deposited in huge trash bins, chances of generating harmful gases are very high. If the generated gas level is not checked at regular intervals, then there is a possibility of leaking out excess generated gas in the environment and can cause harmful effect on surrounding nature as well as human beings. Hence gas sensors are typically installed for such trash bins. The Sensor such as MQ135 is a low power and low-cost gas sensor which is sensitive to various gasses such as Methane, CO_2, NH_3, Benzene, LPG, Alcohol, and Smoke. MQ135 sensor along with Controller and Modem can provide generated gas information to control system for data analysis and needful action. If it is observed that generated gases reach to a predefine limit, then the trash bin is emptied as per standard procedure.

Note that data from all the installed sensors of Smart Trash Bin is communicated to the trash bin controller at regular interval. Trash Bin Controller is like a brain of Smart Trash Bin and is the only component which maintains the communication of Smart Trash Bin with the external world. The trash bin controller wirelessly communicates the consolidated data in a decided message format to the iSmartWMS Server securely. The wireless repeaters shall be used to cover appropriate connectivity range wherever required. The message from Smart Trash Bin controller is expected to contain at least following information.

- Message ID: Message Identifier
- Trash Bin ID: Trash Bin Identifier
- Trash Bin Location Coordinates
- Sensor Type: Gas/Temp/Humidity/Weight etc.
- Time Stamp: Date and Time
- Sensor Data: Data generated from Sensor
- EOM: Message Checksum

The whole message packet then encrypted with suitable encryption algorithm such as AES128/AES256 and then communicated to iSmartWMS Server for further action. Note that the Smart Trash Bin Controller and iSmartWMS Server have two-way communications. Apart from regular data from trash bin controller, iSmartWMS Server can also request or enquire specific Sensor data from specific trash bin as per requirement. Based on such requests the trash bin controller sends the enquired sensor data to iSmartWMS Server as required.

(2) Smart Waste Truck

Smart Waste Truck (SWT) is one of the most important components in Smart Waste Management Systems. The SWTs play the most crucial role in waste management of collecting and transporting the waste to various places as per requirements. In iSmartWMS instead of the simple garbage collector, SWT is suggested to use. SWTs have following features which makes it the most recommended vehicle for garbage collection and disposal.

- Strong and robust waste container with dumpster lift
- Robotic Arm for automated waste collection
- Facility to store wet as well as Solid waste separately

- Facility to indicate waste level
- Equipped with accelerometers, Air-quality sensors, infrared cameras, and wireless signal monitors
- Support for 24x7 secured Wireless Communication
- Installed with GPS and Client system for real time communication with Waste Management Server

SWTs can communicate with iSmartWMS Server through a secure wireless communication and can receive alerts and notifications as well as route optimization information, during travelling and while collecting waste from geographically distributed Smart Trash Bins.

(3) iSmartWMS Server

The iSmartWMS Server can be considered as brain of the entire waste management process. It is basically a dedicated physical cloud server accessed over internet remotely. The iSmartWMS Server Application is responsible for following.

- Communicate with each Smart Trash Bin Controller periodically
- Communicate with other devices such as Smart Waste Truck controller, Landfill station controller, with Administration staff over web interface, Recycling Plant Controller and with iSmartWMS Database
- Maintain communication status with all the required controllers and report communication failure if any for suitable action
- Run Smart Waste Management Application and carry out all the required data analytics on the received waste related data
- Store the Waste Management Data updates from Smart Trash bins and other controllers into the data base with appropriate timestamp
- Generate alerts and notifications in case of any emergency situations with respect to waste management
- Maintain the fill level status information of each trash bin and provide instruct to SWTs about trash bins which needs to be emptied
- Provide optimized route information to SWTs for garbage collection
- Receive the recycled material related information from Recycling plat controller and maintain such information in the database
- Receive the landfill material related information from landfill station controller and maintain such information in the database
- Generate the dashboard and maintain the real-time information about waste management providing crucial information such as
    - Number of filled trash bins
    - Number of empty trash bins
    - Number of underfilled trash bins
    - Number of trash bins which needs immediate servicing
    - Number of SWTs collecting waste
    - Garbage collection optimized route information
    - Total Kg of waste collected in a day and over a period of time
    - Total Kg of waste recycled in a day and over a period of time

- Total Kg of waste dumped in landfill in a day and over period of time
- Communication Status information with each trash bin controller

- Provide web interface to administration stakeholders and generate the necessary reports for them for offline analysis

Note that the Application Server front end and back end can be developed through Java or C#.Net technologies. Data analytics algorithm can be developed in R or MATLAB programming language and can be subsequently integrated with the Application Server as Class Package and or through a link library. The server can be hosted on any available cloud platform such as CloudX, CloudSigma or any cost effective off the shelf cloud platform so that it can be securely accessed over internet.

(4) iSmartWMS database

iSmartWMS database is also one of the most important elements, and it is used to store and retrieve all the waste management related data. Note that from security perspective it is recommended to store encrypted data. This database can be either build up through the open source robust and powerful databases such MySQL, MongoDB, PostgreSQL, Redis etc. and or can be implemented with one available through off the shelf cloud platform.

(5) Recycling Plant Controller

Recycling Plat Controller is responsible to provide mainly recycled material related information to the iSmartWMS Server. Recycling plant controller receives this information through a weighing scale system and or through a dedicated operator interface. Operator feeds in the required information in plant controller User Interface system on daily basis. This information is then subsequently communicated back to ISMARTWMS Server periodically and based on demand. Following information can be generated by Recycling Plant Controller.

- Received Kg waste material on given day
- Recycled Kg material on given day
- Total Kg waste material received over last week
- Total Kg waste material received so far in last one month
- Total Kg waste material received so far in last one year
- Total Kg material recycled over last week
- Total Kg material recycled so far in last one month
- Total Kg material recycled so far in last one year
- Recycled Items information
- Information about Normal operation/ Alert /Emergency Situation
- Health Status information

(6) Landfill Station Controller

Landfill Controller is responsible to provide mainly landfilled material related information to the iSmartWMS Server. Similar to Recycling plant controller, Landfill Controller too receives the landfill material related information through a weighing scale system which is used to measure the weight of the deposited waste

and or through a dedicated operator interface. Operator feeds in the required information in Landfill Controller User Interface system on daily basis. This information is then subsequently communicated back to iSmartWMS Server periodically and based on demand.

Following information can be generated by Landfill Station Controller.

- Received Kg waste material on given day
- Total Kg waste material landfilled over last week
- Total Kg waste material landfilled so far in last one month
- Total Kg waste material landfilled so far in last one year
- Information about Generated/emitted Gas on given day
- Information about Normal operation/ Alert /Emergency Situation
- Health Status information

8. RESULTS AND DISCUSSION:

In this paper the iSmartWMS system is mainly discussed at concept level. Due to time and budget constraints, it was not possible to implement the iSmartWMS system in totality. However, proof of concept of iSmartWMS is developed with limited functionality to test at laboratory level environment. Simulated data with respect to waste collection was generated and tested with iSmartWMS Server to check its data analytics related performance, ability to generate alerts and notifications with respect to emergency situations and or situations where any trash bin needs urgent service. By using google map of a specific geography and simulated trash bin data, iSmartWMS SWT route Optimization data generation capability was also tested successfully. Finally, through web interface a secure access was provided with iSmartWMS server for authenticated users and dashboard related data display capability of iSmartWMS server was tested A simple user-friendly front-end User interface is developed with C# for the iSmartWMS Server Application configurations and reporting. For database, I used the MySQL which proved to be simple but very effective for this application. Since the system was tested with limited simulated data, the full potential and capability of iSmartWMS system could not be tested. However, overall, the iSmartWMS system worked well. The results found very encouraging. The User feedback was collected during lab testing and many users appreciated the developed solution.

9. CONCLUSION:

The testing of POC of iSmartWMS System successfully demonstrated that iSmartWMS solution effectively carried out all the intended functionalities. Due to limited test data and in absence of real-life waste material related data, full potential of iSmartWMS PoC could not be tested and it is difficult to judge the overall performance of iSmartWMS as a Smart Waste management system. However, the encouraging results confirmed that iSmartWMS can be effectively used for Smart Waste Management if implemented fully. To take full advantage of the benefits offered by iSmartWMS, it is highly recommended to develop the full-fledged system as per stated requirements and building blocks.

10. FUTURE WORK:

Based on the encouraging results obtained through verification and validation of iSmartWMS PoC, it is recommended to develop and implement full-fledged iSmartWMS system. It is also recommended to integrate it with any available Smart City infrastructure and validated against real life waste generated data. During laboratory testing of iSmartWMS PoC some users provide valuable suggestions as follows.

- Like web interface, provide iSmartWMS access over smartphone for easy and convenient access for authorized administrative staff. This will provide more flexibility to admin staff for using and maintaining the system.
- Apart from visual indication, audio alarm should also be provided periodically if any trash been need immediate servicing.
- Provide facility to integrate iSmartWMS System software with the Smart City existing IT Infrastructure
- Facility to view Smart Trash bin contents video footage to authorized users

Considering the usefulness and value lies in above listed suggestions, it is recommended to consider the above listed improvements as well while implementing the iSmartWMS based Smart Waste Management Solution.

REFERENCES:

[1] Kodwo Miezaha, Kwasi Obiri-Dansoa, Zsófia Kádárc, Bernard Fei-Baffoea, et al. (2015). Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. Elsevier, *Waste Management*, *46*(1), 15-27.

[2] Kellow Pardini, Joel J.P.C. Rodrigues, Ousmane Diallo, et al. (2020). A Smart Waste Management Solution Geared towards Citizens. *Sensors*, *20*(1), 1-15.

[3] Pedro Branco, liKim Bolton, Mattias Eriksso. (2020). Environmental impacts of waste management and valorisation pathways for surplus bread in Sweden. *Waste Management*, *117*(1), 136-145.

[4] Ian Tiseo (2020). Global waste generation outlook by region 2016-2050. https://www.statista.com/statistics/233613/waste-generation-worldwide-by-region/. Accessed on 29/04/2021.

[5] Introduction Types of Waste – ESCAP. https://www.unescap.org/sites/default/files/CH08.PDF. Accessed on 29/04/2021.

[6] Muncipal Solid Waste Management Manual Part II (2020). Central Public Health and Environmental Engineering Organisation (CPHEEO). Ministry of Urban Development, Government of India. 3-41.

[7] Dr. Dipak Gade. (2019). Introduction to Smart Cities and Selected Literature Review. *International Journal of Advance and Innovative Research*, *6*(2), Part – 4. 7-19.

[8] Insung Hong, Sunghoi Park et al. (2014). IoT-Based Smart Garbage System for Efficient Food Waste Management. Hindawi, *The Scientific World Journal*, *2014*(1). 1-14.

[9] María-Victoria Bueno-Delgado, José-Luis Romero-Gázquez, et al. (2019). Optimal Path Planning for Selective Waste Collection in Smart Cities. *Sensors*, *19*(1). 1-14.
[10] Yann Glouche, Paul Couderc. (2013). A Smart Waste Management with Self-Describing objects, The Second International Conference on Smart Systems, Devices and Technologies, IARIA. 63-70.
[11] Zeki Oralhan, Burcu Oralhan, and Yavuz YİĞİT. (2016). Smart City Application: Internet of Things (IoT) Technologies Based Smart Waste Collection Using Data Mining Approach and Ant Colony Optimization. The International Arab Journal of Information Technology, *14*(4). 423-427.
[12] Popa, C. L., Carutasu, G., Cotet, C. E., Carutasu, N. L., & Dobrescu, T. (2017). Smart city platform development for an automated waste collection system. *Sustainability*, *9*(11), 1-15.
[13] Dr. Dipak Gade. (2019). Technology Trends and Digital Solutions for Smart Cities Development. *International Journal of Advance and Innovative Research*, 6(1), Part – 4. 29-37.
[14] Eunice David Likotiko, Devotha Nyambo, Joseph Mwangoka. (2017). Multi-agent based IOT Smart Waste Monitoring and Collection Architecture. *International Journal of Computer Science, Engineering and Information Technology*, 7(5).1-14.
[15] Behzad Esmaeiliana, Ben Wangb, Kemper Lewisc, et al. (2018). The future of waste management in smart and sustainable cities: A review and concept paper. Elsevier, Waste Management, 81. 177-195.
[16] Kellow Pardini et al. (2019). IoT-Based Solid Waste Management Solutions: A Survey. *Journal of Sensor and Actuator Networks*, *8*(1). 1-25.
[17] Florin-Constantin Mihai and Mohammad J. Taherzadeh. (2017). Introductory Chapter: Rural Waste Management Issues at Global Level. Intech, Book: *Solid Waste Management in Rural Areas*. 1-12.
[18] The Impact of the 4th Industrial Revolution on the Waste Management Sector. https://www.iswa.org/knowledge-base/the-impact-of-the-4th-industrial-revolution-on-the-waste-management-sector/?v=c86ee0d9d7ed. Accessed on 29/04/2021.
[19] Landfill Gas to Energy Turning waste into energy. https://www.advanceddisposal.com/for-mother-earth-2/education-zone/landfill-gas-to-energy.aspx. Accessed on 29/04/2021.
[20] Alexey Medvedev, Petr Fedchenkov, Arkady Zaslavsky, et al. (2015). Waste management as an IoT enabled service in Smart Cities. *Springer*, 1. 1-13.
[21] Tran Anh Khoa, Cao Hoang Phuc, et al. (2019). Waste Management System Using IoT-Based Machine Learning in University. *Wireless Communications and Mobile, Computing*, *2020*(1). 1-13.
[22] Asim Zeb, Qurban Ali, Muhammad Qaiser Saleem. (2018). A Proposed IoT-Enabled Smart Waste Bin Management System and Efficient Route Selection. *Journal of Computer Networks and Communications*, *2019*(1). 1-9.
[23] Sani Abba and Chinaka Ihechukwu Light. (2020). IoT-Based Framework for Smart Waste Monitoring and Control System: A Case Study for Smart Cities. *Engineering Proceedings*, 2(1), 1-10.

[24] Gianni Minetti (2020). Smart waste, an opportunity cities should not trash. https://www.smartcitiesworld.net/. Accessed on 29/04/2021.
[25] Theodoros Anagnostopoulos, Arkady Zaslavsky, Kostas Kolomvatsos, et al. (2017). Challenges and Opportunities of Waste Management in IoT-Enabled Smart Cities: A Survey. *IEEE Transactions on Sustainable Computing*, *2*(1). 275-289.

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APPENDIX -1: Published Papers – 03

Smart Cities Development during and post COVID-19 Pandemic

ABSTRACT

Purpose: *The Smart Cities due to their important role in infrastructure building activities and offering smart services to their residents in living enjoyable life, are always in limelight and discussions. Current COVID-19 pandemic has however changed the situation and have forced us to rethink the way we operate, carry out day to day activities and services. COVID-19 pandemic has changed the normal routine life to significant extent, damaged the economies of many countries, shifted our business priorities and so on. In such situations, how can Smart Cities remain unaffected due to COVID-19? This paper has analysed and discussed in detail the impact of COVID-19 pandemic on Smart Cities operations and development and also, how this impact can be measured. It has described in detail how Smart Cities has changed their priorities and how they are more focusing on building Smart Healthcare facilities, Smart Isolation Wards, Smart Medicare facilities, services related to Telemedicine, Virtual Doctor, dedicated COVID-19 Command and Control Centres and so on. The paper has also highlighted the post COVID-19 Pandemic era for Smart Cities development and operations. Finally, the paper has concluded that Smart Cities development during and post COVID-19 Pandemic has witnessed a short obstacle in its growth journey, Smart Cities are definitely going to win the war against COVID-19 and will become Smarter in future to tackle such pandemics.*

Design/Methodology/Approach: *This research paper made use of available secondary data in research journal papers, online books, white papers, and dedicated websites on the research subject area to analyses the impact of COVID-19 Pandemic on Smart Cities Development and Operations.*

Findings/Result: *Due to COVID-19 Pandemic, it is observed that many sectors growth slow down due to budget cut and finance constraints, however certain sectors such as Medical Infrastructure, Insurance and eCommerce have seen booms, this has made Smart Cities to have strong focus on certain Smart Services related to Medical facilities, IT infrastructure to facilitate contact less transactions, Telemedicine Service, Smart Isolation Wards etc. whereas services with respect to entertainment parks, tourism etc slowed down due to less priority and budget constraints..*

Originality/Value: *Based on the available secondary data, this research has identified impact of COVID-19 on ongoing Smart Cities development and also how its priorities and focus got shifted to build up certain services and infrastructure. The paper has also highlighted post COVID-19, how Smart Cities development, operations and maintenance activities will be affected.*

Paper Type: *Secondary data-based Research*

Keywords: Smart City, IoT, Digital Twin, Artificial Intelligence, Data Analytics, COVID-19

1. INTRODUCTION:

The COVID-19 pandemic left unprecedented impacts not only on individuals but

also on the major segments of societies including industries, education, business and trades, governments, environments and almost all the activities of the mankind as a whole. In the beginning of January 2020, no one had any idea that a small outbreak of COVID-19 in Wuhan, capital of Hubei Province of China, which was initially considered as China specific outbreak, will go and spread widely to the whole world with in few months of time and will cause millions of people hospitalization and killings worldwide. By this time, it is also clear that this pandemic is not going to go away soon and with limited stock of reliable vaccine for COVID-19 as of now, mankind needs to prepare to stay with COVID-19 for longer duration. No doubt that this bitter truth has forced us to change our day to day activities, the way we were doing business, office activities, travels, transactions, meetings and so on. The way we were living before COVID-19 phase is not going to return soon and quite possible that COVID-19 has forced us to permanently change some of our routine activities. We are currently undergoing industry 4.0 revolution and the fact that this pandemic has happened in the middle of our digital revolution journey, is not gone unnoticed. The most advanced countries such as USA, UK, Russia, France, Germany, Spain etc. which are forefront in technology upgradation, innovation, modern facilities, and infrastructure are currently worst affected by COVID-19 pandemic.

Smart Cities due to its smart infrastructure and well governance are always ready and prepared for such kind of disaster be it god made or man-made and can comparatively do a better job in facilitating better pre and post medical facilities and treatment [1]. Globally, almost all the countries have put forward medical treatment and COVID-19 safety related activities at highest priority, keeping and provisioning maximum budget for it. Obviously for other activities budget is either slashed or no more budget is available. This has made other domains and industries greatly impacted but in COVID-19 phase, in reality, this has boosted development of Smart Cities with better medical infrastructure and facilities. It is estimated by United Nations that 68% of the world's population will live in urban areas by 2050, and more and more people will migrate to Smart Cities in coming period in hope of getting better livelihood. Let us see in detail how Smart Cities are fighting against COVID -19.

2. PROBLEM STATEMENT:

COVID-19 pandemic has drastically affected our businesses and day to day activities. It has also impacted various business sectors including Smart Cities. We felt that there is a need to determine how Smart Cities development and operation activities are coping up with the current pandemic situation. Is there any way to identify how Smart Cities development and operations are affected due to COVID-19 pandemic and how we can quantify it, what tools are there to evaluate such impact? Such data will definitely help to further boost Smart Cities development, operations, and maintenance activities during and post COVID-19 pandemic.

3. RESEARCH OBJECTIVES:

COVID-19 pandemic impact on Smart Cities development and operations is very vast and complex subject. It is not possible to completely cover each and every aspect related to COVID-19 pandemic impact on Smart Cities. However, with the

available time constraints, limited tools and limited available literature, the research is carried out keeping in mind following broad objectives

- Study the existing available research papers, white papers, online blogs, research reports from SMEs and Government Organisations and dedicated website on the research subject area.
- Identify the important services of Smart Cities which are got heavily impacted (either positively or negatively) due to COVID-19 Pandemic.
- What current tools and technologies are used to measure and quantify COVID-19 pandemic impact on Smart Cities Development, Operations and Maintenance related activities.
- Analysis and discussion on post COVID-19 era for Smart Cities development and operations.

4. METHODOLOGY:

This research is entirely based on study and analysis of existing literature available on COVID-19 pandemic effect on Smart Cities development, operation, and maintenance. It is observed that not many research papers are available on this subject and hence we mainly focused on study of white papers, conference papers, online books, blogs, and dedicated websites for tackling COVID-19 pandemic and Smart Cities. Specific keywords and phrases such as "Smart City", "COVID-19" "COVID-19 impact" "COVID-19 effect on Smart Cities" "Smart Cities fight with COVID-19" "Smart City and COVID-19", were used while identifying relevant online literature. The collected literature was then analysed considering the data provided, quantified information, tools and technologies discussed and proposed, finance related data, notes on affected geographies, patients related data, etc. to identify challenges faced by Smart Cities to tackle COVID-19 pandemic and its impact on their services considering operating cost, manpower and required infrastructure for dealing with COVID-19 Pandemic. We also went through the existing Interviews of Subject Matter Experts, Researchers, and Industry Professionals to understand their stand on how Smart Cities will emerge post COVID-19 era.

5. RELATED WORKS:

Pandemic like COVID-19 is not new on the earth. The world has experienced similar situations such as the Marseille plague in 1720, cholera pandemics around 1817 and 1823, Spanish flu Pandemic around 1918 and 1919, Asian Flu in 1957, Hong Kong flue in 1968, and the most recent Swine Flu in 2009 [2]. Coronavirus Disease 19 (COVID-19), caused by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), and the first case of COVID-19 was detected in December 2019 in China (World Health Organization, 2020). The commonly reported symptoms of the virus include fever, persistent cough, fatigue, and loss of taste or smell [3]. In the case of COVID-19, the source of infection is mainly due to the infected patients. According to the clinical evidence of previous respiratory syndromes, respiratory droplets and personal contact are found as primary transmission methods [4]. COVID-19 pandemic has affected everyone however older people, socially and economically disadvantaged populations are at higher risks of becoming infected. Lorenz Seidlein, Graham Alabaster, et al, in their

paper have highlighted that crowding is also one of the important factors in COVID-19 infection and spread [5]. Authors feel that crowding is difficult to quantify and address, however, in many ways, it is linked to socioeconomic status and can be defined in terms of floor space/person instead of population density. Wealthy and well-off people can afford more floor space and can avoid public transportation, however, the low-income group population doesn't have such kind of freedom and hence prone to get infected due to COVID-19.

For the first time in 21st Century, the world witnessed the most devastating impact due to pandemic like COVID-19 which is still ongoing in the year 2021 and unfortunately, we were not ready, not prepared for it. Second thing, even though we are in the 4th stage of the industrial revolution and technologically much more advanced as compare to our 20th-century era, still it seems we miserably failed to predict the adverse impact of COVID-19 pandemic across the globe. Many scientists, researchers, and professors during COVID-19 period started working on remedies to tackle the situation to the best possible extent either by accelerating the research in identifying COVID-19 detection tests and to reduce the time it takes to produce results, COVID-19 vaccines trials, and the emergency measures to prevent COVID-19 waves in future. Nenad Petrovic, Vlado Dimovski, et al, in their paper stated that to deal with COVID-19 pandemic situation in Smart Cities, more innovative solutions and sophisticated methods are needed. They highlighted the need for data-driven applications as an important tool to enable the quality of life and well-being of citizens[6]. They suggested the use of mobile apps developed using AppSheet and Google Apps Script technologies and demonstrated how these Apps can be used to limit the spread of COVID-19 and provide assistance to infected people. The authors also stated an example of Smart Cities Seoul and Singapore, which were the first Smart Cities to develop technological solutions based on data-driven applications to help their citizens during COVID-19. Along similar lines, Ibrahim Hashem, Absalom Ezugwu, et al, proposed a machine learning-based framework in their research paper to curtail the spread of COVID-19 epidemic specifically in Smart Cities [7]. The authors stated that the novel mathematical model can generate the results based on the collected and analysed data with respect to COVID-19 pandemic, using a machine learning algorithm, and the results can be extensively used to prevent the spread of COVID-19, in forecasting future epidemic, diagnose cases, effective contact tracings, monitor COVID-19 patients, track COVID-19 vaccine development and so many such activities and provide a better understanding of the virus in smart cities.

Linda Hantrais, Paul Allin, et al, in their research paper has successfully demonstrated how the COVID-19 Pandemic has accelerated the growth in worst impacted business areas by making them adopting digital transformation techniques and accelerating their operation through online transaction, online meeting, social connect over network, online business meetings, online data collection and analysis and so on [8]. Such businesses obviously start showing growth by improved productivity. But such activities also demanded to pump in more investment in digital infrastructure.

To avoid the rapid spread of COVID-19 infections, governments of many countries extensively used lockdown as the only option. Mikiharu Arimura, Tran

Vinh Ha, et al, in their research paper has shown that how the COVID-19 infections are greatly affected the densely populated areas of the Sapporo City of Japan before and during the lockdown [9]. Their study reveals how a rapid transit system involves a higher risk of spreading COVID-19 due to the close contact with high passenger density inside the cab, it is mainly because public moves to private cab travel during lockdown when public transportation system was not available. Though lockdown severely affected the economy and financial conditions across the globe, it also helped in many ways specifically with respect to the environment. Recent studies and conducted surveys revealed that lockdown extensively helped to improve the air quality specifically in Smart Cities and urban areas where more anthropogenic activities are present [10]. Some studies conducted worldwide indicated remarkable declines of AQI were observed in NO2 (44% to 13%), ozone (20% to 2%) and PM2.5 (28% to 10%) during the first two weeks of the lockdown in 27 countries [11].

According to Bo Li, Yo Peng, et al, COVID-19 directly impacted populated and commercially prospered regions like Huangzhou, China. Their study reveals the relationship between built environment attributes and confirmed COVID-19 cluster size. They have stated that the well-connected and steady supply of medical service is associated with high commercial prosperity at the community level and it directly, indirectly, and positively affects the COVID-19 cluster size. Ayyoob Sharifi and Amir Reza Khavarian-Garmsi in their review paper tried to identify the most impacted urban sectors due to COVID-19, which requires better preparedness to deal with similar pandemics in the future [12]. The authors feel that COVID-19 has fundamentally altered the way the cities are going to be managed and governed in the future. They also claim that the actions being taken in coming years to tackle COVID-19 will determine how the cities will be developed and managed to post COVID-19 era, in a more sustainable manner.

Chunwen Xu, Xillian Luo, et al, in their paper have highlighted the future of Smart Cities post COVID-19, and they also provided useful suggestions for building future healthy Smart Cities. They stressed the need of establishing a national popularization mechanism for health science, improving the emergency security mechanism, and establishing a multi-industry coordination mechanism [13]. The authors also strongly suggested using Artificial Intelligence-based applications to deal with various services such as logistics supply chain, traffic management, infection detection, vaccination, etc. for modern data-based Smart Cities. Klaus R. Kunzmann, in his research paper elaborated on the likely impact COVID-19, will have on Smart City development and its policies to apply digital technologies in urban development [14]. He provided 10 narratives related to returning to normal life post CPOVID-19, the revival of Car Mobility, digital culture, and entertainment, the demise of non-digital creative industries, nearby or home tourism, public sector boostings etc., and anticipated that Smart City development will experience a boost after COVID-19.

6. COVID-19 IMPACT ON SMART CITIES DEVELOPMENT:

COVID-19 has slowed down the overall growth for many countries due to forced lockdown and increased expenses to tackle the pandemic situation. Also, in efforts to provide relief to citizens from mounting medical expenses, many governments

have also provided a lot of concessions and relaxation in taxation. However, despite reduced workforce and decreased tax revenues, globally, many governments and NGOs, WHO and other global private organizations are deploying advanced technology-based solutions such as IoT, Big Data, Digital Twins, Data Analytics, Cloud Computing, Cyber Security, etc. to help combat the worst case impact due to COVID-19 pandemic by monitoring the health, safety, and living standard of the citizens [15]. Though there will not be much budget to undertake many development activities, which can also cause to slow down Smart Cities development on some of the fronts, it is sure that technology deployment at larger scale to combat war against COVID-19 pandemic, and larger investment in technology can definitely boost health, hygiene and medical infrastructure related development activities in Smart Cities. With the upcoming investment, it is also expected that Smart City technology providers can witness a steady adoption of solutions for various other areas such as smart buildings, smart utilities, smart transportation, and smart citizen services.

According to US based leading technology research and advisory firm ARC Advisory Group following are some of the selected examples which prove that additional investment on technology front by some the leading nations are boosting the Smart Cities development around the globe during COVID-19 phase.

(6) Smart City investment around USA and Canada

US and Canada have many large Smart Cities and municipalities in North America are very diverse in size as compare to other parts of world. In this region, a huge number of medium sizes and smaller cities are investing in smart city projects heavily. Refer Figure 1 which is representing the top 3 focus areas in Smart City development in North America.

(7) China boost Smart City Investments and Technology Initiatives

China's "new infrastructure initiative" program got widespread attention and priority in the wake of COVID-19, using increased investment in smart city technologies to promote innovation and boost the economy while tackling COVID-19 posed threats and challenges. China has announced that it is going to significantly increase investments in high speed internet based on 5G, data centres, smart grids, and other smart city-related areas. Aggregating sources of data across cities has already been started as a major part of the initiative and shall support significant growth in smart city platforms.

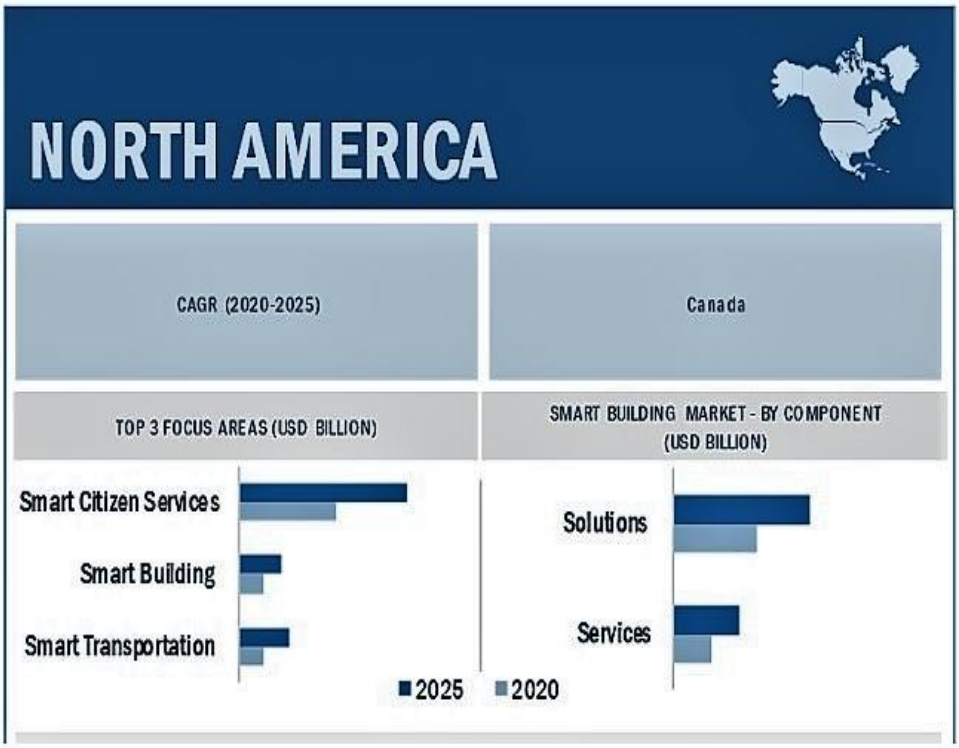

Figure -1: Smart City Focus Areas in North America
(Source : MarketsandMarkets™ Smart Cities Report)

(8) Singapore Increases Technology Investment by 30 Percent

Singapore is one of the early adopters of Smart City Technologies. Singapore government announced in June 2020 that to better fight COVID-19 pandemic, it is going to increase its investment in information technology by 30 percent. The Singapore Government Technology Agency (GovTech) announced that it would spend around $3.5 billion in 2020, up from $2.7 billion in FY 2019.

(9) Investment into Data Management and Analysis Tools by New Orleans and other US Cities

Many US cities have established data processing centres based on new technology tools to track key trends with respect to COVID-19 pandemic and powerful dashboards representing data with respect to new infections, fatalities, recoveries, recovery rate, etc. with geographical data to determine which areas require more attention. For example, the city of New Orleans in Louisiana has setup dashboard by using tools like Power BI to help with data trends for COVID-19.

(10) UAE invested in AI based system

In United Arab Emirates, the impact of smart city technologies to control the virus' spread can also be seen, where the UAE government is using Artificial Intelligence (AI) based Smart System to ensure that social distancing and lockdown related guidelines are followed by its citizens. The system uses data captured by Smart Helmets installed with Thermal Cameras, which helps the local police to detect COVID-19 suspects from safe distance. The System also helps the administration by identifying people who are roaming on roads with their vehicles without having valid pass. This Information is collected by

system by reading the number plates of vehicles and matching the details with those vehicles who have been issued pass to occasional travel on justified medically or emergency situation ground.

(11) India invested in Smart Cities Infrastructure

In India as well, Indian government has taken a lot of initiatives in boosting investment in the Smart Cities infrastructure and medical infrastructure facilities development, which has kept the government agencies ahead in curbing the spread of deadly Corona virus. The Indian Medical Council, with the new guidelines issued by the ministry of health and family welfare and as per recommendations from NITI Aayog, has allowed remote delivery of Medical Services during the lockdown period. These new guidelines allow doctors to recommend prescriptions to patients based on textual, telephonic, and video conferencing and also through WhatsApp Chat, Emails, and messaging services. With these new norms in place, people can consult with the doctors and medical specialists over mobile through video call or normal audio call without needing to go out for in person meeting and thus effectively reducing risk of deadly corona virus spread. The Mobile App "Aarogya Setu" is developed by the Government of India for combined fight against COVID-19 by connecting essential health services with the people of India. Refer figure 2 which is showing the GUI provided by Aarogya Setu App.

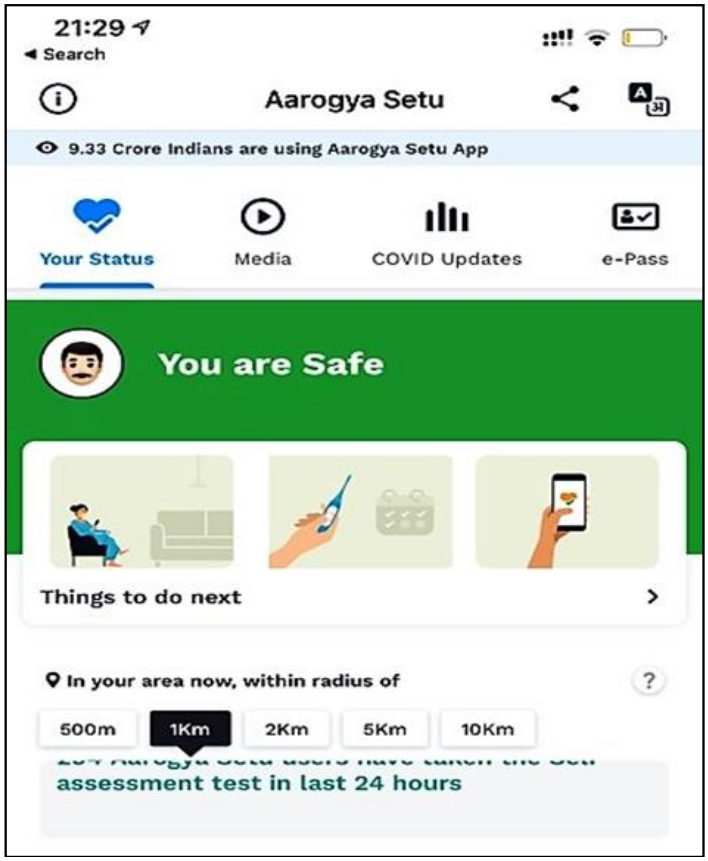

Figure -2: Aarogya Setu App
(Source : Aarogya Setu App, Government of India)

The "Aarogya Setu" app is aimed at reaching out the app users proactively by informing and alerting them about risky areas, providing them dashboard with

recommendations about COVID-19 infections chances, facility to book online vaccinations slots, alerting them about nearby COVID-19 Infections and information about best practices and relevant advisories pertaining to the containment of COVID-19. It should be noted that Aarogya Setu App is available in 10+ local languages and became the world's fastest app to reach 50 million downloads within two weeks of its launch.

7. SMART CITIES INITIATIVES IN INDIA TO TACKLE COVID-19:

Indian government has also taken a lot of initiatives in deployment of advanced technology-based tools across country and boosting infrastructure development across various Smart Cities to ensure effective handling and reducing the impact of COVD-19 pandemic situation. As part of the Indian government-funded Smart Cities Mission, 45 cities have established and make operational COVID-19 Integrated Command and Control Centers (ICCC). Refer figure 3 which has shown the block diagram of typical ICCC used in Smart Cities. These centers were established to serve as quasi-war rooms to manage contact tracing activities, monitor and effectively handle the lockdown state and to deal with emergency situations arising out of COVID-19 pandemic [16-17].

Some of the selected case examples of such Smart Cities in India are as follows.

(1) Mangaluru Smart City

Under Mangaluru Smart City Project, Karnataka State has setup a dedicated call centre as telemedicine facility for monitoring and advising the citizens under self-quarantine. Under this project a Command and Control Centre is also established along with dedicated professionals from Mangaluru Corporation, Police and Doctors.

(2) Bhopal Smart City

Under Bhopal Smart City Project, an Integrated Command and Control Centre is established and operated by state of Madhya Pradesh. This centre is operated as a helpline and used for tele-counselling for COVID-19 Patients with the help of trained station staff and Medical professionals. The centre's helpline is integrated with 104 service and toll-free numbers of ICCC.

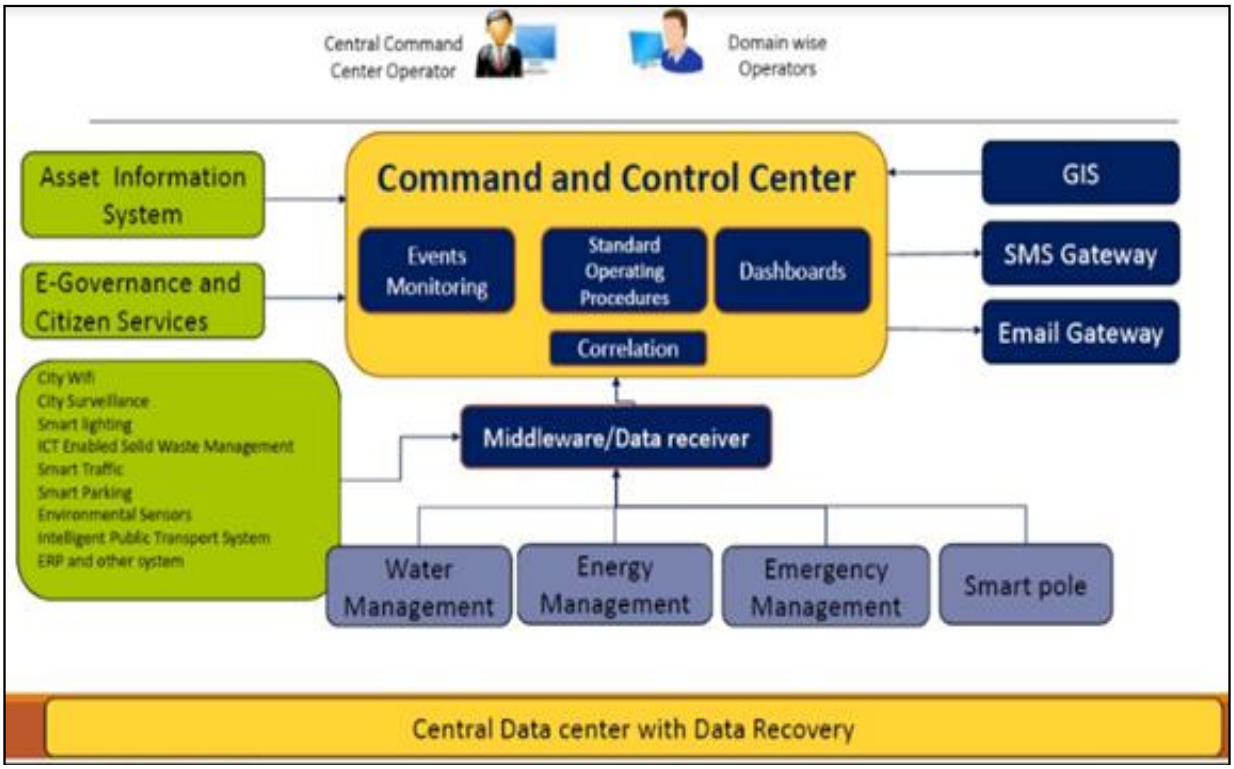

Figure -3: Typical ICCC for Smart City
(Source :Smartnet Library, Government of India)

(3) Kanpur Smart City

Under Kanpur Smart City Project, state of Uttar Pradesh has setup dedicated ICCC specifically to help the citizens to deal with COVID-19 Pandemic by providing telemedicine facilities through toll free telephone help lines as well as through video conferencing.

(4) Nagpur Smart City

In Maharashtra State, Nagpur Municipal Corporation (NMC) under Nagpur Smart City Project has launched a Coronavirus Mobile App to help citizens to identify patients with corona virus infection related symptoms. The App is very simple and user friendly where the citizens have to fill the online information form related to their symptoms and the app detects the possibility of Corona Virus infection to the citizens. In case of confirm identified symptoms related to COVID-19, the app automatically notifies to the team of NMC doctors for further recommended actions including admitting the patient to COVID-19 Cell or an isolation ward to undergo necessary treatment.

(5) Varanasi Smart City

In Uttar Pradesh State, the established integrated command and control centre to deal with COVID-19 pandemic, a GIS (Geographical Information System) based dashboard is effectively uses to identify lockdown violations, quarantine leakages, essential commodities delivery and facilitate emergency alert response.

According to MHUA (Ministry of Housing and Urban Affairs) India, the new initiatives by various Smart Cities across India has helped the district

administrations in not just tracking suspected cases of Corona virus infected people but also monitoring the successful implementation of months long nationwide lockdown.

8. HOW COVID-19 AFFECTED 'SMART CITY' PRIORITIES:

Before COVID-19 development and construction of smart facilities in Smart Cities was on higher priority. The objective was to offer a better lifestyle to all its citizens at the earliest. Offering Smart Medical facilities was also one of the objectives, but it was not on highest priority. As stated earlier, due to concessions offered in taxation and lower revenue collection, the budget is either not available or slashed for other development activities. Also, due to prolonged lockdown, it became difficult to get ready workforce. This has definitely impacted Smart Cities development as well. Apart from COVID-19 related investments in Technology and relevant Medical Infrastructure, development for other projects in Smart Cities are significantly impacted and delayed, such projects are new bridge constructions, new high ways, futuristic skylines, futuristic restaurants, and shopping malls, modern sports facilities, smart-city led lighting system, new educational institutions, smart traffic management related Projects, projects related to nightlife and leisure activities, new Parks and side-walks constructions etc. Obviously, all these projects went on backfoot due to COVID-19 pandemic, and medical infrastructure and relevant technology-related projects got higher priority. In May 2020, Financial Express has reported that due to COVID-19 pandemic, an imposed prolonged lockdown across India, has halted Smart City projects worth close to Rs 1 lakh crore, rendering thousands of workers jobless and causing large-scale damage of building materials. City Monitor from Mediagroup.com has reported that Sidewalk Labs abandoned its Waterfront Toronto project in May 2020 citing the reason for the economic pressures of the global pandemic. There are so many such examples of popular projects which were considered as a top priority before COVID-19 and subsequently got either delayed, scaled-down, or abandoned in COVID-19 phase. It is sure that the pandemic has highlighted the need for better medical infrastructure, hygiene, and better environment accelerated digital city planning and greater communication with citizens for massive population levels to be sustainable. Also, with change in priorities, Smart City development may see an investment shortfall in near future for some of the development projects and can witness a massive jump in smart medical facilities development [18-23].

9. MEASUREMENT OF COVID-19 IMPACT ON SMART CITIES:

It should be noted that till all the population is not vaccinated, social distancing and lockdown restrictions found as an effective way to control the spread of deadly Corona Virus infections. However, after seeing worldwide economic recession due to prolonged lockdown in many countries, people have realized the fact that continuous lockdown cannot be the effective solution to curb the spread of the deadly COVID-19 pandemic. Recent announcements from some of the major countries including the USA and India to lift the lockdown restrictions and opening of business activities, makes the medical institutions around the world think that this can cause to sudden increase the spread of the COVID-19 pandemic and can be very well considered as the second wave of Corona infections. Under

such situations it is always better to have some ideas that how much impact will be there by gradually lifting the lockdown in selected areas.

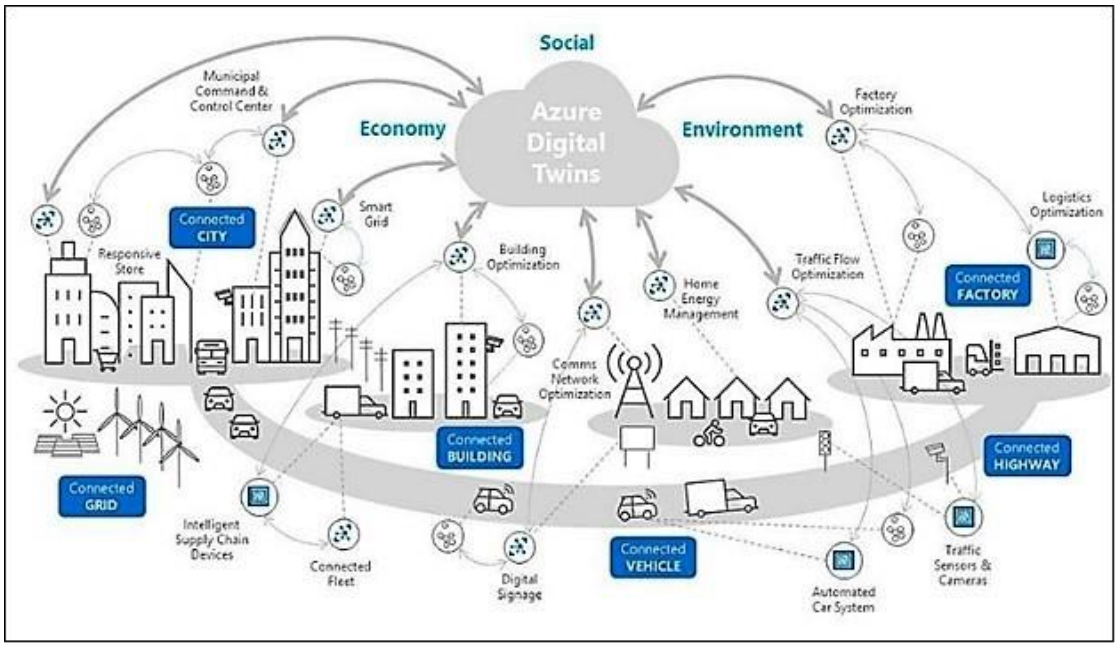

Figure -4: Azure Digital Twins for Smart City
(Source: Microsoft Azure Blog on Digital Twins)

Experts have claimed that to measure such impact on Smart City, Digital Twin of Smart Cities can help. Digital Twin is basically the virtual model of the system which can exhibit almost the same behavior when subjected to specific simulated situations like a real system which will undergo the same real situations and can behave in the same manner. This technology is possible with the help of advanced IoT sensors which are used to detect certain input conditions and with the help of augmented and virtual reality helps to build the digital model of the real system under the test and observations. Refer to figure 4, it has shown the block diagram of Azure based Digital Twin of a typical Smart City. Digital Twin of Smart City will offer great help for the governments and administration bodies to quickly assess the emergency situation and its impact on Smart City operation well ahead of time by checking the behavior with its Twin through simulated conditions. This can help Government to better analyze the situation and in determining the safety and economic implications while taking critical decisions such as relaxing lockdown or while imposing fresh lockdown. Also, it will greatly improve the government's ability while making new policies for Smart Cities. Virginia University's Biocomplexity Institute has developed a Digital Twin Simulation Platform for Smart City that could help local government authorities to analyze and better anticipate the COVID-19 spread, which can also help the local government in understanding the impact of Corona virus-related policies. It should be noted that earlier Digital Twins for Smart Cities were used to improve disaster management mostly, however in the COVID-19 crisis phase, Digital Twins of Smart Cities are used for better analysis and management of COVID-19 pandemic.

10. CAN SMART CITIES WIN THE FIGHT AGAINST COVID-19:

COVID-19 pandemic has literally paralyzed the worldwide economy by forcing prolonged lockdown in many countries and by imposing stringent restrictions while performing day-to-day essential activities. COVID-19 devastating impact on governments and civil societies has made a deep scar and wound which will take a long time for healing. Global scientists are making their best efforts to have clinically proven and reliable vaccine for COVID-19 should be available at the earliest, but till now most of the COVID-19 Vaccines are in trial stage and not found 100% effective. Having said all this, does it mean that mankind is going to lose hope? The answer is definitely NO. Smart Cities with Smart infrastructure are in fact helping the governments in the best fight with the COVID-19 pandemic [24-29]. Worldwide developed, more developed and developing countries are effectively using sophisticated technology-enabled tools of Smart City such as e-governance, telemedicine, e-consultation, GIS-enabled monitoring system, Mobile App enabled alert and notification system augmented and virtual reality-based digital twins to assess and analyze COVID-19 pandemic effect. Smart Cities have also emphasized the importance of the digital transformation in many forms of work such as online virtual education, remote work and executions, teleconsultations, online trading, e-commerce platform, and many such environmentally friendly practices which have resulted into drastic reduction in the carbon footprint, noise pollution, traffic, and its congestions. With so many tools and technologies in hand, Smart Cities are found as an effective weapon to many countries governments to fight against the deadly coronavirus pandemic. It should also be noted that the investments made in relevant tools and technologies related to Smart City medical infrastructure development can be used in other urban cities and towns in countries where Smart Cities are not set up and built as of now. The results that we have so far in curbing the spread of COVID-19 due to Smart City technologies, are making non-developed and or underdeveloped countries as well to initiate Smart Cities setting up and building. Smart Cities have greatly enhanced the concept of public-private partnership (PPP), and the collaboration between the City administration authorities including municipalities and the innovation ecosystem in fighting against the deadly COVID-19 pandemic. No doubt that such a framework is very effective in bridging capability gaps and needs and thereby it is sure that in the coming days, Smart Cities shall definitely win the war against COVID-19.

11. SMART CITIES DEVELOPMENT AND OPERATIONS POST COVID-19:

It is true that due to COVID-19, we need to now make some of the practices as part of life on a continuous basis such as social distancing, hygiene maintains, washing hands periodically in a day, wearing the mask, readiness for medical emergencies, and so on. Definitely, this also has impacted the way Smart Cities are developed, operated, and maintained. It is widely accepted that the COVID-19 pandemic has made us rethink and reorder the economic and governance landscape across the globe, it has also necessitated reprioritization of many of the things and now the focus has directed in specific sectors and areas such as medical, disaster management, remote operations, virtualization, eCommerce, online transactions,

cybersecurity, etc. Thus, it is clear that post COVID-19 environment has shifted focus and priorities and brought more emphasis on certain aspects such as accelerating medical and healthcare infrastructures, efficient deployment of mass health services, health surveillance, health insurance, and remote Medicare services. For Smart Cities, the new mantra has emerged and that is to accelerate health services at larger scale using the latest tools and technologies. Enable telemedicine helpline, facilitate remote operations, allow contactless transactions, and keep the bandwidth of the service free to tackle emergency crises. “Many of the changed requirements and behaviours by the pandemic such as touchless, safety-oriented, community resilience, etc. will persist even when the crisis wanes,” according to Gartner.

The social and economic disruption due to COVID-19 pandemic situation has impacted even the tool and technologies to a greater extent. For example, it is now obvious that IoT sensors are in more demand than ever before, in operating smart infrastructure and Smart buildings, due to their facilitation of enabling the remote data-driven operation to present true monitoring and operational scenarios. According to Gartner Report-Market Trends: 5 Smart City IoT Deployment Trends to Drive Innovation Opportunities, post-COVID-19, IoT shall play an important role in smart cities due to the demanding focus on safe and secure connected building, smart infrastructure for city operation, such as road toll collection through contactless technology, city asset tracking, smart traffic management, smart metering and assisted living, outdoor surveillance. The Gartner Report also noted that In post-COVID-19 Smart Cities, technologies such as Artificial intelligence, IoT along with digital twins, can facilitate predictive modelling techniques which can enable Smart Cities to determine safety, security and effective implementation of various policies useful to deal with any pandemic situations.

It should be noted that during COVID-19 some of the Smart Cities (such as Taipei, Seoul, Hongkong, Singapore) performed excellently over others in dealing with the pandemic situation quickly and effectively not because they already had experience of dealing with similar virus pandemic situations like Severe Acute Respiratory Syndrome (SARS), but due to their effective and immediate actions in the deployment of smart technologies which greatly assisted them to tackle crises at the initial stage itself.

Post COVID-19 can also possibly make some of today's "nice to have" services as essential services such as digital transformation, smart health monitoring, telemedicine, tele-counselling, Virtual Doctor, assets hygiene, smart isolation wards, and so on. Some SMEs and key stakeholders think that COVID-19 is just a short obstacle in the Smart Cities growth path due to reduced budgets and shifting priorities, however, post COVID-19, the Smart Cities can witness a huge jump in technology investment and deployment to enable city residents better and fear-free life. We are sure that during and after the COVID-19 pandemic, our shifting priorities and focus can only make Smart Cities smarter and better.

12. CONCLUSION:

The COVID-19 pandemic has changed the day to day activities and the way we were living our life so far to a significant extent. Social distancing, maintaining

cleanliness, contactless transactions are now becoming norms. Smart Cities also have been forced to shift their priorities and now Smart Cities are more focusing on building Smart Medical Services such as Telemedicine, Virtual Doctor, powerful Medical Infrastructure, Smart Isolation Wards, dedicated Command Control Centres to effectively tackle any pandemic situation and so on. Due to severe budget cut and prolonged imposed lockdown due COVID-19, Smart Cities are giving lower priority to services such as building Tourism spots, entertainment Parks, Social Gathering events and similar such activities. On the other hand, due to COVID-19 pandemic some benefits are also seen for example due to extended lockdown, many Smart Cities witnessed significant improvement in air quality, the pollution reduced drastically and citizens could breathe fresh air, also many river waters which were polluted from log time due to continuous dumping of waste, seen improvement in the overall quality of water and water start looking very clean. It is also revealed that despite poor economies, Smart Cities are in fact making good progress comparing to other businesses in building Smart Medical facilities since for such activities they have received generous funding support from Governments, NGOs, and Public Private Partnership bodies. Smart Cities are overall fighting well with COVID-19 pandemic and will continue to tackle smartly for any such pandemic in future. Post COVID-19, it is hoped by scientists, researchers, and SMEs that Smart Cities development will not slow down rather it will be accelerated to well cope with any unforeseen situations like COVID-19 Pandemic.

REFERENCES:

[1] Dr Gade, Dipak. (2019). Introduction to Smart Cities and Selected Literature Review. *International Journal of Advance and Innovative Research, 6/2* (VI), 7-15

[2] Hisham Abusaada & Abeer Elshater. (2020). COVID-19 Challenge, Information Technologies, and Smart Cities: Considerations for Well-Being. *International Journal of Community Well-Being, 3*, 417–424.

[3] Lauren M. Andersen, Stella R. Harden, Margaret M. Sugg, Jennifer D. Runkle Taylor E. Lundquist. (2021). Analyzing the spatial determinants of local COVID-19 transmission in the United States. *Elsevier, Science of the Total Environment 754*, 1-10.

[4] Bo Li,You Peng, He, Mingshu Wang, Tao Feng. (2021). Built environment and early infection of COVID-19 in urban districts: A case study of Huangzhou. *Elsevier, Sustainable Cities and Society, 66*, 1-10.

[5] Lorenz von Seidlein, Graham Alabaster, Jacqueline Deen, Jakob Knudsen. (2021). Crowding has consequences: Prevention and management of COVID-19 in informal urban settlements. *Elsevier, Building and Environment,188*, 1-9.

[6] Nenad N. Petrović, Vlado Dimovski, Judita Peterlin, Maja Meško, Vasja Roblek. (2021). Data-Driven Solutions in Smart Cities: The case of COVID-19 Apps. Proceedings of the World Wide Web Conference, 1-9.

[7] Ibrahim Abaker Targio Hashem, Absalom E. Ezugwu, Mohammed A. Al-Garadi, et al. (2020). A Machine Learning Solution Framework for

Combatting COVID-19 in Smart Cities from Multiple Dimensions. *medRxiv*, 1-68.

[8] Linda Hantrais, Paul Allin, Mihalis Kritikos, Melita Sogomonjan, Prathivadi B. Anand, Sonia Livingstone, Mark Williams & Martin Innes (2021) COVID-19 and the digital revolution, *Contemporary Social Science, 16*(2), 256-270.

[9] Mikiharu Arimura, Tran Vinh Ha, Kota Okumura, Takumi Asada. (2020). Changes in urban mobility in Sapporo city, Japan due to the COVID-19 emergency declarations. *Elsevier, Transportation Research Interdisciplinary Perspectives, 7*, 1-14

[10] Franck Fu, Kathleen L. Purvis-Roberts and Branwen Williams.(2020). Impact of the COVID-19 Pandemic Lockdown on Air Pollution in 20 Major Cities around the World. *MDPI, Atmosphere, 11*, 1-18.

[11] Zander S.Venter, Kristin Aunan, Sourangsu Chowdhury, Jos Lelieveld. (2021). Air pollution declines during COVID-19 lockdowns mitigate the global health burden, *ScienceDirect, Environmental Research,192*, 1-4.

[12] Ayyoob Sharifi, Amir Reza Khavarian-Garmsir.(2020).The COVID-19 pandemic: Impacts on cities and major lessons for urban planning, design, and management. *Elsevier, Science of the Total Environment, 749*, 1-14.

[13] Chunwen Xu, Xilian Luo, Chuck Yu and Shi-Jie Cao. (2020). The 2019-nCoV epidemic control strategies and future challenges of building healthy smart cities. *Sage, Indoor and Built Environment, 29*(5), 639–644.

[14] Klaus R. Kunzmann.(2020). Smart Cities After Covid-19: Ten Narratives. *Taylor & Francis, disP - The Planning Review, 56*(2), 20-31.

[15] Shukla, AK. (2020). COVID-19 crisis: Govt uses Smart City infrastructure to keep essential services rolling. Retrieved from *https://government.economictimes.indiatimes.com/* on May 30, 2021.

[16] Smart Cities Mission. (2020). Retrieved from *http://smartcities.gov.in/* on May 30, 2021.

[17] Smart Cities. (2020). Retrieved from *http://mohua.gov.in/cms/smart-cities*.php on May 30, 2021.

[18] Siva Soorya MT. (2020). How COVID accelerated smart city development. Retrieved from *https://gcn.com/* on May 30, 2021.

[19] Lara Williams. (2020). How COVID-19 is shifting 'smart city' priorities. Retrieved from *https://citymonitor.ai/* on May 30, 2021.

[20] Editors Smart City Hub. (2020). Digital twins of smart cities key to understanding impact of COVID-19 measures. Retrieved from *http://smartcityhub.com/* on May 30, 2021.

[21] Milly Xiang. (2020). Retrieved from *https://www.gartner.com/en/documents/3994916/market-trends-5-smart-city-iot-deployment-trends-to-driv* on May 30, 2021.

[22] Daniel G. Costa, João Paulo J. Peixoto. (2020). COVID-19 pandemic: a review of smart cities initiatives to face new outbreaks. *IET Smart Cities 2*(2), 64-73.

[23] Sara Eltarabily, Dalia Elghezanwy. (2020). Post-Pandemic Cities - The Impact of COVID-19 on Cities and Urban Design. *Architecture Research,10*(3), 75-84.

[24] Yusra Amir, Sanchari Deb, et al. (2021). Real World Solutions for Smart Cities Transportation to be Pandemic Ready. *IEEE Xplore, ICRCICN*, 159-164

[25] Zaheer Allam, David S. Jones. (2020). On the Coronavirus (COVID-19) Outbreak and the Smart City Network: Universal Data Sharing Standards Coupled with Artificial Intelligence (AI) to Benefit Urban Health Monitoring and Management, *MDPI, Healthcare 8*, 46, 1-9.

[26] María del Carmen Olmos-Gómez, Mónica Luque-Suárez, Soraya Mohamed-Mohamed and Jesús Manuel Cuevas-Rincón. (2020). Validation of the Smart City as a Sustainable Development Knowledge Tool: The Challenge of Using Technologies in Education during COVID-19, *MDPI, Sustainability, 12*, 8384, 1-18.

[27] Angeliki Kylili , Nicholas Afxentiou , et al. (2020): The role of Remote Working in smart cities: lessons learnt from COVID-19 pandemic. *Taylor & Francis, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 1-17

[28] Mohammad Shorfuzzaman,M., Shamim Hossain, et al. (2020) Towards the sustainable development of smart cities through mass video surveillance: A response to the COVID-19 pandemic Sustainable Cities and Society. *Elsevier, Sustainable Cities and Society, 64*, 1-11.

[29] Junyi Zhang. (2020). Transport policymaking that accounts for COVID-19 and future public health threats: A PASS approach. *Elsevier, Transport Policy, 99*, 405-418.

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4.	Class and description of the work	:	LITERARY/ DRAMATIC WORK
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6.	Language of the work	:	ENGLISH
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9.	Year and country of first publication and name, address and nationality of the publisher	:	2020 INDIA SRINIVAS PUBLICATION , UNIT OF SRINIVAS UNIVERSITY, A. SHAMA RAO FOUNDATION, G. H. S. ROAD, MANGALORE-575001 INDIAN
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11.	Names, addresses and nationalities of the owners of various rights comprising the copyright in the work and the extent of rights held by each, together with particulars of assignments and licences, if any	:	DIPAK SHAMLAL GADE , FLAT 402, SRI RAGHAVA ENCLAVE, PLOT NO 62, SRI PRABHUPADA TOWNSHIP, KONDAPUR, HYDERABAD-500084 INDIAN AITHAL P.S. , FLAT NO: 103, FANTASY RESIDENCY, KARNGALPADY, MANGALORE-575001 INDIAN
12.	Names, addresses and nationalities of other persons, if any, authorised to assign or licence of rights comprising the copyright	:	N.A.
13.	If the work is an 'Artistic work', the location of the original work, including name, address and nationality of the person in possession of the work. (In the case of an architectural work, the year of completion of the work should also be shown).	:	N.A.
14.	If the work is an 'Artistic work' which is used or capable of being used in relation to any goods or services, the application should include a certification from the Registrar of Trade Marks in terms of the provision to Sub-Section (i) of Section 45 of the Copyright Act, 1957.	:	N.A.
15.	If the work is an 'Artistic work', whether it is registered under the Designs Act 2000 if yes give details.	:	N.A.
16.	If the [illegible] rtistic work', capable of being registered as a [illegible] gns Act 2000.whether it has been applied to an [illegible] trial process and ,if yes ,the number of times	:	N.A.
17.		:	

816/2021-CO/L

Da[illegible]: 12/01/2021

Date of Receipt : 12/01/2021

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DEPUTY REGISTRAR OF COPYRIGHTS

APPENDIX -2: COPYRIGHT – 02 – Research Paper

Copyright Office
Government of India

सत्यमेव जयते

Extracts from the Register of Copyrights

Dated : 10/06/2021

1.	Registration Number	:	**L-104292/2021**
2.	Name, address and nationality of the applicant	:	DR. DIPAK SHAMLAL GADE , FLAT 402, SRI RAGHAVA ENCLAVE, PLOT NO: 62, SRI PRABHUPADA TOWNSHIP, KONDAPUR, NEAR LUXOR APARTMENT, HYDERABAD, TELANGANA-500084 INDIAN
3.	Nature of the applicant's interest in the copyright of the work	:	AUTHOR
4.	Class and description of the work	:	LITERARY/ DRAMATIC WORK
5.	Title of the work	:	SMART CITY WASTE MANAGEMENT THROUGH ICT AND IOT DRIVEN SOLUTION
6.	Language of the work	:	ENGLISH
7.	Name, address and nationality of the author and if the author is deceased, date of his decease	:	DIPAK SHAMLAL GADE , FLAT 402, SRI RAGHAVA ENCLAVE, PLOT NO: 62, SRI PRABHUPADA TOWNSHIP, KONDAPUR, NEAR LUXOR APARTMENT, HYDERABAD, TELANGANA-500084 INDIAN P. S. AITHAL , SRINIVAS UNIVERSITY, VICE CHANCELLOR, SRINIVAS NAGAR, MUKKA, SURATHKAL, MANGALORE, KARNATAKA, INDIA-575023 INDIAN
8.	Whether the work is published or unpublished	:	PUBLISHED
9.	Year and country of first publication and name, address and nationality of the publisher	:	2021 INDIA SRINIVAS PUBLICATION , SRINIVAS UNIVERSITY, SRINIVAS NAGAR, MUKKA, SURATHKAL, MANGALORE, KARNATAKA, INDIA-575023 INDIAN
10.	Years and countries of subsequent publications, if any, and names, addresses and nationalities of the publishers	:	N.A.
11.	Names, addresses and nationalities of the owners of various rights comprising the copyright in the work and the extent of rights held by each, together with particulars of assignments and licences, if any	:	DIPAK SHAMLAL GADE , FLAT 402, SRI RAGHAVA ENCLAVE, PLOT NO: 62, SRI PRABHUPADA TOWNSHIP, KONDAPUR, NEAR LUXOR APARTMENT, HYDERABAD, TELANGANA-500084 INDIAN P. S. AITHAL , SRINIVAS UNIVERSITY, VICE CHANCELLOR, SRINIVAS NAGAR, MUKKA, SURATHKAL, MANGALORE, KARNATAKA, INDIA-575023 INDIAN
12.	Names, addresses and nationalities of other persons, if any, authorised to assign or licence of rights comprising the copyright	:	N.A.
13.	If the work is an 'Artistic work', the location of the original work, including name, address and nationality of the person in possession of the work. (In the case of an architectural work, the year of completion of the work should also be shown).	:	N.A.
14.	If the work is an 'Artistic work' which is used or capable of being used in relation to any goods or services, the application should include a certification from the Registrar of Trade Marks in terms of the provision to Sub-Section (i) of Section 45 of the Copyright Act, 1957.	:	N.A.
15.	If the w[illegible] 'Artistic work', whether it is registered under the De[illegible] f yes give details.	:	N.A.
16.	[illegible]ic work', capable of being registered as a [illegible]s Act 2000.whether it has been applied to an [illegible]ial process and ,if yes ,the number of times	:	N.A.
17.		:	

Di[illegible] 10737/2021-CO/L

Date of Application : 06/05/2021

Date of Receipt : 06/05/2021

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DEPUTY REGISTRAR OF COPYRIGHTS