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URBAN SUSTAINABILITY ANALYTICS: HARNESSING BIG DATA FOR SMART CITY PLANNING AND DESIGN

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Abstract
We develop a conceptual framework based on a systematic and comprehensive literature review on urban sustainability analytics. Building our argument by drawing on data collected from ESI ThoughtLab, KPMG, McKinsey, and Osborne Clarke, we performed analyses and made estimates regarding most needed changes to improve smart cities' living environment (%), the return on, and the economic benefits of, investments in smart city pillars by maturity stage (%), and how smart city applications can contribute to a safer urban environment (%). The data for this research were gathered via an online survey questionnaire and were analyzed through structural equation modeling on a sample of 3,800 respondents.
Keywords: urban sustainability, big data analytics, smart city, planning, design.

1. INTRODUCTION

With the assistance of digital technology, urban areas emerge as adjustable to the events and circumstances that shape it, in a comparable manner to how organisms come to be receptive. (Picon, 2015) Smart data devices and patterns, if adequately advanced and tested, can assist city planners in

being competent enough to make relevant public choices. (Pelton and Singh, 2019) A smart city thoroughly puts into effect digital technologies to decrease resource input, enhance its citizens' wellbeing, and boost the competitiveness of the local economy in an environmentally sound way. (Gassmann et al., 2019) Cutting-edge smart technologies are being advanced and harnessed to various urban systems and associated operations and mechanisms to preserve resources, decrease pollution levels, cut down GHG emissions, reorganize processes, and improve wellbeing (Bibri, 2018).

2. CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

Both cognizant and corporeal, the smart city is developed on the link among large volumes of elementary occurrences. (Picon, 2015) Smart cities display sensors everywhere in urban spaces feeding instantaneous data, partially harvested from smartphones, back to utilities, while vehicles have GPS or RFID identifiers. (McLaren and Agyeman, 2015) By harnessing smart data modeling approaches, change may be directed in a more harmonious manner (Hayhoe et al., 2019; Kubík & Zůvala, 2018; Peleckis et al., 2018; Popescu Ljungholm, 2019; Valaskova et al., 2018) to enhance performance, safety, and coherence of operations. (Pelton and Singh, 2019) Internal harmonization is needed throughout the integrated smart city transformation operation (Androniceanu & Popescu, 2017; Kenrick et al., 2019; Milward et al., 2019; Pera, 2015; Rodney et al., 2019; Whittle et al., 2019), consequently being a key task of the urban administration, which regulates and handles cutting-edge development processes. (Gassmann et al., 2019) A smart city is an array of context-sensitive systems rooted in pervasive computing (Ashander et al., 2019; Kliestik et al., 2018; Nica, 2018; Pera, 2019; Šandal & Křupka, 2018; Wilson, 2019), in which urban settings interact with people and things by the agency of embedded devices and sensors. The employment of big data analytics and context-aware computing grouped as an equipment of data-driven advanced approaches, methods, and patterns (Atwell et al., 2019; Kovacova & Kliestik, 2017; Nica et al., 2019a, b; Pickard et al., 2019; Tuffnell et al., 2019) provides the likelihood of smart sustainable urban spaces in which natural resources can be handled and organized harmlessly, reliably, and smoothly in an intelligent manner to enhance societal and economic results. (Bibri, 2018)

3. METHODOLOGY AND EMPIRICAL ANALYSIS

Building our argument by drawing on data collected from ESI ThoughtLab, KPMG, McKinsey, and Osborne Clarke, we performed analyses and made estimates regarding most needed changes to improve smart cities' living environment (%), the return on, and the economic benefits of, investments in

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smart city pillars by maturity stage (%), and how smart city applications can contribute to a safer urban environment (%). The data for this research were gathered via an online survey questionnaire and were analyzed through structural equation modeling on a sample of 3,800 respondents.

4. RESULTS AND DISCUSSIONS

The digital tools of smart cities enable the enhancement of its operation and sustainability, in addition to an increase in the standard of living for their citizens. (Picon, 2015) The usefulness of smart data analysis is determined by the advancement of the most precise devices and collaborative patterns of change within more massive systems operational throughout cities. (Pelton and Singh, 2019) Big data analytics and its applications are instrumental in carrying out the core features of smart sustainable cities (Bourke et al., 2019; Kovacova et al., 2019; Nica, 2019; Popescu et al., 2018a, b; Tuyls & Pera, 2019), that is, operation and logistical service performance, wellbeing improvement, natural resources upgrade, and intelligent governance of systems and facilities. Smart sustainable cities can provide an unbiasedly assessed, instantaneous analysis of the operations managing and coordinating urban life, resulting in environmental sustainability. Big data processing technologies gather, preserve, organize, explore, and interpret massive volumes of information on urban systems and spheres to identify practical knowledge and harness it to improve decision making and insights. (Bibri, 2018) (Tables 1–5) .

TABLE 1 - TOP ISSUES FACING BUSINESSES BY MATURITY LEVEL (%)

	Leader	Transitioning	Beginner
Improving business attractiveness	26	23	21
Ensuring inclusiveness/income equality	20	24	11
Driving economic development	27	23	15
Coping with population growth	28	21	14
Building jobs and business opportunities	10	13	21

Sources: ESI ThoughtLab; our survey among 3,800 individuals conducted September 2019.

TABLE 2 - WHAT BENEFITS IS YOUR CITY NOW GAINING FROM ITS SMART CITY INVESTMENTS? (%)

Attract residents and tourists	41
Better public services	56
Attract business and private investment	61
Safety and security	54
Economic competitiveness	67
Ability to adapt and innovate	69
Productivity of city workers	72
Productivity of businesses and residents	74
Additional revenue	65
Easier commute and access to services	39

Sources: ESI ThoughtLab; our survey among 3,800 individuals conducted September 2019.

TABLE 3 - WHERE STAKEHOLDERS WANT CITIES TO INVEST MORE (%)

	Citizens	Businesses
Providing data to make businesses/consumers more aware of energy use	61	56
Installing smart grids that use embedded sensors to manage waters, gas, and electric services	55	53
Installing environmental sensors to provide continuous monitoring of air quality, pollution, etc.	54	51
Improving coordination of power generation and power demand	58	45
Using predictive maintenance planning to focus on key environmental areas	56	41
Offering incentives for installing responsive devices and appliances	58	42
Focusing on distributed generation from renewable sources and micro-grids	55	39

Sources: ESI ThoughtLab; our survey among 3,800 individuals conducted September 2019.

TABLE 4 - TO WHAT EXTENT DO YOU AGREE THAT PPP (PUBLIC/PRIVATE) JV STRUCTURES ARE LIKELY TO BE THE MOST EFFICIENT WAY TO FUND SMART TECHNOLOGY NATIONAL INFRASTRUCTURE PROGRAMS? (%)

Strongly agree	29
Agree	53
Disagree	15
Strongly disagree	3

Sources: Osborne Clarke; our survey among 3,800 individuals conducted September 2019.

TABLE 5 - MOST NEEDED CHANGES TO IMPROVE SMART CITIES' LIVING ENVIRONMENT (%)

Availability of affordable housing	55
Reducing traffic congestion and improving transport/mobility	74
Improvement of recycling/waste management and infrastructure for recyclable waste collection	72
Availability of green space/parks	71
A living environment that is more accommodating to elderly and disabled residents	67
Reducing pollution	77
Reducing the carbon footprint	76
Urban redevelopment	62

Sources: KPMG; our survey among 3,800 individuals conducted September 2019.

The chief goal of the smart city represents the pursuit for upgraded environmental regulation, via cutting down its energy consumption or the amount of produced waste. (Picon, 2015) Proficiently managing the issue of effectiveness and the consistency of concerted undertakings represents an essential demand of smart city transformations. (Gassmann et al., 2019) Cities presupposed human settings where smart ways out in concert with the objectives of sustainable advancement can be identified, created, used, evaluated, and enhanced. Powerful computers, ubiquitous networks, and groundbreaking techniques and algorithms can integrate a vast diversity of sensors and link a range of datasets to further far-reaching and massive computational and analytical ways out, configuring the informational setting of smart sustainable urban areas. Big data analytics can find solutions to intricate decision-making issues concerning sound urban advancement by more thoroughly scrutinizing, making sense of, assessing, and fashioning smart sustainable cities. The big data pattern guiding the shift from smart sustainable cities in the direction of a concatenated and integrated strategy into urban advancement is in a permeating route directed toward concernedly activating unobstructed furtherance on numerous scales

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and smoothing the path to reshaping sustainable advancement architecture to attain the deep-rooted objectives of sustainability. (Bibri, 2018) (Tables 6–8).

TABLE 6 - THE RETURN ON INVESTMENTS IN SMART CITY PILLARS BY MATURITY STAGE (%)

	Beginner	Transitioning	Leader
Environment	2.4	7.6	22.4
Mobility	4.7	7.4	16.7
Public health	0.5	6.3	11.8
Economy	0.3	5.1	6.8
Governance	7.2	10.3	6.2
Infrastructure	10.4	11.4	6.1
Payment systems	4.4	5.3	6.2
Public safety	4.7	4.1	5.7
Talent/Education	0.2	4.6	6.3
Budget/Financing	0.4	4.4	0.3

Sources: ESI ThoughtLab; our survey among 3,800 individuals conducted September 2019.

TABLE 7 - WHERE RESIDENTS THINK CITIES SHOULD MAKE TRANSPORTATION INVESTMENTS (%)

Using data to improve transportation routes	67
Improving the speed/reliability of public transportation	63
Using real-time data to respond quickly to traffic issues	59
Offering payment accounts for all transportation modes	62
Sharing data with public on traffic, roads, etc.	57
Providing more travel options (bikes, ferries, etc.)	54
Providing electric vehicle charging stations	57
Using my data to personalize travel suggestions	56
Planning for autonomous vehicles	56
Exploring drones/driverless trucks for moving goods	54

Sources: ESI ThoughtLab; our survey among 3,800 individuals conducted September 2019.

TABLE 8 - TO WHAT EXTENT DO YOU AGREE WITH THE FOLLOWING STATEMENTS ABOUT SMART CITIES IN ITALY? (%)

	Strongly agree	Agree	Disagree	Strongly disagree
There is insufficient regulation/ government incentive to encourage investment in smart grid technologies.	39	46	11	4
The expansion of renewable energy on the grid is the main driver for much-needed investment in energy storage and smart grids.	23	58	16	3
Energy consumers generally understand and are convinced by the benefits of installing smart meters.	15	50	24	11
The roll-out of intelligent transport systems (e.g., the connected car, autonomous/driverless cars, next-generation smart ticketing, improved urban mobility schemes) is a priority for Italy's transport authorities.	37	28	25	10
Italy's roll-out of electric smart meters to over 90% of points of delivery (as of 2014) has resulted in significant behavioral changes.	20	38	38	4
The Public Private Partnership financing schemes available in Italy (e.g., project financing, project bonds) are sufficient to develop and finance smart cities projects.	21	15	47	17

Sources: Osborne Clarke; our survey among 3,800 individuals conducted September 2019.

Breakthrough infrastructure constitutes the setting up for building smart cities. (Pelton and Singh, 2019) Smart city decision-makers should grasp the urban infrastructure in a consolidated, comprehensive

manner and carry out informed decisions. (Gassmann et al., 2019) Smart sustainable cities produce vast quantities of data on almost every urban operation, which should be judiciously preserved for managing, inspection, and distribution. Urban settings are being incessantly actualized through sensorial, informational, and interactive operations. Big data and context information in urban analytics should be adopted and capitalized on designedly with the aim of surveilling, sensing, exploring, and organizing smart sustainable cities. The harnessing of big data analytics in public sector planning can essentially alter the manner smart sustainable cities can operate and be administered soundly, competently, and safely. (Bibri, 2018) (Tables 9–13).

TABLE 9 - HOW HAVE RIDE-SHARING APPS CHANGED YOUR BEHAVIOR? (%)

I still use my personal vehicle, but I use it less.	29.60
I use public transportation less.	25.40
I use taxi cabs less.	13.70
No impact.	13.20
I stopped using taxi cabs.	6.90
I stopped using public transportation.	6.70
I sold my car or decided not to purchase a car.	4.50

Sources: ESI ThoughtLab; our survey among 3,800 individuals conducted September 2019.

TABLE 10 - TO WHAT EXTENT DO YOU AGREE THAT PROJECT FINANCE STRUCTURES WILL BE USED TO FUND THE ROLL-OUT OF SMART TECHNOLOGY IN THE NEXT THREE YEARS? (%)

Strongly agree	17
Agree	65
Disagree	16
Strongly disagree	2

Sources: Osborne Clarke; our survey among 3,800 individuals conducted September 2019.

TABLE 11 - WHERE IS INVESTMENT IN SMART TECHNOLOGY COMPANIES MOST LIKELY TO COME FROM IN YOUR COUNTRY IN THE NEXT THREE YEARS? (%)

Private equity/Venture capital funds	74
Corporate investment (through private or publicly owned companies)	67
Government (through government-backed funds)	35
Government (through direct grants/tax breaks)	28
Utilities	24
Government (through direct procurement or publicly owned institutions)	23
Institutional/Infrastructure funds	21
Crowdfunding	19
Sovereign wealth funds	7
Bonds	4

Sources: Osborne Clarke; our survey among 3,800 individuals conducted September 2019.

TABLE 12 - THE ECONOMIC BENEFITS OF INVESTMENTS IN SMART CITY PILLARS BY MATURITY STAGE (%)

	Beginner	Transitioning	Leader
Reducing time needed for city travel and transportation	21	28	27
Promoting economic development and performance	28	36	35
Increasing productivity of businesses and residents	46	47	56
Increasing ability of city to adapt and innovate	28	57	54
Improving economic competitiveness	38	47	46
Attracting businesses/private investment	15	26	24

Sources: ESI ThoughtLab; our survey among 3,800 individuals conducted September 2019.

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TABLE 13 - HOW SMART CITY APPLICATIONS CAN CONTRIBUTE TO A SAFER URBAN ENVIRONMENT (%)

Fatalities (% decrease in addressed fatalities by application)	
Gunshot detection	2.4
Predictive policing	4.9
Real-time crime mapping	3.6
Personal alert applications	0.8
Data-driven building inspections	0.8
E-hailing (private and pooled)	0.7
Congestion pricing	1.4
Intelligent traffic signals	0.9
Crime incidents (% decrease in incidents by application)	
Predictive policing	12.7
Home security systems	15.3
Real-time crime mapping	12.4
Smart surveillance	6.4
Personal alert applications	4.7
Smart streetlights	5.9
Emergency response (% decrease in average emergency response time by application)	
Emergency response optimization	21.9
Personal alert devices	2.2
Smart surveillance	4.9
Real-time crime mapping	3.2
Gunshot detection	0.8
Home security systems	0.7
Intelligent traffic signals	9.4

Sources: McKinsey; our survey among 3,800 individuals conducted September 2019.

5. CONCLUSIONS AND IMPLICATIONS

A coherent technological infrastructure is vital for the advancement of smart cities. (Gassmann et al., 2019) Big data analytics aims maximization and intelligent decision backing associated with the supervision, optimization, administration, and coordination of urban systems (Challoner & Popescu, 2019; Kral et al., 2019; Nickell et al., 2019; Popescu & Ciurlău, 2019; Trettin et al., 2019) as controlling and designing big data-driven decision-making processes. (Bibri, 2018) By harnessing smart city planning and investment devices developed on intelligent data analytics (Kanovska, 2018; Kwasny et al., 2019; Pera, 2014a, b; Putnam et al., 2019; Westbrook et al., 2019; Zhuravleva et al., 2019), urban areas can make more financially rewarding investment decisions and reduce the force of investment risks. (Pelton and Singh, 2019) The raw data generated by smart cities' various sensors and servers should be formatted for coherent inspection, interpretation, and use. (Picon, 2015)

Note

The interviews were conducted online and data were weighted by five variables (age, race/ethnicity, gender, education, and geographic region) so that each country's sample composition reliably and

accurately reflects the demographic profile of the adult population according to the country's most recent census data. The precision of the online polls was measured using a Bayesian credibility interval. An Internet-based survey software program was utilized for the delivery and collection of responses.

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