Swarm Intelligence Applications for the Cities of the Future

Leonor Marques Mano Domingos *and*
Maria José Sousa (*eds.*)

CRC Press
Taylor & Francis Group
A SCIENCE PUBLISHERS BOOK

Swarm Intelligence Applications for the Cities of the Future

Editors
Leonor Marques Mano Domingos
ISCTE - University Institute of Lisbon
Lisboa, Portugal

Maria José Sousa
ISCTE - University Institute of Lisbon
Lisbon, Portugal

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business
A SCIENCE PUBLISHERS BOOK

This cover has been created using images generated using OpenArt.AI

First edition published 2025
by CRC Press
2385 NW Executive Center Drive, Suite 320, Boca Raton FL 33431

and by CRC Press
4 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

CRC Press is an imprint of Taylor & Francis Group, LLC

Library of Congress Cataloging-in-Publication Data (applied for)

ISBN: 978-1-032-65675-5 (hbk)
ISBN: 978-1-032-65677-9 (pbk)
ISBN: 978-1-032-65678-6 (ebk)

DOI: 10.1201/9781032656786

Typeset in Times New Roman
by Prime Publishing Services

Acknowledgements

The editors would like to extend their deepest gratitude to the Scientific Committee whose invaluable expertise and unwavering dedication have made this book possible. Their insightful guidance, thorough reviews, and constructive feedback have significantly enriched the quality of this work. The editors would like to specifically acknowledge: Dr. Filipa Osório, specialist in Digital Architecture and Parametric Design; Prof. David Ferraz, expert in Public Policies, Sociology, Economics, and Management; Prof. Helena Belchior, specialist in Environment, Sustainability, Social Policies, and Education; Dr. Pedro Mariano, expert in Optimization Algorithms, Artificial Intelligence, and Machine Learning; and Prof. João Pavia, expert in Big Data, Machine Learning, and Cybersecurity.

A special thank you to Prof. Vasco Rato for his support and perspective, for which the editors are profoundly grateful and, also, for writing the foreword for this book. The editors also extend their appreciation to the contributing authors whose innovative research and commitment to excellence have been fundamental to this publication. Additionally, heartfelt thanks go to the technical staff and administrative team, whose hard work behind the scenes ensured the smooth progression of this project. Their support and dedication have been instrumental in bringing this book to fruition.

Lastly, the editors wish to thank their families and friends for their unwavering support. Their encouragement and patience have been a constant source of motivation. Thank you to everyone who contributed to making this book a reality.

Foreword

Since ancient times, cities have been a center of social, economic, and cultural governance. The very diverse structures that have been developed to manage the common space have depended, to a greater or lesser extent, on the ability to seek and maintain consensus. In the governance models characteristic of contemporary liberal democracies, the notion of representativeness is decisive. Proximity between representatives and those they represent plays a critical role as an instrument for legitimizing the exercise of power, i.e., public policies that are designed and implemented with the aim of improving people's well-being within the context of available resources. In cities, this proximity is particularly important because, by definition, due to the territorial scale involved, this is the level of decision-making with the most immediate impact on people's lives.

Today, cities are facing huge challenges associated with, among other things, climate change, the scarcity of resources, the loss of biodiversity, social phenomena such as migration, the lack of affordable housing, or major changes in the structure of the economy and employment. On the other hand, the technological development of the last decade has brought with it a whole new capacity to produce and distribute content very easily and very quickly. The fact that, in general, this content is not curated, makes it possible to construct, sometimes legitimately and sometimes illegitimately, different narratives of the same reality. In this context, those governance models are being questioned. Citizens increasingly seem to perceive that they are not properly represented by elected representatives, which leads to a progressive distancing from those who govern. Thus, a model that aims to nurture consensus for a balanced management of the common good, with respect for all people, tends to lose meaning.

The application of co-governance models will certainly be part of the solution. Various experiments have been carried out, generally successfully. However, if the governance model is gradually changed, the ability to negotiate and generate consensus must always be ensured. This is, after all, about strong coexistence between people who share a territory and who have to find ways of managing it together.

Recent developments allow, today, for a fantastic capacity to collect and analyze information, giving it customized meaning. So the question seems obvious: what is the role of the latest technology, and its future developments in creating new opportunities for mediation that contribute to once again ensuring common ground for debate and consensus, in the legitimate aspiration for better

living conditions, within the limits of ecosystems to support life on Earth and, in particular, in cities?

This book aims to contribute to answer this question.

Swarm intelligence explores and draws potential from collective and decentralized behavior. It has a scalable nature and the ability to deal with complex and dynamic systems such as cities. Its application will be part of the future of urban management, directly involving citizens and contributing to more resilient and inclusive cities.

Vasco Rato
May, 30th 2024

Preface

As the world accelerates into an era of rapid urbanization and technological innovation, the cities of tomorrow are being shaped by forces that challenge traditional paradigms of urban planning, governance, and social interaction. This book, *Swarm Intelligence Applications for the Cities of the Future*, emerges from the intersection of architecture, public policies, and digital technology—fields that are increasingly intertwined as we seek to build cities that are not only smarter but also more sustainable, resilient, and equitable.

As editors, we have curated a collection of cutting-edge insights that address some of the most pressing challenges facing future cities. At its core is the concept of swarm intelligence, rooted in the collective behaviour of decentralized systems. This book explores how these principles can be harnessed to create urban environments that are more adaptive, efficient, and responsive to the needs of their inhabitants.

Chapters cover a diverse array of themes, crucial for the future of cities, emphasizing the integration of community voices and sustainable practices into urban development. Covering social learning, citizen engagement, and green policies in the digital age, while highlighting the importance of transparency in enhancing urban resilience. The role of technology in public safety, energy management, and healthcare is also examined, with innovative approaches presented for optimizing safety, comfort, and sustainability. Additionally, urban design and infrastructure and reimagined, by addressing how cities can adapt to evolving healthcare needs and future uncertainties while integrating Building Information Modelling and Life Cycle Assessment for more sustainable building practices.

In bringing together these varied yet interconnected themes, this book provides a comprehensive overview of the opportunities and challenges that lie ahead for urban environments. It is our hope that the ideas and solutions presented within these pages will inspire architects, policymakers, urban planners, and technologists to collaborate in crafting cities that not only meet the demands of the future but also enhance the quality of life for all their inhabitants.

As we stand on the brink of this exciting new era, we invite you to explore the possibilities and potentials of swarm intelligence in shaping the cities of the future.

August, 2024

The editors,
Leonor Domingos
Maria José Sousa

Contents

List of Contributors

Andrea Brambilla
Design & Health Lab, Department of Architecture, Built Environment, and Construction Engineering, Politecnico di Milano
Andreia de Bem Machado
Federal University of Santa Catarina, Brazil.
António Sacavém
Universidade Europeia, Portugal.
Bruno Mataloto
ISTAR – Information Sciences and Technologies and Architecture Research Center, ISCTE-IUL – University Institute of Lisbon.
Carlos Coutinho
Department of Information Science and Technology, ISCTE – University Institute of Lisbon
Davide Calandra
University of Turin, Department of Management "Valter Cantino".
Diogo da Silva
Associação Visionarium.
Erica Isa Mosca
Design & Health Lab, Department of Architecture, Built Environment, and Construction Engineering, Politecnico di Milano
Gabriel Osório de Barros
Director for Economic Analysis at the Office for Strategy and Studies (GEE) of the Portuguese Ministry of Economy and Maritime Affairs.
Ginevra Degregori
University of Turin, Department of Management "Valter Cantino".
Giovanni Borsoi
CERIS, Civil Engineering Research and Innovation for Sustainability, Instituto Superior Técnico, University of Lisbon.
Helena Belchior Rocha
Department of Political Science and Public Policy. ISCTE – University Institute of Lisbon
João Carlos Ferreira
Department of Applied Digital Technologies. ISCTE – University Institute of Lisbon

João Poças Martins
CONSTRUCT—GEQUALTEC, Faculty of Engineering (FEUP), University of Porto.
João Rodrigues dos Santos
ISEC Lisboa – Instituto Superior de Educação e Ciências, Portugal.
Leonor Domingos
Department of Applied Digital Technologies, ISCTE – University Institute of Lisbon.
Manuel Pio Silva
CNET – Centre New Energy Technologies.
Maria José Sousa
Department of Political Science and Public Policy ISCTE – University Institute of Lisbon.
Mohamed Nour El-Din
CONSTRUCT—GEQUALTEC, Faculty of Engineering (FEUP), University of Porto.
Nuno M.M. Ramos
CONSTRUCT—GEQUALTEC, Faculty of Engineering (FEUP), University of Porto.
Pedro F. Pereira
CONSTRUCT—GEQUALTEC, Faculty of Engineering (FEUP), University of Porto.
Rafael Rodrigues
CNET – Centre New Energy Technologies
Ricardo Resende
ISTAR-Information Sciences and Technologies and Architecture Research Center, ISCTE – University Institute of Lisbon, Department of Applied Digital Technologies.
Sara Parece
ISTAR-Information Sciences and Technologies and Architecture Research Center, ISCTE – University Institute of Lisbon, School of Technology and Architecture.
Silvana Secinaro
University of Turin, Department of Management "Valter Cantino".
Stefania Stellacci
ISTAR – Information Sciences and Technologies and Architecture Research Center, ISCTE-IUL – University Institute of Lisbon.
Stefano Capolongo
Design & Health Lab, Department of Architecture, Built Environment, and Construction Engineering, Politecnico di Milano.
Tianzhi Sun
Design & Health Lab, Department of Architecture, Built Environment, and Construction Engineering, Politecnico di Milano.
Vasco Rato
ISTAR-Information Sciences and Technologies and Architecture Research Center, ISCTE – University Institute of Lisbon, School of Technology and Architecture.

1 Social Learning and Citizens' Engagement in Future Cities

Andreia de Bem Machado,[1*] Gabriel Osório de Barros,[2]
João Rodrigues dos Santos[3] and António Sacavém[4]

1. Introduction

The initial decades of the 21st century have seen a significant rise in urbanization, with an estimated 68% of the global population now living in cities (United Nations, 2018). This shift necessitates advanced, sustainable solutions to manage urban complexity, for which Swarm Intelligence offers a compelling strategy, leveraging collective intelligence for problem-solving (Bonabeau et al., 1999). This chapter delves into Social Learning and Citizen Engagement, critical elements in this approach. Social Learning involves learning from peer interactions within a social framework, a key to spreading knowledge and fostering community-level innovation for sustainable city living (Bandura, 1977; Wenger, 1998). Citizen Engagement denotes the active participation of citizens in governance, essential for creating inclusive and responsive urban environments (Cornwall, 2008; Irvin and Stansbury, 2004). Acknowledging that top-down methods fall short for modern urban challenges, this chapter emphasizes that the future of urban planning lies in bottom-up, citizen-powered strategies that are sustainable and resilient (Benkler, 2006). It aims to showcase how Social Learning and Citizen Engagement, within the context of Swarm Intelligence, can cultivate cities that are more aligned with their residents' needs, promoting efficiency, sustainability, and a stronger community spirit (Bonabeau et al., 1999).

2. Swarm Intelligence: A Key to Future Cities

Swarm Intelligence is an emerging field that utilizes principles derived from the collective behavior of decentralized, self-organized systems to solve complex

[1] Federal University of Santa Catarina, Brazil.
[2] Director for Economic Analysis at the Office for Strategy and Studies (GEE) of the Portuguese Ministry of Economy and Maritime Affairs.
[3] ISEC Lisboa – Instituto Superior de Educação e Ciências, Portugal.
[4] Universidade Europeia, Portugal.
Email : gabriel.barros@gee.gov.pt; joaopaulo.santos@iseclisboa.pt; antonio. sacavem@universidadeeuropeia.pt
* Corresponding author: andreia.bem@ufsc.br

problems (Bonabeau et al., 1999). The application of Swarm Intelligence to the urban context provides innovative ways to address complex issues inherent in rapidly evolving urban systems.

Swarm-based principles can be used to optimize various facets of urban living, from traffic management and infrastructure planning to environmental conservation and resource management. For instance, the use of Swarm Intelligence in traffic management systems can optimize traffic flow, reducing congestion and travel times (Dorigo and Stützle, 2004). Similarly, swarm-based solutions can enable more efficient use of resources by coordinating usage based on demand patterns across the city (Di Caro et al., 2005).

At the heart of Swarm Intelligence lies the principle of simple agents interacting to generate complex, efficient, and adaptive solutions (Bonabeau et al., 1999). This aligns closely with the concepts of Social Learning and Citizen Engagement, the key for future city development.

- **Facilitating Social Learning:** As cities grow increasingly interconnected, the need for effective Social Learning mechanisms becomes paramount. Social Learning, in the context of Swarm Intelligence, involves the exchange of knowledge and experiences between individuals, allowing for collective problem-solving and the diffusion of innovative solutions (Wenger, 1998). Similar to how birds learn to flock or fish to school, humans in urban environments can learn and adapt behaviors based on the collective intelligence of the group. Such social learning processes can enhance the efficiency, adaptability and resilience of urban systems, contributing to the overall livability of future cities.
- **Promoting Citizen Engagement:** Active citizen engagement is a linchpin for the successful application of Swarm Intelligence principles in urban settings. The more citizens actively participate and share their data and feedback, the more accurate and effective the swarm-based solutions become. Citizen engagement can take many forms, from contributing data through smart devices and Internet of Things (IoT) networks to participating in decision-making processes about urban development (Irvin and Stansbury, 2004). Active citizen engagement not only improves the effectiveness of swarm-based solutions but also fosters a sense of community and shared ownership of urban spaces.
- **Creating Responsive Cities:** Through Social Learning and Citizen Engagement, Swarm Intelligence can facilitate the development of responsive cities, which are characterized by their adaptability to the needs and behaviors of their citizens (Batty, 2013). By constantly learning from the behavior of its inhabitants, akin to the principles of Swarm Intelligence, a city can dynamically adapt its services, infrastructure, and policies (Cardullo and Kitchin, 2019). This constant adaptation and learning can lead to the creation of 'smart' cities - urban environments that leverage digital and telecommunication technologies to become more efficient, sustainable, and in-tune with their inhabitants' needs (Caragliu, Del Bo, and Nijkamp, 2011; Giffinger and Gudrun, 2010).

Consequently, this results in urban spaces that are not just designed for people, but dynamically evolve with them (Townsend, 2013).

In summary, Swarm Intelligence provides an innovative framework for managing the complexities of future cities. By integrating the principles of Social Learning and Citizen Engagement, swarm-based solutions can tap into the collective intelligence and adaptive capacity of urban dwellers.

3. Essential Concepts and Applications of Swarm Intelligence in Social Learning

Swarm Intelligence plays a pivotal role in social learning, leveraging the collective behavior of agents for interaction and knowledge sharing, as posited by Natarajan (2018). It draws inspiration from natural systems, such as bird predation strategies, to create algorithms applicable to human societies (Zhang and Qiu, 2020; Trelea, 2003). Key concepts of Swarm Intelligence in social learning include observation and imitation, where agents mimic successful behaviors, facilitating learning through imitation, with entropic forces playing a significant role (Tao, 2018; Wissner-Gross and Freer, 2013).

Social influence and information sharing are also integral, enabling agents to affect each other's behaviors and share knowledge, leading to collective decision-making and adaptive social behavior (Yang, 2023). This decentralized and adaptive organization enables complex behavioral patterns and systematic adjustment without a central authority (Acemoglu and Ozdaglar, 2011).

In collaborative learning, particularly through Internet of Medical Things (IoMT) and online learning communities, Swarm Intelligence promotes knowledge exchange and problem-solving, contributing to social skills improvement (Cheng et al., 2023; Tomar, 2017; Halepoto, 2017; Ramzan et al., 2022). Moreover, Swarm Intelligence fosters diversity and inclusion in social learning by encouraging interaction among diverse agents.

Personalized recommendation systems, such as those used by YouTube or Netflix, utilize Swarm Intelligence techniques to tailor content to user preferences (Tao, 2018; Bonabeau and Meyer, 2013). Adaptive learning platforms like Knewton and Peer-Predict leverage are Swarm Intelligence tools for customized learning experiences and collaborative knowledge exchange.

In social networks and online games, Swarm Intelligence techniques aid in collaborative learning and scientific advancements, as seen in Foldit and Stack Exchange, where users collectively solve puzzles or rank the best answers (Shi, 2015; Jeevana et al., 2020; Cheng, 2016). The Artificial Bee Colony algorithm exemplifies the application of Swarm Intelligence in algorithmic solutions for user engagement (Önder et al., 2014).

Swarm Intelligence's transformative potential in Social Learning is immense, shaping the social fabric through decentralized, self-organizing principles that enhance user experiences and inform decision-making. The next section aims to explore case studies demonstrating Swarm Intelligence's successful application

in social learning, underscoring its effectiveness in creating adaptive, responsive, and inclusive communities.

4. Presentation of Relevant Case Studies

There are several examples of research projects in this area. Miao et al. (2023), for instance, in their study, "applied ten swarm intelligence-based algorithms to investigate their potential for energy-saving optimization control in an HVAC [heating, ventilation, and air-conditioning] system".

In a completely different area of research, according to Wang et al. (2013), "task allocation is a key issue of agent cooperation mechanism in Multi-Agent Systems". The case study *Ant Colony Optimization for Task Allocation*, initially presented by Marco Dorigo, in 1992, as part of his doctoral thesis (Colorni et al., 1991), explores how ant colony optimization algorithms can be applied to optimize task allocation in a social learning scenario. It investigates how a swarm of artificial ants can collectively learn and adapt their behavior to efficiently allocate tasks among themselves.

Another example of a very common study area within the scope of swarm intelligence applied to social learning is *Bird Flocking Behavior and Consensus Decision Making*. This study area examines the flocking behavior of birds and how they collectively make consensus decisions, such as selecting a new migration route. One of the case study examples in this area is *Collective Decision-Making in Homing Pigeons: Larger Flocks Take Longer to Decide but Do Not Make Better Decisions* (Santos, et al., 2017). In the last paragraph of the study, it is possible to read: "Pigeon flock decision-making is overall a remarkable phenomenon, illustrating the complexity of collective animal movement." By studying birds' social learning mechanisms, researchers gain insights into how to design algorithms for collective decision-making in swarm intelligence systems.

Another important case study in the scope of this chapter, for example, is "*What Can Honeybees Tell Us About Social Learning*?, developed by Clark and Kimbrough (2020). The study focuses "on aspects of the model pertaining both to imitation and social learning and to the model as kind of metaheuristic". Honeybee swarms exhibit sophisticated social learning behavior, where individual bees share information about the location of new food sources through dances. This assumes particular interest for research around swarm intelligence.

One last example of a very interesting research area within the scope of the theme under analysis in this chapter is *Opinion Dynamics in Social Networks*. This research area focuses on the dynamics of opinion formation and diffusion in social networks. In this regard, Acemoglu and Ozdaglar (2011) conclude that "social networks play an important role in opinion formation in practice [simply] because we tend to talk to people in our social network". By analyzing how opinions spread and evolve within a network of individuals, researchers gain insights into collective decision-making, information cascades, and the emergence of social consensus.

All the previous case study examples highlight the application of swarm intelligence principles to social learning scenarios, providing valuable insights into collective decision making, task allocation, information sharing, and opinion dynamics within a swarm. Ultimately, they all revolve around one of the key aspects of swarm intelligence: the algorithmic calibration needed to improve social learning systems.

This section provided a comprehensive exploration of a range of research projects that exemplify the application of swarm intelligence in social learning scenarios. These findings collectively highlight the potential of swarm intelligence in facilitating social learning, whether through energy conservation, task allocation, decision-making, or information sharing. Each case study has helped deepen our understanding of the diverse applications of swarm intelligence, demonstrating its adaptability and utility across a broad range of contexts.

Moving forward, we turn our attention to the more social aspect of swarm intelligence: its potential to transform citizen engagement in various scenarios, from local community decisions to disaster response. In the next section, we delve into how the principles and applications of swarm intelligence can foster an active, empowered, and engaged citizenry, reflecting on a range of scenarios such as policymaking, crisis management, and smart city initiatives. Through this exploration, we will broaden our understanding of how swarm intelligence can be harnessed to create more inclusive, effective, and resilient social systems.

5. Infusing Citizen Engagement

Swarm intelligence, inspired by social insects, is highlighted to enhance citizen engagement and collective decision-making. This concept allows groups, like schools of fish or ant colonies, to surpass individual knowledge when responding to challenges, as noted by Ioannou (2017). Tang et al. (2021) emphasize its advantages in adaptability and performance, while Schranz et al. (2021) explore human interaction with swarms, and Metcalf et al. (2019) suggest it allows for merging individual insights in real-time, aiding in decision-making.

The application of swarm intelligence is broad, including disaster response in smart cities, where citizens contribute like a 'swarm' to crisis management, demonstrating collective problem-solving as seen in the work of Palen et al. (2010). Rosenberg (2015) argues that this not only speeds up consensus but also fosters unity among participants.

Swarm intelligence can also facilitate operational scenarios, such as guiding drone swarms in disaster relief, where human influence can optimize the swarm's effectiveness, a concept explored by Rodriguez and Hilaire (2023). Zedadra et al. (2019) and Alfeo et al. (2019) discuss its role in smart cities, where citizens actively engage with urban infrastructure, contributing data that inform decision-making and resource management.

A practical case is the Boston Marathon bombing, where swarm intelligence was evident in the public's instinctive collaboration, a study of which was undertaken by Marcus et al. (2019) from the Harvard National Preparedness Leadership Initiative.

In summary, swarm intelligence offers a paradigm where collective behavior and input can lead to more effective decision-making and problem-solving, with potential applications in community participation, smart city development, and emergency responses. The theory, supported by various studies, suggests an approach to harness the collective power of citizens, leading to inclusive and resilient social systems. The next step is a bibliometric study to deepen the understanding of swarm intelligence literature.

The aim of the next section is to quantify the body of research dedicated to the intersection of social learning, citizen engagement, and future cities, using a bibliometric study. Bibliometrics is a field that utilizes mathematical and statistical methods to analyze and map documents and citations within a specific area of study. By leveraging this tool, we can explore the research landscape in a more organized and systematic manner, identifying key contributors, emerging trends, and important publications in the field.

6. Methodology

The bibliometric analysis conducted through the Web of Science database focused on scientific literature concerning social learning and citizen involvement in future cities. This study was structured into three main stages: planning, data collection, and bibliometric analysis. Bibliometrix, compatible with the Web of Science and described as a comprehensive RStudio package for quantitative research by Aria and Cuccurullo (2017), facilitated the bibliometric assessment. This approach allowed for the organization of crucial information such as temporal distribution, key authors and institutions, as well as the frequency and impact of publications in the field (Bibliometrix, 2022). Linnenluecke (2019) emphasized that Bibliometrics applies mathematical and statistical methods to analyze bibliographic records, aiding in a systematic representation of research outputs and minimizing biases. The study, following an exploratory-descriptive classification, aimed to elucidate the state of research on the topic, with a systematic search executed in July 2023, without language or temporal limitations. It included only 'article' type documents, resulting in 138 indexed papers from 1998 to 2023, and it underlined the significance of clear search term definitions in the planning phase.

7. Bibliometrics Results

As a result of this collection, it was identified that the 138 documents identified in the search were written by 437 authors, linked to 41 different countries. A total

of 551 keywords were used. Table 1 presents the result of this data collection in a general bibliometric analysis.

Table 1 Bibliometric data.

Description	*Results*
MAIN INFORMATION ABOUT DATA	
Timespan	1998: 2023
Sources (Journals, Books, etc.)	109
Documents	138
Annual Growth Rate %	7,43
DOCUMENT CONTENTS	
Keywords Plus (ID)	433
Author's Keywords (DE)	551
AUTHORS	
Authors	413
Authors of single-authored docs	24
DOCUMENT TYPES	
Articles	113
Articles; early access	3
Articles; proceedings paper	3
Proceedings papers	15
Reviews	4

The eligible articles in the Web of Science database were published from 1998–2023. In 1998, only one article was published. There was a significant increase in publications from the year 2016, in that year, 12 documents were published.

Of the 138 papers, there is a varied list of authors, institutions, and countries that stand out in the research on Social Learning and citizens engagement in future cities. When analyzing the 20 countries with the highest number of citations in the area, it can be seen that the USA stands out with 36% of the total citations, a total of 144 citations. In the second place, the United Kingdom stands out with 13% of the citations.

Figure 1 presents the intensity of publication by country and the relationship established between them, through citations between published works, the