Cognitive Systems for Urban Planning: A Literature Review

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Abstract. The need of citizens engagement in modeling the vast amount of services provided by governments has led to mechanisms where people are seen as sensors. Development policies, processes, and aims are evolving regarding urban planning in order to use citizens-generated data as input in the intelligent systems. This data may be a rich source to mine citizens' current requirements, detect serious problems in a city and determine what is urgent and what is not. Citizens as sensors is a new paradigm that transforms the idea of *efficiency* implemented in a "smart city" into the notion of *resilience* oriented to "cognitive cities". In this regard, a systematic literature review of how intelligent systems have been employed towards modeling cognition in urban planning was conducted. This work propose a classification on how intelligent systems are being approached: Implementations in intelligent governance, big data and analytic solutions, fuzzy methods, and application scenarios toward cognitive urban planning. Moreover, this study details a comparison of the approaches mentioned above in terms of technology targeted and/or computing methods employed, as well as the advantages of the proposed works and their limitations. The results of the present review revealed that previous studies contributed with combined strategies that apply soft computing methods, but the implementation of empirical validations has not been studied in depth.

Keywords: Cognitive cities · Urban planning · Collective intelligence · Big data · Fuzzy methods · Cognitive computing · Smart cities

1 Introduction

Knowledge and the learning process that emerge from people-to-people and people-to-data interactions transform them and the social environment around.

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In information applications, this social and data-oriented phenomenon is known as collective intelligence [49]. When collective intelligence serves as a baseline in information sciences, generalizations may be inferred because the system learns patterns from the behavior of the whole community. For example, the local government of certain city might propose a specific Web-based recycling program taking into account the ideas, participation and the particular conditions of the community. Then, improving the functioning of the city is an effect of self-empowering initiatives performed by heterogeneous social actors (and not as an outcome of technology companies or business strategies) [9].

People engaging in community-based platforms may offer a collective understanding of the world around them, get involved in discussions and contribute with solutions. Then, new forms of generation of knowledge are experienced. The use of intelligent algorithms to solve complex problems is extended to various domains. However, as *cognition* is recently considered in areas such as town planning, territory organization and e-participation, the application of artificial intelligence merged with collective intelligence strategies is hardly used to solve the resilience challenges of cities. Generally, collective intelligence is applied in scenarios where machines are deficient and are unable to perform a task [35]. The identification of how human factors and technology are approached together may be relevant, guide systems design and give directions for future research.

Classifying, comparing, recognizing, and explaining the social environment are cognitive factors that have proven to be useful in information systems. Then, from this arises the idea of seeing "people as sensors" in E-Government and E-Participation applications. This paper aims to survey and analyze existing cognition-based systems to detail the opportunities for innovating and supporting the progress of cities. We adopt a systematic approach to analyze and aggregate the outcomes of significant empirical studies in *Urban Planning*. Such studies may apply different methods and address various problems in the context of cognitive urban planning. Thus, our objectives are:

- Presenting a systematic review and analysis of the different domains related to the methods and strategies applied towards cognitive cities. We highlight the advantages and limitations found;
- Analyzing the main challenges in the field of cognitive cities and addressing them with options or solutions;
- Describing the key areas where future studies could change the cities while improving their resilience.

The remainder of the paper is structured as follows: Sect. 2 classifies the relevant articles in methods for cognitive urban management systematically. Section 3 discusses cognition modeling mechanisms and categorizes them; Sect. 4 reflects the results and comparison of the reviewing strategies; finally, in Sect. 5, we conclude the work done in this study.

2 Systematic Literature Review

With regard to urban management, the concept "smart cities" leaves new urban challenges out of reach. These challenges not only require improved efficiency, but also demand approaches based on sustainability and resilience [18]. To better understand how the problems related to Cognitive Urban Planning have been addressed, this section describes a *systematic literature review* (SLR) of the technological strategies applied in the domain. To provide an evidence-based transparent study, we analyzed the methods, cases and experiences gained from different research works. Then, to obtain a balanced and objective summary we formulated a question, identified the relevant studies, evaluated their quality, summarized the research evidence, and interpreted the findings [7]. We use a repeatable methodology that supports the presented SLR where the different experimental contexts may be assessed and the outcomes aggregated [3,6]. The *SLR* selection procedure is presented in the following section.

2.1 Article Selection Process

The strategy performed to select the articles have four steps: *i)* Build the search query from keywords; *ii)* Article selection based on the year of publication and its language; *iii)* Article selection based on the reputation and validity of the publisher; and *iv)* Article selection based on the content of its 'Abstract'. The first step consists of combining some keywords to formulate the search. The use of logical operators may enhance the query. We established the relevant words and noun phrases and employed them to create the query: *"cognitive cities" OR "cognitive city" urban plan citizens requirements information systems data*. This has been searched in *Google Scholar* which presented us with the related academic articles ordered according to the ranking algorithms employed by the Google search engines (a general explanation may be found in [4]). As a result, the search system extracted 135 articles from books, chapters, master and PhD thesis, journals, conferences, executive reports, working papers, notes and workshop papers. In the step *ii)*, to make sure that the most recent research works are considered, the adopted strategy was oriented to remove the articles published before 2010. Moreover, a quality criterion that we applied was to filter out the articles that were written in a language other than English. After this, we obtained a total of 105 papers. The step *iii)* was conducted with the aim of choosing only high-quality articles for their further analysis. To do so, we focused on the articles retrieved from journal publications, book chapters, and conferences published by Springer, Elsevier, IEEE, and ACM. Journals that were indexed in Scopus or listed in Scimago Journal Ranking were also included in our study. Then, reports, working papers, books, and thesis, as well as invalid journal/conference articles were excluded. The amount of the remaining articles was of 53. In last step, the 'Abstracts' of the articles were studied by the authors. If they contained a part of the keywords and were related to cognitive cities they were considered as relevant to the subject matter. In this regard, 42 academic articles were finally selected for their analysis.

2.2 Articles Classification

To have an overview of the selected articles, we classify them considering the year of publication and the publisher. The papers in our study were published in the range of 2010–2019. Figure 1 presents a matrix with the number of articles found per year and publisher. As it can be seen, before 2016 there was a small quantity of papers related to the topic (10 articles that represent the 23.81%). Besides, in 2010 and 2013 no article was presented. In the last four years (2016–2019), the interest in researching methods which involve cognitive and information systems for urban planning has increased (32 out of 42); so much so that in the first two months of 2019 there are already nine articles. In 2016, Springer stands out among the publishers with eight articles. This result was expected given that in this year the Springer book "Towards Cognitive Cities" [45] was released and most of the chapters were chosen for our study. If we consider as categories the publishers Elsevier, Springer, IEEE, and ACM, as well as the 'Other' (high-quality) indexed journals, it is shown that 45.24% of the chosen articles were published by Springer. This publisher commonly seems to lead the number of publications over the time. Moreover, it should be noted that 26.19% of the articles belong to the IEEE. Figure 2 shows that the majority of the articles are book chapters (17 papers that represent the 40.48% of the total). The presence of journal papers in our study is of 33.33% while the 26.19% belongs to the conference papers. Most of the IEEE and ACM articles are conference papers. On the other hand, only one journal article was extracted from Elsevier.

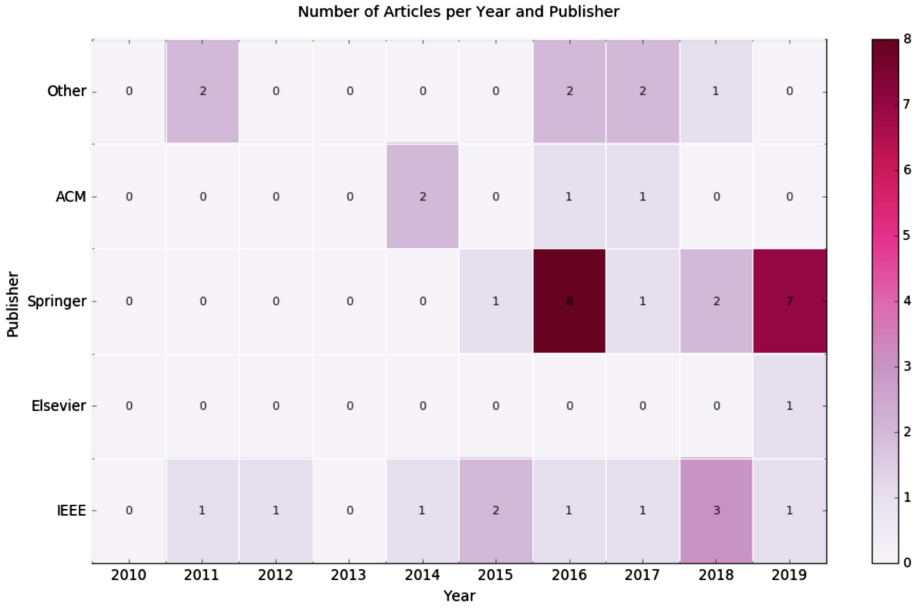

Fig. 1. Number of selected academic articles per year and publisher.

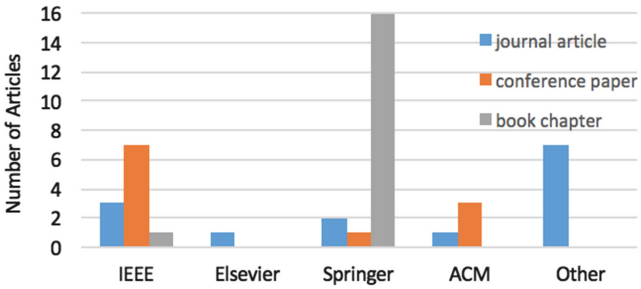

Fig. 2. Number of selected academic articles per kind of paper.

Table 1. Classification of the articles according to categories

Category	NumArticles	Percentage (%)	Articles in
Intelligent governance implementations	17	40.47	Table 2
Data-oriented problems	9	21.43	Table 3
Fuzzy models-based	9	21.43	Table 4
Application scenario solutions	7	16.67	Table 5

Based on the content of the articles, we classified them in four categories depending on their adopted strategy:

1. Intelligent governance implementations. Articles whose concerns were related to transformations in cities, theoretical contexts and the use of cognitive computing.
2. Data-oriented problems. Articles that target (big) data processing, privacy and visualization.
3. Fuzzy models-based. Articles that employed fuzzy theory as a main approach.
4. Application scenario solutions. Particular solutions to address a specific citizen/location/service problem.

According to the presented categories, Table 1 details the number and the corresponding percentage of the articles classified in each of them. Almost 41% of the articles belong to the category 'Intelligent governance implementations' (Table 2). The categories 'Data-oriented problems' and 'Fuzzy models-based' have 9 articles each (Tables 3 and 4, respectively). Finally, only 7 papers were fund as 'Application scenario solutions' (Table 5).

Table 2. Articles whose strategy is based on intelligent governance implementations

Publisher	Year	Article and reference	Journal/Conference /Book name
IEEE	2019	A Conceptual Model for Intelligent Urban Governance: Influencing Energy Behaviour in Cognitive Cities [34]	Designing Cognitive Cities
Springer	2019	Designing Cognitive Cities [50]	Designing Cognitive Cities
Springer	2019	Possibilities for Linguistic Summaries in Cognitive Cities [20]	Designing Cognitive Cities
Springer	2018	Advancing Cognitive Cities with the Web of Things [14]	New Advances in the Internet of Things
Taylor & Francis	2018	Intelligent or smart cities and buildings: a critical exposition and a way forward [19]	Intelligent Buildings International
IEEE	2018	Smart Governance for Smart Cities [47]	Proceedings of the IEEE
Taylor & Francis	2017	Computing Brains: Learning Algorithms and Neurocomputation in the Smart City [54]	Information, Communication & Society
Springer	2016	Granular Computing as a Basis of Human-Data Interaction: A Cognitive Cities Use Case [53]	Granular Computing
Springer	2016	Maturity Model for Cognitive Cities [52]	Towards Cognitive Cities
Springer	2016	From Smart to Cognitive: A Roadmap for the Adoption of Technology in Cities [40]	Towards Cognitive Cities
Springer	2016	Innovative Urban Governance: A Game Oriented Approach to Influencing Energy Behavior [33]	Towards Cognitive Cities
Springer	2016	Digital Personal Assistant for Cognitive Cities: A Paper Prototype [25]	Towards Cognitive Cities
Springer	2016	Towards the Improvement of Citizen Communication Through Computational Intelligence [44]	Towards Cognitive Cities
Inst Construction & Architecture	2016	Stratigraphy of the Smart City Concept [30]	Architektura & Urbanizmus
IEEE	2012	Intelligent Governance of Large-Scale Engineering Systems: A Sub-Systemic Approach [10]	IEEE International Systems Conference SysCon 2012
IEEE	2011	Citizens as Sensors: The Cognitive City Paradigm [38]	8th International Conference Expo on Emerging Technologies for a Smarter World
Wiley Online Library	2011	Informational Cities: Analysis and Construction of Cities in The Knowledge Society [48]	Journal of the American Society for Information Science and Technology

Table 3. Articles that offer big data and analytics solutions

Publisher	Year	Article and reference	Journal/Conference/Book name
Springer	2019	The Role of Interpretable Fuzzy Systems in Designing Cognitive Cities [1]	Designing Cognitive Cities
Springer	2018	Using Geocoding and Topic Extraction to Make Sense of Comments on Social Network Pages of Local Government Agencies [31]	Electronic Government
IEEE	2018	Enabling cognitive smart cities using big data and machine learning: Approaches and challenges [36]	IEEE Communications Magazine
Springer	2017	Managing Urban Resilience Stream Processing Platform for Responsive Cities [28]	Informatik-Spektrum
ACM	2017	City Ranking Based on Financial Flux Indicator Clustering [2]	Proceedings of the 18th Annual International Conference on Digital Government Research
Open Access Journal	2016	Data-Driven Participation: Algorithms, Cities, Citizens, and Corporate Control [51]	Urban Planning
Springer	2016	Cognitive Cities, Big Data and Citizen Participation: The Essentials of Privacy and Security [8]	Towards Cognitive Cities
Springer	2015	Big Data and Analytics for Government Innovation [37]	Big Data and Analytics: Strategic and Organizational Impacts
IEEE	2014	Visual Analysis of Public Utility Service Problems in a Metropolis [55]	IEEE Transactions on Visualization and Computer Graphics

3 Cognition Models in Urban Planning

The recent advancements in technology have made human experiences and abilities to reason be considered as part of intelligent systems' *adapting processes*. For cities that evolve quickly -and are expected to be resilient- this means to merge computing (automation) which provides a collaborative platform for discovery with the responses, actions, data and feedback of human users [21]. One of the seminal works on "Cognitive Cities" is the proposed by Novak (1997) [42]. His research provided the theoretical foundations to *invent* intelligent environments which people could interact with. Once our behavior is recognized, these real or virtual environments would know our strengths, weaknesses and needs and respond to us. Therefore, various strategies to provide these new environments (or resilient cities) with the abilities to perceive, retain, retrieve, repeat, compare, transform and generate patterns may be developed. Next, we analyze

Table 4. Articles whose strategy is based on fuzzy models

Publisher	Year	Article and reference	Journal/Conference/Book name
Springer	2019	Using Fuzzy Cognitive Maps to Arouse Learning Processes in Cities [15]	Designing Cognitive Cities
IEEE	2018	Fuzzy Reasoning in Cognitive Cities: An Exploratory Work on Fuzzy Analogical Reasoning Using Fuzzy Cognitive Maps [12]	2018 IEEE International Conference on Fuzzy Systems
IEEE	2017	Striving for Semantic Convergence with Fuzzy Cognitive Maps and Graph Databases [13]	2017 IEEE International Conference on Fuzzy Systems
ACM	2016	Synchronizing Mind Maps with Fuzzy Cognitive Maps for Decision-Finding in Cognitive Cities [17]	2017 Proceedings of the 9th International Conference on Theory and Practice of Electronic Governance
IEEE	2016	Personal Digital Assistant 2.0 – A Software Prototype for Cognitive Cities [22]	2016 IEEE International Conference on Fuzzy Systems
IEEE	2015	Enhancing Multidirectional Communication for Cognitive Cities [23]	2015 Second International Conference on eDemocracy eGovernment (ICEDEG)
IEEE	2015	Fuzzy Knowledge Representation in Cognitive Cities [24]	2015 IEEE International Conference on Fuzzy Systems
ACM	2014	Applying the Fuzzy Analytical Hierarchy Process in Cognitive Cities [27]	Proceedings of the 8th International Conference on Theory and Practice of Electronic Governance
ACM	2014	Applying Fuzzy Ontologies to Implement the Social Semantic Web [46]	SIGWEB Newsl

the 42 selected articles according to the categories explained before with the purpose of presenting an in-depth understanding. Additionally, we discuss the employed approaches, advantages and limitations, as well as differences between the articles.

3.1 Intelligent Governance Implementations

Intelligent governance allows cities' authorities to innovate their services and structures by embedding learning, memory creation and experience retrieval. In

Table 5. Articles that provide application scenario solutions

Publisher	Year	Article and reference	Journal/Conference/Book name
Springer	2019	A Dynamic Route Planning Prototype for Cognitive Cities [26]	Designing Cognitive Cities
Springer	2019	Towards Cognitive Cities in the Energy Domains [11]	Designing Cognitive Cities
Springer	2019	Extending Knowledge Graphs with Subjective Influence Networks for Personalized Fashion [5]	Designing Cognitive Cities
Elsevier	2019	A System View of Smart Mobility and its Implications for Ghanaian Cities [43]	Sustainable Cities and Society
Public Library of Science	2017	How Green are the Streets? An Analysis for Central Areas of Chinese Cities Using Tencent Street View [32]	PloS one
Springer	2016	Cognitive Cities: An Application for Nairobi [16]	Towards Cognitive Cities
SAGE Journals	2011	Spanish Cities in The Knowledge Economy: Theoretical Debates and Empirical Evidence [41]	European Urban and Regional Studies

this regard, the introduced *intelligence* through information technology improves urban governance constantly. Intelligent governance is one of the cognitive strategies that includes human beings and other cognitive entities to implement techniques that reconfigure cooperation capabilities and build a sustainable, responsible individual/collective behavior [39]. In this section, we describe and summarize the 17 articles that presented diverse intelligent governance implementations. Finally, they are compared in Table 6.

The book "Designing Cognitive Cities" (2019) gathers the most current research in the domain of cognitive urban governance. Three of these articles ([20,34,50]) address problems by proposing intelligent governance solutions. For example, in [34], Maunsouri and Khansari study the impact and use of ICTs (information and communication technologies) in urban planning regarding the efficiency of cities' energy systems. They present a government multilayered model where human-institutional, physical, and data factors are brought together to improve sustainability. Tabacchi *et al.* focus on the design of cognitive cities [50]. They present the approaches 'Action Design Research' and 'Ontological Design' to explain how their principles can be applied in urban planning. Moreover, the authors summarize intelligent techniques that may be useful in citizen communication in a cognitive city. To communicate with citizens in comprehensible ways, in [20], the authors propose linguistic summaries based on fuzzy logic. In other words, the extracted and processed city-related data may be verbalize through linguistic summaries.

D'Onofrio *et al.* propose the use of the Web of Things (WoT) in cognitive cities [14]. WoT is the IoT extended by using Web standards and the authors present a comparison of the two technologies. Features like maintainability, privacy, programmability, security and standards are analyzed in both cases showing that the WoT has some advantages over the IoT. In [19], the difference of the meaning of 'smart city' and 'intelligent city' is established. In this article,

the authors present a study of the related literature to motivate their research in intelligent buildings design. Finally, they demonstrate that the two terms complement each other and explain this with a cognitive city model. In the same way, Razaghi and Finger detail a conceptual governance approach in [47]. They offer insights about the combination of technology complex sociotechnical systems, systems theory, and governance literature for adaptation of city models. Another conceptual research is presented in [54]. Its authors analyze the new kinds of 'brain/code/spaces' where the environment is provided with brain-like functions of learning and 'human qualities' of cognition.

In [53], Wilke and Portmann study the implementation and representation of information granules for data legibility. Human-data interaction is the center of their investigation as a means to support collective decision making in pervasive computing environments. Terán *et al.*, in [52], analyze the cognitive processes for government decision-making as well. They propose a five-layer eGovernment framework and assess its performance in three different applications. With regard to decision making for citizens' quality of life, in [40], technology infrastructure for smart cities is analyzed. Moreover, the authors propose a roadmap to a planned adoption of technology based on the detail of the different current challenges that cities face. In [33], governing mechanisms where quantitative and computational processes are included are presented as strategies for policy making. The authors employ city sensors and smart devices to create an interactive environment for collaboration.

After proposing theoretical models, in [25], the authors of the article develop and evaluate a meta-app prototype named *cogniticity*. The goal is to ensure a good work-life balance for citizens and help them to manage their time and be productive. On the other hand, to deal with the communication gap between citizens and government, [44] proposes the use of computational intelligence approaches such as CWW (Computing With Words) and Fuzzy Classifiers. In this article, collective cognitive systems are raised as a solution for social exclusion and incomprehension in terms of the efficiency of communication among the government actors. In order to understand what a green, sustainable, open, and rational city means, Legény *et al.* analyzes the concept of Smart City by considering several distinct layers of 'introduced intelligent components' [30]. The layer-based structure considers the 'smart people' as a core element to transform people lives and the environment. In [10], the authors implement the concept of intelligent governance in Hoboken, New Jersey following the Complex, Large-scale, Inter-connected, Open and Socio technical (CLIOS) methodology. With the aim of providing a view of its general application in large-scale urban systems, performance indicators and key subsystems are identified and interrelated. Mostashari *et al.*, in [38], propose an architectural process approach where cognition is integrated into the urban processes. The sub-systems like energy, water, transportation, the emergency services system, and the system of information and communication were analyzed to identify their role in a cognitive city framework. In [48], the bias in informational cities is studied. The clusters and spaces for personal contacts and implicit information sharing could cause polarization.

Therefore, this conceptual article details the indicators that measure the degree of 'informativeness' of a city.

Summary of Articles Whose Strategy Is Based on Intelligent Governance Implementations. In the previous section, we analyzed 17 intelligent governance strategies. In Table 6, we compare the most important advantages and limitations of each article.

3.2 Big Data and Analytics Solutions

Technology advancements and social changes have given decision power to citizens and enhanced democracy. In this regard, online collective decision making is oriented to solve urban infrastructure problems and contribute in public policies. Therefore, governments are implementing big data applications where the huge amounts of citizen-generated data can be processed and transformed in useful information. Next, data-oriented solutions are detailed.

In [1], Alonso *et al.* present the extraction of valuable knowledge as a challenge generated in the Big Data era. In the article, it is explained how the interaction of cities' intelligent devices and people should be addressed to be effective. Besides, in order to handle (or *interpret*) large amounts of high-dimensional and heterogeneous data, fuzzy logic and its application to Cognitive Cities is presented. A more specific research is presented in [31]. To analyze the users' comments on a social network page of the local government of Rio das Ostras, Brazil, a method based on Part of speech (POS) tagging is proposed. In fact, the authors' strategy is based on the identification of mentioned locations and most frequent topics in comments to be shown for real-time decision making. Mohammadi and Al-Fuqaha study the problem of the waste of unlabeled data which is extracted from smart devices [36]. They propose a framework which employs Deep Reinforcement Learning combined with semi-supervised learning to build a Smart Agent that senses the environment. In [28], a cognitive governance framework with the name of 'Stream Processing Platform for Responsive Cities' is presented. Different applications are revised by the authors in the context of urban resilience. In [2], the authors present a method that implements clustering and regression strategies in order to group cities based on their financial features. The motivation behind this is the need for comparison of cities that are *similar* and later identifying their degree of 'smartness'. In [51], Volunteered Geographic Information (VGI) is studied as a means to enhance passive civic participation. The goal of the proposed research is to make a city truly responsive through people's data analysis. A detailed analysis of the motivations to employ VGI in local planning and citizen engagement is carried out. Cavoukian and Chibba, in [8], analyze the concerns about privacy and security in a cognitive city. They state that the 7 Foundational Principles of Privacy by Design, which are detailed, may introduce the required trust in applications of cognitive cities.

In [37], Morabito analyses the use of crowd-sourced human observation, or Crowdreporting to train artificially intelligent public systems. As a result, he

Table 6. A comparison of the most important advantages and limitations of the intelligent governance implementations in cognitive urban planning

Article	Targeted/Used Technology	Advantage	Limitation
[34]	- User Experience - Social Computing - City-Wide Sensor Network	Model enhance citizens behavioural pattern towards sustainability values	An effective education system for citizens to speed with learning capabilities should be facilitated
[50]	- Metaheuristics - Fuzzy Logic - Computational Intelligence Classifiers - Computing with Words	Emphasis on the users as active participants in the design process and design as a sociocultural process	Being able to interpret the nonverbal communication and identify the actors make the communication infrastructure a complex system
[20]	- Natural Language Processing - Big data - Fuzzy logic	No need of collecting sensitive data from citizens	Computational effort is an significant issue when calculating the summaries
[14]	- IoT - WoT - Big Data	WoT influence city development (from smart to cognitive cities)	WoT applications have not yet been applied in real-world scenarios
[19]	- Sustainability assessment tools - Health-related assessment tools	The mutual performance of smart and intelligent elements in a city impacts the potential of its services	The lack of clarity may be confusing for the professionals and stakeholders
[47]	- Parallel/Quantum computing - Mobility as a service - Fuzzy logic - Cloud computing - Machine Learning	Real-time communication and opinion sharing channels allow a better governance of urban complexity	Complex future cities require a close collaboration among interdisciplinary experts (system scientists, urbanists, mathematicians, etc.)
[54]	- Machine learning - Cognitive computing - Neurocomputational devices	Brain-inspired environments are cognitive cities with 'human qualities' and not hard-coded 'programmable cities'	Neurocomputational and the notion of the 'social life of the brain' are in their initial exploration
[53]	- Granular calculus - GIS - Granular geometry	Decision making processes can be developed in real time over maps	Though experimental technologies several tests are compulsory before it can be applied widely
[52]	- Geolocation/IoT -Recommender engines - Online Communities	Citizens participation improves government services, intelligence of the crowds for eEmpowerment	Dynamic profiles of citizens need to be updated automatically; then, strategies have to be design in advance
[40]	- Open data portals - Social Media data - Gamification	The quality of life for citizens using technology as an enabler is possible due to its growing potential	Technology is simply one part of city systems, better analysis and better delivery models are required
[33]	- Gamification - Crowdsourcing platforms - City-Wide Sensor Network	Interactive games encourage the users to participate and change their energy consumption behavior	Rely on city sensors and calibration of instruments depending on the case
[25]	- Fuzzy cognitive maps - Cognitive computing - Semantic Web	The prototype got constructive feedback, and may be helpful to develop apps and improve citizens' living	Privacy is considered as a major challenge for the meta-app users
[44]	- CWW - Metaheuristics - Geospatial Analysis - Fuzzy Ontologies	Described approaches may become useful to improve citizens-government communication	Experiments have to reach real world application and case studies from different domains need to be included
[30]	- Internet of People - Internet of Services - IoT	The components of the layer model interact to each other and integrate an intelligent combination of inputs	Smart City is a broad concept and there is no a general applicable model
[10]	CLIOS process	CLIOS is helpful in the transformation of cities and critical aspects may be modeled for governance	Key performance indicators are dependent on the city features; then, the list presented are not decisive
[38]	- Wireless sensors - Crowdsourcing platforms - Human-only sensors	In the design of the logical architecture of a Cognitive City the proposed framework may be an effective guideline	The performance of the framework need to be evaluated when large-scale information is used in cognitive responses.
[48]	- Cognitive infrastructures - Knowledge management - Information retrieval	Information science and urban informatics can contribute to the construction of digital cities	Conceptual hypotheses that need empirical studies on selected cities

details a recommendation list towards Smart City development. His study is based on the use of sources of data and their application in public engagement, in the creation of new models in public management and the challenges of big data in the public service transformation. The oldest article presented in this section was published in 2014 [55]. Here, a visual analytics process based on the main tasks of utility service management to make the related issues more understanding was implemented. The aim is to address the daily issues or emergencies related to utility services that arise due to the increasing rate of city construction, vandalism and infrastructure failures. Then, as part of their strategy, they used aggregation and clustering methods to find some patterns and events that could help administrators in making informed decisions.

Summary of Articles that Propose Big Data and Analytics Solutions. Previously, we analyzed 9 data-oriented solutions and how citizens information is employed. In Table 7, we compare the most important advantages and limitations of the seen articles.

3.3 Fuzzy Models-Based Research

Knowledge representation is required for a better understanding of the citizens' information and the data generated from urban processes. However, acquiring and processing the imprecise urban data which is mostly expressed in natural language is a challenge. Fuzzy models are employed to represent concepts or objects and establish fuzzy relationships between them [29]. Generally, when fuzzy models are used, approximation errors or strong assumptions are introduced to maintain the ability to deal with uncertainty and create soft decision boundaries. Then, by using fuzzy models it possible to represent complex urban constructs.

In [15], the authors analyze how Fuzzy Cognitive Maps (FCMs) are used in the design of a cognitive city. Based on the state-of-the-art related to the domain of FCMs and learning algorithms, [15] concludes that the implementation of FCMs facilitates the acquisition and representation of the interconnected urban data. In the same way, in [12], D'Onofrio *et al.* propose a conceptual framework based on fuzzy analogical reasoning and FCMs. Its goal is to emulate human analogical reasoning by using cognitive computing so it can be implemented in an urban dialogue system. In [13], the use of FCMs combined with graph databases as a solution for urban data management is also explored. In this research, issues about storing FCMs are analyzed; consequently, 47 graph databases employed for this purpose are evaluated and compared. D'Onofrio *et al.*, in [17], analyze the role of cognitive computing when working with FCMs to process information that was acquired using mental models (MMs).

The research presented in [22] shows a mobile application prototype of a personal digital assistant. The goal of the project is to improve calendar and mobility management in cognitive cities by implementing soft computing strategies. Likewise, in [23], Kaltenrieder *et al.* describe the technical foundations of

Table 7. A comparison of the most important advantages and limitations of the data-oriented solutions in cognitive urban planning

Article	Targeted/Used Technology	Advantage	Limitation
[1]	- Big Data - Interpretable fuzzy systems - Computational theory of perceptions	Interpretable fuzzy systems makes intelligent applications understandable and facilitates the interaction with citizens	Building interpretable fuzzy systems requires careful design
[31]	- POS tagging - Regular expressions - Social media data	The method (and developed app) allows to observe the citizens' claims that emerge in a particular city	Dictionaries such as POS and ZIP codes corresponding to locations are needed beforehand
[36]	- Semi-supervised learn - Deep Reinforcement Learning or DRL	DRL solves certain limitations of using RL alone	The model cannot reside on IoT resource-constrained devices
[28]	- Urban complexity - Cognitive design computing - Computational urban design	Urban infrastructures based on cognitive systems makes cities be responsive to changes	Responses need to be triggered in a timely fashion, then the need of distributed event stream processing
[2]	- Regression analysis - Financial data analysis - Clustering algorithms	The method allows to observe city tendencies and may guide government decisions to have a better city performance	Obtaining the particular kind of financial data may be a challenge
[51]	- VGI - Mobility as a service - Myopic algorithms - Big Data - Web 2.0 apps	Data-driven civic participation helps municipalities to engage with citizens through passive forms of interactions	Lack of control by citizens and municipalities over data-driven participation efforts (loss of empowerment, transparency and efficiency) when private corporations involved
[8]	- Big Data - Internet of Everything - Ubiquitous computing - Privacy by Design	Using a Privacy by Design framework may encourage innovative design approaches that consider both privacy and the system's goals	Privacy choices (how much and to whom share personal data) depends on the context of the citizens; so, they should have their privacy control
[37]	- Crowdsourcing - IoT - Big Data - Open government tools	People can provide real-time feedback teaching the system how to behave	Smart apps and open collaboration platform can become the critical infrastructure for the application of big data
[55]	- Clustering - Geo-spatial visual analytics - Temporal visual analytics	Visual analytics process applied for city utility service may help administrators to discover/solve problems	Various visual analytics tools, aggregation methods and interaction techniques need to be combined

a meta-app for cognitive cities in the context of e-governance. They implement the Fuzzy Analytical Hierarchy Process (FAHP) for decision making which is embedded as part of the app architecture in the data processing phase. In [24], the transition of smart cities to cognitive cities is explained through the analysis of cognitive computing. Here, also FCM is studied as a strategy to represent cities' information or knowledge and oriented to the interaction of users and technology. In [27], the Fuzzy Analytical Hierarchy Process is introduced as a method to extract cities' information. It is used as part of an interactive framework where fuzziness is present in the interactions between city entities and citizens. On the other hand, [46] shows how fuzzy ontologies may be used in Web Knowledge Management (representation, reasoning and aggregation) for

cognitive cities to address the uncertainty in data. Besides, Social and Semantic Web are combined to improve human-computer interactions and enhance results of the application of digital humanities research.

Summary of Articles Whose Strategy Is Based on Fuzzy Models. In the previous section, we analyzed 9 solutions that employed fuzzy theory. In Table 8, we compare the most important advantages and disadvantages of each article.

Table 8. A Comparison of the Most Important Advantages and Limitations of the Solutions based on Fuzzy Logic

Article	Targeted/Used Technology	Advantage	Limitation
[15]	- Fuzzy logic - Fuzzy sets - Computing with words - Learning Algorithms - FCMs	Learning algorithms have the ability to enhance FCMs and together can be applied during the transformation from smart to cognitive cities	Research in this field is being recently explored
[12]	- Cognitive computing - Structure Mapping Theory - Fuzzy Analogical Reasoning - Graph data bases	Connecting large amounts of information by using FCMs, urban services might perform better and support the citizens	The development of humanistic retrieval processes in urban systems needs further research
[13]	- FCMs - Graph data bases - Cognitive Fuzzy Systems - Semantic Web	FCMs are modifiable and allow to simulate urban dynamic systems	A comparative performance analysis between graph database systems might be required depending on the context
[17]	- FCMs - Fuzzy clustering - Granular computing - Cognitive computing	Imprecise information existing in the city systems may be process by the approach because it is based on soft computing	To aggregate various FCMs, their linguistic information has to be translated into numeric values (manual process)
[22]	- FCMs - Fuzzy interval algebra - Graph databases	The combination of fuzzy grey cognitive maps with fuzzy temporal algebra may offer enhancements of the prototype	User evaluations (experts included) related to the performance of the prototype are needed
[23]	- FAHP - WebKnowARR framework - Graph databases	FAHP enables decision-making despite of the existence of uncertain knowledge	Data privacy issues arise
[24]	- NLP - Question - Answering retrieval - Knowledge graphs - FCMs	The prototype may be useful to aggregate existing knowledge about diverse topics about the city and its services	Privacy and security concerns need to be addressed
[27]	- FCMs - FAHP - Granular computing	The app improves public transportation of a city, traffic jams and accidents can be avoided	The app works properly with big amounts of data (limited to big cities, then)
[46]	- FCMs - Fuzzy ontologies - Granular computing	Social Semantic Web may be seen as a solution of cities' knowledge representation	Lack of evaluation of presented theoretical approaches

3.4 Application Scenario Solutions

The strategies to use technology, theories and data in the development of cognitive cities have been presented in the previous sections. Next, certain implementations, application scenarios and cases where those strategies have been applied are detailed. In [26], a prototype applied to dynamic route planning in the city of Bern, in Switzerland, is presented. The software prototype uses Bern's data taken from Google Maps as input and target the travel industry to improve users experience. Cuenca *et al.*, in [11], address issues like efficiency, sustainability and resilience in the *energy* domain. The use of Semantic Web and Semantic Ontologies in the management of cities energy is presented. In [5], fashion is targeted as a leisure and consumption activity in cognitive cities. The authors propose an ontological approach to model subjectivity in the domain and extract knowledge (categorizations of entities) useful in the economic development of cities.

Peprah *et al.*, in [43], target the vehicular traffic as an urbanization problem in Ghanaian cities. They propose a conceptual framework to first evaluate the mobility-smartness of Ghanaian cities and then the authors discuss how it can be operational. As conclusion, the article proposes road infrastructure investment and involvement of people in technological government solutions. In [32], Long and Liu propose a method to quantify cities greenery automatically. The authors implemented their method in 245 Chinese cities to measure how green their streets are. In [16], the authors analyze through a case study how 'smartness' and 'cognitivism' may be applied in an emerging country's city. A method for processing text messages based on cognitive computing is proposed regarding sanitation problems in slums of Nairobi, Kenya. Méndez and Sánchez, in [41], analyze the indicators that make Spanish cities join the *knowledge society*. Their findings show that cities in metropolitan areas have implemented services based on knowledge and are supported by qualified human resources. Medium-sized and small cities have made more effort than the former to introduce technology and have specialized industries.

Summary of Articles that Provide Application Scenario Solutions. In Table 9, we compare the most important advantages and disadvantages the 7 studied articles.

4 Result and Comparisons

Some of the approaches to model cognition in urban planning have been detailed in the previous section. The analyzed articles have based their proposals on diverse mechanisms in order to introduce *cognition* in urban governance ans/or government services. According to this, we considered four main categories where the authors provided *1.* intelligent governance implementations, *2.* Big Data and analytics solutions, *3.* strategies is based on fuzzy models, and *4.* application scenario solutions. Considering these categories, it was seen that each presents some challenges. For instance, there is a lack of implementation of conceptual

Table 9. A comparison of the most important advantages and limitations of the solutions presented through application scenarios

Article	Targeted/Used Technology	Advantage	Limitation
[26]	- Fuzzy logic - Fuzzy set theory - Graph databases	The prototype shows more flexibility on sightseeing trips because of the creation of dynamic routes	More research is needed to expand the prototype to other contexts different from the travel industry
[11]	- Semantic Ontology - Smart Grids - Semantic Web	Cognitive systems have a broad potential in city energy management (semantic models for representing energy data)	Cognitive cities in the energy domain face many challenges to reach mass market deployment
[5]	- Ontologies - Knowledge graphs - Subjective influence networks - Machine learning	Features generated in the influence network may be integrated into machine learning systems	Validation of the presented theoretical assumptions are needed
[43]	- IoT - Big data - Web 2.0	The framework may be used as a guide to implement the process of city smart mobility	Lack of validation and application of the proposed framework
[32]	GIS - Google Street View (GSV) image recognition - Color composition analysis	Street-view pictures are available even for developing countries and the framework allows their analysis to measure greenery	The study was limited to the analysis of urban areas
[16]	- Fuzzy logic - Fuzzy information granulation - Fuzzy clustering	Applications that are based on low-tech solutions are feasible to be used in small cities	Other problematic areas were not analyzed due to the early stage of the approach
[41]	- Urban intelligence - Urban development indicators - Knowledge-intensive business services	Recommendations from the perspectives of knowledge society and knowledge economy are proposed to improve urban development	Study oriented to city development which may not be relevant for urban planning

frameworks in real cases. In fact, many of the frameworks and/or prototypes were not validated with empirical studies.

Big data processing, analysis and visualization is one of the most relevant topics among the articles. It has been explored in research where city features like responsiveness and resilience are central. Indeed, data generated in a context of collective intelligence or extracted from crowdsourcing platforms is used in the governance of urban complexity. Computational efforts for meaningful information discovery seem to be the limitation to deal with. On the other hand, soft computing methods have been broadly used to address natural language processing. These methods include fuzzy logic, granular computing, graph databases and computing with words strategies. An entire category of articles has covered this topic and the recent research shows mature models and solutions. Mostly, proposed future work specifies the need of evaluation of theoretical approaches in diverse domains in order to generalize their application. Some of further research suggests the employment of combined solutions to cope problems like constrains regarding existent technology or devices. In this sense, experiments considering the wide variety of cities and their own cultural and societal characteristics

are required to improve cognition in urban planning in future works. During this review, the researchers found that one of the open issues that stands out between the selected articles is related to the privacy of citizens. Privacy concerns are pointed out whenever citizens data is used in governance solutions. Then, it becomes the major challenge to be addressed and regulated.

5 Conclusions

Cognitive human factors such as perception, retention, retrieving, repetition, comparison, transformation and pattern generation are being modeled in machines to provide them with levels of intelligence. However, when we enhance machines' abilities with the collective intelligence of users, we are embedding cognition in the system. Given this, the active participation of the citizens in the construction and transformation of towns provide the places with degrees of resilience. The cities capability to adapt to certain circumstances and, in this case, offer a specific solution has been studied recently in order to create new opportunities. Then, we have presented a SLR of the state-of-the-art papers. Depending on the publication year, publisher and journal rank, each article was either included or excluded. To verify the relevance of these articles, their 'Abstract' and how related they were to cognitive computing and related concepts were studied. Finally, 42 academic articles have been analyzed. The first articles that talk about cognitive urban planning were published in 2011. Moreover, the largest quantity of articles in the studied topic appeared in 2016. Springer is the publisher with most articles extracted. We have compared and evaluated the content of the articles after classifying them in four main categories. The classification depended on the kind of solution or approach implemented. Furthermore, we identified the advantages of the diverse proposals and the limitations or challenges that have to be addressed in future research.

The methods and frameworks summarized in this SLR paper, show that intelligence may be embedded as a component of future cities. Indeed, the effort for combining machines, humans and communities have promoted research topics where technologies like IoT, Big Data, Semantic Ontologies, Crowdsourcing, Ubiquitous Computing and Web 2.0 are significant. Various disciplines such as urbanism, computer science, sociology, ethics require to work and converge to promote opportunities for innovating in various application areas. Specifically, Social Collective Intelligence opens research challenges and opportunities for scientists in both computer science and social sciences to tackle relevant problems. Novel approaches to benefit policy-makers, local governments and citizens will be based on understanding the ways how technological advances support the progress of society and economy.

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