Advances in Urban Planning in Developing Nations

Data Analytics and Technology

Edited by Arnab Jana

ADVANCES IN URBAN PLANNING IN DEVELOPING NATIONS

This book studies the increasing use of data analytics and technology in urban planning and development in developing nations. It examines the application of urban science and engineering in different sectors of urban planning and looks at the challenges involved in planning 21st-century cities, especially in India.

The volume analyzes various key themes such as auditory/visual sensing, network analysis and spatial planning, and decision-making and management in the planning process. It also studies the application of big data, geographic information systems, and information and communications technology in urban planning. Finally, it provides data-driven approaches toward holistic and optimal urban solutions for challenges in transportation planning, housing, and conservation of vulnerable urban zones like coastal areas and open spaces.

Well supplemented with rigorous case studies, the book will be of interest to scholars and researchers of architecture, architectural and urban planning, and urban analytics. It will also be useful for professionals involved in smart city planning, planning authorities, urban scientists, and municipal and local bodies.

Arnab Jana is an assistant professor at the Centre for Urban Science and Engineering, and associate faculty at the Centre for Policy Studies, Indian Institute of Technology (IIT) Bombay, India. He works in the field of urban infrastructure policy and planning, primarily focusing on public health policy, application of ICT in urban and regional planning, sustainability, and environmental issues. He was visiting faculty at Hiroshima University, Japan, in 2016. He has a Ph.D. in Urban Engineering from the University of Tokyo, Japan. He was awarded the prestigious Monbukagakusho Scholarship by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Government of Japan. He is also an alumnus of the Asian Program of Incubation of Environmental Leadership (APIEL), University of Tokyo. He has a Master's in City Planning from IIT Kharagpur. He has guided several doctoral and postgraduate students and has authored numerous peer-reviewed articles in journals, conferences, and books.

ADVANCES IN URBAN PLANNING IN DEVELOPING NATIONS

Data Analytics and Technology

Edited by Arnab Jana

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

First published 2021
by Routledge
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

and by Routledge
605 Third Avenue, New York, NY 10158

Routledge is an imprint of the Taylor & Francis Group, an informa business

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
Names: Jana, Arnab, editor.
Title: Advances in urban planning in developing nations : data analytics and technology / edited by Arnab Jana.
Description: Abingdon, Oxon ; New York, NY : Routledge, 2021. | Includes bibliographical references and index. Identifiers: LCCN 2020053706 (print) | LCCN 2020053707 (ebook) | ISBN 9780367528669 (hardback) | ISBN 9780367549688 (paperback) | ISBN 9781003091370 (ebook)
Subjects: LCSH: City planning–Developing countries–Data processing. | City planning–Technological innovations–Developing countries. | Urbanization–Developing countries. | Quantitative research.
Classification: LCC HT169.5 .A38 2021 (print) | LCC HT169.5 (ebook) | DDC
307.1/216091724–dc23
LC record available at https://lccn.loc.gov/2020053706
LC ebook record available at https://lccn.loc.gov/2020053707

ISBN: 978-0-367-52866-9 (hbk)
ISBN: 978-0-367-54968-8 (pbk)
ISBN: 978-1-003-09137-0 (ebk)

Typeset in Bembo
by SPi Global, India

CONTENTS

FIGURES

TABLES

CONTRIBUTORS

Ronita Bardhan is university lecturer of Sustainability in Built Environment at the Department of Architecture, University of Cambridge, UK, and leads the Sustainable Design Group. She works on data-driven sustainable habitat design, energy decisions, and gender equality in Global South.

Moumita Basu is an assistant professor at the Department of Computer Science, UEM, Kolkata, India. She is pursuing PhD from IIEST Shibpur, India. Her research interests include NLP and IR in the area of disaster management.

Ravinder Dhiman is assistant professor at School of Disaster Studies, Tata Institute of Social Sciences, Mumbai, India. He was awarded PhD in Urban Science and Engineering from IIT Bombay, India. He works in science-policy instruments for coastal development.

Saptarshi Ghosh is assistant professor at the Department of Computer Science and Engineering, IIT Kharagpur, India. His research interests include social media analysis, legal analytics, and healthcare analytics.

Arun B. Inamdar is professor with Centre of Studies in Resources Engineering and IDP in Climate Studies at IIT Bombay, India. His research interests are Integrated Coastal Management, Remote Sensing, and Geospatial Science.

Kevin Joshi is a PhD candidate at the Centre for Urban Science and Engineering, IIT Bombay, India. An engineer by training, his research is at the intersection of energy management and policies for distributed generation and storage.

Pradip Kalbar is an assistant professor at the Centre for Urban Science and Engineering at IIT Bombay, India. Prior to joining IIT Bombay as faculty, he worked for two years as a postdoctoral researcher at the Technical University of Denmark (DTU). His area of research includes urban water and environmental management.

Vaibhav Kumar is currently a postdoctoral fellow at IIT Kanpur. He received his PhD from IIT Bombay. His research focuses on geoinformation intelligence while combining the concepts from transportation, built-form planning, environment, disasters, and health infrastructure management.

Krithi Ramamritham has spent almost equal lengths of time at the University of Massachusetts, Amherst, and at IIT Bombay as a chair professor in the Department of Computer Science and Engineering. His current research involves applying computational approaches to energy management, based on the SMART principle: Sense Meaningfully, Analyze and Respond Timely. He is a Fellow of the IEEE, ACM, Indian Academy of Sciences, National Academy of Sciences, India, and the Indian National Academy of Engineering. He was honored with a Doctor of Science (Honoris Causa) by the University of Sydney.

Ahana Sarkar is currently an assistant professor at Hiroshima University, Japan. She received PhD from the Centre for Urban Science and Engineering, IIT Bombay, India. She researches on urban planning, built-environment design, environmental quality, and building performance. By architect as training, she holds a Master's in City Planning from IIT Kharagpur.

Divya Subramanian received her doctorate from CUSE, IIT Bombay, India, and M.Arch from BAS, Norway. An academician, urbanist, and architect, she specializes in urban amenities' evaluation focusing on the marginalized section of society for sustainable development in developing nations.

Varun Varghese is currently an assistant professor at Hiroshima University, Japan. He received his PhD from IIT Bombay, India. His research interests include analysis of activity-travel behavior, impacts of ICT on transportation, and application of machine learning techniques for transportation planning.

Deepank Verma is currently postdoctoral researcher at Technische Universität Braunschweig, Germany. He has a PhD in Urban Science and Engineering from the IIT Bombay, India. He works on DL-based applications in computer vision, audio analysis, and remote sensing.

PREFACE

21st-century urbanization has two unique features; firstly, the unparalleled and inescapable phenomenon of urbanization and secondly the role of data analytics in solving complex urban challenges. While urbanization has imposed new threats of livability, mechanization and the opportunity of computation and analytics to assess the imposed pressures promote the capability to evaluate and undertake informed decisions in advance that might improve the quality of life. This book analyzes the phenomenon of urbanization in the developing nations focusing on India and discusses the opportunity of reshaping the field of urban planning with more accurate and dynamic data.

Urban science and engineering with a multi-dimensional construct and being a multidisciplinary field encourages application and engineering solutions to overcome urban and related problems. In this book several approaches have been discussed that intersect cross-sectional disciplines such as urban planning, civil engineering, computer science, building sciences, urban geography, and many others. This book borrows developed applications in several fields and illustrates through examples of the approaches that would be helpful to solve urban problems.

This book is divided into three parts. Part I discusses sensing and computation in urban planning. Part II covers applications involving network and spatial planning. Part III contains discussions on informed decision-making and management in planning process. Each part comprises of several chapters elaborately discussing an urban planning agenda together with the methodology to analyze the various forms of data. Some of the chapters also discuss the methodology to collect primary data both in the form of survey as well as data generated from various sensors and their consequent drawbacks.

With the smart framework emerging as a new agenda of urban development, urban sensing became means of data procurement. While on one hand, auditory and visual sensing is recently a tool for urban perception, deep learning techniques can be utilized to model and investigate the association of human perception with mental health and well-being. Further, this has assisted urban managers and policy makers in making informed decisions regarding urban aesthetics and site planning by-laws. Sensing also has its direct and wider applications in the field of climate and measuring environmental characteristics. These sensors-based data contribute toward deriving at solutions for complex urban-ecology and designing climate-sensitive and sustainable urban form. This book has looked into the cross-sectional usability and applications of urban sensing, thereby elucidating its importance in future city planning.

Another significant, concurrent pluri-disciplinary aspect of urban science and engineering covered by this book is spatial planning, where the epistemology and concepts of network analysis, spatial-temporal analysis are being executed to solve complex urban problems including location-allocation of facilities, finding minimum impedance routes, and optimizing service area of facilities. Furthermore, with unprecedented urbanization coupled with the rapid growth of vehicular traffic, environmental pollution, congestion on roads, and the deteriorating quality of travel as experience are some of the urgent challenges faced by policymakers. The design of sustainable transportation planning and management policies is highly data-intensive. This book covers the networking and routing algorithms, big data as well as occupant survey data to analyze the importance of ICT in urban and transportation planning in the digital era.

Decision-making and management in urban planning has always remained crucial in developing better cities. Among many, decision-making has its wide application in the fields of spatial geoscience, urban forms and open spaces, integrated coastal management, disaster management, healthcare delivery systems, and monitoring housing environment. The last part of this book further explores similar studies from across the world and discusses the policy implications of decision-making and highlights the challenges and benefits of integrating varied management techniques in urban planning. While geospatial and decision science algorithms have been integrated to identify the stress and vulnerability of areas from technical, social, and eco-environmental point of view, similar techniques using data platforms and portals have been developed for better management of urban sectors including open space, solid waste management, and infrastructure delivery system. On the other hand, data-driven statistical analysis is also being used for identifying determinants of public health condition, environmental aspects which can further pave toward the formulation of forthcoming sustainable habitat, and urban planning guidelines. Resource allocation during the aftermath of natural disasters is another problem imposed over the authorities of developing nations due to a lack of real-time first-hand information. This book covers the usage of Twitter and other online social media data for finding different resource-needs and resource-availabilities during such disaster events.

Overall this book comprises of several chapters discussing the premise of applications in different sectors of urban planning while introspecting the challenges for planning the 21st-century cities of developing nations. The varying sections covering pertinent topics coupled with case-based illustrations and aggregated into a form of single book aid urban researchers in bridging the knowledge of the application of urban science and engineering in forthcoming urban planning.

Arnab Jana
Indian Institute of Technology Bombay

ACKNOWLEDGMENTS

This work was supported by the grant titled Centre of Excellence in Urban Science and Engineering for Training and Research in Frontier areas of Science and Technology (FAST) funded by Ministry of Education Government of India [grant numbers 10009280].

ABBREVIATIONS

ACH Air Changes Per Hour
AI Artificial Intelligence
AMI Advanced Metering Infrastructure
ANPR Automatic Number Plate Recognition
API Application Programming Interface
ARTM Average Response Time Model
BCI Brain–Computer Interface
BES Building Energy Simulation
BL Binary Logit
CAPI Computer Assisted Personal Interviews
CATI Computer Assisted Telephone Interviews
CBD Central Business District
CDR Call Detail Records
CEMP Community Energy Management Platforms
CES Community Energy System
CFD Computational Fluid Dynamics
CNN Convolutional Neural Network
CPCB Central Pollution Control Board
CRZ Coastal Regulation Zone
dB Decibel
DBN Deep Belief Networks
DG Distributed Generation
DL Deep Learning
DPM Discrete Phase Model
DSS Decision Support Systems
e-IEQ Experiential Indoor Environmental Quality
ERS Emergency Response Services

ESA	Existing Situation Analysis
EWS	Economically Weaker Sections
FAR	Floor Area Ratio
FCD	Floating Car Data
fNIRS	Functional Near-Infrared Spectroscopy
GAN	Generative Adversarial Networks
GDP	Gross Domestic Product
Geo AI	Geospatial Artificial Intelligence
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSI	Geological Survey of India
GSV	Google Street View
HETUS	Harmonized European Time Use Surveys
HSR	High-Speed Railway
HTL	High Tide Line
IAQ	Indoor Air Quality
ICM	Integrated Coastal Management
ICT	Information and Communications Technology
IEQ	Indoor Environmental Quality
IIA	Independence of Irrelevant Alternative
IMD	Indian Meteorological Department
IoT	Internet of Things
ITA	Incremental Traffic Assignment
LDA	Latent Dirichlet Allocation
LHS	Latin Hypercube Sampling
LIG	Low-Income Group
LMA	Local Mean Age of Air
LoS	Level of Service
LSTM	Long Short-Term Memory
LTL	Low Tide Line
MAA	Mean Age of Air
MCDM	Multi-Criteria Decision Making
MCGM	Municipal Corporation of Greater Mumbai
MCLP	Maximal Covering Location Problem
MDCEV	Multiple Discrete-Continuous Extreme Value
MDG	Millennium Development Goals
MERC	Maharashtra Electricity Regulatory Commission
MIG	Middle Income Group
ML	Machine Learning
MNL	Multinomial Logit
MoEFCC	Ministry of Environment, Forest and Climate Change, Government of India
MoHUA	Ministry of Housing and Urban Affairs, Government of India

MoSPI	Ministry of Statistics and Programme Implementation, Government of India
MoUD	Ministry of Urban Development, Government of India
MPCE	Monthly Per Capita Expenditure
MVDS	Microwave Vehicle Detection System
NB	Naïve Bayes
NDZ	No Development Zone
NHTS	Nationwide Household Travel Survey
NRPS	National Rail Passenger Survey
NSGA	Non-Dominated Genetic Algorithm
NSSO	National Sample Survey Office
OGD	Open Government Data
OSM	Online Social Media
PCV	Physical Coastal Variables
PHC	Primary Health Centre
PII	Personally Identifiable Information
PMAY	Pradhan Mantri Awas Yojana
POS	Public Open Spaces
QoL	Quality of Life
RANS	Reynolds-Averaged Navier–Stokes
RoI	Return on Investment
RS	Remote Sensing
SARS	Severe Acute Respiratory Syndrome
SBS	Sick Building Syndrome
SDG	Sustainable Development Goals
SODM	Single Objective Decision-Making
SRA	Slum Rehabilitation Authority
TB	Tuberculosis
T&D	Transmission & Distribution
ULB	Urban Local Body
UN	United Nation
URDPFI	Urban Regional Development Plans Formulation and Implementation
UT	Union Territory
WHO	World Health Organization

1

URBANIZATION AND DATA ANALYTICS

Arnab Jana and Ahana Sarkar

1.1 Urbanization and its impacts

Urbanization is among many noteworthy drifts of the current era, promoting and delivering the buttress and impetus for global change. The swing toward a progressively urbanized world establishes a transformative dynamism that can be coupled for a more sustainable development route, with cities leading toward addressing many of the comprehensive challenges of the 21st century, including poverty, inequality, unemployment, environmental degradation, and climate change. Over the last two decades, cities have emerged as the world's economic platforms for production, innovation, and trade. Urbanization has helped millions escape poverty through increased productivity, employment opportunities, improved quality of life, and large-scale investment in infrastructure and services (*World Cities Report 2016: Urbanization and Development - Emerging Futures*, 2016). This transformative power of urbanization has been facilitated by the rapid deployment of ICT.

Post-industrial revolution and since the beginning of the 21st century, urbanization rate has increased phenomenally. The global proportion of the urban population has witnessed a spike from 13% in 1900 to 29% in 1950 and is further expected to be around 70% by 2050 by following a similar trend. This would advertently double the 3.5 billion urban dwellers worldwide in 2010 to 6.3 billion by 2050; however, most of the growth is expected to occur in small- and medium-sized cities. At the same time, overall levels of urban residents' consumption are rising, placing a greater strain on the resource base and increasing the imperative to allocate natural assets fairly and equitably. While megacities are the focus of much attention, it is the medium-sized cities (with populations of 1–5 million) that will experience the fastest rates of urban growth, and most of the world's urban population will live in small cities of less than one million by 2050 (Elmqvist et al., 2013).

The scale of urbanization is unparalleled in terms of population size, urban extent, and the sheer number of large urban areas (conurbations). In 1900, while there were no cities with a population of ten million or more, today, there are nearly 400 cities with a population of more than ten million with the Tokyo-Yokohama urban agglomeration having a population of nearly 40 million. Another important characteristic of the century is the rate of urbanization. While it took all of history until 1960 for the world population to reach one billion, an additional 26 years doubled it to two billion and further escalating at a rate of one billion per decade thus amounting to 7.59 billion. The last but not the least crucial statement is that "the geography of urbanization is shifting". The world's 20 fastest-growing urban regions are in Asia and Africa, not Europe or North America. The urban transition in Europe and South America occurred in the 1950s through the 1970s. Urban growth in the coming decades will take place primarily in Asia (China and India in particular) (Elmqvist et al., 2013).

In India as well as in overall South Asia, the percentage of urban population has been growing at a similar rate (see Figure 1.1). While cities have been the engine of growth, economic prosperity, housed creativity, and nurtured entrepreneurs, cities played a major role in global problems such as climate change, while untamed growth has led to the crisis in infrastructure availability, upsurge in energy demand, deteriorated living conditions and consequently adverse health impacts. As cities and the citizens are getting more digitally connected, the impact of ICT on automation and streamlining to services are being conceived to improve transparency, reduction of information divide among the citizens. This calls for an agenda to study the intermixing of all the dimensions and their interplay in modern-day cities (Batty, 2012), but the digital divide might remain a major drawback in developing nations.

While we attempt to study the impacts in silos, we often end up in non-deterministic results. One of the fundamental causes as Jane Jacobs has pointed out is cities are complex systems and their components are strongly interrelated (Jacobs, 1961).

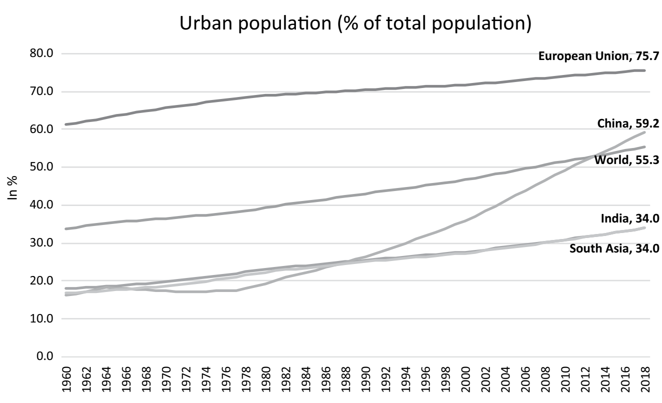

FIGURE 1.1 Urban population (% of total population)
Source: United Nations Population Division. World Urbanization Prospects: 2018 Revision; https://data.worldbank.org/; accessed May 25, 2020

While there is an argument that "doubling the population of any city requires only about an 85% increase in infrastructure" (Bettencourt & West, 2010). Bettencourt & West (2010) stated, "*It is as yet unclear whether this is also true for cities undergoing extremely rapid development, as in China or India, where data are poor or lacking*". Accordingly, the authors pointed out the opportunity we hold to collect *detailed data* to analyze and establish linkages between development and "*undesirable consequence*".

1.2 Development, planning, and urbanization

The Current model of urbanization is unsustainable in many aspects: environmentally, socially, and from an economic perspective (*World Cities Report 2016: Urbanization and Development - Emerging Futures*, 2016).

- Unprecedented urban growth and city expansion has largely endangered low-density suburbanization and has contributed precariously to climate change.
- Socially, it generates multiple forms of inequality, exclusion, and deprivation, which also creates spatial inequalities and disparity, often characterized by slums and informal habitations.
- From an economic perspective, the current model of urbanization, especially in developing nations, is unsustainable due to widespread unemployment, unequal access to basic services and amenities, poor management of labor, and deteriorated health and quality of life for many.

There is an urgent requirement of a new agenda that should be implementable, universal, rights-based, multi-sectoral, and spatially integrative, inclusive, equitable, people-centered, green, and measurable. The new urban agenda should promote cities and human settlements that are environmentally sustainable, resilient, socially inclusive, safe and violence-free, economically productive, better connected, and contribute to transformation.

1.2.1 Role of ICT in urbanization

Cities signifying more than 70% of global energy demand, turns up as a protagonist in steering the sustainable energy agenda forward. Sustainable and reliable urban mobility, for example, offers well-organized access to goods, services, jobs, social networks, and activities while limiting both short- and long-term adverse consequences on social, economic, and environmental services and systems. Singapore, Hong Kong, and Tokyo are examples of cities where the costs of car ownership and use have been set high and planning strategies have emphasized mass transit, walking, and cycling. Innovative mobility services such as e-hailing, autonomous driving, in-vehicle connectivity, electrification, and car-sharing systems offer multimodal, on-demand transportation choices. More compacted, better-connected cities with low-carbon transport could help cities save as much as US$3 trillion in infrastructure investments over the next decade (*Better Growth, Better Climate: The New Climate Economy Report*, 2014).

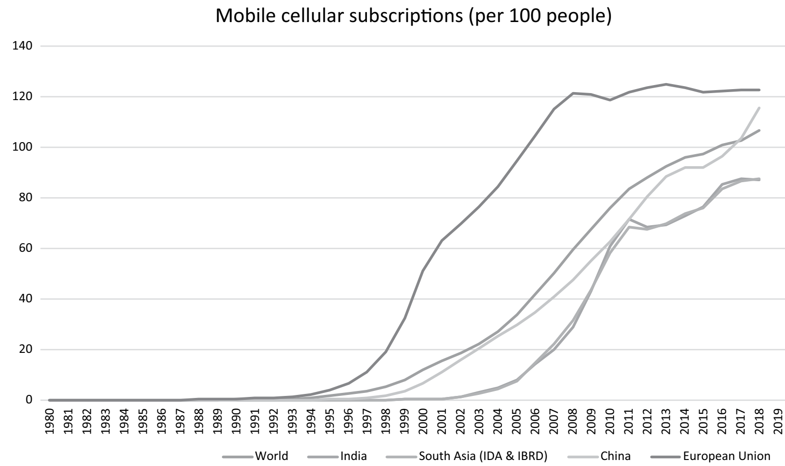

FIGURE 1.2 Mobile cellular subscription per 100 people from 1980 to 2018
Source: https://data.worldbank.org/; accessed May 25, 2020

Over the last era, urbanization has been simplified by the fast utilization of ICTs, and the employment of city data to make informed decision-making and propel a global movement toward efficient cities. The internet has advanced fast since its commencement, stimulating vast innovation, miscellaneous network enlargement, and augmented user engagement in a virtuous circle of progress. Internet users reached over 4.4 billion in 2019. The total number of mobile cellular subscriptions across the globe has reached 7.86 billion as of 2018[1], 1.17 billion of which is from India. Moreover, there are about 86.9 mobile cellular subscriptions per 100 people (see Figure 1.2). For the vast majority of urban dwellers in developing nations, mobile telephony is probably the only tool that guarantees connectivity. The deployment of ICTs in cities supports innovation and promotes efficiencies in urban infrastructure leading to lower-cost city services. Cities like Hong Kong and Singapore are distinguished instances of economies that were able to make this dive by digitizing their infrastructure.

UN-Habitat has enlisted the following key facts to be noted while developing sustainable cities and communities:

- When well planned and managed, urbanization can expressively improve the economic scenarios and quality of life for the common, initiate and steer innovation and productivity, add to national and regional development, eradicate poverty, and move toward social inclusion.
- Understanding the potential gains of urbanization is not automatic.
- Urban space can be a planned entry point for cities in motivating sustainable development.
- There is an urgent demand for more cohesive development, strong financial planning, service delivery, and strategic policy choices.

- Supportable, strong, and comprehensive cities are often the outcome of good governance that includes operative management; land-use planning; jurisdictional organization; all-encompassing citizen contribution; and effective financing.
- Technology solutions and the active use of data are providing city leadership with novel tools and openings for effective change.

1.2.2 Habitat planning and urbanization

Upcoming approaches to housing should be essentially considered while looking into the sustainable future of cities and the benefits of urbanization. Housing comprising approximately 70% of land use in urban cores is a major determinant of urban form and densities. Housing also provides employment and contributes to inclusive development. Nonetheless, over the last 20 years, lack of housing being central to national and international development agendas is the major blind-spot and is consequently rising toward the disordered and dysfunctional spread of many cities and towns. Additionally, the housing shortage imposes a challenge over government housing authorities and is difficult to quantify. In 2010, as many as 980 million urban households lacked decent housing, as will another 600 million between 2010 and 2030. One billion new homes are needed worldwide by 2025, costing an estimated $650 billion per year, or US$9-11 trillion overall. Besides, shortages in qualitative deficiency are much superior to those in quantity and are largely ignored.

Aligning with *SDG*[2] *11.1: by 2030, ensure access for all to adequate, safe, and affordable housing and basic services and upgrade slums,* UN-Habitat has pointed out the need for a novel approach that keeps housing at the center of urban policies. The goal should be to integrate housing into national urban policies and UN-Habitat's strategic thinking on planned urbanization.

1.3 Predictability of urban future

Despite uncertainties linked to the increasing speed of technological and societal evolution, important features of future urbanism can be predicted at the regional and global levels and even sometimes for local situations. Comparative urban studies have brought results about universal processes and typical trajectories in the history of urban systems. There is a need for analytic description that provides the basis for designing robust dynamic models as well as realistic scenarios for exploring a diversity of possible urban futures.

Quantitative approaches to understanding the growth and emergence of cities together have its ability to sustain economic activities and have been attempted by several researchers. Scalability and biological metaphors of cities such as "living system", "organism", "urban metabolism", and so on have been the notion to understand the structure and dynamics of human socialization. Bettencourt et al. (2007) argued that irrespective of complexity, diversity, and geographic variability, "*cities belonging to the same urban system obey pervasive scaling relations with population size*".

Attempts to study typical trajectories of the city's evolutions highlighting history of urban systems to generalize into a universal process while simulating possible future are noted in recent researches (Pumain & Reuillon, 2017).

1.4 Urban science/informatics

Recent metropolises, as machines of the new data economy, have observed the revolution or replacement of city services from legacy infrastructures and service delivery models in the 20th century to on-demand transport, intelligent water systems, responsive lighting, and distributed energy resources. Consequently, the millions of connections and communications taking place in cities on a given day, for example, volume of energy used, transport flows, movement of people, traffic, water and waste, transactions, social media interactions are leading to a huge repository of "data exhaust". This data exhaust of the cities, similarly growing at an unprecedented rate, adds value to government and researchers to apply data-driven methodologies to improve the quality and efficiency of city services and life (Barns, 2018).

For the cities of South Asia, which has predominantly emerged organically, it is hard to derive the quantitative construct of city form and function given the heterogeneity of economic status, diversity of religious and cultural practices. While the concept of "science of cities" (Batty, 2013) orients toward a more formalized approach of city planning, the definition of "urban science" by (Kontokosta, 2018) seemed to be more appropriate for the context of cities in the global South.

Kontokosta, 2018 defined Urban Science as "*scientific study of cities through experimentation and interdisciplinary research. It can be defined by its objective to understand urban dynamics using observational or measured data and scientific methods from physical, natural, and social sciences*". The term Urban Science refers to "*a computational modeling and simulation approach to understanding, explaining and predicting city processes*", while Urban Informatics is explained as "*an informational and human-computer interaction approach to examining and communicating urban processes*". Indeed, there is a strong and recursive relationship between data-driven urbanism and urban science/informatics, with the former providing the raw material and applied domain and the latter providing fundamental ideas and the key tools to enact city analytics and data-driven decision-making. Thus, urban science coupled with urban informatics paves a way toward the computational understanding of city systems. However, concerning the former, higher priority has been provided on the development of innovative data analytics that utilize machine learning techniques, visual analytics, computational simulations, statistical analytics and prediction, and optimization modeling on one hand and geography and urban modeling, climate modeling, digital mapping on the other hand.

1.4.1 Urban sensing

With the smart framework emerging as a new agenda of urban development, urban sensing became means of data procurement. Privacy of the users, especially the identification of personal information still remains a major concern for the deployment of big data in mainstream policymaking. Therefore, governance of individual data, policy of the usage of data for identified purposes, and data security have been key issues. Zheng et al. (2014) categorized urban sensing into three typologies, namely,

i) traditional sensing and measurement – installation of sensors to collect a typology of data,
ii) passive crowdsensing – when the collected data can be used for other purposes, and
iii) participatory sensing – when users share their data and information.

1.4.2 Urban data analytics

Software-driven technologies and urban big data have become integrally crucial for sustainable development and appropriate functioning of cities consequently turning data-driven urbanism to be the key mode of production for future cities. The essence of data-driven urbanism lies in the holistic and computational understanding of city systems that transforms and reduces the urban life complexity to a set of logic and rules, underpinned by rationality and realistic epistemology. Figure 1.3 demonstrates a taxonomy of varying data analytics in smart city management and urban planning.

The result is a vast deluge of real-time, fine-grained, contextual and actionable data, which are routinely generated about the cities and their citizens by a range of public and private organizations, including (Kitchin, 2016):

- utility companies (use of electricity, gas, and water);
- transport providers (location/movement, travel flow);
- mobile phone operators (location/movement, app use, and behavior);
- travel and accommodation websites (reviews, location/movement, and consumption);
- social media sites (opinions, photos, personal information, and location/movement); crowdsourcing and citizen science (maps, e.g. OpenStreetMap; local knowledge, e.g. Wikipedia; weather, e.g. underground);
- government bodies and public administration (services, performance, and surveys);
- financial institutions and retail chains (consumption and location);
- private surveillance and security firms (location and behavior);
- emergency services (security, crime, policing, and response); and
- home appliances and entertainment systems (behavior and consumption).

These urban big data, it is contended, produce a highly granular, longitudinal, whole understanding of a city system or service and enable city systems to be managed in real-time. While some of these data are generated by local authorities and state agencies, much of the data are considered a private asset. The latter are generally closed in nature, though they might be shared with third-party vendors (such as city authorities, often for a fee) or researchers (using a license). In some cases,

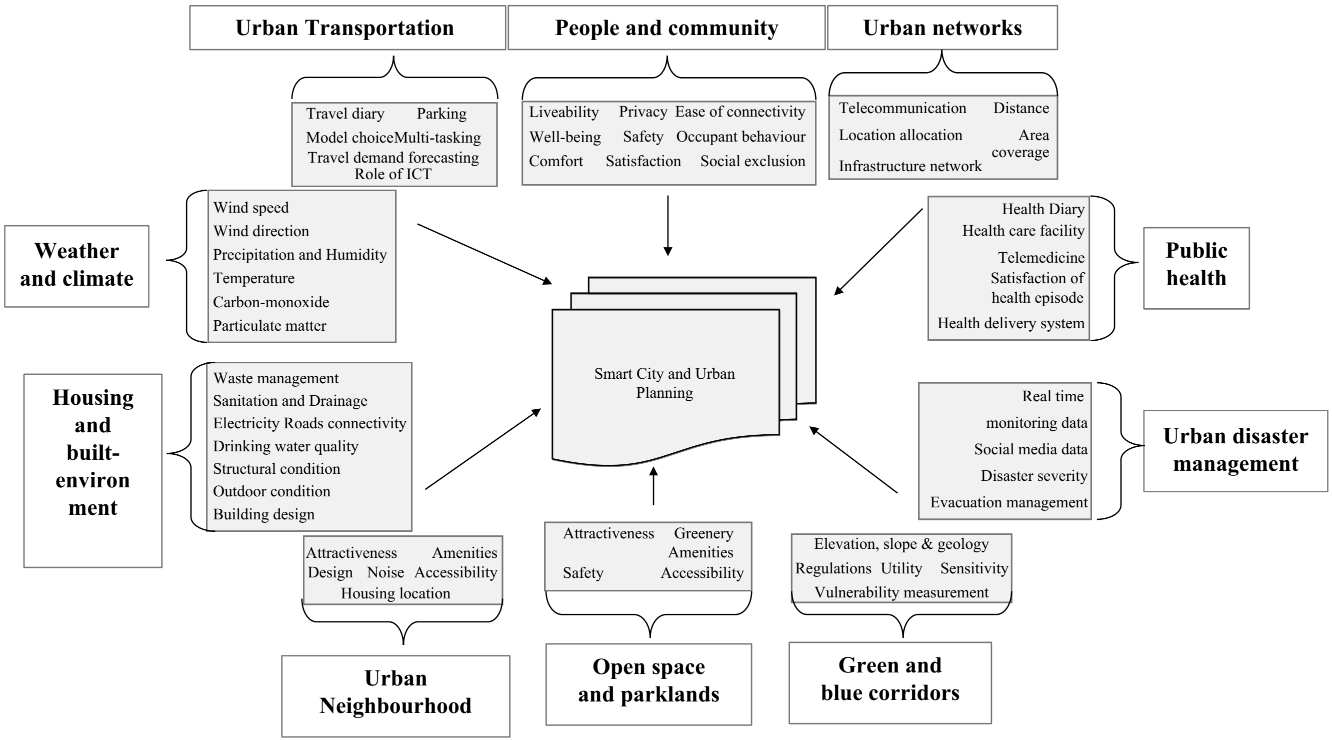

FIGURE 1.3 A taxonomy use of varying data analytics in smart city management and urban planning.
Source: Author's compilation