AN INTEGRATED ICT BASED FRAMEWORK FOR SMART SUSTAINABLE CITIES IN A TROPICAL ENVIRONMENT

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ABSTRACT

There is major demographic shift occurring globally, for the first time in human history more people live in cities than in a rural environment. It is estimated that today approximately 50 % of the world's population lives in an urban environment and this is estimated to grow to up to 70 % by 2050. Tropical areas are an increasingly critical region on the world map, home to more than 40 % of the world's population and generating about 20 % of global economic output.

Traditional approaches of reducing carbon foot-print of cities include (i) alternative sources of energy, such as solar, (ii) environment friendly living such as recycling, and development of energy efficient equipment and buildings. An integrated approach of managing energy consumption and related sustainable activities within a city with the help of Information & Communications Technologies (ICT) can enable capture of energy and sustainability data at the finest granularity level. This data can be used to develop analytics and to manage the overall sustainable behavior of city.

This paper describes an integrated framework for managing various aspects of cities that would balance / optimize the various complex and conflicting priorities such as safety, security, efficient city services, education, and health care with the objective of reducing overall energy consumption. Information is power. Such information would also enable people and managers of the city to benchmark with other equivalent areas, adopt best practices and develop best of breed sustainable policies.

This paper will examine the role of ICT in a smart eco-city and propose a robust and methodologically sound approach for a sustainable energy efficient eco-city which will tie together the end-user (citizen) experience across the multiple dimensions ranging from healthcare, living, workplace, shopping, education, transport and government above with the internet and its technology backbone infrastructure.

INTRODUCTION

Across the world, cities account between 60-80 % of the global energy consumption and greenhouse gas (GHG) emissions.

The number of "mega-cities" defined in terms of population in the excess of 10 million, has grown from 3 in 1975 to over 25 over the next 10-15 years (Toppeta, 2011). There are currently 102 smart city projects running worldwide including Songdo ($42B) in Korea, Lavasa ($100M), Kochi, DMIC Corridor in India, 18+ cities in China including Ningbo ($6B), Wuxi, Cafeidian, Beijing, Shanghai, Shenyang, Masdar ($22B) in Abu Dhabi. Tropical Asia features predominantly in this list of "mega cities".

There are many physical infrastructural aspects of a typical city among them the following are pivotal :

a. Buildings
b. Utilities & Energy
c. Mobility (Transport)
d. Water Management

ICT forms one the great equalizers to help balance / optimize against the various complex and conflicting priorities such as safety and security, efficient city services, education, and health care. ICT is what makes the city "smart", enabling connectivity, aggregate and analyze real-time and historical data to take appropriate action, facilitate social and other interactions, helping spur economic, social, and environmental sustainability, and therefore enhance the quality of life for citizens.

This paper examines the role of ICT in a smart eco-city and proposes a robust and methodologically sound approach in the form of an integrated framework which ties both physical infrastructure and information technologies (ICT) for a sustainable energy efficient smart eco-city.

PHYSICAL INFRASTRUCTURE ELEMENTS

In reviewing the literature, we found that there has been considerable research related to "smart and sustainable" for each of the four infrastructure pivots mentioned earlier – Buildings, Mobility, Utilities/Energy and Water. The impact of this research has been considerable in advancing the state of art in their individual "siloed" domains but in aggregate has not addressed the relationships and influence of one vertical domain on another for example the relationship between utilities & energy and water or mobility (transport).

Buildings: Buildings form undoubtedly the largest footprint in high-dense or mega cities. Stifter and Kathan (2011) describe buildings in such future smart cities as key infrastructural component in leveraging the fact that high-dense cities lack space and

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buildings in such places predominantly occupy more than two-thirds of gross area. The building and city infrastructure represents the state of the art in civil engineering. In recent times, efforts in minimizing energy consumption in buildings became fore runner than simple architecture.

Alarmingly, research evidences (Price, Michaelis et al. 1998, de Ia Rue du Can and Price 2008) are available today that buildings – places of work, living, navigation & leisure in urban environment, have been one of the greatest contributor to greenhouse gas emissions (GHG). In addition, several climate scientists and researchers in (Rizwan, Dennis et al. 2008, Yang, Lau et al. 2010, Loughner, Allen et al. 2012) have found that urban geometry constituting of mass of buildings largely contribute to the imbalance in urban microclimate through a phenomenon widely noticed as Urban Heat Island (UHI). In addition, rapid efforts are underway through constitutionalizing building codes and standards such as U.S. LEED, Green Mark Scheme, BREAM among many, which are making striving efforts through efficient use of building components, systems and practices to keep building's ecological footprint under control.

Many proposed frameworks & operational models through case studies (Agarwal, Weng et al. 2011, Rezaie, Esmailzadeh et al. 2011, Sioshansi 2011, Milan, Bojesen et al. 2012) serve promising evidence to potentially meeting the rising energy demands through distributed and decentralized energy hubs in such cities. With the technological competence available around the corner, the concept of building integrated micro grid (BIMG) evolved. Combining already available power generation technologies, predominantly photovoltaics (PV) in the building context to conceptualize building integrated photovoltaics (BIPV). Sioshansi (2011) observed that BIMG could offset 90% of building's tertiary energy loads, which operate fundamentally on direct current (DC) power conveniently by having a DC micro grid for the building scale. This made realizing net-zero energy buildings (nZEB) practical.

Collection of these features makes conventional buildings 'smarter'. By this we mean, various active building systems like HVAC, lighting, mobility, plumbing etc. We can now interact with passive systems like envelope (facade, shades) through ICT to optimize operational energy efficiency without compromising occupancy comfort. Building Management Systems (BMS) help achieve this through central co-operative actions among these disparate systems. Conventionally, BMS is achieved through wired means such as Supervisory Control and Data Acquisition (SCADA) (Figueiredo and Sá da Costa 2012) while in recent times several intelligent building management systems combined pervasive wireless technology non-invasively (Oksa, Soini et al. 2008, Wong and Li 2009).

Utilities & Energy: Constantly making new peaks in terms of demand, energy is critically required for plethora of tasks & activities ranging across city's day-to-day events. The three most important aspect of Energy are (1) exploration for new sources of energy (2) efficient management of existing non-renewable energy sources (3) effectively combining the two above. While first is beyond the scope of this study but the other two aspects can be addressed with the help of smart grids, smart energy management systems and so on in this work.

A major constraint of energy is its efficient storage. To overcome this constraint, we need a system of production and consumption of energy in real time. Smart grids are the examples of such innovative architecture. Smart grids (Massoud Amin and Wollenberg 2005) are the combination of conventional & modern non-fossil based energy systems glued seamlessly by advanced ICT technologies. This step forward leverages on totally desperate energy systems - few centralized and many distributed sources talking to each other in real-time. While there is no single definition of the Smart Grid, the expectation is that the current grid network with advanced sensors and actuators and a highly secure networking infrastructure to improve grid efficiency, performance, and reliability..

Agarwal et al (2007) presented technological components & their use methods to demonstrate 'micro grid' framework at campus or city scale which conceptualizes a framework addressing the integrity of diverse forms of distributed energy sources - fossil & non-fossil based, local co-generation and storage facilities.

Zero Net Energy (ZNE) concepts can be extended to the scale of campuses, complex, town or even a city. As a word of caution (Zhivov, Liesen et al. 2011) study reminds that for ZNE to be applied at wide scale, seamless blend of energy conservation through efficient systems & practises through building management systems at every individual building level, utility management and control, and power distribution systems all should have capability to integrate to on-site renewable in real-time.

Platt, Berry et al (2012) highlight the challenge in realizing such a smart grid, which is limiting enthusiasm for its large-scale adoption. Hence, as an alternate Platt proposes *microgrids*, which are a collection of geographically proximate, electrically connected loads and generators. It's tree-like structure strikes advantage over the conventional radial structure of the grid, which forms the core challenge in modernizing the control and operation of contemporary power system.

Orecchini and Santiangeli (2011) assert that sustainable energy future foresees no predominance of one source over the other but a proper energy mix, based on locally available resources and needs. This necessitates need for intelligent management of a complete set of energy sources and vectors such as electricity, heat, hydrogen, bio- or non bio-fuels, which goes beyond smart grid to an Intelligent Energy Networks (IEN).

Inspired by the way revolutionary 'Internet' technology has been embraced by the world, Katz et al (2011) brings out the principles in formulating a new information-centric energy network for 21st century. This approach can help achieve improved efficiency in how energy is generated, distributed, consumed and how to agilely dispatch it to where it is needed by appropriately integrating intermittent energy sources and loads to match available energy.

Mobility: Mobility (transport) is one of the four significant pillars of Smart city framework. It broadly includes different ways in which dwellers of a city communicate from one place to another. It comprises mainly the public and the private transport. The residents of a smart city expects the transportations facilities to be safe, low cost, time efficient, comfortable as well as environmental friendly (Haque, Chin et al. 2013).

In the field of Mobility, researchers have developed innovative, cost efficient and environment friendly ways of transportation. The most momentous are innovations in area of electric and solar power vehicles. Though there are multiple challenges with cost and efficiency of these vehicles, indeed it is a revolutionary move in area of future transportations

To examine the different available modes of transportations based on the aforementioned expectations, there is a need to define parameters quantitatively to judge the different mobility solutions. Safety of a transport solution can be determined by number of accidents per unit time caused due to particular mode of transport system. There is always a trade-off between cost and time efficiency when transportation is concerned. However, with help of efficient Mass Rapid Transit Systems (MRT), a balance between cost and time can be maintained for the majority of the population of the Smart City. There are various dimensions to measure the environmental impact due to transportation. The amount of different poisonous gases in the atmosphere of the city per unit volume of air determines the environment impact (Haque, Chin et al. 2013). Going forward, there is a tremendous need for trans- potation modes, which are electric, powered or runs on green fuels like Liquefied Petroleum Gas (LPG).

Gunnar and Kent (2009) have discussed a smart-transportation framework where the right transportation mechanism needs to be selected best of available options, quality of life to be provided, energy consumption and pollution impact. Kim et al (2010) have proposed a scheme for optimal job ordering in electric vehicle charging station. For example, if there is a limited charging station of scarcity in available electrical energy, the smart city framework needs selection the vehicles to charge to maintain all aspects of a city. Such decisions on mobility not only influence the transportation aspects of a smart city but all other aspects of a city life.

To improve the quality of mobility, we need to integrate the mobility pillar with the ICT infrastructure layer. This will enable the smart decisions at both individual level (for example going to office by metro rail vs. private vehicles) and at the community level (expanding the road will allow more frequent bus services, which may be better than expanding another metro-rail network in the area). This layer not only connects mobility with rest of the three major pillars of smart city, it also connects to the above layers in the proposed framework. An example application would be to determine the optimal transport mechanism (mobility pillar) from location to another location if currently an event is going in the football stadium (building pillar).

Water: With water forming the most vital component (Ausubel and Herman 1988) of any urban livelihood combined with the fact that water as a resource is at its critical tipping point in many urban cities (Brown, Keath et al. 2008), it is relevant to compose water in the context of future smart city framework.

Water and wastewater treatment is an essential ingredient in the successful and sustainable operation of an urban environment. Some needs include :

- Minimize water consumption, ensure water quality, maintain and operate the system efficiently under consistent operation
- Automatically detect, analyze and respond to malfunctions and optimize asset use.
- Include various sources of water both from conventional sources, surface and ground water, from reused water from processes like desalination.

There is a clear analogy between applying "smart" technologies to water infrastructure and smart-grid technologies, which are being proposed and tested to not only make the grid run more efficiently but also use more renewable energies. Water agencies can optimize their operations with improved data gathering and processing for example, real time on-line leakage detection mechanisms, water quality indices and better water security.

Olsson (2012) discusses that instrumentation, control and automation (ICA) is an essential ingredient for water and wastewater treatment systems. The scope of such ICA includes (1) Keeping the plant running (under operation: mostly controlled automatically) (2) satisfying effluent requirements (automatic control of dissolved oxygen, sludge age, return sludge etc) and (3) maximizing energy efficiency and optimizing plant capacity.

Some roles where ICT shall continue to play key role in a smart water grid as presented in (Olsson 2012) includes

- Modelling for control through sensor and actuators
- Data analysis and monitoring including leaks
- process control aspects in waste water treatment
- Controlling drinking water system

Nguyen, Zhang et al. (2010) have developed an intelligent model to categorize residential water end use events. The aim of this study was to disaggregate water flow data collected from high resolution smart water meters into different water end use categories such as shower, washing clothes etc.). The researchers developed a complex pattern matching algorithms, which are able to automatically categorise collected flow trace data points received from wireless data loggers into particular water end-use categories. They have conceptualized a Knowledge Management System (KMS), which is able to collect real-time water consumption data through a smart water metering system, transfer and store the data into a knowledge repository, analyze and disaggregate data into a registry of end use events.

Shihu (2011) proposes an Advanced Metering Infrastructure (AMI) to achieve the goals of water distribution network optimization. Online flow, pressure and water quality data is essential to the hydraulic and water quality model calibration that make the water system management digital and reasonable. A set of online monitor sensors including smart flow and pressure meters, water quality sensors, smart water consumption meters and leakage monitoring sensors were installed in the water distribution networks which was connected to a SCADA system.

Lima and Navas (2012) propose an automated system for remote metering and sub-metering of water and electricity (internal to the residence, installed at interest points) and then integrated into a structured knowledge tool. Such a tool will enable utilities to allow their customers to analyze monitor and control their consumption of these services in real time. Such an integrated approach provides customers and utility companies with compiled reports containing the historical use, daily and hourly forecasts, and projected savings due to changes in consumption habits and/or use of more efficient equipment.

Allen, Preis et al. (2012) present an end to end, integrated hardware and software centric, on-line, real time diagnostic and monitoring system called Water Wise, which was successfully implemented in Singapore to optimize system operations, manage leakage control more effectively, minimize disruptive repairs and maintenance. Water Wise's sensing and software platforms have helped improve the operational efficiency of the water supply system in Singapore.

ICT ACTING AS AN INTEGRATOR

ICT forms the nervous system of the most of the models proposed for future smart cities. Authors have categorized them as Internet of Things (IoT) and Internet of Services (IoS). The first represents the infrastructure and later represents the applications of ICT (Hernández-Muñoz, Vercher et al. 2011). Current ICT infrastructure in the cities cannot support the requirement of Smart cities in terms of data collection and processing.

In the last decade, the research community has perceived and acknowledged the big innovations, which took place in ICT infrastructure and its applications. It includes the major telecom platform, ubiquitous sensor networks (handheld, distributed ambient sensing & actuating nodes) and data centres (including processing and storage). We have seen emergence of 3G/4G telecom and data networks which provides enormous bandwidth. On the other hand, sensors have become smarter and more efficient and are available to accurately measure any phenomenon of a city. ICT applications comprise of the intelligent integrated applications, which runs on ICT infrastructure, which hides the underlying complex system and offers simplistic means for the end-users with rich and easy interaction. Some examples are e-commerce, telemedicine etc. In the context of smart cities, ICT provides the connectivity among the various backbone activities of any typical city. It offers end-user with intuitive means to take smart decisions. The innovations in ICT provided an opportunity for researchers in aforementioned domains to collaborate in conceptualizing and designing Smart cities framework. This leads to an integrated architectural model of Smart Cities.

EXISTING INDUSTRY CITY FRAMEWORKS

Recognizing that ICT is a major facet in Smart and Sustainable cities, a variety of leading industry players such as IBM, LG, Living PlanIT have launched platforms for the urban landscape.

IBM (IBM 2013) (Michael Kehoe 2011) has launched a "Smarter Planet" initiative which consists of a multifaceted approach to developing more sustainable and intelligent cities and therefore the planet. From its vast experience working with many urban environments across the world, it has developed key domains that factor into cities. These include Analytics, Buildings, Cities, Communications, Computing, Education, Energy, Government, Healthcare, Retail, Safety & Security, Traffic and Transportation and Sustainability.

IBM believes that across all of these domains, there will always be capabilities or attributes in a city that fall "in between" – hence the need to aggregate and "integrate" cross-domain information. All the relevant information can be collected, analyzed and then appropriate action taken by the decision makers or city administration.

The initial focus is on critical, city-wide issues which need to be addressed via the integration and analysis of real time and historical data from the following four domains - public safety, transport/traffic management and water management. In a smart city, this central repository of information can be classified as an "Intelligent Operations Center (IOC)" which acts as a central "city dashboard". Different an analytical capabilities and rules engines for the different domains are built into the IOC.

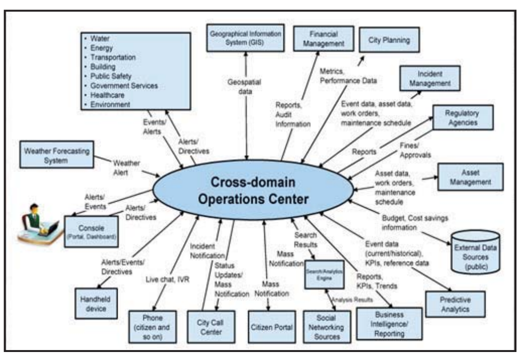

Figure 1 IBM Intelligent Operations Center

The detailed technology infrastructure beneath this IOC is reflected in an architecture which has 3 tenets: Instrumented, Interconnected and Intelligent.

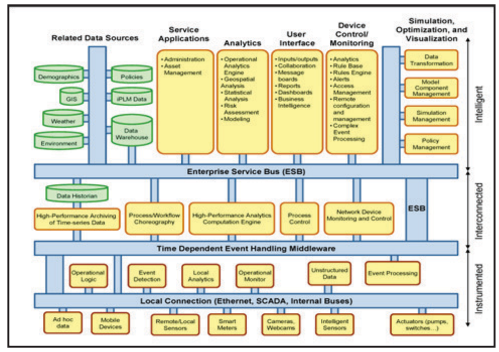

Figure 2 IBM Smarter Planet Platform

Living PlanIT (LivingPlanIT 2013) has developed an operating system for cities that looks just like a PC operating system that it calls UrbanOS or the Platform for the 'Industrialization of the Internet'. It intelligently monitors and automates traffic lights, air-conditioning, water management systems which influence the quality of life while driving down the costs of operating a city. In their view, the city is a network which behaves analogous to the nervous system in the human body (think buildings and streets) with many distributed sensors gathering data and then synthesizing actions.

UrbanOS is a programming platform and operating infrastructure which collects, aggregates, orchestrates and analyzes the data from the sensor and intelligent device environment distributed across the different sub-systems: buildings, traffic, energy, water, waste, education, and transportation. It has four major layers / components: End-Use Applications, Supervisory Layer, Controls and Sensory or Hardware.

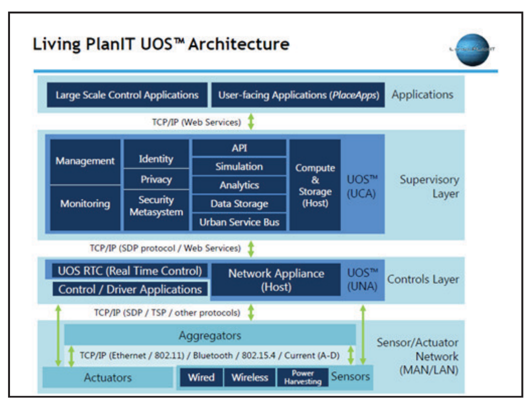

Figure 3 Living PlanIT Urban OS Architecture

With an open Applications Programming Interface (OpenAPI) approach, the premise is that end-use applications will be written by partners who are best in class.

LGCNS (LGCNS 2013) has developed a Smart Green City Solution which uses ICT as an integrator for city services. It includes Digital Signage, Environmental Monitoring, Intelligent Traffic, Intelligent Street lighting, Smart Metering, Smart green homes, Smart Green Buildings, Smart Grid, New and Renewable Energies, Water Management, Maintenance, Operations, Surveillance and finally an Integrated Control Center similar to IBM to pull it altogether. The solution enables a variety of devices and facilities to be controlled by a single system just like a computer OS facilitates and hardware components.

Figure 4 LGCNS Smart City Solution

PROPOSED FRAMEWORK

Based on the various efforts that have been observed, it is proposed to have a unifying approach. Consider a set of foundational pillars (Buildings, Utilities & Energy, Mobility and Water), which are integrated by several layers of ICT centric technologies. This enables the cross-fertilization of combined solutions transcending multiple verticals for example, Energy and Water, Mobility and Water, Buildings, Energy and Mobility. This will lead to a true optimized citywide solution.

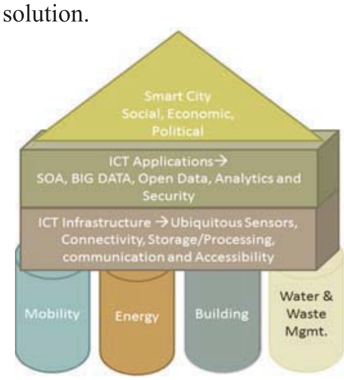

Figure 5 Proposed ICT based Framework for Smart Cities

Since the four pillars have been discussed at length in this paper we shall now focus on the three ICT layers.
(1) ICT Infrastructure
(2) ICT Core Applications
(3) End User Applications and Experiences.

<u>ICT Infrastructure</u> This layer is the interfaces with the core pillar of proposed architecture in the bottom and supports the ICT application layer on the top. The main functions of this layer are the following:

Sensors and their networks: The Sensors are hardware devices, which monitors different resources. These sensors are built in such way that these perform without notifying their presence in a system. These are tailored and customized for a particular purpose. The sensors are categorized broadly into two groups. They are (1) Homogeneous sensor: group of sensors of same purpose and interface (2) Heterogeneous sensors: group of sensors having different purpose and interfaces. In Smart City perspective, sensors constitute a smart environment (Filipponi, Vitaletti et al. 2010). It provides an eco-system in which different objects interact with each other. The major use of sensors in ICT infrastructure layer is monitoring and control. The most recent development of sensors for the Smartcities are categorized as Ubiquitous Sensor Networks (USN) (Hernández-Muñoz, Vercher et al. 2011) .

Communications and connectivity: Communications form the nervous system of ICT infrastructure. With 4th Generation (4G) of telecom technology, Smart cities have access to enormous bandwidth, which can support wide range of ICT applications. As the cost of deployment of a communication technology in a smart city is a huge cost, pre-planning and choice of technology may reduce the initial cost of deployment. This requires a fine-grained calculation of bandwidth and connectivity requirement of a smart city ahead of its deployment. At the same time, low-power, low bandwidth wireless networks like Zigbee are developed exclusive for such ubiquitous indoor wireless networks. And devices such as gateways and edge-routers (Jiang, Dawson-Haggerty et al. 2009) are used for necessitating low power wireless personal area networks (LoWPAN) onto Wide area network (WAN).

Storage/Processing: With recent advancement in ICT, we notice a paradigm shift in the way people use the computing resources. Laptops and Desktops are being replaced by the large-scale server farms. There are some fundamental challenges in these models. They are (1) storage (2) processing (3) security, (4) latency and (5) Power. The solutions to first three changes are dependent on innovation in datacentres across the globe but the later two are dependent on the location of the datacentre. The latency of any application increases with increase in distance from user to the datacentre, which host the application. Therefore, the Smart city design should incorporate scope for large-scale data centre, which can host city specific application with low latency. The power consumption in modern datacentre is in range of Mega Watts of energy, so the energy planning of smart city should take into account this requirement.

ICT Applications are mainly divided into two groups. They are (1) Core applications (2) User applications.

The core applications are used for monitoring, maintenance and proper functioning of the Smart cities. These applications provides interface to the ICT infrastructure layer. The major functions are data gathering, storage, security and accessibility. The core applications will need to be provided by various agencies. For example, an energy agency can provide interfaces to access various energy level data such as available energy, predicted generation capacity. The transportation agency can provide the interfaces to for retrieving data about current traffic conditions, any breakage in metro rail, current petroleum price, cost, schedule of bus, bus fare etc. The building department can provide the data related to current occupancy in each building, surrounding conditions (temperature, humidity).

The user level applications will be developed by commercial or non-commercial entities (such as University labs, open source communities) using these interfaces. For example, an optimal route application may need to use interface provided by transportation agency, energy agency and building department to combine the data received from all these sources and decide optimally which is the best route and mode to move from one location of the city to another location. Such a framework will allow innovative companies and services to come up using the core application framework.

End-Use Applications & Experiences Technology and its underpinnings (or overpinning in terms of applications) carry little or no meaning to the average citizen or public who benefits from it. People can relate to technology only in terms of what they experience in their daily lives and can be epitomized in the form of “end-user experiences”. Each end-user experience will be based on a set of vertical “industry” or “context” specific solutions. Some examples include:

- Building Management Solutions
- Green focused Social Applications
- Smart Homes
- Smart Office Solutions
- Smart Car Park Management
- Smart Water
- Smart Hospitals

CONCLUSION

Information is power & leverage this power of information technology is wisdom. Such information would also enable people and managers of the city to benchmark their sustainable practices with their counterpart cities and thus develop best practices and breed sustainable policies.

This paper has discussed the 4 pivotal pillars related to cities – Buildings, Utilities & Energy, Mobility and Water. In order to integrate these pillars into a comprehensive city solution, ICT is seen as the unification layer. The ICT aspects have been broken into 3 layers – starting with the infrastructure, core applications and finally the “visible” end user applications and experiences.

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