The Potential Smart City Outcomes for Urban Sustainability: A Hierarchical Dirichlet Processing analysis

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Purpose of Research

Due to the growth of population living in urban areas, that will reach two-thirds of the world´s population by 2030 (UNWTO 2017, 2020), and the consequent challenges regarding air pollution, congestion, waste management and human health (OECD 2012), urban sustainability has become a key objective for cities (Ahvenniemi et al. 2017).

In line with the original definition of sustainable development (WCED 1987), a city can be defined to be sustainable "if its conditions of production do not destroy over time the conditions of its reproduction" (Castells 2000). The urban sustainability concept evolved over time by passing from a strong environmental focus to embracing citizens' quality of life (Ahvenniemi et al. 2017). Thus, urban sustainability is defined as "achieving a balance between the development of the urban areas and protecting the environment with an eye to equity in income, employment, shelter, basic services, social infrastructure and transportation in the urban areas" (Hiremath et al. 2013). Thus, urban sustainability comprises three dimensions that need to be simultaneous achieved (Ahvenniemi et al. 2017):

- The environmental dimension refers to the optimal use of environmental resources, maintaining essential ecological processes and helping to conserve natural heritage and biodiversity. The environmental dimension encompasses the ecosystem wellbeing, which is a condition in which the ecosystem maintains diversity and quality, its capacity to support all life, and its potential to adapt to change to provide future options (Michael, Noor, and Figueroa 2014).
- The socio-cultural dimension deals with community wellbeing and how people's needs can be addressed to improve quality of life. It embraces the notion of equal opportunity for people development, respecting the community's socio-cultural authenticity, conservation of their

cultural heritage, and contributing to intercultural understanding and tolerance. It also includes the notion of community empowerment, where citizens are engaged with the community and increase control over their lives by having access to public information and facilities (OECD 2004).

- The economic dimension refers to the ability of businesses to ensure viable, long-term economic growth by providing socio-economic benefits fairly distributed among all stakeholders. The economic dimension refers to the growth, development, and productivity that have guided conventional development science in the past. Economic growth will trickle down to the poor through a market allocation of resources, sustained levels of growth and consumption, and the assumption that natural resources will be natural are unlimited. It implies a system of production that satisfies present consumption levels without compromising future needs (Michael, Noor, and Figueroa 2014).

To push municipalities to achieve urban sustainability, the European Union (European Commission, 2014) and United Nations (2016) have set ambitious climate and energy targets for cities for the coming years. They also provide funds for smart city projects that can help address such societal issues (Dameri 2013).

The literature provides various definitions of the smart city concept, most of them converge on the key role of ICT and digital technologies in urban planning, particularly for innovative transport systems, infrastructures, logistics and green and efficient energy systems (Ahvenniemi et al. 2017; Angelidou 2014). The proliferation of innovative digital technologies makes the development of a smart city challenging for local decision-makers because they afford to develop a smart city project and select the proper digital technologies for addressing city needs (Grossi and Pianezzi 2017). From one municipality to another, different visions of the smart city plan can coexist and adapt to local specificities and context with a consequent impact of the implementation of smart city policies (Esposito et al. 2021).

The extant literature review reports that smart city projects positively impact and support some dimensions of urban sustainability without achieving the three dimensions of urban sustainability (Ahad et al. 2020; Yadav et al. 2019). These studies follow a IT-dominant perspective that considers digital technologies as the main driver for urban sustainability (Angelidou 2014; Grossi and Pianezzi 2017). This perspective privileges the "smartness" features of digital technology over the civic sphere, particularly, citizens are not involved during the smart city projects even though they will become users of these technologies (Hollands 2015). For instance, the adoption of internet of thing (IoT) – based application supports the socio-economic dimension by reducing rissk in critical situations such as floods, hurricanes, tsunami through sensor data analysis (Grossi and Pianezzi 2017). Thus, IoT-based application can contribute to the protection of population leaving in areas subject to critical weather conditions. Still, IoT- based technologies can support the economic sustainability as local decision makers can use such information to plan and maintain viable and more resilient economic activities in the long run (Ahad et al. 2020). Also, the adoption of a GIS-based transportation system – powered by solar energy – allows one to acquire real-time information on traffic congestion and provide useful information to citizens to avoid traffic jams and find potential routes. Thus, such a system supports environmental sustainability by reducing CO_2 emissions and using clean energy (Aina 2017). Finally, the availability of open data related to the city supports economic sustainability because such open data help entrepreneurs in the decision-making process for opening a new business (Ahad et al. 2020). Therefore, there is a lack of studies exploring how smart city adoption simultaneously supports the three dimensions of urban sustainability.

To address this gap, we conduct a hierarchical dirichlet processing on data retrieved from the "Territoire intelligent 2019" call where Belgian municipalities can propose smart cities initiatives by proposed smart city projects in order to support the three dimensions of urban sustainability in order to receive financial funds. Thus, we mine the smart city drivers for urban sustainability.

The study addresses the following research question: "How do smart city adoption support urban sustainability?"

We contribute to the literature in two ways. We illustrate the proper mix of digital technologies to achieve urban sustainability. Secondly, we explain that the socio-technical interplay between technologies and citizens are the main driver for urban sustainability.

Research Methods and data

In this paper, we investigate how smart city adoption supports the three dimensions of urban sustainability. We tackle this research issue by studying the Walloon call for projects "Smart Territory" of 2019, particularly the answer to question 46. The call for projects funds smart city adoption to support urban sustainability. 88 smart city projects were submitted. Geographically, the analysed projects are distributed between the different Walloon Provinces as follows: 10% in Namur, 13% in Walloon Brabant, 21% in Luxembourg, 26% in Hainaut and 30% in Liège.

To apply for the call, local decision-makers had to fill in a form to identify, as precisely as possible, the nature of their smart city projects project. For the purposes of this study, we analysed question 46. This question asks about the urban sustainability impacts expected by the decision-makers after the implementation of their smart city project.

Our data analysis protocol was composed of two steps: (i) a Hierarchical Dirichlet Process (HDP) analysis and (ii) a qualitative analysis.

The Hierarchical Dirichlet Process (HDP) thematic model analysis (step i) allows to analyse the content of the question 46. It is an unsupervised machine learning technique used to derive categories from linguistic data (Yee Why Teh et al. 2006; Yee Whye Teh and Jordan 2010). First, the software performs a lexical processing of the words used by the policymakers. Then, it gathers them according to their occurrence and degree of correlation. Finally, the software generates different archetypes that it considers statistically relevant (Yee Why Teh et al. 2006).

In practice, we prepare the dataset for the analysis based on all the 88 projects proposals sent to the call, of which 8 are OCR-type documents and thus unable to be efficiently pre-processed. Therefore, our final dataset comprises 80 documents. In particular, the dataset is made of the following variables: project ID (integer number from 1 to 88), single project name (given by the authors within the attached document proposal), and the response text inherent to question 46. Text data were preprocessed, removing stop-words after tokenization and we lemmatized our corpus using fr_core_news_md-2.2.0 from SpaCy library , a natural language tool for assigning context-specific token vectors, part-of-speech (POS) tags, dependency parse and named entities. The final dataset includes 2,864 tokens (each token= 1 word).

Hence, we perform the HDP topic model to find any meaningful latent topics underlying on Territoire intelligent corpus. To this end, we chose to rely only on Noun, Adjective and Verbs POS tags.

Appendix 1 provides the set of the first 10 topics thrown by HDP model, ordered in a descending scale by their significance. For each topic, we also provide a set of 20 most relevant words (measured by their probability to be assigned to a specific topic).

We then qualitatively interpret (step ii) all the categories and the associated documents based on the results of the HDP thematic model. Thus, we clarify and understand the 10 motivations of Walloon local decision-makers in the context of smart city projects for urban sustainability. In Table 1, we report the ten categories with a label and the different urban sustainability that the theme is associated.

THEME NR:	PROPOSED THEME NAME	SOCIO-CULTURAL SUSTAINABILITY	ECONOMIC SUSTAINABILITY	ENVIRONMENTAL SUSTAINABILITY
1	Strengthening the communal identity	X		
2	Strengthen the local economy		X	
3	Strengthen social links	X		
4	Improving energy consumption			X
5	Reducing the environmental footprint	X		X
6	Improve safety	X		
7	Improve access to administrative public services	X		X
8	Improve the mobility in the city	X		
9	Reduce CO2 emissions			X
10	Strengthen the link between the administration and the citizens	X		

Table 1 Label of the ten categories and the related urban sustainability dimensions

Findings

This section presents how smart city technology adoption supports urban sustainability.

Environmental Sustainability

Local decision-makers adopt energy systems to monitor energy consumption and automate the optimization of energy consumption in city infrastructures. Energy systems support environmental sustainability by reducing energy consumption during non-working hours and help to mitigate energy consumption during working hours. Such technology also allows to detect potential energy infrastructure problem and address energy loss.

Furthermore, digital platforms can embed ramifications for environmental-friendly best practices. Such games contribute to raising awareness among citizens about ways to reduce the individual environmental impact by providing personalized advice on erroneous habits and possible more sustainable changes to be adopted on a daily basis. Citizens need to be informed and trained to use such games and municipalities can stimuta their usage by promoting them with economic rewards. Similarly, municipalities adopt digital platforms to reduce CO2 emissions.

Digital platforms embeds a smart transport system that helps citizens avoid traffic jams and mitigate vehicle CO2 emissions. Digital technologies can also promote sustainable mobility through virtual forums, where citizens can discuss and create walking and bicycle routes around cities.

Socio-cultural Sustainability

The adoption of intelligent sensors systems supports social sustainability by improving citizen safety and mobility. Such systems can monitor areas that are more vulnerable to natural disasters. Thus, the analysis of such data can forecast these potential disasters and allow citizens evacuate from such areas. Also, intelligent sensors systems support emergency aids to intervene promptly. Furthermore, intelligent sensors systems support citizen mobility because sensors are implemented in intelligent parking. Thus, citizens can quickly find free spots for their cars.

Similarly, we found that digital platforms – i.e. mobile applications or interactive websites - support this sustainability dimension by strengthening the communal identity and the cohesion between citizens and local administrations. Digital platforms can be developed to boost stakeholders' interactions by smoothing information exchange. Thus, information can flow easily among city stakeholders to simplify interactions among them and empower them. Particularly, digital platforms facilitate dialogue between citizens and administrations. Administrations can digitalise their services. Thus, bureaucratic procedures result in simplified and more accessible to citizens. Citizens need to be educated to use such complex systems to address potential digital divide issues.

A further feature that digital platform embed is the intelligent transport system that citizens can use in order to find several forms of transportation according to their needs. Such technologies allows to interconnect different forms of public transport – e.g. metro, bus - and carpooling. Thus, citizen enhances accessibility of the city.

Finally, digital platform support socio-economic sustainability by strengthening social links among city inhabitants. Social links are core elements of a community development. Strengthening and creating social links within a community allows to develop a more dynamic local life and enhance social cohesion. To this end, digital platforms are developed to facilitate the interaction among city actors of different sectors – i.e. cultural and sport spheres. Digital platforms can also include maps and schedule of various events organized in the city and facilitating as well as making more secure the purchasing process of event tickets. In addition, these platforms allow a higher flow of information among different sectors that allows also the sharing of materials such as equipment and communal spaces.

Economic Sustainability

In order to strengthen local economic development, several municipalities can adopt digital platforms – i.e. mobile application - where federations of local businesses can promote their activities and encourage local citizens to visit local shops. Citizens can use such a digital catalogue and find offers of local businesses to purchase goods to fulfil their needs. Citizens can also use digital catalogue to go shopping after cultural events or different city events. Moreover, the use of intelligent parking systems allows citizens to find temporally defined time periods parking close the local shops encouraging shopping in the city. As a result, smart city adoption can support the growth of local businesses.

Lastly, we found that the adoption of an energy management system supports the economic dimension because it reduces energy consumptions of municipalities saving money that can be use for novel services for the citizens.

Theoretical, Empirical, and Managerial Implications and Contribution

The scientific literature reveals that city adoption does not support the three dimensions of urban sustainability because local decision-makers focus on technical aspects of digital technologies of the smart city without considering citizens. The study result addresses this gap proposing an alternative socio-technical vision of smart city adoption, where local decision-makers need to consider both technical digital technologies together to the citizen during the smart city development plan and adoption. The hierarchical dirichlet process extracts 10 themes representing how smart cities adoption support urban sustainability. In the 20 most frequent words for each of them, we found several words related to the citizens' awareness and involvement in smart city projects and the need to educate and train them for technology use (see Table 3).

Keyword:	Occurrence in Theme(s):
To Understand	1
Citizen	1,2
Wise	2
Awareness	3
To involve	4
Collaborative	4
To Inform	5
To form	6
Education	7
Consider	8
To Stimulate	8
To train	9
Family	7,8,9
Dialogue	10

Table 2 Keywords illustrating citizens involvement in smart city projects

To answer the research question, smart city adoption supports the three dimensions of urban sustainability with a strong interplay between citizens and digital technologies. More specifically, the adoption of a digital platform supports the three dimensions of urban sustainability. It encourages city shopping by helping citizens find local shops and businesses to promote their activities (economic dimension); it reduces Co2 emissions by embedding digital transport systems and gamification to teach environmental-friendly best practices to citizens (environmental dimension). Digital platform adoption enhances social cohesion by allowing citizens to communicate with the administration and other citizens (social sustainability). At the same time, citizens need to be trained to use these technologies leading them to contribute to sustainability practice as creators of discussion and content.

Moreover, the monitoring and analysis of energy systems data allow reducing the energy use of citizens and municipalities (environmental dimension) with a consequent reduction of taxes (economic dimension). Lastly, the adoption of intelligent sensors systems helps prevent natural disasters when installed in risky areas and helps find parking when installed on parking areas (socioeconomic dimension).

This study offers implications for researchers. Future studies can investigate how to involve citizens during the development and plan of smart city projects, the potential barrier for citizen involvement and how the municipalities address them. This study has implications for policymakers. They have to provide funds for smart city projects both to purchase digital technologies and for communication plans and training activities for citizens that will use the technologies.

Appendix

1	2	3	4	5	6	7
to understand	cultural	tool	ballad,	Decrease	sensor	naturl
Application	Stubbron	convention	Control	issue	system	wave
Connectivity	To preserve	bus	Classic	Team	To form	Traffic jam
To install	To energize	all	Economic	Involve	Animation	Subsidy
Maintenance	Citizen	producer	to strengthen	Loade	Innovative	transport
Singularly	Translate	different	medium	Vocation	level	Town
Adaption	need	to cross	Leak	collaborative	To invent	family
Purchase	federation	decision maker	progress	obviously	Consumption	Progress
Merchant	wise	awareness	To end	Fracture	Stubborn	'similar
Air	last	behind	sucess	riparian	To wait	neighborhood
To keep busy	watch out	code	Game/act	To favor	Urgency	cliche
Building	health	media	Land	Thursday	Reduced	Education
Space	bridge	ensure	To represent	Proportion	Tissue	evolution
Return	set	flat	pole	Face	Pum	fundamentally
Collective	chief	account	taken	Reseal	wicked	Year
Reinforce	mutualise	bike	To support	To support	educated	commercial
State	To give,	to pay	Rarefaction	start	pastry shop	induce
Citizen	to return	unique	Drop	Inform	slow	Vehicle
Pilot	athletic	digital	Rate	Production	concerning	Govern
Fundamentally	To assess	challenge	Consumption	Level	Last	advice
8	9	10				
Accident	System	Wave				
Concert	Panel	case				
To consider	Drinkable	evolved				
News	raw	diffusion				
Opportunity	Simple	greenhouse				
Origin	laxity	To associate				
Flood	family	Term				
To stimulate	controlled	Called				
Evolved	to access	cultural				
Traffic jam	difficult	electricity				
Venue	second	caterers				
Wifi	vehicle	reluctant				
Carburize	Fortnight	unoccupied				
Trained	Give back	wise				
Challenged	Unemploymen t	alone				
Legislation	Bus	To convince				
Attractiveness	To decrease	anticipation				
Family	audit	near				
Connected	onvergence	knowledge				
consideration	idea	dialogue				

Appendix 1 Results of the Hierarchical Dirichlet Process

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