The Application of the Internet of Things to Enhance Urban Sustainability

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This article examines opportunities and challenges faced by planners when applying Internet of Things (IoT) as a tool to facilitate urban sustainable development in the context of the Smart Cities movement. As an important element in the Smart Cities concept, IoT is expected to enhance urban sustainability through the sensor network that detects and transmits environmental data. However, there are still various challenges that add a layer of difficulty to the process of using IoT to achieve this goal. The article first identifies the concept and relationship of three key background issues: Smart Cities, Internet of Things, and sustainability. Then the article investigates the challenges of using IoT technology to assist urban sustainability in various aspects. Next, the article proposes possible responses to those challenges through three fields of application: waste management, smart streetlights, and smart homes. It is of great importance for urban planners to understand the complexity of these challenges due to the interdisciplinary nature of such applications. Therefore, it is essential for the field of urban planning to collaborate with other sectors to better utilize IoT technologies towards sustainability.

This article examines the challenges of applying the Internet of Things (IoT) technologies in the context of the Smart Cities for the purpose of enhancing sustainability at the urban scale. Specifically, the article overviews the concept, features, and challenges of IoT as a building block of Smart Cities notion.[1] The article serves as a background survey for urban planners who wish to integrate their design practice within the context of the Smart Cities and the rapid development of information-communication technology. The challenges posed here are inherently cross-disciplinary and cannot solely be solved by physical design. However, these challenges can still inform designers of potential directions in practice and collaboration.

Definition of Research Area

The research is framed with the following key topics:

Smart Cities

The term "Smart Cities" developed within the context of rapid urbanization and the consequent challenges with economic development, resource management, energy use, and environmental pollution.[2] The term contains various meanings in its political, sociological, ecological, and technological aspects. This article focuses on the application of information-communication technology to "engage citizens, deliver city services, and enhance urban systems" according to the Smart Cities and Sustainability Initiative by the American Planning Association (APA).[3]

Among the various notions associated with Smart Cities, one interpretation explains Smart Cities as being composed of three domains: technology, people, and institutions.[4] The "technology" domain addresses the need to build basic infrastructure, both physical (hardware) and virtual (wireless networks), to implement information-communication technology in urban areas. The "people" domain emphasizes innovation, learning resources, and human capital that serve as catalysts to boost Smart City development. The "institution" domain indicates the importance of government support in the development of Smart Cities.[5]

Internet of Things

Internet of Things is a concept of connecting daily objects with an interactive network through wireless communication mediums such as Radio-Frequency Identification (RFID) tags, sensors, and smartphones.[6] IoT has the potential to be applied in many fields, such as industry, transportation, and civic infrastructure.[7] While the different application fields require different IoT frameworks and technology, this article focuses on the "Urban IoT," which establishes an information infrastructure to manage and optimize public services.[8] The application of IoT technology is believed to be an important technological trend in the Smart Cities movement, as mentioned in the APA initiative.[9] It is described as a "building block to realize a unified urban-scale information-communication technology (ICT) platform, thus unleashing the potential of the Smart City vision."[10] The sensor network that detects specific environmental data is a typical application of IoT in sustainable development. Its implementation requires three infrastructural components: sensing, cloud computing, and data. Although the three components are listed from the technological perspective, behind them there is a series of social demands, economic drivers, and governmental requirements.

Sustainability

Like Smart Cities, sustainability is not a new term for urban planning theory and practice. Its definition is highly contentious and debated in planning literature. Because this article aims to provide a background of research for urban planners on the application of the Internet of Things in sustainability fields, the definition of sustainability here also must tie to the urban planning field. Among the various aspects of sustainability, one of the aspects states that sustainability is a mode of development that guarantees a coherent, continuing balance between supply and demand. According to the APA, there are three specific outcomes required for sustainable urban planning:[11]

- A sustainable development should have a plan that ensures equality among all groups.
- The communities built based on sustainable principles should be "resilient, diverse and self-sufficient."
- A sustainable development should contribute to a "healthy" environment, not only from the natural perspective, but also from economic and social perspectives.

From the three outcomes listed above, it is clear that sustainability for urban planning is a concept beyond just the handling of natural resources; rather, sustainability is regarded as a paradigm expected to apply to various aspects of society. In fact, the definition of sustainability still is controversial for its vagueness and inconsistency.[12] Because this article examines the application of IoT technology at an urban scale, which is primarily concerned with environmental sensor networks at this stage, this article chooses the environmental aspect of sustainability as the definitional proof for investigation and arguments.

Role of IoT in Sustainability

IoT is believed to be a significant method among the information-communication technologies involved with the Smart Cities movement, particularly in the domain of sustainable development. Because the application of IoT is deeply embedded in the context of Smart Cities, which serves as a paradigm for the development of IoT technology, planners should be able to draw a link between Smart Cities and the notion of sustainability. Conceptually, the APA Smart Cities and Sustainability Initiative regards Smart Cities as an extension of sustainability in that Smart Cities seeks to maximize benefits for the most people with minimal costs and impacts, which echoes the very goal of sustainability.[13] In a model that divides Smart Cities into multiple layers, the "green city layer" also indicates the potential that the Smart Cities concept has in improving the environment.[14] An example of this can be found in the Smart Cities Initiative of the European Strategic Energy Technology Plan, which seeks to reduce greenhouse gas emissions by 40 percent by 2020 through Smart City implementations.[15] However, there are also voices contending that the bond between the concept of Smart Cities and ecological sustainability is still weak, in that the Smart City idea is used more for marketing than for infrastructural needs.[16]

Smart Cities, the basis for the application of IoT technology in the urban context, has established its conceptual connection with sustainability. Before exploring the specific ways of evaluating the performance by IoT in urban sustainable development, it is essential to understand the primary position IoT has in the entire process of sustainable development. As introduced before, the application of IoT technology within the field of sustainability is primarily through a sensor network that detects certain data. The data collected by the IoT sensor network would be used to evaluate existing environmental conditions, track performance of certain devices, or optimize future actions in some environmental measurements. All these functions of IoT application are associated with information collection in the preliminary stage of problem solving. This is not to say that IoT technology is at a secondary position in the sustainable development process. Although it appears that IoT technology does not seem to be a "critical" step, the information collected through the sensor network built by IoT technology is of great importance in understanding environmental performance or resource consumption.

Challenges with IoT Technology in the Realization of Sustainability

Listed below are some of the major challenges when using Internet of Things technology to enhance urban sustainability. In response to these challenges are suggestions regarding how planners can take a variety of approaches to resolve these challenges.

Span

Span concerns the density of sensor devices and the geographical range the network covers. The span of a sensor network is dependent on three factors: physical operation, policy motive, and financial feasibility. Physical operation includes the selection of installment locations based on detecting needs, the design and running of the network system, and maintenance and development. In the case of applying sensor networks in urban sustainability infrastructure, the coverage and location of specific devices can often be a citywide matter, which requires collaboration among policy makers, urban planners, and technicians. When a sensor network becomes denser, it can reach a higher level of precision, whereas the larger scale of the network would also lead to a higher cost for building the infrastructure. Thus, the span of sensor networks is an essential factor to consider when designing the IoT system to enhance urban sustainability. Although the design of the infrastructural system is a highly technical issue in the information technology field, the role of urban planners cannot be neglected. The specific location of installments can impact the physical form of cities and buildings. Moreover, the decision to either add external devices to existing infrastructure or embed devices within new infrastructure would also affect construction and renovation costs.

Span within a certain sensor network determines the coverage and strength of data detection. In the broader planning phase of IoT projects, span can also involve the range of data needed to assess and demonstrate need. The type of IoT system deployed and the kind of data tracked are two issues closely associated with the needs and purposes of building such a system. Compared to the question of "where to install," the question of "what to install and what to detect" is more crucial to discuss at the initial phase of the project, which in turn implies the important role urban planning professionals can play in this stage.

Fault Tolerance

The extent to which the sensor network system is resilient to system failure is another issue to consider. For example, taking sensor networks at the civic level, the sensors are often not able to carry security protection methods, which makes it relatively easy to eavesdrop on important information.[17] Therefore, given the relatively low information capacity of individual sensor devices, data security is an important issue. Another problem related to fault tolerance is the questioning of optimization by Adam Greenfield. According to Greenfield, the goal of the current Smart City movement is a seamless user experience. However, the other side of such "seamless" optimization is the resulting difficulty in finding locations of defects when failure happens.[18] One aspect of this issue that may be relevant to urban planners is the idea of flexibility, which not only suggests the ability to adapt based on technology, but more importantly, the role of human factors that technology is not able to address.

Urban planners and designers can respond to the problem of fault tolerance by shifting the trajectory of thinking from the pursuit of sustainability towards the notion of "resiliency," as inspired by resilience in ecological systems. Previously defined as the aptitude of a system to go back to a constant equilibrium point after fluctuation,[19] the concept of resilience has moved to a new state that measures the extent to which the system adjusts itself to a new equilibrium.[20] The latter definition of resilience emphasizes the importance of flexibility and adaptability in the dynamic context. When adopting the idea of resilience within the Smart City movement, flexibility and adaptability are of great significance in considering the mechanism of the sensor network system. For instance, the span of sensor devices mentioned previously might change according to changing needs for the detection range and preciseness; consequently, the physical form of the city or building may need to meet the varying configuration of infrastructure. Also, the devices are expected to bear multiple uses or be embedded within existing infrastructure. This raises new challenges for designers to consider new functions of furniture or building segments.

Lack of Incentive

As Greenfield suggests, a significant feature of Smart Cities is that enterprises (rather than governments and institutions) are playing a crucial role in inventing technical systems and paradigms for the notion of Smart Cities.[21] Such reliance on the commercial sector reflects the importance of business factors in the application of IoT technology at the urban scale. However, this characteristic of Smart Cities may lead to a lack of incentive for building a sustainable sensor network due to its limited profit potential. One of the ways to alleviate this problem is to incorporate sustainable features with other functions, as seen in the application of smart homes. The collaboration among technological endeavors and real estate developers may also significantly contribute to the business vision of

IoT in the sustainability field.

The need for incentives to build the IoT network at the urban scale requires collaboration among various sectors of the city, such as government, planning professionals, technical firms, and real estate developers. Existing examples suggest that there are diverse ways to address the collaboration and application of IoT technologies in urban sustainability. In the case of Padova, Italy, the Padova Smart City project contains contributions from both the public and private sectors: the municipality of Padova provided financial support for the project, the University of Padova conducted a feasibility analysis as well as data processing, and a firm called Patavina Technologies designed the software system as the technical core of the project.[22]

Ownership of Data

Most of the literature on IoT emphasizes the significant meaning of IoT for city administrators in terms of optimized management.[23] However, there arises the issue of the ownership of data retrieved from the sensor network. The administrator-centric mode is a common feature within the Smart Cities movement, neglecting the fact that a great amount of data is related to citizens and users.[24] The absence of public access to data may lead to a difficulty for citizens when perceiving the benefits of a sensor network, leading to an increased difficulty in obtaining funding and public support.

In fact, the process of collecting data from the public domain in the application of sensor networks can have dualistic interpretations in terms of data ownership. On one hand, public participation in this process is a form of citizen science with a great potential of incorporating public efforts within Smart Cities movements.[25] On the other hand, the monitoring relationship between citizens and environmental data remains vague. Referred to as a scientific method enacted and realized by citizens from non-scientific fields, citizen science is not believed to be a mature mechanism. It is difficult to find the balance between public participation as "raw material" and professional interference as "processing efforts."[26] In the case of IoT sensor networks' purpose to capture environmental data all over the city, the public should have access to the knowledge of what the data collected is used for as an important means of citizen science application. In response to the concern for ownership of data collected from the sensor network, urban planners need to make a stronger effort to build a bridge between professionals and the public in order to incorporate public participation within Smart Cities movements. This is particularly important for projects using data directly from households, such as smart home monitoring and smart grid data tracking.

Adverse Effect

Although the proposed sensor network is designated to improve urban sustainability, it is crucial for system designers, administrators, and users to be aware of the possible negative consequences of the network. The energy cost of constructing such a sensor network is one of the possible adverse outcomes. Another issue is the rebounding effect, in which the raised efficiency of energy use would in turn result in increased amounts of energy use.[27] This leads to the unpredictable nature of planning and policy outcomes. However, there are still ways to reduce the potential adverse effects.

For urban planning professionals, the adverse effect may take place through the renovation of current infrastructure towards IoT sensor network and other technologies. Although physical design may not be a determining factor of the impacts, it is still of great importance for urban planners and designers to bring efficient approaches to achieve needs. Also, even though some adverse effects can occur only after the system starts operating, there are still several ways to avoid such unwanted consequences through careful planning and evaluation. Similarly, as with the previous challenges, the alleviation of adverse effects requires collaboration among different fields.

Vision of IoT Application and Urban Sustainability

Waste Management

One exemplary application of IoT technology in urban sustainability is waste management. Intelligent waste containers are installed to track waste load levels to optimize garbage processing and reduce potential pollution. For instance, a system of sensed garbage bins sends data to the control center to determine the optimal collection time and route for collector trucks.[28] In another project in Seoul, South Korea, smart garbage systems have been used to reduce food waste by tracking the weight of food garbage.[29]

The challenges discussed in the previous section can also occur in this type of application. If the purpose of the smart waste management system is merely to optimize time and routes for collection trucks, the cost of installation may surpass the benefit. Thus, it is important to think about the scope of such a project—not only in terms of density and coverage of data tracking—but also the complexity level of the system. For instance, the smart waste management system may capture various types of data ranging from garbage filling levels to toxic substances. If the feature of waste tracking can be combined with other functions, such as toxic substance detection, the system can have a more thorough contribution to urban sustainability.

Smart Streetlights

Another practice related to sustainable issues is the use of smart streetlights that adjust streetlight intensity according to ambient brightness. An example of smart streetlights is the Smart City Project in Padova, Italy, where public street lighting is monitored through wireless nodes which check lighting levels to optimize lighting energy cost. In addition, the streetlight poles are also equipped with multiple sensors that detect environmental data such as humidity, carbon dioxide emissions, and noise.[30] Such an adaptive system can be considered an important step forward in municipal sustainability because the system can be designed and constructed based on existing infrastructure without excessive modifications of the current urban form.

A challenge related to smart streetlights is fault tolerance. Different from waste manage systems, which only capture data, public street lighting is an essential infrastructure for cities at night, and the temporary failure of the lighting control system may lead to serious safety problems. Therefore, having an alternative system may be a solution for the fault tolerance challenge faced by the smart streetlight system.

Smart Homes and Intelligent Residential Districts

The "smart home" is also a popular trend within the application of Internet of Things technology related to sustainability at the residential scale, as the central component of the Intelligent Residential District.[31] This includes optimization of lights, temperature, and humidity so as to reduce energy costs. From the urban planning perspective, a mode of data tracking is potentially a connection to a smart grid, in which electricity resources are allocated efficiently at the neighborhood or city level.[32] In fact, sustainability is believed to be only one aspect of the smart home, as today the smart home practice seeks to cover a wide range of issues beyond energy use, such as security and medical care.[33] Still, the smart home is playing a significant role in the future of IoT. Different from the previous two examples, the smart home concept can be applied both at the residential scale and at the civic scale. The residential scale seeks to integrate IoT technology with household energy operations as a way of helping residents increase their home energy efficiency. At a larger scale, individual smart homes can create a larger intelligent network that tracks local performance in terms of residential energy use. Such an intelligent residential district can be an effective tool for urban planners to analyze energy use patterns at a local scale.

The potential of smart homes to form an intelligent residential network brings both benefits and challenges for urban planners. Data ownership is one of the challenges. Using the energy tracking method to reduce energy costs is a desirable feature inside the household, but there would be a greater potential to optimize the entire system if the households could connect into a larger network and share their statistics to implement the idea of the smart grid. In the meantime, communities and residents may consider such data to be private. Hence, the advantage of the smart home system is limited if the data cannot be connected in a larger network.

Conclusion

This article explores the relationship between the Internet of Things and sustainable urban development, with challenges of applying IoT technology in urban sustainable development. The development and application of IoT technology are closely associated with the Smart Cities movement, while the ongoing trend of applying information-communication technology in cities and buildings may bring new issues and challenges for urban planners to address. Before investigating the challenges and proposing solutions, it is important to understand the role of sensor networks as only one component of a larger system with various mechanisms. Because the function of a sensor network is capturing necessary environmental data, the network is largely a tool to gather information for further studying, processing, and responding. In the context of the Smart Cities movement, urban planners need to be aware of the role each information-communication technology is playing in order to better utilize the technologies.

The challenges of IoT are often entangled in a complex chain. Therefore, they may need to be resolved together instead of separately. For instance, the span of the sensor network is an essential factor that determines the cost of building such infrastructure, which in turn may impact the public and private sectors' incentive to invest in the project. The issue of security and privacy would also affect the public's willingness to participate, and thus result in a gap between the public and decision makers. In many cases, the challenges cannot be separated and the relationship between factors must be examined in order to untangle and work past the complex series of obstacles present in the implementation process.

To resolve the entangled challenges faced by the IoT network for building a more sustainable city, the mere power of urban planners is not sufficient. As technologies of Smart Cities develop, it will be impossible to realize the framework's potential if any sector is isolated and working in a silo. In the case of Smart Cities, collaboration is particularly important because of the multiple layers of the movement including business, technology, politics, and economics. Urban planners sit at the intersection of these fields, but their impact has been limited to this point. This article suggests that in the application of IoT technology, urban planners would do well to apprehend the importance of understanding and enhancing collaboration among various sectors. ■

Endnotes

1. Andrea Zanella, Nicola Bui, Angelo Castellani, Lorenzo Vangelista, and Michele Zorzi. "Internet of things for smart cities." *IEEE Internet of Things Journal* 1, no. 1 (2014): 22.

2. Chourabi, Hafedh, Taewoo Nam, Shawn Walker, J. Ramon Gil-Garcia, Sehl Mellouli, Karine Nahon, Theresa A. Pardo, and Hans Jochen Scholl. "Understanding Smart Cities: An Integrative Framework." In *System Science (HICSS)*, 2012 45th Hawaii International Conference, 2289.

3. American Planning Association. "Smart Cities and Sustainability Initiative." (2015): 6.

4. Taewoo Nam, and Theresa A. Pardo. "Conceptualizing Smart City with Dimensions of Technology, People, and Institutions." In Proceedings of the 12th Annual International Digital Government Research Conference: Digital Government Innovation in Challenging Times, 285.

5. Nam and Pardo, 286.

6. Luigi Atzori, Antonio Iera, and Giacomo Morabito. "The Internet of Things: A Survey." *Computer Networks* 54 (15) (2010): 2787-2805.

7. Harald Sundmaeker, Patrick Guillemin, Peter Friess, and Sylvie Woelfflé. 2010. "Vision and Challenges for Realising the Internet of Things." *Cluster of European Research Projects on the Internet of Things*, European Commision.

8. Zanella, Andrea, Nicola Bui, Angelo Castellani, Lorenzo Vangelista, and Michele Zorzi. 2014. "Internet of Things for Smart Cities." *IEEE Internet of Things Journal* 1 (1): 22-32.

9. American Planning Association. "Smart Cities and Sustainability Initiative." (2015): 6.

10. Ibid.

11. American Planning Association. *APA Policy Guide for Planning for Sustainability*. https://www.planning.org/policy/guides/adopted/sustainability.htm

12. Marino Gatto. "Sustainability: Is It a Well Defined Concept?." (1995): 1181-1183.

13. American Planning Association. *APA Policy Guide for Planning for Sustainability*. https://www.planning.org/policy/guides/adopted/sustainability.html

14. Sotiris Zygiaris. "Smart City Reference Model: Assisting Planners to Conceptualize the Building of Smart City Innovation Ecosystems." *Journal of the Knowledge Economy* 4 (2) (2013): 217-231.

15. Ibid.

16. Anna Kramers, Mattias Höjer, Nina Lövehagen, and Josefin Wangel. "Smart Sustainable cities–Exploring ICT Solutions for Reduced Energy use in Cities." *Environmental Modelling & Software* 56 (2014): 52-62.

17. Luigi Atzori, Antonio Iera, and Giacomo Morabito. "The Internet of Things: A Survey." *Computer Networks* 54 (15) (2010): 2787-2805.

18. Adam Greenfield. *Against the Smart City: A Pamphlet.* Do Projects 2013.

19. Stuart L. Pimm. "The Complexity and Stability of Ecosystems." *Nature* 307 (5949) (1984): 321-326.

20. Crawford S. Holling. "Resilience and Stability of Ecological Systems." *Annual Review of Ecology and Systematics (*1973): 1-23.

21. Adam Greenfield. *Against the Smart City: A Pamphlet. Do* Projects 2013.

22. Angelo Cenedese, Andrea Zanella, Lorenzo Vangelista, and Michele Zorzi. "Padova Smart City: An Urban Internet of Things Experimentation." *IEEE (*2014).

23. American Planning Association. *APA Policy Guide for Planning for Sustainability*. https://www.planning.org/policy/guides/adopted/sustainability.html

24. Adam Greenfield. *Against the Smart City: A Pamphlet.* Do Projects 2013.

25. Janis L. Dickinson, Jennifer Shirk, David Bonter, Rick Bonney, Rhiannon L. Crain, Jason Martin, Tina Phillips, and Karen Purcell. "The Current State of Citizen Science as a Tool for Ecological Research and Public Engagement." *Frontiers in Ecology and the Environment* 10 (6) (2012): 291-297.

26. Karin Bäckstrand. "Civic Science for Sustainability: Reframing the Role of Experts, Policy-Makers and Citizens in Environmental Governance." *Global Environmental Politics* 3 (4) (2003): 24-41.

27. Jeroen CJM Van den Bergh. "Energy Conservation More Effective with Rebound Policy." *Environmental and Resource Economics* 48 (1) (2011): 43-58.

28. Andrea Zanella, Nicola Bui, Angelo Castellani, Lorenzo Vangelista, and Michele Zorzi. "Internet of Things for Smart Cities." *IEEE Internet of Things Journal* 1 (1) (2014): 22-32.

29. I. Hong, S. Park, B. Lee, J. Lee, D. Jeong, and S. Park. 2014. "IoT-Based Smart Garbage System for Efficient Food Waste Management." *The Scientific World Journal* 2014: 646953. doi:10.1155/2014/646953 [doi].

30. Angelo Cenedese, Andrea Zanella, Lorenzo Vangelista, and Michele Zorzi. "Padova Smart City: An Urban Internet of Things Experimentation." *IEEE (*2014).

31. Baoan Li, and Jianjun Yu. "Research and Application on the Smart Home Based on Component Technologies and Internet of Things." *Procedia Engineering* 15 (2011): 2087-2092.

32. Andrea Zanella, Nicola Bui, Angelo Castellani, Lorenzo Vangelista, and Michele Zorzi. "Internet of Things for Smart Cities." *IEEE Internet of Things Journal* 1 (1) (2014): 22-32.

33. Baoan Li, and Jianjun Yu. "Research and Application on the Smart Home Based on Component Technologies and Internet of Things." *Procedia Engineering* 15 (2011): 2087-2092.

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