URBAN INTELLIGENCE: A CONCEPTUAL MODEL FOR SMART CITY RESEARCH AND PRACTICE

INTRODUCTION:

Cities are comprised of multiple elements including physical (infrastructure), political, economic, and environmental that interact in a complex manner (Cristiano et al. 2020). The complex interactions in part make it difficult to address the urban challenges we are facing today. Recent advancements in Information and Communications Technology (ICT) have provided us with novel ways to tackle the urban challenges. Advancements in ICT have, to some degree, contributed to the popularity of smart cities. The term smart city was first used in the 1990s in the context of leveraging telecommunications for the development, planning, and management of cities (Gibson, Kozmetsky, and Smilor 1992). In general, the concept of smart cities is seen as a solution to the challenges brought upon by urbanization and population growth (Silva, Khan, and Han 2018), and traffic, pollution, energy consumption, waste treatment (Benevolo, Dameri, and D’Auria 2016). Akin to many other studies (Zubizarreta, Seravalli, and Arrizabalaga 2016; R. Dameri 2013; Eremia, Toma, and Sanduleac 2017; Nilssen 2019), in this study, we treat smart city as a *concept*. We consider the term *concept* as a label used to generalize a specific idea or an attribute to a wide range of situations (Brachman 1977). For example, the concept of a *car* can be seen as a generalization of the idea of motorized vehicles with four wheels. A concept has three aspects: events or objects to be studied (e.g., motorized vehicles), ideas or attributes that apply to the objects (e.g., four wheels), and a label (e.g., car). In the context of smart cities, *smart city* (label) is the generalization of the idea of leveraging technology to improve the cities’ functions (objects). Overall, smart city can be considered as a goal-oriented concept. In this study, instead of focusing on smart city as a goal, we investigate the general process that should be adopted to achieve this goal.

What exactly is a smart city and what are its characteristics? Before attempting to answer these questions, we must remember that a smart city is before all a city. A city is more than a space with a physical form and with boundaries. A city possesses many heterogeneous parts (infrastructures) that work together for the benefit of the people who inhabit that space. Additionally, beyond infrastructure, a city possesses social, cultural, political and environmental elements. Therefore, if we think of smart city as a solution (or vision) to improve the overall functioning of a city, then improvements must come from the heterogeneous parts including social, cultural, political etc. Generally, studies that focus on providing insights or solutions to urban challenges define smart city within the context of their studies. Multiple definitions of smart city have made it difficult to provide a single coherent narrative to smart city. The domain in which smart city concept is applied could affect how smart city is viewed or understood. Therefore, the concept should be viewed in relation to the domain. The lack of structure and coherence in research has partly contributed to the confusion surrounding smart city. Despite the popularity of smart city concept, the research still lacks structure and is divided into multiple ideas (Mora, Bolici, and Deakin 2017).

Many studies have attempted to dispel the confusion around smart cities. Studies have tried to provide structure by either reviewing existing literature or by doing bibliometric and scientometric analyses (Zhu et al. 2020; Silva, Khan, and Han 2018; Ismagilova et al. 2019; Albino, Berardi, and Dangelico 2015; Adapa 2018; Meijer and Bolívar 2016; Anthopoulos 2015; Laufs, Borrion, and Bradford 2020; Lim, Edelenbos, and Gianoli 2019; Cocchia 2014; Kyriazopoulou 2015; Israilidis, Odusanya, and Mazhar 2021; Tran Thi Hoang, Dupont, and Camargo 2019; Ismagilova et al. 2020). The main objectives of those studies were to uncover major themes and common elements in smart city research. While the insights gained from these studies help construct a representation of smart city and its components, they do not provide a coherent understanding of the smart city process. Establishing a relationship between the major themes uncovered in the above literature review studies might be helpful in achieving coherent understanding of the process.

Furthermore, the fragmentation of smart city research makes it difficult to track progress within and across each theme. This fragmented research can also lead to favoring a few aspects of smart city more while neglecting other aspects. To address this issue, Mora, Bolici, and Deakin (2017) argue for the development of “a model or mode of scientific inquiry that not only manages to bridge the structural division…but does it in a format the content of which adds up to more that sums-of-its-parts”. Similarly, Meriton et al. (2020) argue that it is important “to examine the utility of ongoing research to practice” with the use of a model, particularly in emerging areas of research.

The vast nature of smart city, however, makes it difficult to provide structure with one model that covers its every aspect in detail. In this study, we focus on smart city research related to urban infrastructure purely. This study aims to develop a conceptual model that acts as a bridge between the goals of a smart city and the actualization of the goals. The conceptual model here is a process consisting of different stages, each completed successively to attain the goal. The stages in the process are in part developed based on the research themes identified from our literature review analysis. Focusing on the *process* instead of the *goals* can also help practitioners make more informed decisions. Further, the model can help narrow the structural divisions present in smart city research, thus providing clarity to researchers to carry out future research. To that end, the objectives of this study are twofold: a) perform a bibliometric analysis to find the major trends in smart city research and b) based on these major trends, develop a model to guide the actualization of smart city goals and future smart city research.

The following sections of this article are organized as follows. Section 2 provides a brief review of the smart city literature. Section 3 presents the methodology used to identify the major research trends. Section 4 introduces and explains the Urban Intelligence (UI) model. Finally, section 5 provides the conclusion of this study.

LITRERATURE REVIEW:

*Definitions of the smart city concept:*

Studies have often defined the smart city concept within the context of their research. For example, Nam and Padro (2011) associated smart city with innovation in technology, management, and policy, whereas Meijer and Bolivar (2016) associated it to acquiring and mobilizing human capital. This practice of study-specific definitions has partly made it difficult to create a unifying definition of smart city. And many definitions of smart city have technology at its core. Many researchers, however, have also argued that the smart city concept needed a more holistic view with the inclusion of components such as sustainability, social and human capital, education, and economy.

Table 1 lists several definitions of smart city from the literature that either take a purely technocentric approach or that adopt a more holistic view.

Table 1: Definitions of smart city

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| View | Authors | Definitions |
| Technocentric | Chen (2010) | cities that “take advantage of communications and sensor capabilities sewn into the cities' infrastructures to optimize electrical, transportation, and other logistical operations supporting daily life, thereby improving the quality of life for everyone.”  |
| Washburn et al. (2010) | “the use of Smart Computing technologies to make the critical infrastructure components and services of a city—which include city administration, education, healthcare, public safety, real estate, transportation, and utilities—more intelligent, interconnected, and efficient.” |
| Marsal-Llacuna et al. (2015) | *“*toimprove urban performance by using data, information and Information Technologies (IT) to provide more efficient services to citizens, to monitor and optimize existing infrastructure, to increase collaboration between different economic actors and to encourage innovative business models in both the private and public sectors*.”* |
| Nam and Padro (2011) | smart city as “as one with a comprehensive commitment to innovation in technology, management and policy”, while also addressing the lack of research into the management and policy side of those technological innovations |
| Hall et al. (2000) | “a city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rail/subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens”. |
| Holistic | Giffinger et al. (2007) | “a city well performing in a forward-looking way in economy, people, governance, mobility, environment, and living, built on the smart combination of activities of self-decisive, independent and aware citizens”. |
| Caragliu et al. (2011) | city to be smart when it invests “in human and social capital and traditional (transport) and modern (ICT) communication infrastructure, fuel, sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance.” |
| Angelidou (2016) | smart cities as “a conceptual development model that aspires to use ICTs for the development of a city’s human, collective, and technological capital, with the ultimate scope of increasing urban sustainability”. |
| Komninos et al. (2006) | “territories with high capacity for learning and innovation, which is builtin the creativity of their population, their institutions of knowledge creation, and their digital infrastructure for communication and knowledge management.” |
| Meijer and Bolivar (2016) | “ability to attract human capital and to mobilize this human capital in collaborations between the various (organized and individual) actors through the use of information and communication technologies.” |
| Benevolo, (2015) | creating a better urban area by aiming at reducing its environmental footprint and at creating better quality of life for citizens.  |

Given the importance of urban infrastructure in cities generally, Sarwat et al. (2018) noted that a well-developed and coordinated infrastructure system should be a part of the smart city, in addition to providing reliable services to people. Hence, some studies argue that operating and managing urban infrastructures is integral in the smart city, and many studies have proposed solutions that utilizes advancements in ICT in the pursuit of that vision (Sánchez et al. 2013; Amini, Mohammadi, and Kar 2019; AL-HADER and RODZI 2009; Jokinen, Latvala, and Lastra 2016). In contrast, many smart city studies also question the value of technology to operate physical (critical) infrastructure, arguing that technology can create new interdependencies that might make cities more vulnerable (Rong, Yan, and Zhang 2018; Du et al. 2016). The paradoxical nature of the centrality of technology in creating a smart city—potentially making critical infrastructure more vulnerable—would benefit from having a clearer understanding of the concept of smart city and the research on smart city. In an emerging research area like smart city, mapping “the core literature contributions to a definitional schema of a research area” (Rose and Sanford 2007) can be helpful to understand the research area given its fragmented nature.

METHODOLOGY:

As mentioned, this study focuses on the urban infrastructure element of smart city. For the conceptual model to minimize the structural division in the smart city research, the model needs to align with existing smart city research. Therefore, the first step in developing a model is to identify the main research trends in the smart city literature. The following sections explains the methodology used to identify the research trends.

*Natural Language Processing:*

Firstly, all articles published with terms “smart city” or “smart cities” along with “infrastructure” in their title, keywords, or abstract were collected from the SCOPUS database. The search was carried out on February 17, 2021. In total, there were 4,220 articles, including journal articles, book chapters, and conference papers published between 1984 and 2020. Natural Language Processing (NLP), combined with clustering analysis, were used to identify the major research themes in the literature. Both techniques are defined below.

*Data:*

The data used in this study was the abstract of each article. Prior to using the abstracts, we removed abstracts that contained less than 100 words, yielding 3,987 abstracts. Data preprocessing is encouraged in NLP as the text contains non-essential information such as prepositions and pronouns that might affect the results. As recommended by Ayadi et al. (2019), the following preprocessing steps were performed.

1. Normalization
2. Stemming and Lemmatization
3. Stop words removal.
4. Tokenization

First, as part of normalization, we removed all punctations in the text and converted all the text into lower case. Second, we stemmed the words. Stemming is the process of reducing the word to its present tense form; for example, “proposing,” “proposed,” and “propose” are stemmed into one word “propose.” Similarly, lemmatization converts plural words into their singular form and removes gender pronouns while retaining the meaning of the sentence. For instance, the word “data” is reduced to “datum” and “cities” is reduced to “city.” Third, all stop words are removed—stop words are words that do not provide useful information on the context such as “a,” “the,” and “in.” Finally, tokenization is the process of cataloging individual words from each abstract-by-abstract id and sentences id. For example, when tokenized, the sentence “Apply today released its new product” becomes [“Apple,” “today,” “released,” "its,” “new,” “product”]. Applying the four preprocessing steps, the sentence becomes [“apple,” “today,” “release,” “new,” “product”]. After preprocessing, each abstract has become a list of tokenized sentences. The tokenized sentences were used to get the word embeddings of each word using NLP.

In this work, we used Word2vec (Mikolov et al. 2013), which is one of the probability-based methods that takes the neighbor words (contexts) as inputs and predict the most probable word from a collection of words that could be observed (Bartusiak et al. 2019). Word2vec uses a neural network architecture with one hidden layer of *N* neurons that takes a sequence of words as inputs. We used a pretrained model from a Python package called spaCy (Honnibal et al. 2020). The pretrained model uses a similar neural network architecture explained above and was run on multiple texts (corpus) like Wikipedia and news articles for training. The abstracts were then given as inputs to the model to extract the *N*-dimensional vectors for each word. Finally, all the words’ vectors from each abstract are averaged to get one vector for each abstract, which was used for clustering analysis.

*Clustering analysis:*

The vectors extracted for each abstract are used to cluster abstracts into different groups. The clustering technique used in this study is K-means clustering (Steinley 2006). K-means clustering is an iterative procedure that essentially minimizes the distance between a cluster’s centroid to its data points. The centroid of a cluster is simply a coordinate of the center of a cluster. In K-means, the number of clusters $k$ is predefined.

As the number of clusters $k$ is predefined, we used a combination of both the silhouette coefficient and the elbow method to find the optimal number of clusters. The silhouette coefficient is a measure of cluster density and separation (Layton, Watters, and Dazeley 2013). The silhouette coefficient is used to evaluate how defined the clusters are, and its value is between -1 and 1. In other words, it measures whether, on average, the points assigned to a cluster are closer to one another rather than to the points of another cluster. A *k* value resulting in a higher silhouette coefficient is preferable as it means the clusters are more clearly defined. The elbow method utilizes the distance between the data points $x\_{j}$ in each cluster $C\_{i}$ and the cluster’s centroid $c\_{i}$. It then calculates the within-clusters sum of squares (WSS) of the Euclidean distance between each data point and the cluster’s centroid across all clusters (Asri, Mousannif, and Al Moatassime 2019). A lower WSS value is usually preferred. Here, we combined results from the above two methods to find the optimal number of clusters $k$.

*Results:*

For our dataset, we tried *k* values ranging 2 to 20 clusters and calculated the silhouette coefficients and WSS values. The highest silhouette coefficient and lowest WSS was found for $k$ = 5 (see Appendix: Figs. 1A and 1B).

Subsequently, each cluster was examined separately to find the dominant research theme. We examined each cluster by combining all the abstracts in each cluster into one to extract the information on the trend it represents. We found the following major research themes:

1. Sustainability
2. Smart computing infrastructure
3. Smart transportation
4. Smart energy
5. Smart data transmission

Overall, these clusters show four distinct themes: sustainability, computing, infrastructure (transport and energy), and data. The most frequent words found in each cluster is shown in the form of wordclouds in the Appendix I section; a wordcloud is a visual representation of words observed with high frequency in a text. The trends were inferred using two information: words that occurred more frequently, and words that are specific to each cluster, meaning words that are seen only in one cluster.

From this analysis, we can infer that “sustainability” is one of the principles goals associated with smart urban infrastructure. Moreover, the majority of smart city studies are focused on energy and transportation infrastructure. Given the transport and energy are some of the major sectors that are often associated with causes of environmental concerns, this result is expected. Smart computing and data transmission, which involve sensing, communicating, transmitting, and computing or processing data also seem to be predominant themes in the smart city literature. *Sensing* may be related to sensors and technologies that are used to collect data for both energy and transportation sectors. Similarly, *communication* can be relevant to the transportation sector as research on vehicle-to-vehicle communication and autonomous vehicle technologies has grown significantly. Finally, *computing* or *processing* may be related to the approaches and advancements made in fast and efficient processing of Big Data. The themes identified can even be shown as a sequence; see Figure 1.



Figure 1: Cluster themes are shown in sequence.

The sequence in Figure 1 shows a process of first setting a goal, followed by gathering the necessary data, and then by processing the data. This process, however, is not complete because the results of the processed data should, ideally, affect decision makers decisions toward smart city as a goal. The next section explains how the information from Figure 1 are used in developing the conceptual model.

URBAN INTELLIGENCE:

In the urban infrastructure literature, the term “intelligent” appears often, generally in the context that infrastructure should be managed and operated “intelligently.” In fact, the terms “intelligent” and “smart” are often used interchangeably although they mean different things. In particular, *intelligence* is a process whereas *smart* is the result of that process. For example, MacFarlane defines intelligence as “a process, or an innate capacity to use information in order to respond to ever-changing requirements. It is a capacity to acquire, adapt, modify, extend and use information in order to solve problems” (MacFarlane 2013). Given the difference in meaning between intelligence and smart, we can formulate an *urban intelligence model* as a process that leads to a smart city.

In the literature, the term “urban intelligence” (UI) has been used in different contexts, including in urban planning (Webber, 1965; Roche, 2017; Berezowska-Azzag, 2013) and health care (Lai et al. 2020; Oni et al. 2016). Here, we define UI as a model with four sequential stages progressing toward smart city goals (Figure 2). The sequential UI stages are as follows:

1. Monitor
2. Model
3. Interpret
4. Recommend



Figure 2: Urban Intelligence Model

Stage 1 – Monitor:

Smart data transmission is one of the research themes identified from the clustering analysis in section 3. Both themes have data as their core element. Often acquiring data is the first step toward a smart city goal. In the definition of intelligence, the acquisition of information is also the first step. Here, we use to term *Monitor* as a general term that encompasses all means to acquire and manage data.

In smart city research, studies have provided contributions towards data acquisition and management. For example, a study by Daniel and Doran (2013) discusses the roles and advantages of integration of geomatics with ICT in implanting smart city initiatives. The contribution of the study by Daniel and Doran (2013) highlights the potential of geomatics in data collection. Additionally, Balasubramani et al. (2020) proposed a smart data management framework to manage urban infrastructure data.

Stage 2 – Model:

*Model* is a representation of the behavior of a system. Within the concept of smart city research, it generally involves processing of the acquired data from the Monitor stage to understand the current state of the systems and possibly to predict its future state. Modeling can be applied to individual infrastructure separately (i.e., stand-alone behavior) or to multiple infrastructures together (i.e., integrated infrastructure behavior). Models range from simple to complex depending on the goals. For example, daily energy consumption can be modeled to inform and predict future energy consumption. In the above example, a simple regression can suffice if the goal was prediction of future energy use. On the other hand, if the goal is to model the interaction of multiple systems together then it would need more than a simple regression. Part of the intelligence process is to adapt in the event of changes in the systems’ behavior. Modeling the behavior can be used to identify the sudden changes in the system.

To that end, Machine Learning (ML) has made it relatively easier to model complex interactions of systems. Modeling can allow us to simulate complex behaviors of infrastructure systems for different “what if” scenarios. Understanding the behavior of a system under different scenarios can help respond more quickly to changes for example. In terms of smart city research, studies have applied methods ranging from regression to ML. For instance, a model developed using Support Vector Machine (SVM) algorithm was implemented to predict hourly traffic flow in Aarhus City (Mahdavinejad et al. 2018).

Stage 3 – Interpret:

The third stage is *Interpret*. Interpretation follows the results obtained in the modelling stage. The need for interpretation can be vital especially in complex models. The inherent uncertainties present in the data can impact model’s results. Acknowledging and managing uncertainties is an important part of intelligence process. It involves knowing model’s assumptions and nature of dependent variables used in the model. Hence, taking uncertainties into account could improve decision-making process. In most cases, results of the model should not be taken at face value. Most models have parameters inbuilt as a part of its results that can help with interpretation. For example, R2 is a resultant parameter in a regression model, which is the percent of variance in the data explained by the model. Higher R2 value does not necessarily mean the model performs better. Therefore, results of the model should be examined in conjunction with its R2 value and the dependent variables. Moreover, interpreting results will be more difficult in cases where the model does not have interpretation parameters. ML algorithms can be helpful in modeling more complex systems (Lee and Derrible 2020; Movahedi and Derrible 2021), however, interpreting the results can be difficult (Kerui and Xiaofeng 2020)().

Stage 4 – Recommend:

The final stage of the UI model is *Recommend*. The interpreted results are used in the decision-making process. The recommendations are then proposed to make decisions, whether they are made by people or by an algorithm. For example, recommendations to policy makers might involve providing policies that have higher chances success. These policies would be evaluated in the Model and Interpret stages and ranked based on the success rate. In contrast, recommendations can be given as an input to an algorithm that controls an autonomous system in the event of an anomaly detection. For instance, a recommendation to apply the brakes can be sent to an autonomous vehicle if the relative speed of other vehicles in the proximity crosses a certain threshold. In both examples, the recommendation can eventually become an action to be taken.

CONCLUSION:

The popularity of smart city has garnered interests from the academic community to advance the smart city research. The consensus on the definition of smart city is still lacking, therefore, studies defined smart city within their research context. The use of technology towards smart city seems to be the common element in most of those studies. Apart from technocentric aspect of smart city, in recent times, smart city studies started to include human-centric elements. Altogether, the nature of smart city research seems to be fragmented. In the vast fragmented domain of smart city, a model might be needed to bring coherence to the smart city research to facilitate the future research. We consider smart city concept as a process to achieve an end goal. The goal might differ based on the area under study, for example, transportation, economy, or governance. Despite the different kinds of goals, it is important to have a process that helps with the realization of that goal. The process is a series of steps that need to be performed to attain a smart city goal.

In this study, we developed a model based on the process towards realization of smart city goals. The advantage of this model is that it is easier to understand and implement and it is flexible. Further, it also helps to minimize the research fragmentation in the future research. Our model is developed based on the technology and urban infrastructure area of smart city research and is called urban intelligence. Being a process-oriented model, one of the advantages of UI is that it is flexible: it can be extended or even linked with other models. For instance, UI could be linked with existing concept like digital twins. Digital twin is a digital representation of physical systems, which can be used to model the complex behaviors between infrastructures. For example, study by Mohammadi and Taylor (2019) explored the effectiveness of combining digital twins and game theory to model complex interactions of infrastructures with technology and social dynamics for successful implementation of smart city initiatives.

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