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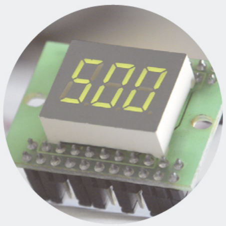


Framework de Tomada de Decisão para Last-Mile Sustentável

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Decision-Making Framework for Sustainable Last-Mile

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"Uncertainty can be a guiding light"

Bono

Acknowledgements

Firstly, I would like to thank everyone who stumbles across this dissertation, especially the young people, for there is a weight on their shoulders to make sustainability a responsibility and not a dream. It is up to us now. Let's turn on the bright lights.

I should also thank everyone who contributed, directly or indirectly, to the development of this work, either it being former teachers or the interviewed experts.

This work is part of a larger project developed by the Centre for Enterprise Systems Engineering (CESE), one of the departments of the Institute for Systems and Computer Engineering, Technology and Science (INESC TEC), and financed by National Funds through the Fundação para a Ciência e a Tecnologia (FCT) within the e-LOG project (EXPL/ECI-TRA/0679/2021).

This work would be very different without the immensely important contribution of both advisors – Dr. António Amaral and Dr. Tânia Fontes. Thank you for your continued support and guidance in studying this urgent topic.

To my family and my heroes, I promise to continue doubting, unsettling, and wondering what will come next.

Abstract

The e-commerce growth, propelled by factors like globalization, urbanization, or the COVID-19 pandemic, has been raising the demand for logistic activities. This affects the entire supply chain, especially the last-mile, as it is considered the most ineffective part of the supply chain and a source of negative externalities.

Although various solutions promise to alleviate these problems, understanding them and selecting the best has proven to be difficult due to conflicting criteria, multiple perspectives, and trade-offs. The vicissitudes of complex and sensitive urban contexts like historic centers also contribute to this difficulty.

This work contributes an integrated framework that may assist the involved stakeholders in decision-making. To this end, this work is based on a three-part methodology.

The extensive systematic literature review developed provided an integrated overview of this fragmented research area. This review confirmed the multidisciplinary nature of the topic, as there is an increasing number of studies conducted under very different perspectives. Furthermore, it was found that the economic dimension is the most considered; the most polluting countries contributed little to the research; and the solutions involve trade-offs.

The literature review supported the definition of the hierarchical model that structures last-mile operations in historic centers. This model was evaluated by interviewing a group of experts. After integrating the experts' feedback, the model was quantified by the same experts according to an AHP-TOPSIS approach. This quantification had as a case study the historic center of Porto, Portugal.

The experts considered the three sustainability dimensions identically important. Air pollution was the most valued sub-criterion whereas Visual pollution was the least. All last-mile solutions considered in the model achieved similar results, therefore suggesting a combined distribution strategy. Nevertheless, the use of parcel lockers is the most favorable solution and seems adequate in Porto's historic center.

Keywords: Sustainability, Last-mile logistics, E-commerce, Systematic literature review, AHP, TOPSIS.

Resumo

O crescimento do *e-commerce*, impulsionado por fatores como a globalização, a urbanização ou a pandemia de COVID-19, tem aumentado a procura por atividades logísticas. Isto afeta toda a cadeia de abastecimento, principalmente a última-milha, por ser considerada a parte mais ineficaz da cadeia de abastecimento e uma fonte de externalidades negativas.

Embora existam várias soluções que prometem aliviar estes problemas, entendê-las e selecionar a melhor tem se provado difícil devido a critérios conflituosos, múltiplas perspetivas e *trade-offs*. As vicissitudes de contextos urbanos complexos e sensíveis como os centros históricos também contribuem para essa dificuldade.

Este trabalho contribui um *framework* integrado que pode auxiliar os *stakeholders* envolvidos na tomada de decisão. Para este fim, este trabalho é baseado numa metodologia composta por três partes.

A extensa revisão sistemática da literatura desenvolvida forneceu uma visão integrada desta área de investigação fragmentada. Esta revisão confirmou o caráter multidisciplinar do tema, pois há um número crescente de estudos conduzidos sob perspetivas muito diferentes. Além disso, verificou-se que a dimensão económica é a mais considerada; os países mais poluentes contribuíram pouco para a pesquisa; e as soluções envolvem *trade-offs*.

A revisão da literatura suportou a definição do modelo hierárquico que estrutura as operações de última-milha em centros históricos. Este modelo foi avaliado entrevistando um grupo de *experts*. Após a integração do *feedback* dos *experts*, o modelo foi quantificado pelos mesmos de acordo com uma abordagem AHP-TOPSIS. Esta quantificação teve como caso de estudo o centro histórico do Porto, Portugal.

Os *experts* consideraram as três dimensões da sustentabilidade identicamente importantes. O subcritério relativo à poluição atmosférica foi o mais valorizado, enquanto o menos foi o relativo à poluição visual. Todas as soluções de última-milha consideradas no modelo alcançaram resultados semelhantes, sugerindo uma estratégia de distribuição combinada. No entanto, o uso de *parcel lockers* é a solução mais favorável e é aparentemente adequada para o centro histórico do Porto.

Palavras-Chave: Sustentabilidade, Logística de última-milha, *E-commerce*, Revisão sistemática da literatura, AHP, TOPSIS.

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List of Acronyms

AHP Analytic Hierarchy Process

AIJ Aggregation of Individual Judgments

AIP Aggregation of Individual Priorities

API Application Programming Interface

AV autonomous vehicle

B2B Business-to-Business

B2C Business-to-Consumer

CDP Collection and Delivery Point

CESE Centre for Enterprise Systems Engineering

CO_2 carbon dioxide

DEMATEL Decision Making Trial and Evaluation Laboratory

ERP Enterprise Resource Planning

EU European Union

FCT Fundação para a Ciência e a Tecnologia

GDP Gross Domestic Product

GHG greenhouse gas

GPS Global Positioning System

HARP Heightening Awareness of Research Philosophy

ICE Internal Combustion Engine

ICT Information and Communications Technology

IF Impact Factor

INESC TEC Institute for Systems and Computer Engineering, Technology and Science

ISEP	Instituto Superior de Engenharia do Porto
MCDA	Multiple-Criteria Decision Analysis
MCDM	Multiple-Criteria Decision-Making
MIT	Massachusetts Institute of Technology
NO$_X$	nitric oxide
PM	particulate matter
QR	Quick Response
RFID	Radio-frequency Identification
SLR	systematic literature review
TKA	title, keywords, and abstract
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
UCC	Urban Consolidation Center
UNESCO	United Nations Educational, Scientific and Cultural Organization
VRP	Vehicle Routing Problem
WHO	World Health Organization
WMS	Warehouse Management System

List of Symbols

Symbol	Description
i	Alternative
CI	Consistency Index
CR	Consistency Ratio
j	Criterion
k	Decision-maker
D	Decision matrix
x	Decision matrix element
λ_{max}	Eigenvalue
v	Ideal solution vector element
J'	Negative criteria
V^{k-}	Negative ideal solution vector
R	Normalized matrix
r	Normalized matrix element
m	Number of alternatives
n	Number of criteria
K	Number of decision-makers
J	Positive criteria
V^{k+}	Positive ideal solution vector
C	Relative closeness coefficient
RI	Random Index
S^-	Separation from the negative ideal
S^+	Separation from the positive ideal
W	Weight vector
w	Weight vector element

Chapter 1

Introduction

The advent of globalization allowed consumers and businesses to trade in different countries, popularizing the development of e-commerce practices. According to Eurostat [1], European Union (EU) consumers' interest in e-commerce grows each year, pointing out that 74 % of internet users shopped online in 2021. With this trend, consumers' requirements change, as they start demanding more customization and more convenience [2].

The recent COVID-19 pandemic and subsequent restrictions also led to a significant change in consumers' and businesses' behavior, increasing even more the adoption of e-commerce practices [3]. In this context, businesses seek to identify marketing and competitive opportunities by offering faster and cheaper deliveries to their customers [4].

All these factors increase the demand for logistic activities, especially on the last-mile, i.e., the last stretch of a parcel delivery service, from the last logistic center to the recipient's destination point [5].

This first chapter is dedicated to introducing this topic of research. The chapter begins with the presentation of the context in which this research is inserted, followed by the description of the research objectives and the expected outcomes. The remaining section of this chapter outline how the dissertation is structured.

1.1 Context

The supply chain's last-mile is considered very ineffective and expensive, accounting for 13–75 % of the total supply chain cost [6]. These costs can change depending on several factors like delivery failures or delivery time windows.

Last-mile operations also result in social and environmental externalities such as high levels of greenhouse gas (GHG) emissions, air and noise pollution, traffic congestion and accidents [7]. These impacts mainly affect urban areas where pressure has increased due to the growing population and consequent urbanization, as 60 % of the world's population will live in urban areas by 2030 [8].

Although there is an urgency to mitigate these internal and external costs, changing the last-mile has proved to be difficult because of its multidisciplinary nature. Nevertheless, different academic and industry sectors are studying the current problems of the last-mile logistics and exploring innovative solutions to reinvent the industry, thus optimizing these problems.

In fact, a visit to DHL's largest logistical infrastructure in Porto, Portugal confirmed this urgency for reinvention, with its manager classifying their operation status as "outdated". Considering the dimension of DHL, there is cause for alarm.

This problem is exacerbated as every solution has advantages and disadvantages, adding complexity to the decision-making, as the solutions must be evaluated under various conflicting criteria that range from the technical feasibility to the environmental benefits it generates. Moreover, the decision must consider the vicissitudes of the city the solution will be part of, as a city is usually composed of contrasting contexts with distinctive needs.

The historic center is a complex, sensitive, historically and socio-economically important sector of a city, indispensable for its sustainable development. Therefore, it is imperative to ensure a balanced and integrated approach that preserves the city's past without limiting its present and future.

The already highly ineffective last-mile operations face new obstacles within the context of a historic center, as social exigencies like the population's well-being, the economic returns of tourism, or the damage caused to historical landmarks are all new factors to take into consideration, thus adding even more complexity to these operations.

This dissertation is part of a larger project called e-LOG developed by the Centre for Enterprise Systems Engineering (CESE), one of the departments of the Institute for Systems and Computer Engineering, Technology and Science (INESC TEC) – a private non-profit research association, with Public Interest status, dedicated to scientific research and technological development, that links the academic world to businesses, public administration, and society. The main objective of the mentioned project is to develop a decision support tool for the assessment and design of innovative services for parcel delivery.

1.2 Objectives

The main objective of this dissertation was to provide a decision-making framework that may help different sectors (e.g., academia, industry, public administration) to further understand the last-mile problem and its possible solutions.

Therefore, the following research questions were considered:

- **RQ1:** How can the last-mile research field be characterized?
- **RQ2:** How can the last-mile operations in historic centers be structured into a hierarchical model?
- **RQ3:** Which criteria and solutions are prioritized for last-mile operations in historic centers?

In order to answer these research questions, this work is composed of three interlinked parts. Firstly, to answer RQ1, this dissertation includes an extensive systematic literature review (SLR), supported by a bibliometric analysis, that provides a holistic and comprehensive overview of the sustainable last-mile research field.

To answer RQ2, this dissertation is based on the definition of a hierarchical model that structures last-mile operations in historic centers. This model was evaluated by conducting interviews with experts.

Lastly, to answer RQ3, this model was quantified under a Multiple-Criteria Decision-Making (MCDM) approach based on a case study of the historic center of Porto, Portugal. The used MCDM methods – Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) – will comparatively evaluate different criteria and sustainable last-mile solutions according to the experts' inputs.

This work is expected to provide a holistic and diversified framework to stakeholders that could deepen their knowledge about the topic of sustainable last-mile, thus aiding decision-making processes and inspiring future research. It is also expected that this work raises awareness of a very urgent problem.

To this end, it is expected that the extensive literature review provides a clearer overview of this research area, by not only answering the question of "what" has been studied, but also "who" studied it, and "how", "when" and "where" it has been studied. A specific projected result is the confirmation of the fragmented nature of the research literature and the multitude of different involved stakeholders with conflicting perspectives. Moreover, with the development of the hierarchical model and its evaluation and quantification, it is also expected the gathering of valuable expert insights that deepen the understanding of an alarming low discussed topic such as the last-mile operations in historic centers, and suggest an advantageous last-mile solution within this context.

1.3 Dissertation structure

The dissertation is organized into six chapters. This first chapter introduces and contextualizes the dissertation by describing its relevancy and urgency, research background, objectives, and structural outline. Chapter 2 consists of the literature review that provides a quantitative and qualitative characterization of the studied field, by discussing the main sources, authors, countries, etc., as well as the main concepts and strategies approached in the literature. Chapter 3 presents and justifies the adopted methodology, describing the research design including the data collection and analysis techniques used. Moreover, it also addresses the research's quality and ethics. In Chapter 4, the developed model is defined, evaluated and quantified. The consequent interpretation of the results is presented in Chapter 5. Lastly, in Chapter 6, the dissertation is summarized, and new research avenues and potential limitations are presented.

Chapter 2

Systematic literature review

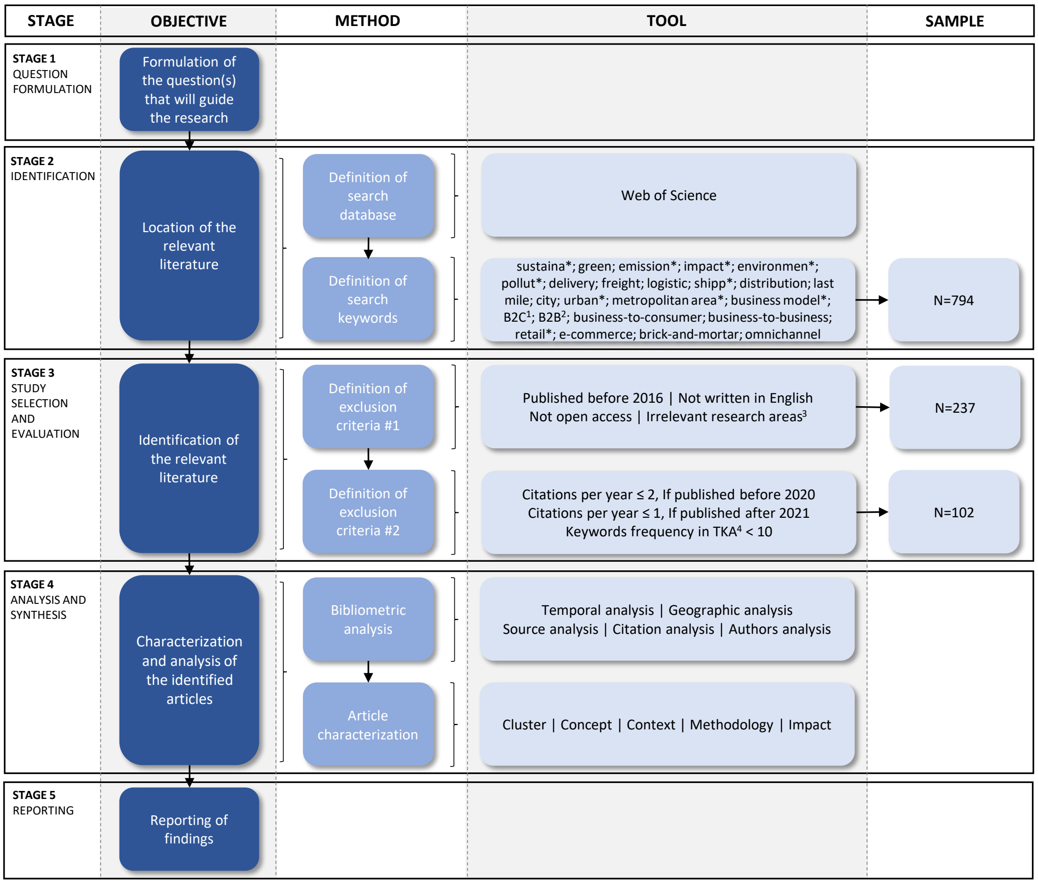
The last-mile operations and city logistics involve a multitude of stakeholders with conflicting agendas. This attracts researchers with different perspectives, methodologies, and research areas, which results in a fragmented research field. Thus, interpreting and understanding this field in depth and as a whole is rarely approached in the literature but is an indispensable step for achieving truly effective solutions.

To this end, the present chapter provides the first contribution of this work by characterizing the examined research area with a comprehensive systematic literature review of academic studies. This chapter also provides the background for the entire research presented in this dissertation.

2.1 Systematic literature review methodology

A systematic literature review or SLR is a methodical process that aims to analyze the state-of-the-art of a particular subject field [9]. A SLR differs from the classic narrative-based review by following a strict set of guidelines, and by adopting a replicable, scientific and transparent process [10]. The SLR presented in this document was based on the five-stage guideline proposed by Denyer & Tranfield [11]. Figure 2.1 illustrate the process followed.

The first stage is the definition of the scope of the systematic review. According to Thomas et al. [12], the most efficient way to do this definition is by formulating review questions. Therefore, the presented SLR aims to answer the research questions RQ1.1 and RQ1.2:



[1] Business-to-Consumer (B2C).
[2] Business-to-Business (B2B).
[3] For example: Public, Environmental & Occupational Health; Food Science & Technology; Biodiversity & Conservation.
[4] title, keywords, and abstract (TKA).

Figure 2.1: SLR methodology followed.

- **RQ1.1:** How can the last-mile research field be bibliometrically characterized?

- **RQ1.2:** How can the last-mile research field be thematically characterized?

The second stage is based on a search aimed at assembling a comprehensive list of documents relevant to the review purposes [11]. The database used in this search was the Web of Science, because it contains a wide collection of research publications and most of the journals are peer-reviewed [13]. The search query used was:

- **SQ1:** TS=((“sustaina*” OR “green” OR “emission*” OR “impact*” OR “environmen*” OR “pollut*”) AND (“delivery” OR “freight” OR “logistic” OR “shipp*” OR “distribution” OR “last mile”) AND (“city” OR “urban*” OR “metropolitan area*”) AND (“business model*” OR “B2C” OR “B2B” OR “business-to-consumer” OR “business-to-business” OR “e-commerce” OR “retail*” OR “brick-and-mortar” OR “omnichannel”))

This search query was directed to the TKA of the documents, and allowed the identification of publications that approach the subject of urban logistics of different business models with a focus on sustainability. This search was conducted between February and March 2022, and resulted in a preliminary sample of 794 publications.

In order to preserve the ideals of a systematic literature review, in the third stage, two sequential objective screenings were executed. The first screening was executed by applying the respective database filters, while the second one was executed with a Microsoft Excel spreadsheet. These screenings aimed to select only scientifically and thematically relevant studies.

The first screening consisted of the exclusion of articles: (i) published before 2016; (ii) not written in English; (iii) not open access; and (iv) classified with irrelevant Research Areas, for example, Public, Environmental & Occupational Health; Food Science & Technology; and Biodiversity & Conservation. This first screening resulted in 237 documents.

The second screening was then applied to this sample. This screening is based on another set of exclusion criteria: (i) publications with an average citation number per year less than or equal to two, if published before 2020; (ii) publications with an average citation number per year less than or equal to one, if published after 2021; and (iii) publications where the keywords used in the search query, appear less than 10 times in its title, keywords, and abstract. This screening resulted in the 102 documents included in the following analyses.

The following stages provide quantitative and qualitative insights about the topic. To this end, there are several analysis techniques that can be considered for assessing and synthesizing researches [14, 15]. Accordingly, a bibliometric review was developed to evaluate the reviewed publications quantitatively. Due to the heterogeneous nature of the themes approached in the reviewed articles, and to further assess each article, a thematic analysis based on the bibliometric analysis was conducted. Moreover, each publication was also classified according to the conceptual theme, the geographical context, the sustainability dimensions considered by the authors, and the research methodologies adopted.

2.2 Bibliometric review

A bibliometric review quantitatively analyses and evaluates a scientific research area [16]. Based on the various metrics listed by Donthu et al. [17], the developed bibliometric review comprises analyses of the authors, sources, research areas, affiliated countries and the publication years. It also includes evaluations based on the h-index, the number of citations, and the Impact Factor (IF). The capabilities of the VOSviewer software in clustering and mapping data were also used to perform co-authorship and co-occurrence cluster analyses [18].

To investigate how the studied topic's academic interest has evolved over the last years, the temporal distribution of the 102 publications was computed (Figure 2.2). It is worth noting that the less productive year was 2016 with nine articles and the more productive was 2021 with 29 articles. It should also be noted that only the first months of 2022 were considered, thus the small number. The growing trend demonstrates that there is an increasing attention given by the research community.

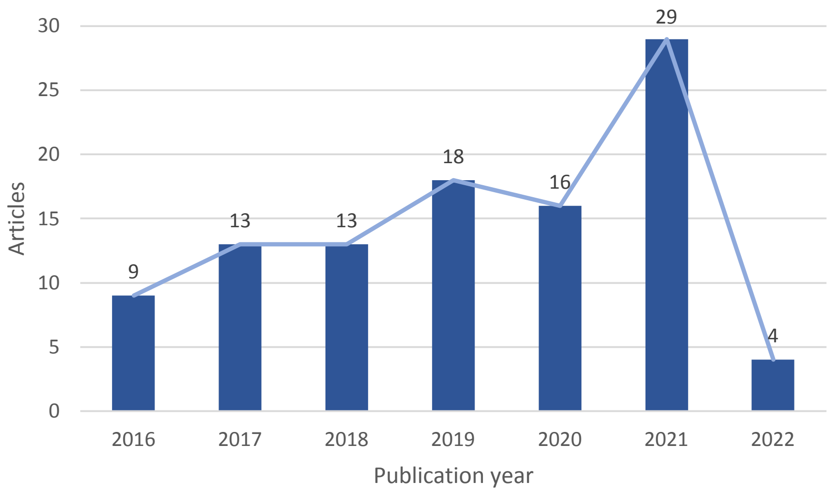


Figure 2.2: Temporal distribution of the reviewed literature.

The characterization of the different academic journals and conferences identifies which contributed more and had a higher impact. Table 2.1 depicts the top 10 sources regarding the number of publications in the sample. The results highlighted *Sustainability* as the journal with the most contributions and *9th Int. Conf. on City Logistics* as the conference with the most papers. It is also relevant to point out that 84 % of the sample are journal articles, of which 10 % are reviews.

Table 2.1: Top 10 sources according to the number of publications in the reviewed literature.

Source	**Type**[1]	**Art.**
Sustainability	J	31
European Transport Research Review	J	4
9^{th} Int. Conf. on City Logistics	C	4
Journal of Cleaner Production	J	3
Int. J. of Physical Distribution & Logistics Management	J	3
Transportation Research Part D: Transport and Environment	J	3
Int. J. of Logistics: Research and Applications	J	3
Research in Transportation Economics	J	3
2^{nd} Int. Conf. Green Cities-Green Logistics For Greener Cities	C	3
Transportation Research Part A: Policy and Practice	J	2

[1] J: Academic journal; C: Conference proceedings.

The IF was used to evaluate the journals where the literature was published. This metric is based on the Journal Citation Reports™ 2020 Ranking which measures the frequency that the average publication in a journal has been cited in a particular year [19]. The results listed in Table 2.2 highlight that the *Resources Conservation and Recycling* (IF: 10.204), the *Journal of Cleaner Production* (IF: 9.297) and the *Environmental Science & Technology* (IF: 9.028) are the journals with the highest academic impact. Moreover, 15 % of the considered literature sample is associated with these top 10 journals.

Table 2.2: Top 10 journals according to the IF.

Journal	**IF**[1]
Resources Conservation and Recycling	10.204
Journal of Cleaner Production	9.297
Environmental Science & Technology	9.028
Transportation Research Part C: Emerging Technologies	8.089
Sustainable Cities and Society	7.587
Journal of Retailing and Consumer Services	7.135
Transportation Research Part E: Logistics and Transportation Review	6.875
Int. J. of Physical Distribution & Logistics Management	6.309
Int. J. of Logistics Management	5.661
Transportation Research Part A: Policy and Practice	5.594

[1] Source: Journal Citation Reports™ 2020 [20].

Each publication is associated, on average, with more than one research area. Examining these research areas further characterizes the research field. The results in Table 2.3 show that the most frequently associated research area is Science & Technology - Other Topics, followed by Environmental Sciences & Ecology, Transportation, and Business & Economics. The diversity of the research areas confirms the multidisciplinary nature of the topic and the multiple perspectives adopted by the different research communities.

Table 2.3: Top 10 research areas in the reviewed literature.

Research area	**Frequency**
Science & Technology - Other topics	44
Environmental Sciences & Ecology	40
Transportation	34
Business & Economics	23
Engineering	10
Operations Research & Management Science	9
Computer Science	8
Urban Studies	4
Energy & Fuels	4
Geography	2

A geographical analysis of the different affiliated countries in each of the selected publications aims to identify the regions with the most contributions to the research field. This analysis showed that 33 different countries have contributed to the research. As shown on the world map in Figure 2.3, the country that contributed the most was Italy with 19 articles, followed by England with 15 articles, and Spain with 10 articles. It's also worth noting that both developed and developing countries are represented, as well as every continent except Antarctica. These results demonstrate that urban logistics and last-mile operations are research areas with worldwide interest.

Notwithstanding this broad interest, it is clear that Europe leads the research efforts on sustainable last-mile concepts, as more than half (58 %) of the 33 different countries identified are European countries. As a matter of fact, there is at least one Europe-affiliated researcher in 78 % of the publications included in the review sample. A reason for this could be the strong commitments made by European governmental institutions towards sustainable development, like the European Green Deal [21].

The fact that the Asian and North American regions are so low represented (15 % and 12 % of publications, respectively) should also be mentioned, as these regions are among the most polluting according to various indicators and sources. Asian countries distinctly populate the rankings for the countries with the most particulate matter (PM), carbon dioxide (CO_2) and other pollutants [22, 23, 24]. Moreover, the United States and China contributed to almost half of the total CO_2 emissions in 2020 (45 %) [22], while the EU-27 only contributed 7 % [22].

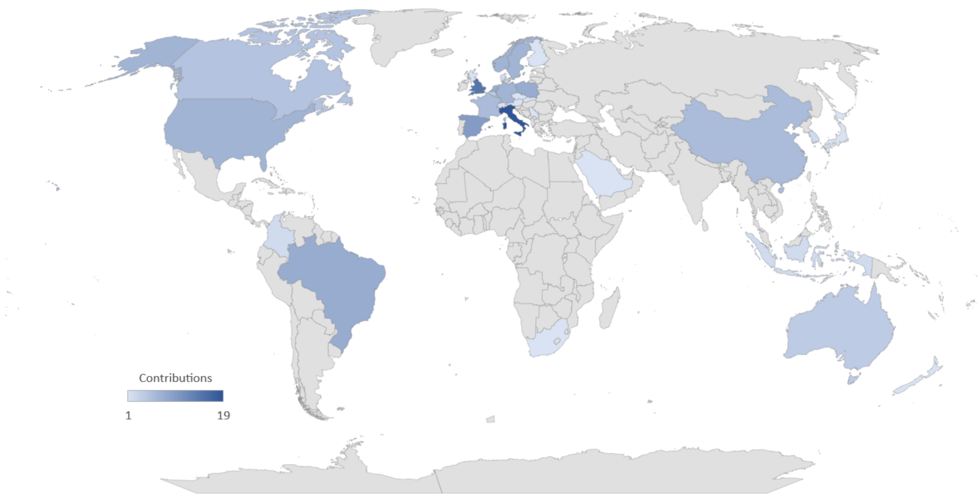


Figure 2.3: Geographical distribution of the reviewed literature.

The analysis of the proficiency and impact of the authors was based on the number of contributions by author and the h-index – an indicator representative of the scientific productivity and relevance of an author, defined as the number of publications with a citation number higher or equal to the total number of publications [25]. The results listed in Table 2.4a identify Marcucci, E., de Oliveira, L.K. and Gatta, V. as the authors with the most contributions, with five publications each. As stated in Table 2.4b, Huijbregts, M.A.J. and Savelsbergh, M. are the most relevant authors, with a h-index of 54 and 51, respectively, being classified as "outstanding scientists" by Hirsch [25]. Moreover, the main research area according to personal profiles of these 10 highlighted authors, adds evidence to the multidisciplinary nature of the last-mile and city logistics problem.

Table 2.4: Top five authors according to the (a) number of articles in the reviewed literature and (b) h-index.

(a) Number of articles.

Author	**Research area**[1]	**Articles**
Marcucci, E.	Transport economics	5
de Oliveira, L.K.	Urban logistics	5
Gatta, V.	Sustainable transport	5
Cherrett, T.J.	Urban logistics systems	4
Iwan, S.	City logistics	4

(b) h-index.

Author	**Research area**[1]	**h-index**[2]
Huijbregts, M.A.J.	Industrial ecology	54
Savelsbergh, M.	Optimization	51
Davies, N.	Mobile computing	38
Juan, A.A.	Operations research	36
Ben-Akiva, M.E.	Transportation systems analysis	34

[1] Source: Google Scholar [26] and Massachusetts Institute of Technology (MIT) [27].
[2] Source: Web of Science [28].

The co-authorship analysis deepens the characterization of the research community by identifying the patterns of collaboration and the relationships between researchers. The map presented in Figure 2.4 depicts the largest collaboration network identified in the literature sample, with 27 connected authors. This network mainly consists of researchers affiliated with Brazilian institutions, indicating the presence of a large research community in this country. This could justify why a developing country is the fourth with the most contributions to the research area (8 articles). Furthermore, in this network, there are three researchers affiliated with French, English and North American institutions, confirming the existence of worldwide collaboration networks studying the last-mile.

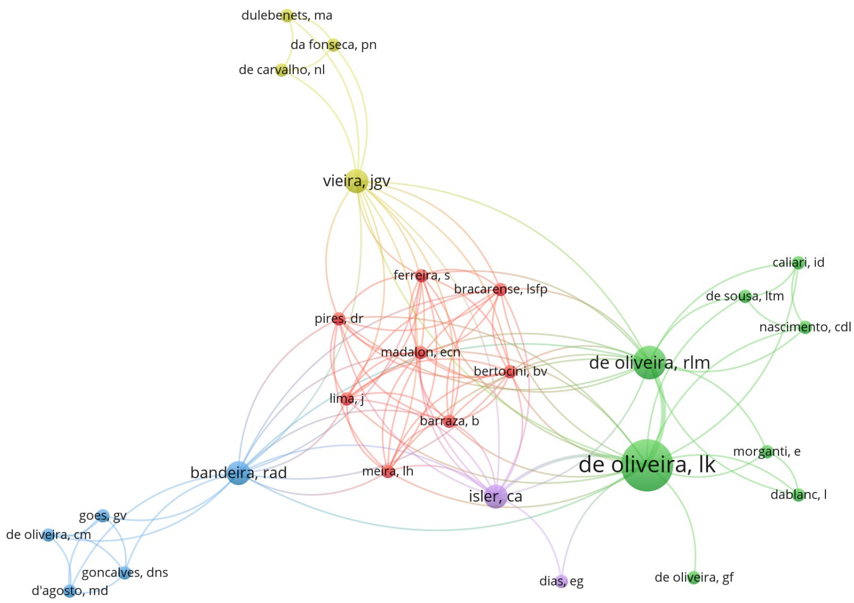


Figure 2.4: Co-authorship map of the literature.

Examining the citation frequency can provide insights about the most influential publications in a research field [17]. The results listed in Table 2.5 demonstrate the top 10 most influential publications present in the review sample. The results show that the work by Savelsbergh & Van Woensel [29] is the most influential with 242 citations, followed by the work by Allen et al. [4] with 95 citations, both being published in academic journals. The work by Cleophas et al. [30], with 84 citations, is the most influential literature review published in an academic journal, while the work by Lemke et al. [31], with 48 citations, is the most influential conference proceeding in the reviewed sample.

Table 2.5: Top 10 most cited publications in the reviewed literature.

Ref.	**Author**	**Publication year**	**Type**[1]	**Citations**[2]
[29]	Savelsbergh & Van Woensel	2016	J	242
[4]	Allen et al.	2018	J	95
[30]	Cleophas et al.	2019	R	84
[5]	Lim et al.	2018	R	81
[32]	Arnold et al.	2018	J	50
[33]	Pan et al.	2017	J	49
[31]	Lemke et al.	2016	C	48
[34]	Taniguchi et al.	2016	C	48
[35]	de Oliveira et al.	2017	R	42
[36]	Lachapelle et al.	2018	J	38

[1] J: Academic journal; R: Review; C: Conference proceeding.

[2] Source: “Times Cited in All Databases” by Web of Science [28].

The co-occurrence analysis helps to identify the most relevant concepts discussed in the articles. The map, presented in Figure 2.5, considers the co-occurrence and relevancy of the keywords of each publication. From the observation of the map, it is clear that four concepts stand out: “city logistics”; “last-mile”; “urban freight transport”; and “e-commerce”. These are the four most frequent concepts in the analyzed publications. The map also suggests that all concepts are directly or indirectly related.

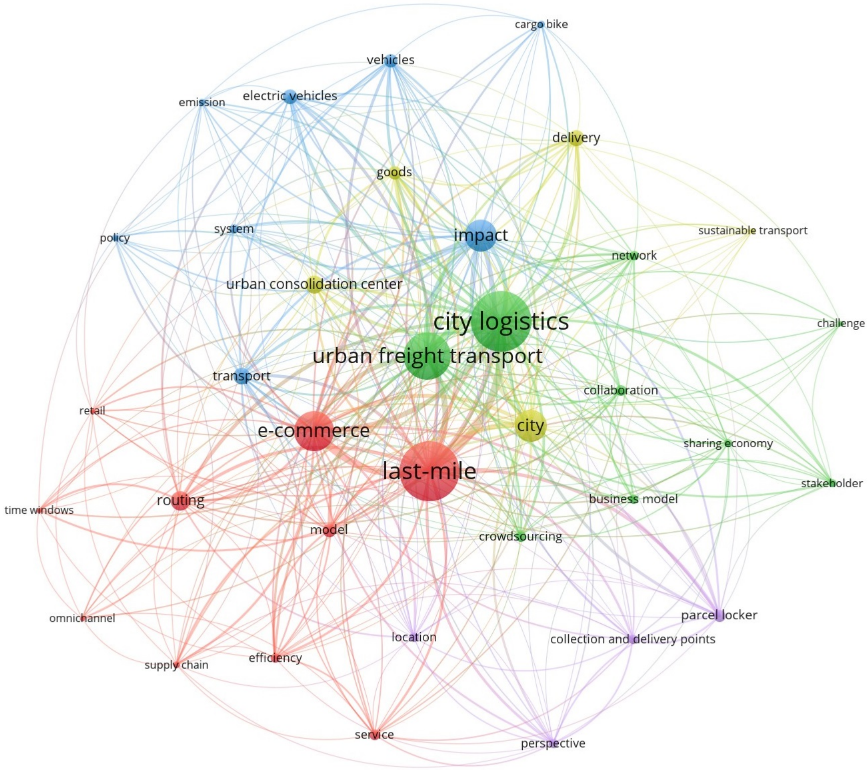


Figure 2.5: Co-occurrence map of the literature.

Five clusters are identified in the above map. The green cluster aggregates keywords related to innovative business models such as those based on collaboration, sharing economy or crowdsourcing, where the involvement of stakeholders is fundamental. The violet cluster maps the relation between alternative delivery methods and their location and the different perspectives involved. The blue cluster groups terms related to the adoption of alternative vehicles such as cargo bikes or electric vehicles. The yellow cluster is fundamentally related to logistic infrastructures like the Urban Consolidation Center (UCC) and the associated delivery schemes. The red cluster combines keywords associated with operational optimization such as routing, time windows and efficiency, with keywords associated with the urban supply chain and different commerce channels.

2.3 State-of-the-art review

The clusters identified in the previous section were the basis for classifying the reviewed articles. Therefore, the articles in the literature sample were classified based on six clusters: (i) Supply chain & channels, (ii) Delivery methods & attributes, (iii) Innovative vehicles, (iv) Logistic infrastructures & schemes, (v) Operational optimization, and (vi) Emerging business models.

2.3.1 Supply chain & channels

The supply chain requires a wide variety of activities to fully work. In this context, as stated in Table 2.6, various authors focus on different aspects, from examining the current practices and challenges to comparing traditional and novel channels.

Table 2.6: Commerce supply chain and channels literature summary.

				Dimension		
Ref.	Concept	Context	Method[1]	Env.	Eco.	Soc.
[4]	Practices, Challenges	England	C, T		✓	✓
[5]	Channels		T	✓	✓	✓
[29]	Omnichannel, Challenges		T			
[34]	Packaging		T	✓	✓	✓
[35]	Channels	Brazil	S			✓
[37]	Practices	Australia	C, S			
[38]	Challenges		T	✓	✓	✓
[39]	Practices	England	C, T	✓	✓	✓
[40]	Channels	Norway	S	✓		✓
[41]	Omnichannel, Challenges		T	✓	✓	✓
[42]	Challenges		T			
[43]	Practices	Belgium	M	✓		✓
[44]	Challenges	Europe	C	✓	✓	✓
[45]	Practices	Brazil	M, S		✓	✓
[46]	Packaging		T	✓		
[47]	Research, Channels		T	✓		
[48]	Channels	China	M, S	✓	✓	✓
[49]	Practices	Indonesia	M	✓	✓	✓
[50]	Channels	France	M	✓		
[51]	Challenges	Poland	C, M	✓		
[52]	Research, Channels		T	✓	✓	✓
[53]	Practices	Sweden	C, M			
[54]	Channels	England	M	✓		
[55]	Practices	Spain	C, M	✓		
[56]	Research, Channels		T	✓	✓	✓
[57]	Omnichannel	Singapore	M, S			✓
[58]	Packaging	China	C, M, S	✓		

[1] C: Case study & interview; M: Modeling; T: Theoretical; S: Survey.

The characteristics and activities of the supply chain, especially the last segment of it, are studied by different authors. Loiseau et al. [50] compared the environmental performance of different food supply chains, and concluded that a very short supply chain where sales happen directly on the production site has more negative impacts than a national long supply chain or a short supply chain where sales happen via online or via a retailer. Aljohani & Thompson [37] studied the last-mile delivery practices of freight carriers operating in Melbourne, and found that light commercial vehicles are the most used type of vehicle, delivering to more than 65 stops per day, and that vehicles operate with about half of the full load capacity, mainly because of the time needed for "placing and readjusting" the parcels and the uncertain availability of on-street loading spaces. Comparable results in England were presented by Allen et al. [4] and Bates et al. [39] that used the same data source to identify that 34 % of the mileage performed by company-owned light commercial vehicles is in the goods transport sector, and there are 37 stops per round, 95 % of these being at the curbside, causing conflicts and infringements. In fact, 62 % of the total round time, the vehicle is parked at the curbside while the driver unloads, sorts and delivers the parcels by foot. A similar study conducted in different Brazilian cities added evidence that light commercial vehicles are the most utilized type of vehicle for goods distribution, especially vans [45].

Other researchers opted to develop tools and methods to deepen the knowledge and understanding of the supply chain. Sanchez-Diaz [53] proposed a method for quantifying freight transport trips. The method was applied to examine the freight needs and ordering behavior of different sectors operating in Gothenburg allowing to conclude that the non-perishable goods retail sector generated the most freight trips, surpassing other sectors such as the food, the perishable or the public services commercial sectors. Cardenas et al. [43] developed a calculation tool that estimates the associated external costs (congestion, accident, noise, air pollution and climate change) based on the traveled kilometers. The authors analyzed the spatial distribution of e-commerce deliveries in different regions of Belgium concluding that, although urban areas generate more external costs, rural areas have higher external costs per parcel, due to their low customer geographical density. A causal loop model to understand how the externalities are generated through urban freight was proposed by Hidayatno et al. [49]. Their model depicts that factors like Gross Domestic Product (GDP), e-commerce orders, freight volume, logistics transport utilization, CO_2 emissions, traffic congestion, transport costs, and packaging are all related through reinforcement feedback loops.

The parcel's packaging was also highlighted by some authors. Zhang et al. [58] concluded that 32 % of all waste generated by food delivery services originated from excessive and disposable packaging solutions in Wuhan. In a more detailed study, Escursell et al. [46] point out the associated problems like using excessive packaging or non-renewable materials, based on a review of the current shipping packaging solutions for e-commerce deliveries. For more environmentally conscious packaging, they suggested the use of cellulose-based materials, 3D printing, the adoption of reusable shipping packages or the introduction of policies. 3D printing is also pointed out by Taniguchi et al. [34] as a solution for reducing packaging waste.

The way that COVID-19 impacted the delivery activities of the supply chain was examined by Villa & Monzon [55] and Milewski & Milewska [51]. According to these authors, the lockdown led to a significant increase in e-commerce orders transported, that in turn, resulted in higher CO_2 emissions, but negligible when considering the global reduction [55]. They further pointed out that the demand growth caused by the lockdown increased the efficiency of delivery operations [51].

Besides the COVID-19 pandemic and the challenges already mentioned previously in the last subsections, other factors impacting city logistics are highlighted in the literature. Savelsbergh & Van Woensel [29] identified the population growth and urbanization, e-commerce growth, the desire for speed, the sharing economy, climate change, and sustainability. Bosona [41] added the factor of globalization as it facilitates goods trading around the world, increasing the transport distance, and factors related to geographical difficulties and the historical context of the cities. Complementary, Arvianto et al. [38] found out that fleet increment and inadequate loading/unloading spaces are predominantly developing countries' challenges, while education deficiency, regulation, the emergence of new business models, and network accessibility and capacity are developed countries' problems. Urban growth, environmental challenges, and traffic congestion are common challenges in both types of economies. Boysen et al. [42] included the aging workforce in many industrialized countries, challenging the viability of innovation in physically demanding activities such as parcel delivery, while Allen et al. [4] added as a current challenge the seasonal demand peaks. De Marco et al. [44] analyzed and classified European city logistics measures, identifying the level of pollution, the diffusion of e-commerce and GDP as important drivers of city logistics measures.

The way that the research community examines these challenges is also discussed. In a literature review, Viu-Roig & Alvarez-Palau [56] classified articles based on the type of impact covered, and concluded that the environmental impact is the dimension most frequently dealt with, followed by the social and economic impacts. The technological impact is the least considered dimension but is frequently entailed with the other three dimensions. A similar literature review was conducted by Olsson et al. [52] that yielded disparate conclusions, as economic sustainability is the most covered dimension, followed by environmental sustainability and social sustainability. In a different tone, Feichtinger & Gronalt [47] developed a systematic literature review aimed at the identification of the factors used for environmental impact assessments. The authors found that the factor most included in the calculations of the environmental impact is the modal split (e.g., the share of a transport mode in the overall transport system), while the most commonly used way to measure the environmental effects is GHG and CO_2 emissions.

The comparison of the various channels from different perspectives, such as the impacts or the consumers' opinions is a topic frequently studied in the literature. Shahmohammadi et al. [54] compared three shopping models in the United Kingdom in terms of GHG footprint and concluded that online shopping supported by physical stores reduces the GHG footprint when compared with traditional shopping (i.e., brick-and-mortar), while online shopping not supported by physical store has the higher GHG emissions rate. The authors further showed that pure online shopping platforms could significantly reduce their GHG footprint by replacing delivery vans with electric cargo bikes, and by locating their logistical infrastructures closer to their customers. Bjorgen et al. [40] concluded that home deliveries render more environmental benefits than brick-and-mortar in Norway because of fewer trips and reduced car use.

Examining the consumers' preferences is another way used by academics to differentiate the existing commerce channel modalities. Gatta et al. [48] and de Oliveira et al. [35] studied consumers' preferences on channel choices in Shanghai and Brazil, respectively. Both concluded that home delivery is the preferred mode over "click and pick" and brick-and-mortar. A different approach to compare these channels was followed by Lim et al. [5], as they reviewed and compared the commerce channel models, concluding that push-centric models (e.g., home delivery) favor time convenience over physical convenience; pull-centric models (e.g., brick-and-mortar store) prioritize order response time, order visibility, and product returnability performance; and hybrid models (e.g., parcel lockers) prioritize physical over time convenience.

An emerging commerce channel modality mentioned in the literature is the omnichannel, i.e., reaching customers through various marketing and distribution channels [29]. According to Savelsbergh & Van Woensel [29] omnichannel may enhance the customer experience and increase the customer base, but introduces additional operational complexity for the organizations. Further findings by Bosona [41] identified as challenges associated with this strategy, the fragmentation of online orders; increased complexity of order fulfillment; and high cost associated. In Singapore, Wang et al. [57] stated that consumers do not perceive the current omnichannel system as a "seamless" system.

2.3.2 Delivery methods & attributes

Studying how deliveries occur is done under different approaches that range from proposing alternative methods like the use of a Collection and Delivery Point (CDP) to examining the consumers' perspective. Table 2.7 summarizes this cluster.

Table 2.7: Delivery methods & attributes literature summary.

				Dimension		
Ref.	**Concept**	**Context**	**Method**[1]	**Env.**	**Eco.**	**Soc.**
[4]	Parcel locker, Other	England	C, T		✓	✓
[29]	Parcel locker, Other		T			
[31]	Parcel locker	Poland	S			✓
[32]	Parcel locker	Belgium	C, M	✓	✓	✓
[35]	Parcel locker	Brazil	S			✓
[36]	Parcel locker	Australia	C			✓
[38]	CDP, Off-hours delivery		T	✓	✓	✓
[41]	Parcel locker		T	✓	✓	✓
[42]	Other		T			
[44]	Night delivery	Europe	C	✓	✓	✓
[45]	Off-peak delivery	Brazil	M, S		✓	✓
[48]	Delivery attributes	China	M, S	✓	✓	✓
[51]	Parcel locker	Poland	C, M	✓		
[52]	Parcel locker, CDP, Other		T	✓	✓	✓
[56]	Parcel locker, CDP, Night delivery, Other		T	✓	✓	✓
[59]	Delivery attributes	Norway	M, S	✓	✓	✓
[60]	Off-peak delivery	Brazil	C, S	✓	✓	✓
[61]	Parcel locker	Brazil	M	✓	✓	✓
[62]	CDP	Brazil	M		✓	✓
[63]	Delivery attributes	Brazil	M, S		✓	✓
[64]	CDP	Germany	S		✓	✓
[65]	Parcel locker, Other		T			
[66]	Parcel locker	Italy	M, S		✓	✓
[67]	CDP	New Zealand	C, M, S	✓	✓	✓
[68]	Off-peak delivery, Parcel locker	Poland	M, S	✓	✓	✓
[69]	24/7 delivery	Serbia	M, S	✓		✓
[70]	Parcel locker	Poland	S	✓	✓	✓
[71]	Off-peak delivery	Canada	C	✓	✓	✓
[72]	Parcel locker	Italy	C, S		✓	
[73]	CDP	Finland, Netherlands	C, T, S	✓	✓	✓
[74]	Parcel locker		S		✓	
[75]	Parcel locker	Germany	M	✓	✓	✓

[1] C: Case study & interview; M: Modeling; T: Theoretical; S: Survey.

Parcel lockers, pick-up point networks and similar CDPs are examples of alternative delivery solutions. Parcel lockers consist of unattended small lockers where parcels are delivered to and stored until the consumer collects them, usually by inserting a unique password. This solution is widely discussed in the academic literature, as well as being highly implemented in real-life situations [65]. In their highly cited work, Savelsbergh & Van Woensel [29] consider this type of solution as an opportunity to mitigate the negative effects of direct-to-consumer (attended) deliveries. Some of those adverse effects discussed in the literature are delivery failures and consequent repeated deliveries, and return deliveries, which exacerbate other externalities [41, 4].

A key point for the viability of parcel lockers is their location. In a study conducted in five Australian cities, Lachapelle et al. [36] concluded that these lockers are frequently placed in commercial streets, sites with abundant parking, and near the post office or shopping centers. They also concluded that most are placed in safe sites (e.g., sites with appropriate lighting) and should be placed more frequently in gas stations or shopping centers, so they can be combined with different purposes. Similar results were drawn by de Oliveira et al. [62] in Brazil. These authors concluded that supermarkets and shopping centers are located in high-income areas and in less costly locations for investors, thus making them more economically attractive, whereas post offices, gas stations and drugstores are located in highly populated areas, thus could serve almost the entire city population and stimulate active transportation modes. Kedia et al. [67] added that, although not the preferred location for CDPs due to consumers' low visit frequency, dairies (i.e., small convenience stores) could motivate consumers to walk or cycle to collect their parcels. This would reduce the impacts because they are densely located and operate for longer hours.

The location of parcel lockers is also studied based on consumers' preferences. Researches in Poland [31], Brazil [35] and New Zealand [67] showed that consumers' preferable locations for parcel lockers are in commercial outlets such as shopping centers or supermarkets, mainly because these places are part of their daily commute. According to Pronello et al. [72], Italian decision-makers working in the transport, environment and commerce sectors also prefer parcel lockers to be located inside strategic locations like supermarkets, as they are in line with their current local policies.

Several authors examine consumers' acceptance and priorities toward parcel lockers. The results of these studies show that there is general acceptance and willingness to use these alternative delivery methods among New Zealanders [67], Italian [66], Polish [31, 70], Brazilian [35] and German [64] consumers. Italian consumers are willing to pay more if the parcel locker is located within 500 m of their home and has 24 h accessibility [66]. The 24 h accessibility was even identified as the most attractive criterion in Poland [31, 70], being prioritized over the price, the location and the delivery speed. Moroz & Polkowski [70] additionally concluded that environmental reasons were the least considered criteria for choosing parcel lockers. A similar study in Brazil returned alternative results by stating that the most important criterion is the traceability of the parcel, followed by the flexible delivery time and reduced cost. Moreover, this study stated that, although home delivery is the preferred option for parcel delivery, the use of parcel lockers is an option with high potential demand for the consumers [35].

The acceptance and willingness-to-pay towards a customer-driven central last-mile micro-depot model that acts as a consolidation center that delivers parcels to the consumers and as a collection point where consumers pick up the parcels were studied by Hagen & Scheel-Kopeinig [64]. The results showed that German consumers' would be interested in using it but not paying for it, making the micro-depot not economically viable on its own. A similar model was proposed by Rosenberg et al. [73], which introduced a conceptual shared micro-depot that functions as a consolidation center and as a parcel locker for B2C small parcels, driven by multiple logistics service providers. Based on existing initiatives, the authors proposed adding auxiliary business models to the micro-depot, such as providing charging stations for electric cars or a library of small convenience items to rent. They stated that the shared micro-depot solution mostly has advantages (e.g., reduction of monetary costs for all parties, noise, GHG and air pollutant emissions) but could have disadvantages (e.g., increased movement complexity, lack of accident trackability), and needs stakeholder's involvement for public acceptance.

Besides the opinion of consumers, the other city actors' feedback is considered by Russo & Comi [74], Kijewska et al. [68] and Pronello et al. [72]. The first pair [74] interviewed retailers/receivers and transport and logistics operators to show that most stakeholders have a more positive perspective on measures related to pick-up points like parcel lockers than on measures related to environmental-friendly vehicles or UCCs. In a multi-criteria evaluation of measures for sustainable urban freight transport from the perspective of Szczecin's logistical operators, Kijewska et al. [68] concluded that measures related to alternative delivery systems such as parcel lockers are perceived as positive in terms of implementation possibility and impact on the environment. Pronello et al. [72] found that retailers and most of the large goods transport operators are not interested in the service, but small goods transport operators like DHL and the decision-makers see the parcel locker solution as efficient.

Other parcel delivery alternatives, classified by Boysen et al. [42] as being emerging concepts, are the reception boxes in a consumer's home or an Amazon project for smart door locks that allow the deliverer to open the front door of a home with a smartphone app. Another possibility is to deliver into the trunks of private cars. In this area, partnerships have been developed between Volkswagen and DHL; Volvo and Ericsson; Audi, Amazon and DHL [42, 29]. Delivering to the consumer's workplace could also be a solution for reducing failed home deliveries [4]. Allen et al. [4] and He & Haasis [65] referred to the solution of mobile depots that can be used as parcel storage facilities as being in the testing and development phase by companies like TNT Express in Brussels.

Some authors opted to compare systems based on parcel lockers against traditional systems. In a simulation study, Milewski & Milewska [51] showed that adopting a parcel locker service can significantly reduce the fuel consumption per parcel, mainly because the number of parcels delivered increases when compared with a traditional home delivery. Alves et al. [61] simulated different delivery and re-delivery schemes, concluding that the scenario where parcels lockers were used the most, led to reduced trip length and higher fuel, time, and external costs savings; more parcels delivered without re-delivery; higher profits and lower costs for customers. Arnold et al. [32] simulated and compared two different novel B2C delivery initiatives (parcel lockers and cargo bikes) against traditional home delivery (by van), based in the city of Antwerp. The results showed that using parcel lockers decreases operational costs (e.g., working hours) at the expense of more (potential) external costs (e.g., noise, emissions). Because the opposite occurs in the cargo bike scenario (i.e., higher operational costs and lower external costs), the authors suggested an integration of both modalities. Similar results were obtained in Berlin for the parcel locker scenario [75].

A common concern pointed out by these researches is that the parcel locker solution might imply additional traffic generated by the customers' travel to these points, contributing to the external effects of last-mile delivery. However, according to some authors, these effects could be mitigated by implementing a wide network of parcel lockers near frequently visited places, so that the customers do not generate dedicated trips to these points and to encourage customers to reach them using active modes [75, 70, 61].

Because delivery activities occur predominantly during the day (when customers are not at home), impacts like traffic congestion or failed deliveries are exacerbated [71]. Therefore, some authors studied the shift towards deliveries in different periods. Lazarevic et al. [69] proposed a 24/7 express delivery service and compared its impact versus a traditional express service. By surveying consumers and organizations, and by applying simulation tools, the authors concluded that in Belgrade, there is considerable interest in the service and that it could lead to lower diesel consumption and a consequent decrement in CO_2 emissions. Mousavi et al. [71] conducted a pilot for an off-peak delivery program i.e., parcels are delivered during the evening and overnight hours. The pilot study conducted in Ontario revealed faster delivery speed, zero noise complaints, and lower GHG emissions and other air pollutants. However, service times increased on average during the off-peak hours at the retail stores because it coincides with other activities, making staff busier at that period of the day.

de Oliveira & de Oliveira [60] took a different approach to assess the off-peak delivery alternative by surveying Brazilian stakeholders' preferences and perceptions regarding different city logistics solutions. The authors discovered that off-peak delivery was perceived as efficient by residents and administrators, but as not efficient by carriers and retailers, whose willingness to participate was dependent on the application of some sort of tax exemption. In another study, de Oliveira et al. [45], corroborated the Brazilian retailers' stance toward off-peak delivery. Different results were listed by Kijewska et al. [68], whose evaluation of Szczecin's logistical operators' opinions showed that alternative delivery systems like night deliveries are considered positive solutions by the respondents, as they view it as a solution with high implementation possibility and high environmental benefits. However, the practical implementation of this solution may not be that easy according to the findings of De Marco et al. [44], as they found that night delivery was not implemented in most studied European cities.

Not only alternative delivery methods are discussed in the literature. Several authors [59, 63, 35, 48] focused on examining the delivery attributes associated with delivery services like parcel lockers or home delivery, pointing out the fact that the consumers' priorities and preferences toward these services vary according to the part of the world they live in.

Caspersen & Navrud [59] concluded that in Norway, (female) consumers accept longer delivery times in return for a reduction in polluting emissions, and prioritize the traceability of the parcel over the delivery time, delays or emissions. In Brazil, sociodemographic characteristics such as age or income, and the type of product purchased influence which attributes are prioritized in a home delivery service, as found by Dias et al. [63]. Some examples of these correlations are that delivery fees are the most important attribute for middle-aged consumers and that the delivery fee influences the purchase of electronics, books and leisure products but not beauty or clothing products.

Another Brazil-based study [35] stated that the most important criterion for Brazilian consumers is the information and traceability of the parcel, followed by the flexible delivery time and reduced cost, while Shanghai consumers' preferences assessment showed that factors like product price, service cost and product range are more important when choosing the channel than travel time, lead time or time window [48].

2.3.3 Innovative vehicles

The adoption of alternative vehicles in logistics is a concept well disseminated in the literature. Different authors analyze alternative fuel vehicles like electric vehicles or cargo bikes, but also novel vehicular technologies such as drone or autonomous vehicle (AV). Table 2.8 characterizes the studies focused on innovative vehicles.

Table 2.8: Innovative vehicles literature summary.

				Dimension		
Ref.	**Concept**	**Context**	**Method**[1]	**Env.**	**Eco.**	**Soc.**
[29]	E-vehicle, Cargo bike, Drone, AV		T			
[32]	Cargo bike	Belgium	C, M	✓	✓	✓
[34]	E-vehicle, Cargo bike,		T	✓	✓	✓
[38]	E-vehicle, Cargo bike, AV		T	✓	✓	✓
[39]	E-vehicle, Cargo bike	England	C, T	✓	✓	✓
[41]	E-vehicle, Cargo bike, Drone, AV		T	✓	✓	✓
[42]	E-vehicle, Cargo bike, Drone, AV		T			
[44]	E-vehicle	Europe	C	✓	✓	✓
[52]	E-vehicle, Cargo bike, Drone		T	✓	✓	✓
[56]	E-vehicle, Cargo bike, Drone, AV		T	✓	✓	✓
[65]	E-vehicle, Cargo bike, Drone, AV		T			
[68]	Cargo bike	Poland	M, S	✓	✓	✓
[75]	Cargo bike	Germany	M	✓	✓	✓
[76]	E-vehicle, Cargo bike	Italy	C, M	✓	✓	
[77]	E-vehicle		C, T		✓	
[78]	E-vehicle, Cargo bike, AV		T	✓	✓	✓
[79]	E-vehicle	USA	M	✓		
[80]	E-vehicle	Poland	C	✓		
[81]	E-vehicle	Germany	M	✓	✓	
[82]	Cargo bike	Poland	C	✓		✓
[83]	E-vehicle, Cargo bike, Drone, AV		T	✓	✓	
[84]	Cargo bike, Drone	Spain	M, S	✓	✓	✓
[85]	E-vehicle	Slovakia	M	✓	✓	
[86]	E-vehicle	Italy	M	✓	✓	
[87]	E-vehicle	Europe	M	✓	✓	

[1] C: Case study & interview; M: Modeling; T: Theoretical; S: Survey.

Alternative fuel vehicles such as electric vehicles, hybrid vehicles, vehicles powered by natural gas, hydrogen or other non-petroleum-based fuels are an increasingly important part of the transportation system, with the potential to provide significant benefits [29, 34]. Patella et al. [83] and de Oliveira et al. [78] showed that adopting green vehicles in urban logistics has gathered increasing interest, specifically in using vehicles powered by alternative fuels, such as electric vehicles. Multiple authors simulated and compared the performance of electric and traditional food distribution trucks using real-life data from New York City [79] and Berlin [81]. These authors concluded that there is a significant reduction in energy consumption and GHG emissions when adopting electric vehicles. Similar comparative-based studies added even more evidence that electric vehicles have lower operational and environmental costs than traditional vehicles [87, 86, 76].

The challenges in the adoption of electric vehicles in last-mile operations have been discussed by several authors. Anosike et al. [77] identified, besides others, that operational barriers (e.g., limited driving range), battery issues (e.g., long recharge times) and cost implications (e.g., high investment cost) are among the most commonly associated types of obstacles to the use of these alternative vehicles, while Bates et al. [39], Bosona [41] and Tsakalidis et al. [87] identified as challenges against innovation, the infrastructural and financial complexity of replacing the vehicle fleet with a more sustainable one, namely due to the need for recharging infrastructures (that are not yet widely deployed), and the financial burdens associated with the high acquisition costs and uncertain depreciation rates.

The limited driving range issue is refuted by Martins-Turner et al. [81] that concluded that the battery duration of electric vehicles is suitable for most operations. A field experiment conducted in Poland by Iwan et al. [80] added evidence to the suitability of the electric vehicles' battery capacity in performing last-mile deliveries. Moreover, Settey et al. [85] showed that electric vehicles' driving range could be enhanced if they are recharged during the loading/unloading tasks of their operational routine. Tsakalidis et al. [87] suggest financial incentives, infrastructure support, and carefully designed fiscal and regulatory systems as ways to help circumvent barriers, popularize the e-vehicle and reduce uncertainty.

Cargo bikes are another popular vehicular mode in the literature. Field tests conducted in Stargard by Nurnberg [82], allowed the author to conclude that cargo bikes can help to decrease congestion, noise and air pollution, but needed adequate road infrastructure and policies, community approval, and have to be adapted to the terrain and tasks. The speed and capacity limitations of cargo bikes, and the need for new road infrastructure are also highlighted by Bosona's [41] literature review as the main disadvantages associated with cargo bikes.

Brotcorne et al. [76] analyzed the co-existence of traditional and green vehicles in urban logistics, from a managerial perspective, and concluded that cargo bikes are the vehicular mode associated with higher environmental and operational savings but correspond to a lower number of deliveries per hour. In a simulation study conducted in Antwerp, Arnold et al. [32] found that cargo bikes resulted in an increase in operational costs (e.g., working hours) but decreased the external costs (e.g., emissions, noise) when compared to home deliveries using traditional vans. Because the opposite occurs in the parcel locker scenario, the academics suggested an integration of both modalities. Contradicting results were achieved by Zhang et al. [75] in Berlin, as the use of cargo bikes decreased both operational and environmental costs.

Some literature reviews showed that emerging vehicular technologies such as drones, modular vehicles and autonomous vehicles are being studied by multiple researchers [78, 41, 83]. In particular, Patella et al. [83] classified autonomous vehicles as the most promising and challenging solution for last-mile logistics. However, according to Savelsbergh & Van Woensel [29], their benefits for city logistics, how to effectively employ them, and how to integrate them with traditional vehicles are still unknown. In Pamplona, Serrano-Hernandez et al. [84] concluded that residents prefer unmanned aerial vehicles like drones in the last-mile operations over cargo bikes or traditional vans. Complementary, in a literature review, Bosona [41] mentioned that drones have the potential to highly disrupt the existing urban freight systems, and that drone-based delivery is more expensive than traditional van-based delivery as it implies additional investments such as landing stations, while Savelsbergh & Van Woensel [29] cites Toyota, Amazon and Matternet as examples of companies investing in the use of unmanned aerial vehicles on parcel delivery.

Some of the alternative vehicular technologies were classified according to their academic investigation status and practical implementation status by He & Haasis [65]. In their article, the pair revealed that electric vehicles are on a high level of application and research; cargo bikes have received medium academic interest but high practical implementation; and drones, autonomous vehicles or modular vehicles are not highly investigated nor highly implemented. These results converge to the ones drawn by Boysen et al. [42] that classified in their review various last-mile delivery concepts according to their establishment status. According to the authors, electric vehicles and cargo bikes are a “today’s concept”, drones and small autonomous robots are “near future” concepts, while autonomous vehicles are a “farther future” concept. De Marco et al. [44] found that measures related to the adoption of low-emission vehicles are the most implemented type of city logistic measure, being present in more than 50 % of the 70 studied European cities. Furthermore, according to Arvianto et al. [38], examining novel vehicular technologies like delivery robots, automated vehicles or electric vehicles as innovative solutions for city logistics is more common in developed countries than in developing countries, as these countries are yet to introduce them.

2.3.4 Logistic infrastructures & schemes

Logistic infrastructures like Urban Consolidation Center (UCC) or parking areas are also examined by the research community, as summarized in Table 2.9.

Table 2.9: Logistic infrastructures & schemes literature summary.

				Dimension		
Ref.	**Concept**	**Context**	**Method**[1]	**Env.**	**Eco.**	**Soc.**
[4]	Parking	England	C, T		✓	✓
[29]	UCC		T			
[34]	UCC, Road, Sprawl		T	✓	✓	✓
[38]	UCC, Sprawl, Parking		T	✓	✓	✓
[41]	Parking		T	✓	✓	✓
[44]	UCC, Parking, Road, Micro-depot	Europe	C	✓	✓	✓
[45]	Parking, Road	Brazil	M, S		✓	✓
[52]	Parking, UCC		T	✓	✓	✓
[56]	UCC, Parking		T	✓	✓	✓
[60]	UCC, Parking, Road	Brazil	C, S	✓	✓	✓
[64]	Micro-depot	Germany	S		✓	✓
[68]	Parking, Road	Poland	M, S	✓	✓	✓
[72]	Parking, Road	Italy	C, S		✓	
[73]	Micro-depot	Finland, Netherlands	C, T, S	✓	✓	✓
[74]	UCC, Parking, Road		S		✓	
[85]	UCC	Slovakia	M	✓	✓	
[88]	UCC	Brazil	M, S	✓	✓	✓
[89]	UCC	Sweden, Italy, Netherlands	C	✓	✓	✓
[90]	UCC	England	C, S	✓	✓	✓
[91]	Parking	Singapore	C	✓	✓	✓
[92]	UCC		T	✓	✓	✓
[93]	UCC	Spain	M	✓	✓	
[94]	UCC	Luxembourg, France, Spain, Italy	C, M	✓	✓	✓
[95]	UCC, Sprawl		T	✓	✓	✓
[96]	UCC	Sweden	C	✓	✓	✓
[97]	Parking	Poland	C	✓		
[98]	UCC	Belgium	M	✓	✓	✓
[99]	UCC	England	C, S	✓	✓	✓
[100]	UCC	England	M, S		✓	✓
[101]	UCC	England, Italy	C	✓	✓	✓
[102]	UCC	England, Netherlands	C	✓	✓	✓

[1] C: Case study & interview; M: Modeling; T: Theoretical; S: Survey.

One of the most implemented and studied logistic infrastructures is the (UCC). The UCC is one of the opportunities for improving city logistics, primarily by consolidating the fragmented deliveries, thus reducing the freight vehicle volume going into cities [29]. De Marco et al. [44] added that UCCs are implemented in 50 % of the 70 European cities they studied, making it the second most implemented city logistic measure, only below the adoption of low-emission vehicles.

Different studies evaluated the pros and cons associated with the UCC from different perspectives. In a social cost-benefit analysis of an operational UCC conducted in Antwerp, Kin et al. [98] revealed that the UCC initiative has social (e.g., reduction in noise, accidents and congestion) and environmental (e.g., reduction of fuel consumption and pollutant emissions) benefits, but is not economically viable, mainly due to high initial costs. However, the authors calculated that the UCC becomes financially viable when the dealt volume increases significantly. Similar conclusions were drawn by other authors. van Duin et al. [102] designed an analysis framework to evaluate UCCs, and then applied it to describe three UCC city initiatives. Bristol-Bath UCC and Binnenstad Nijmegen UCC initiatives supported the thesis that, although there are social and environmental benefits, most UCCs are not financially attractive solutions, as they need public subsidies to "break-even" or generate small profits. However, the Regent St. UCC initiative claimed relevant profits. In another study by Bjorklund et al. [89], two of the five European UCC cases analyzed are not financially viable. In a survey-based study of online shopping practices, Cherrett et al. [90] suggested that courier vehicle trips could be significantly reduced by using a consolidation scheme paid by university students and that students would respond positively to this service.

The previous authors also identified seven critical factors for viable business models, of which three stand out: scale up the operations, logistics competence and the use of advanced IT and information systems [89]. These authors stressed the importance of local authorities and municipalities engaging in the initiative. The scale of operations as a critical factor is also highlighted by Estrada & Roca-Riu [93] that analytically studied the necessary conditions for sustainable consolidation schemes, and concluded that a minimal retailer density is needed to ensure positive financial status whereas vehicle costs and other site-related parameters have minor impact on the financial viability of UCCs. The authors further found that consolidation strategies could alleviate the negative externalities, as well as provide cost savings for the carriers, as they exceeded the cost of participating in these strategies.

Guerlain et al. [94] showed that implementing consolidation centers in urban areas could improve other sectors, namely the construction sector. They simulated the implementation of this consolidation center in four European cities and found benefits in terms of congestion, pollutant emissions, vehicle use and load factor. Interestingly, the results demonstrated that three of the four construction sector consolidation centers evaluated have a Payback period equal to 1 i.e., it takes one year to recover the investment cost. An alternative approach was followed by Deng et al. [92] that compared the performance of a UCC and a Peer-to-Peer platform (i.e., a capacity sharing-based platform) and found that the UCC is more profitable and more social-environmental efficient if the carriers' variable delivery cost and the number of carriers are both sufficiently high.

The perspective of stakeholders towards UCC initiatives is also the basis for some studies, like the ones led by Paddeu [99, 100] based on the Bristol-Bath UCC, that pointed out that retailers are very satisfied with the overall service, and that most of them are unaware of what a consolidation center is or how it works, while some retailers complained about the impossibility to set the delivery time and that some parcels were getting damaged. Russo & Comi [74] depicted that supply management measures like the implementation of UCCs are associated with average low benefits by the stakeholders. In Brazil, the UCC is perceived as efficient by carriers and administrators [60], and stakeholders consider criteria like the availability of parking spots, the use of technology or the service level more important in UCC planning in historical cities than insecurity, noise or traffic congestion [88].

In a research aimed at identifying the drivers and barriers associated with a UCC by analyzing the perspective of retailers operating in the city of Bristol (with a UCC) and the city of Cagliari (without a UCC), the authors identified as drivers, aspects like the time savings or the pro-environmental principles, and as barriers, factors like the competitiveness or the public subsidies' dependence [101]. Johansson & Bjorklund [96] indicate that the most important driver to convince retailers to participate in UCCs is the possibility to outsource some services (e.g., storage space, delivery consolidation) to the UCCs and thus gain economic advantages.

Hagen & Scheel-Kopeinig [64] and Rosenberg et al. [73] studied the viability of a micro-depot that acts as a consolidation center and as a parcel collection point. The first academics found that, although consumers would be willing to use it, the micro-depot would not be economically viable because consumers would not pay for it, while the second authors remarked that the shared micro-depot solution that they proposed would have economic viability and social and environmental benefits, but could increase operational complexity.

Another pivotal urban infrastructure is freight loading/unloading parking spaces, an infrastructure particularly challenging to change in order to adapt to the increasing freight volume and changing distribution systems [41]. In fact, Dalla Chiara & Cheah [91] considered arrival rates, parking duration, queue waiting time and driver parking location choice to document evidence of congestion at these spots. These infrastructures were studied in the city centers of Poland [97, 68], Singapore [91], Brazil [60, 45], Italy [72] and multiple European countries [44].

To study these infrastructures, some authors considered the perspective of the main players. Kijewska & Iwan [97], found that inappropriate or unavailable loading/unloading space for delivery vehicles is the biggest obstacle pointed out by the Polish retailers, and de Oliveira & de Oliveira [60] found that Brazilian carriers classify exclusive loading/unloading locations as efficient while carriers, retailers and administrators perceive reservation-based loading/unloading systems as efficient. In another survey, de Oliveira et al. [45] added evidence that most retailers perceive the unavailability of loading/unloading parking areas as an impactful problem, therefore they are willing to accept the regulation of loading and unloading areas. Nevertheless, Pronello et al. [72] point out that, although the loading/unloading bays are perceived by stakeholders as obstacles to efficient delivery operations, their booking is not appreciated as it would increase the complexity of the deliveries. Parallel results obtained by Russo & Comi [74] and Kijewska et al. [68] showed that measures related to infrastructural delivery areas like loading/unloading areas are not considered by most stakeholders as very positive measures when compared to measures related to eco-driving training, alternative delivery systems, collaboration schemes or the use of technological systems.

With a different approach, De Marco et al. [44] confirmed the lack of interest in parking-related measures such as monitoring, booking or dedicated roadside lay-by areas, as the authors found that this type of measures is implemented in less than 20 % of the considered set of 70 European cities.

The most omnipresent urban logistic infrastructure is the road. Therefore, some authors studied exclusive freight lanes or other mobility restrictions as a solution for improving road use. de Oliveira & de Oliveira [60] surveyed the Brazilian stakeholders' preferences and perceptions and stated that exclusive freight lanes are perceived as efficient by carriers, retailers and administrators. According to de Oliveira et al. [45] most surveyed Brazilian retailers agree with the restriction of vehicle circulation as a viable solution. Russo & Comi [74] found that stakeholders are interested in limited traffic zones. The pair also found that measures related to environment-friendly vehicles such as using the vehicle' environmental performance as an access constraint are perceived as efficient by city users, but not by retailers or logistics operators, contradicting Pronello et al. [72] which presented that using the vehicle's emissions as a criterion to permit access to limited traffic zones is consensual among stakeholders while using criteria like the loading factor is not. Taniguchi et al. [34] wrote that applying direct road charging measures such as tolls can lead to more efficient utilization of freight vehicles and avoid the need for additional warehouses. De Marco et al. [44] analyzed European city logistics measures and found that low-emission zones are implemented in almost half of the studied cities, while dedicated freight lanes are the least implemented measure

Hesse [95] and Taniguchi et al. [34] approached the spatial context of logistics, discussing the logistics sprawl problem i.e., the trend of placing logistic infrastructures in the urban surroundings. One of the drivers of logistics sprawl, a problem that can increase the traveled distance by freight vehicles, is the lack of affordable logistics infrastructures in central and inner urban areas [4].

2.3.5 Operational optimization

Different publications have explored how novel technologies and techniques can optimize last-mile operations like vehicle routing. These are listed in Table 2.10, which depicts the geographical context, method and sustainability dimension considered.

Table 2.10: Operational optimization literature summary.

				Dimension		
Ref.	**Concept**	**Context**	**Method**[1]	**Env.**	**Eco.**	**Soc.**
[4]	Technology	England	C, T		✓	✓
[29]	Technology		T			
[33]	Technology		M, S	✓		✓
[34]	Technology		T	✓	✓	✓
[38]	Parking optimization, Technology, Routing		T	✓	✓	✓
[41]	Technology		T	✓	✓	✓
[44]	Routing	Europe	C	✓	✓	✓
[52]	Routing		T	✓	✓	✓
[56]	Technology, Routing		T	✓	✓	✓
[68]	Routing, Technology	Poland	M, S	✓	✓	✓
[72]	Technology	Italy	C, S		✓	
[74]	Technology		S		✓	
[103]	Routing	Italy	M		✓	
[104]	Parking optimization	Singapore	C, M	✓	✓	✓
[105]	Technology	Singapore	C		✓	✓
[106]	Technology		T	✓	✓	
[107]	Parking optimization	Italy	C, M			
[108]	Technology	Europe, Asia	C	✓	✓	
[109]	Technology	Colombia	M	✓	✓	✓
[110]	Technology	South Africa	C		✓	✓
[111]	Technology	USA, Colombia, Spain	M		✓	
[112]	Technology	Europe, Canada, USA	T			
[113]	Routing	Europe	M	✓	✓	
[114]	Routing		M	✓	✓	✓
[115]	Routing		M		✓	

[1] C: Case study & interview; M: Modeling; T: Theoretical; S: Survey.

Urban infrastructures like freight parking spaces are intrinsically linked to fleet operations. Some academics study these operations as an optimization problem. Dalla Chiara et al. [104] designed a random utility model to optimize urban freight parking. Based on simulations, the authors concluded that reducing parking duration, and parking in spaces reserved for passenger vehicles can reduce issues like congestion, air pollution, accidents, delivery costs, and illegal parking. Diana et al. [107] developed a geolocation-based method to optimize urban freight loading and unloading areas' examination using a clustering algorithm with a set of criteria (i.e., number of vehicles, congestion issues, street characteristics and retail locations) to identify the most relevant locations for logistic operations.

Another fleet operation whose optimization could have a significant impact is vehicle routing. Although related measures are among the least implemented measures in Europe [44], and are more relevant in developing countries [38], in the literature, there are different authors focusing on the Vehicle Routing Problem (VRP). Rincon-Garcia et al. [113] introduced a time-dependent VRP optimization model based on a large neighborhood search algorithm that decreases the number of vehicles used, the traveled distance, and the route duration. The authors also showed that imposing a time window substantially increases the cost and the CO_2 emissions. Cerrone et al. [103] demonstrated through a routing optimization model that the routes' cost and length are not affected by the street crossing penalties. Two authors used genetic algorithms to develop models for fleet management optimization. The model proposed by Yang & Wu [115] optimized vehicle routing and showed that the total route length increases as the time windows exigencies increase, while the model proposed by Wang & Bae [114] revealed that using fewer vehicles can reduce the operational costs, but the time windows failures will increase.

Different publications have explored the potential that emerging technologies and techniques like the use of emerging data sources, tracking technologies, Application Programming Interface (API) and mobile apps, or cloud-based technologies have on optimizing logistical operations. Those studies stated that digital connectivity, big data and automation can drive city logistics innovations in order to decrease the negative effects on congestion, safety and the environment [29], and digitalization and automation could result in more efficient, flexible and customer-focused supply chains, reducing externalities like delivery failures [41].

Pan et al. [33] outlined a model based on data mining techniques to optimize last-mile operations of the perishable food products industry. The model uses electricity consumption data of customers' residences to estimate their absence. The results revealed that the model could reduce the number of failed deliveries and the total route length. Taniguchi et al. [34] contributed by describing other applications of big data systems and decision support systems found in the literature. de la Torre et al. [106] found applications of simulation techniques, machine learning and fuzzy-based methods in the optimization of supply chains, transportation services, crowdsourcing logistics, autonomous and electric vehicles, among others. The authors concluded that, because of the different sustainability dimensions to be considered, it is unlikely that the transportation system can be improved using a single method.

Hardware has also been applied to last-mile. As concluded by Perboli & Rosano [112], Radio-frequency Identification (RFID) and technologies based on Global Positioning System (GPS) are extensively used in European smart city projects, whereas the most used technologies in projects in USA and Canada are models based on Information and Communications Technology (ICT), databases and cloud computing. Giusti et al. [108] summarized the methods and results of the multimodality transportation project SYNCHRO-NET. This platform is based on cloud technology and a set of simulation and optimization software that can improve freight and logistics management in real-time. Some of the most relevant results are the reduction of CO_2 emissions, route length and duration, and consequent transportation costs.

The hardware concepts are frequently combined with software solutions such as machine learning and simulation models. Gutierrez-Franco et al. [109] proposed a data-and-model-driven framework for vehicle-related operations optimization. This framework relies on hardware (RFID, GPS); software (e.g., Enterprise Resource Planning (ERP), Warehouse Management System (WMS)); and machine learning, simulation and optimization models. Some of the advantages of the proposed system include reducing the number of vehicles in use, increasing the resource capacity utilization and reducing the cost of fleet operations. The use of apps and API is also the subject of studies. Mkansi et al. [110] examined how the use of mobile applications can optimize e-grocery logistics, namely managing demand and cooperation between competitors. de Kervenoael et al. [105], based on independent delivery workers' practices, stated that using internal technological systems (e.g., parcel Quick Response (QR) codes, logging data, tracking technologies) combined with external applications (e.g., Google Maps, WhatsApp) could lead to more sustainable logistics operations. These external applications can collect data from traffic and meteorological conditions, as well as improve communications. Munoz-Villamizar et al. [111] proposed a model based on Google API to measure the effects of disruptions in last-mile delivery operations. The model was computationally validated on a set of real data from different cities (Boston, Bogotá and Pamplona) and allowed the authors to conclude that cities with larger sizes, limited road networks, and with high customer concentration zones are more sensitive to disruptions.

Pronello et al. [72] adopted a different approach and analyzed the stakeholders' needs for freight optimization apps, and concluded that transport operators only value information regarding aspects like traffic disruptions, parking bays status, or less polluting routes. A similar approach by Russo & Comi [74], as they found that the city stakeholders expect positive benefits from the use of ICT and intelligent transport systems such as apps for booking delivery bays or traffic management.

2.3.6 Emerging business models

Emerging business models have been studied and proposed by various authors. These studies are focused on vertical collaboration schemes like crowdsourcing logistics or the combined transportation of people and freight, as well as horizontal collaboration, for instance, two companies sharing assets [30]. Table 2.11 outline the studies that explore these concepts.

Table 2.11: Emerging business models literature summary.

				Dimension		
Ref.	**Concept**	**Context**	**Method**[1]	**Env.**	**Eco.**	**Soc.**
[4]	Crowdsourcing, Collab.	England	C, T		✓	✓
[29]	Crowdsourcing, Collab., People/Freight		T			
[30]	Crowdsourcing, Collab., People/Freight		T			✓
[34]	People/Freight		T	✓	✓	✓
[38]	Crowdsourcing, Collab., People/Freight		T	✓	✓	✓
[39]	Crowdsourcing	England	C, T	✓	✓	✓
[41]	Collaboration		T	✓	✓	✓
[42]	Crowdsourcing, People/Freight		T			
[52]	Crowdsourcing, Collab.		T	✓	✓	✓
[56]	Crowdsourcing, Collab., People/Freight		T	✓	✓	✓
[68]	Collaboration	Poland	M, S	✓	✓	✓
[74]	Collaboration		S		✓	
[116]	Crowdsourcing	Italy	C, M		✓	✓
[117]	Crowdsourcing	China	M	✓	✓	
[118]	Crowdsourcing	Italy	M, S	✓	✓	✓
[119]	Crowdsourcing	Italy	M, S		✓	✓
[120]	Crowdsourcing	Netherlands	C, M	✓	✓	
[121]	Crowdsourcing		M	✓	✓	✓
[122]	People/Freight	Spain	C, M	✓	✓	✓
[123]	People/Freight	USA	M		✓	
[124]	People/Freight		M	✓	✓	✓
[125]	People/Freight	Netherlands	C, S	✓	✓	✓
[126]	Collaboration	Belgium	M	✓	✓	✓
[127]	Collaboration	England	M, S	✓	✓	
[128]	Collaboration	Netherlands, Canada	C	✓	✓	✓

[1] C: Case study & interview; M: Modeling; T: Theoretical; S: Survey.

Crowdsourcing logistics i.e., the outsourcing of logistic services to a network of people, with benefits for all parties [129], is the emerging initiative most present in the reviewed literature, being classified by Boysen et al. [42] as a "Near future" concept. Several of the crowdsourcing models proposed the use of public transport for last-mile delivery operations. Chen & Pan [117] outlined a system that supports the application of a crowdsourcing model using taxi drivers, data mining and algorithms to optimize routing and scheduling of tasks. Gatta et al. [118] designed an analytical crowdsourcing model where commuters deliver parcels using public transportation systems, specifically using the metro with parcel lockers located inside or near the station. This model could lead to environmental benefits (e.g., less 239 kg of particles per year, on average), but could only achieve economic sustainability if public incentives and subsidies are applied. The same model was used by Gatta et al. [119] to examine the willingness to act as a crowdshipper (supply-side) and to use this service (demand-side). The results showed that the supply side prioritizes the parcel locker location over the remuneration per delivery, while the demand side prefers flexible delivery dates and time windows over lower shipping fees or shipping time. Younger people are more willing to act as a crowdshipper and to use this service.

Seghezzi et al. [116] benchmarked the economic performance of a crowdsourcing-based model versus a traditional express delivery model. The results suggested that the average cost per delivery of a crowdsourcing model is lower for any service level, every number of workers and every vehicle mix except for a "100 % foot" model. The authors also concluded that a crowdsourcing initiative could lead to an additional income source for the deliverers. To support the integration of crowdsourcing practices into a traditional delivery network, Guo et al. [120] proposed a conceptual framework of five basic principles. According to these authors, although an exclusive crowdsourcing system could not totally replace the traditional delivery system, the proposed integration could help reduce the environmental and economic last-mile costs, at the expense of needing a large number of crowdshippers. This need is also pointed out by Savelsbergh & Van Woensel [29], that included crowdsourcing in their list of opportunities for improving city logistics, adding that the compensation for the worker has an impact on the effectiveness of the solution. Bates et al. [39] alerted that this type of initiative could lead to social injustices common with zero-hour contracts, such as low income and lack of benefits or legal support.

Rzesny-Cieplinska & Szmelter-Jarosz [121] contributed by developing a model for benchmarking various crowdsourcing solutions according to the needs of different stakeholders and concluded that the crowdsourcing initiative implemented by Amazon (AmazonFlex) had the most valuable characteristics, as the stakeholders associate it with social benefits such as security or creating a local community. Grabr and Nimber are other examples of crowdsourcing initiatives [42]. Allen et al. [4] who studied the problems of parcel delivery operations in London, stated that, although crowdsourcing is one of the initiatives that can improve last-mile operations by reducing vehicle activity, the emergence of crowdsourcing services by large companies like Uber and Amazon threatens to change the sustainable nature of crowdsourcing and result in dedicated vehicle trips specifically for parcel delivery.

Another "Near future" concept listed by Boysen et al. [42], and considered by Savelsbergh & Van Woensel [29] as having "enormous potential for exciting research" is the combined and integrated transport of people and freight. This solution takes advantage of the public transport infrastructures to deliver parcels and is already being practically implemented in countries like Switzerland and Japan [30, 34].

This initiative is being considered, evaluated and compared by various authors. Villa & Monzon [122] assessed the integrated transport of people and freight by proposing a novel model for e-commerce parcel delivery based on Madrid's underground metro infrastructure. They compared two scenarios (combining people and goods, and using dedicated trains) with the *status quo* scenario (delivery by road transit). The results showed that there are significant reductions in congestion costs, accidents, noise, and air emissions when adopting a metro-based delivery model, in particular, the shared train scenario. Beirigo et al. [123] modeled this integration using mixed-purpose compartmentalized autonomous vehicles. The simulation of various scenarios with different characteristics (e.g., different number of vehicles, different route lengths) allowed to conclude that almost every scenario resulted in higher operational profits when compared to a model without people-freight integration. Cheng et al. [124] proposed two delivery methods (utilizing the minimum and maximum amount of free capacity of each trip) based on the use of public transportation to move passengers and parcels, by exploiting the unused capacity. Analytical and experimental results showed that it was possible to distribute most packages, in under 1 hour in off-peak periods and with little impact on the passenger.

The unused capacity of public transport is also studied by Van Duin et al. [125] that conducted a pilot project in the Netherlands to study the viability of using the unused capacity of public buses to carry parcels and found that this solution led to lower CO_2 emissions, the creation of job opportunities and a sustainable business model. Moreover, Taniguchi et al. [34] stated that this initiative could bring benefits for public transport organizations as it can be an additional revenue stream; logistic organizations would also benefit by reducing transport costs and increasing the frequency and reliability of deliveries; and residents would experience less congestion, noise and air pollution. However, this solution involves extra transshipment costs, additional handling equipment and additional labor for loading/unloading and security tasks.

The idea of using the free or unused capacity is also adopted when developing business models based on collaboration and sharing economy principles. Allen et al.

[4] and Savelsbergh & Van Woensel [29] stated that fostering operational collaboration between parcel carriers in order to reduce the number of operating vehicles or increase resource utilization efficiency is one of the solutions to improve the parcel delivery operations, while Bosona [41] stressed the difficulty in addressing the different competing interests of urban freight logistics actors, and the difficulty in establishing coordination between these actors due to the uncertain and dynamic nature of freight operations. Kin et al. [126] examined the operational feasibility of utilizing the free capacity of cargo trucks to supply small independent stores. Using a computational simulation model, the authors found that it potentially provides an additional revenue source as well as reduces the traveled distances and lead times, in specific, when adopting a centrally located logistic center. Also using a simulation-based study, Zissis et al. [127] concluded that a collaboration model based on retailers sharing fleets and using micro hubs around residential areas, could lead to reductions in distance and operation time, by the use of fewer vehicles.

Enochsson et al. [128], explored the topic of sharing economy across different actors, segments and cities, affirming that municipal governments and organizations are, in general, supportive of sharing economy principles, as they could lead to environmental, social and economic benefits, as well as being a solution for the last-mile problem. Similarly, Russo & Comi's [74] assessment of city users, retailers/receivers and logistical operators' expected outcomes of a set of city logistics measures demonstrated that public-private collaboration measures are expected to produce high benefits.

2.4 Discussion

The previous literature review provided the answers to the research question RQ1 and confirmed the multidisciplinary and fragmented nature of the research field, the multitude of perspectives, and the conflicting interests involved – all main causes for the last-mile problems.

The literature review constitutes an important piece of knowledge in a form of a holistic collection of various insights about the last-mile research. These range from who are the most influential authors and which countries contributed the most to the research field, to which alternatives have emerged in recent years and what are their advantages and disadvantages.

This last insight is an important contribution, as it provides a very practical overview of the different solutions. The advantages and disadvantages of the main last-mile solutions discussed in the reviewed literature are listed in Table 2.12.

Table 2.12: Advantages and disadvantages associated with the main last-mile solutions identified.

Solution	Advantages	Disadvantages
Omnichannel	• Enhance customer experience [29] • Increase customer base [29]	• Additional operational complexity [29, 41] • High cost [41] • Not well perceived by consumers [57]
Parcel locker	• Reduces fuel consumption, trip length and duration, external and internal costs, redeliveries [41, 4, 67, 51, 61, 32] • General consumer's acceptance [67, 66, 31, 70, 35, 64] • General stakeholder's acceptance [74, 68, 72]	• Potential generation of more external costs (e.g., noise, emissions) [32, 75] • Should have 24 h accessibility [66, 31, 70] • Should be placed in frequently visited commercial sites [31, 35, 67, 72]
Off-peak delivery	• Reduces fuel consumption, GHG and other pollutants emissions [69, 71] • General consumers' acceptance [69, 60] • Faster deliveries [71] • No noise complaints [71]	• Non-consensual acceptance among stakeholders [60, 45, 68] • Increased service times [71]
Electric vehicle	• Reduces operational and environmental costs [79, 81, 87, 86, 76] • Battery suitable [81, 80, 85]	• High investment and infrastructural needs [77, 39, 41, 87]
Cargo bike	• Reduces congestion, noise, pollution [82, 76, 32, 75]	• Needs adequate road infrastructure and policies [82, 41] • Speed, load, and terrain limitations [82, 41] • Lower number of deliveries per hour [76] • No consensus regarding operational costs reductions [76, 32, 75]
Autonomous vehicle	• High future potential [83]	• Uncertain benefits and aplicability [83, 29]
Drone	• General consumers' acceptance [84]	• Needs infrastructural investments [41]
Parking-related measures	• Reduces congestion, air pollution, accidents, delivery costs, illegal parking [104]	• Non-consensual acceptance among stakeholders [60, 45, 72, 74, 68]

Table 2.12: Advantages and disadvantages associated with the main last-mile solutions identified – continued.

Solution	Advantages	Disadvantages
Road-related measures	• General stakeholders' acceptance [60, 45, 74, 72] • More efficient resource utilization [34]	
UCC	• Reduces noise, accidents, congestion, fuel consumption, pollutant emissions, costs for carriers [98, 102, 93, 94] • General stakeholders' acceptance [99, 100, 60]	• Not economically viable [98, 102, 89] • Dependent on large scale operation [89, 93, 92]
Technological systems	• Reduces vehicle use, route length and duration, congestion, accidents, environmental costs, re-deliveries, operational costs, cooperation problems [113, 29, 41, 33, 108, 109, 105, 110]	
Crowdsourcing	• Reduces pollutant emissions, operational costs [118, 116] • General willingness-to-use [119] • Additional income source for citizens [116]	• Needs a large number of crowdshippers [120, 29] • Potential social inequalities [39]
People/Freight transport	• Reduces congestion, accidents, noise, pollutant emissions, operational costs [122, 123, 125, 34] • Efficient operation and business model [124, 125, 34] • Low passenger impact [124] • New job opportunities [125]	• Requires extra transshipment costs, handling equipment and labor tasks [34]
Horizontal collaboration	• Reduces the number of vehicles, route length and duration, lead time [4, 29, 126, 127] • Increases resource utilization efficiency [4, 29] • Additional revenue source [126]	• Difficult coordination [41] • General stakeholders' acceptance [128, 74]

The key finding here is that most solutions have at least one disadvantage, usually related to high financial and infrastructural requirements, or the lack of consensus between stakeholders. This adds evidence for the complexity of the last-mile problem as, although there are many strong solutions, there is not a perfect solution, as the improvement of some dimensions will result in the worsening of other important dimensions. Moreover, the lack of consensus is a significant challenge for innovation as it is the involvement of different stakeholders with different perspectives the key for the definition of the goals, the effectiveness of the implementation, and the legitimacy and credibility of the process.

Beyond the bibliometric and thematic analyses, the characterization of the research area was deepened by classifying the literature sample according to the conceptual theme, the research methodologies adopted and the sustainability dimension considered by the authors. This classification is summarized in Table 2.13, depicting the number of articles, and the frequency of each type of method and dimension present in each cluster.

Table 2.13: Literature review summary.

		Method[1]				**Dimension**		
Cluster	**Articles**	**C**	**M**	**T**	**S**	**Env.**	**Eco.**	**Soc.**
(i)	27	30 %	41 %	44 %	26 %	70 %	44 %	59 %
(ii)	32	31 %	41 %	28 %	50 %	56 %	75 %	81 %
(iii)	25	28 %	40 %	48 %	8 %	84 %	76 %	52 %
(iv)	31	48 %	23 %	32 %	35 %	77 %	94 %	81 %
(v)	25	32 %	40 %	36 %	16 %	56 %	84 %	56 %
(vi)	25	28 %	48 %	40 %	24 %	68 %	88 %	72 %
TOTAL	102	38 %	51 %	22 %	29 %	71 %	74 %	64 %

[1] C: Case study & interview; M: Modeling; T: Theoretical; S: Survey.

The number of publications in each cluster is relatively similar, pointing out the diversity of areas of the studied topic, as well as, the effectiveness of the followed systematic literature review methodology in collecting a comprehensive array of the concepts associated with the last-mile. Nevertheless, the most represented cluster is (ii) Delivery methods & attributes, with 32 publications, closely followed by (iv) Logistic infrastructures & schemes, with 31 publications, while the clusters with the least associated publications are the (iii) Emerging business models, (v) Innovative vehicles, and (vi) Operational optimization, each with 25 publications. It should also be noted that, because the city logistics and last-mile topics are characterized by their multidisciplinary nature, some authors adopt wider approaches, conducting studies that cover multiple concepts. Hence some publications and authors are classified with two or more clusters, thus being referred to in more than one subsection. These multi-cluster publications constitute 24 % of the sample and are mostly literature reviews, and evaluations of different measures based on case studies, interviews and surveys. The vast majority of the publications are classified with just one cluster (76 %).

Based on previously established methodology classification schemes [130, 52], the 102 reviewed publications were classified according to the main research methodology adopted. Therefore, four classes were identified: Case studies & interviews (C), Modeling (M), Theoretical (T) and Survey (S).

Modeling is the methodology class with the most publications, constituting more than half of the sample (51 %). This methodology refers to studies conducted with various techniques, for instance, sensitivity analysis, data mining and exploiting APIs, heuristic algorithms, genetic algorithms, (mixed-integer) linear programming, cluster analysis, discrete choice modeling, Analytic Hierarchy Process, agent-based simulation model, Life cycle assessment, and economic-oriented models. Case studies and interviews are the second largest group of methodologies, being adopted in 38 % of articles. In this group are included empirical, comparative and field studies, and qualitative interviews with relevant stakeholders or experts. The other two research methodologies classes are Theoretical studies and Survey-based methods, present in 22 % and 29 % of the papers, respectively. Theoretical publications mainly consist of classic narrative and systematic literature reviews. Surveys are predominantly quantitative studies based on a stated preference questionnaire on consumer behavior, satisfaction and preferences. Moreover, there are surveys focused on the perspective of the stakeholders and experts.

A significant share of publications (34 %) employ two methods, the most common combination being Modeling-Survey, either by using a survey as a data source for modeling techniques or by using a survey to evaluate the model proposed. A reduced lot of publications (3 %) adopt three research methodologies: Kedia et al. [67] used a modified p-median location-allocation model, surveyed consumers' shopping patterns and interviewed courier companies and dairy owners to study collection points; Zhang et al. [58] conducted a field study accompanied by a questionnaire survey, and used life cycle assessment modeling to measure the environmental impact of the food delivery sector; Rosenberg et al. [73] case studied shared micro-depots initiatives, surveyed future residents' behavior and preferences, and theorized about possible extensions and evaluation metrics for these initiatives.

It is interesting to examine how the research methodologies are distributed by thematic cluster. Modeling is the leading methodology class in the clusters (vi) Emerging business models (48 %) and (v) Operational optimization (40 %), because the articles included in these clusters are focused on predicting how novel models can be operationalized, or how the efficiency of the current models can be improved. Case studies and interviews are very frequent in articles of the (iv) Logistic infrastructures & schemes cluster (48 %), as the examination of infrastructures like UCCs or loading/unloading areas is mainly conducted by empirically assessing established initiatives and related operations. Theoretical methods are the most considered methodology in the (i) Supply chain & channels cluster (44 %) and in the (iii) Innovative vehicles cluster (48 %), as publications in these clusters are usually reviews aimed at consolidating the different aspects of the supply chain or the different vehicles. Surveys are the most common method in the (ii) Delivery methods & attributes cluster (50 %), but are very little considered in the clusters (iii) Innovative vehicles (8 %) and (v) Operational optimization (16 %). A justification could be that, because surveys are largely employed to examine consumers' habits and perceptions, they are more important when examining solutions like parcel lockers, whose success is heavily dependent on consumer behavior, whereas solutions like adopting electric vehicles or implementing routing optimization systems are not.

Furthermore, the reviewed articles were classified according to the three dimensions of the so-called "triple bottom line of sustainability": environmental, economic and social. Factors like energy consumption, PM, CO_2 and GHG emissions, noise, or waste are attributed to the environmental dimension; transport costs, delivery times, investment costs or profit margins are examples of economic factors; and security, traffic congestion, or quality of life are social factors.

In this context, the social dimension is the least considered, being present in 64 % of the articles, the environmental dimension is considered in 71 % of the articles, and the economic factor is the most considered dimension, present in 74 % of the reviewed articles. This could indicate that the main goal or motivation for introducing new and innovative solutions is the generation of higher financial profits and lower operational costs.

57 % of the reviewed publications do not consider (simultaneously) the three sustainability dimensions. 50 % only consider one or two dimensions, the pair environmental-economic being the most common (present in 13 % of the sample). A small share of articles (7 %) consisting of four literature reviews and three case studies, do not clearly consider any of these dimensions.

Examining the distribution of the sustainability dimensions by thematic cluster yields that the economic dimension is the most considered in half of the clusters, being present in 88 %, 94 %, and 84 % of the articles associated with the clusters (vi) Emerging business models, (iv) Logistic infrastructures & schemes, and (v) Operational optimization, respectively, adding evidence for the importance of financial viability when proposing a novel system; when evaluating infrastructures like the UCC; or when calculating the cost savings returned by a routing optimization model for instance. The environmental dimension leads in the clusters (i) Supply chain & channels (70 %), and (iii) Innovative vehicles (80 %), as comparing the pollutant emissions of traditional models (e.g., brick-and-mortar, combustion vehicles) against emerging alternatives (e.g., omnichannel, electric vehicles) is a popular way adopted by scholars. Lastly, the social dimension is the most considered in the cluster (ii) Delivery methods & attributes (81 %), mainly because there is a big focus on the consumers' acceptability and preferences towards methods like parcel lockers.

2.5 Chapter summary

This chapter provided a systematic literature review of 102 articles regarding sustainable urban last-mile logistics. The findings demonstrate that the research field is characterized by its multidisciplinary nature, as there is an increasing number of published studies conducted under perspectives that range from Environmental Sciences & Ecology to Transportation. This is further evidenced by the six thematic clusters identified, that encompass a multitude of concepts and solutions from very different perspectives, and by the different methodologies followed.

These findings will support the development of the entire dissertation, as described in the subsequent chapters. Moreover, this chapter can be individualized and should be considered a result of this dissertation in itself, as it provides a holistic and wide overview of this fragmented research area, thus being a good reference for academics and practitioners.

Chapter 3

Methodology

The methodology is a vital part of any study as it lays the entire foundations for the study's development and therefore requires special attention in order to accomplish the objectives. This work followed a three-part methodology.

Firstly, the last chapter's extensive systematic literature review provided a holistic and comprehensive characterization of the research field. This literature search was then expanded, allowing the definition of the hierarchical model that structures last-mile operations in historic centers – a shockingly low addressed theme in the literature. The model was later evaluated and revised according to insights gathered from interviews with experts. Lastly, the revised model was quantified by the experts via questionnaire, allowing the application of the MCDM approach that suggested the prioritization of the criteria and the solutions.

The research is schematized on the flowchart in Figure 3.1, and the rationale behind its design is detailed in this chapter. Therefore, this chapter describes every stage from the adopted research philosophy to which techniques and procedures were used; characterizes the data collection process, justifying the selected tools, the participants, and the interview components; details the data analysis process; and assesses the research quality and ethics.

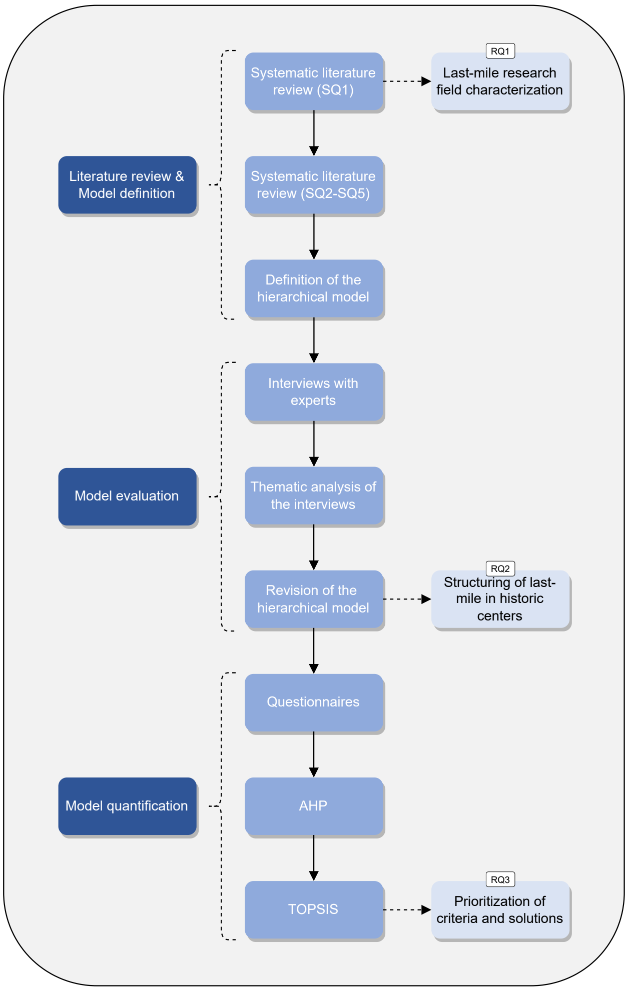


Figure 3.1: Methodology flowchart.

3.1 Research design

The research design follows the structure of the Research Onion framework proposed by Saunders et al. [131]. This framework, presented in Figure A.1, provides practical guidelines through which an effective research methodology can be designed. The Research Onion consists of six main layers, where each one describes a stage of the research process. These layers are: (i) Research philosophy; (ii) Approach to theory development; (iii) Methodological choice; (iv) Strategy; (v) Time horizon; and (vi) Techniques and procedures. Each layer will be discussed in particular in the following subsections, describing the methodological options followed in this work. Part of the theoretical background behind these options is listed in Appendix A.

3.1.1 Research philosophy

The outermost layer of the framework – Research philosophy – refers to the system of beliefs and assumptions about the development of knowledge [131].

The philosophical approach followed was that of critical realism. Essentially, it means that the researcher sees reality as stratified, external and independent, and rooted in objective structures and causal mechanisms; knowledge is historically situated and facts are social constructions; and the researcher is as objective as possible and tries to minimize bias and errors caused by personal views or experiences.

This research philosophy reflects the views the researcher has on the world, thus influences the entire study [131]. Moreover, defining a research philosophy like critical realism contributes to a research's credibility, because it helps maintain constant the various assumptions that an author will make, consciously or unconsciously, throughout a research [131].

3.1.2 Approach to theory development

The research philosophy influences how theory will be framed within the development of a research. According to Saunders et al. [131], a research project will be designed to test theory or to develop theory.

In this context, this dissertation followed an abductive approach. Saunders et al. [131], referring to the use of data in an abductive approach, state that "data collection is used to explore a phenomenon, identify themes and patterns, locate these in a conceptual framework and test this through subsequent data collection and so forth", which perfectly describes the development of this work, as the literature reviews supported the formulation of the model, that was later evaluated, revised and quantified through subsequent data collection.

3.1.3 Methodological choice

A research usually revolves around the use of quantitative and/or qualitative research methods. This use will further define the research purpose.

The model's initial formulation in this work derived from a qualitative literature review; the experts' opinions regarding the model and last-mile operations in historic centers resulted from the qualitative method of semi-structured interviews; and the quantification of the criteria and ranking of the alternatives has more quantitative attributes. Therefore, mixed methods were used. This classification is further supported by Saunders et al. [131] that consider critical realism one of two philosophical positions that are often associated with this approach. Moreover, this work falls under the sequential exploratory research design (qualitative followed by quantitative).

3.1.4 Strategy

The research strategy is based on the selection of the methods used for collecting primary data. The present study combined two different research strategies. The interviews were based on a case study that was later detailed and specified in order to establish a set of common settings for the studied context. The survey strategy was also employed in the form of a questionnaire for the quantification of the model, according to the detailed case study.

For the sake of clarity, the hierarchical model and the interviews considered a general case study, whereas its quantification (with the questionnaire) considered the attributes of a particular (real-life) case study.

3.1.5 Time horizon

The time horizon selected for this research's purposes is cross-sectional because the objective of this research was to capture the perspectives of the participants in a critical time like this, where e-commerce popularity is increasing but supply chains worldwide are suffering debilitating disruptions caused by the echos of the COVID-19 pandemic, the vile war in Ukraine, and the consequent energetic crisis. In specific, the interviews and the collection of data for the multi-criteria analysis lasted one month (between 06/09/2022 and 09/10/2022).

3.1.6 Data collection techniques and procedures

The innermost layer of the framework followed relates to the used techniques for data collection and data analysis.

A relevant aspect in this context is the participants' selection. Because this research is heavily dependent on qualitative insights, selecting the right participants that will contribute to it is particularly important. Accordingly, this work is based on a purposive heterogeneous non-probability sampling approach, as the selection of the sample was based on the researcher's judgment of which participants would contribute the most to meet the research objectives, and because the goal was to define a sample in such a way that it reflects a multitude of perspectives.

Ideally, a researcher would collect data from the entire population of stakeholders, actors, experts, etc., in the diverse sectors related to the studied topic. However, Saunders et al. [131] affirm that this approach would not necessarily provide better results, thus advocating the use of a sample. In fact, many researchers argue that using sampling mechanisms may lead to higher overall accuracy, as the smaller number of studied cases means more time for the design of the data collection process, more time for the data analysis stage, and the collection of more detailed data [131].

Defining the sample size is equally important. For a purposive heterogeneous non-probability sampling, the definition of this parameter is ambiguous and unregulated, therefore dependent on the research questions and objectives [131]. In fact, the quality and validity of the research will be more dependent on the data collection and analysis stages than on the size of the sample [132]. Although there are no rules for the sample size, a recommended approach to address this issue is to continue to collect qualitative data until data saturation is reached i.e., until the additional data collected contributes very little to the research. However, this approach is very impractical and problematic as some researches need to define the number of participants at the design stage [133].

Some authors provide guidance regarding the sample size, suggesting samples ranging between 1 and 60 interviewees [134]. However, most suggestions were not justified by any evidence, leading Saunders & Townsend [134] to conclude that the sample size for qualitative data collection processes ultimately depends upon factors like the research purpose or the researcher's philosophical positions.

Regarding surveys and questionnaires, Saunders et al. [131] state that they are associated with large samples. However, this is not reflective of sample sizes for MCDM approaches. The major advantage of these approaches is that they do not require large sample sizes, in fact, a single qualified expert can lead to representative and robust results according to Saaty & Özdemir [135].

Accordingly, the sample size for the interviews and the questionnaires was composed of nine participants. This sample size proved efficient as the topics started to be repeated in the latter interviews, suggesting data saturation was reached.

The selected participants are all knowledgeable individuals actively involved in last-mile logistics and associated topics. These experts are academic researchers, industry managers, logistics consultants, and higher education teachers, with an average experience of 11 years in different fields of interest. Moreover, the sample comprises different genders and ages, as well as participants living in different cities and continents. This heterogeneity is reflected in a multitude of perspectives, particularly important in assessing the evaluation and generalization of the model.

Table 3.1 characterizes each participant in terms of the used alias, the research area or specialty, and the participant's experience in that area. The data regarding the research area and the experience were provided by the participants themselves. The names of the participants and any other information that could identify them were omitted to preserve the agreed promise of confidentiality.

Table 3.1: Participants' characterization.

Alias	**Expertise**	**Experience**
E1	Mobility; Road traffic	9 years
E2	Transports; Mobility	23 years
E3	Transports; Logistics	5 years
E4	Urban logistics	4 years
E5	Mobility	5 years
E6	Last-mile transports; sustainability	10 years
E7	E-commerce logistics	3 years
E8	Transports; Mobility; Logistics	25 years
E9	Logistics, Supply chain	17 years

This research considered three different data collection methods that allowed the development, evaluation and quantification of the hierarchical model: (A) the secondary data sourced from systematic literature reviews allowed the development of the initial hierarchical model; (B) semi-structured interviews resulted in the qualitative primary data regarding experts' evaluation of last-mile in historic centers and the hierarchical model; and (C) web-questionnaires provided the quantitative primary data related to the model's quantification.

(A) Systematic literature reviews

The first methods used were systematic literature reviews. The extensive and holistic review reflected in Chapter 2 was the main contribution, by providing the necessary contextualization of the last-mile, highlighting the drivers and challenges, and identifying possible goals, criteria and solutions to be considered for the model. The exact process for this (main) review is detailed in Section 2.1.

According to Saaty & Kearns [136], seeing examples of models can aid the structuring of the hierarchy. To this end, considering the fact that the main literature sample had a very limited share of articles based on multi-criteria analyses, four additional, more incisive literature reviews were conducted. In these, part of the methodology was kept unaltered from the one presented in Section 2.1, therefore articles published before 2016; not written in English; not open access; and categorized with irrelevant Research Areas such as General Internal Medicine or Remote Sensing were also excluded from these four additional reviews conducted in July 2022. The search queries for these additional SLRs were:

- **SQ2:** ALL=((“MCDM” OR “MCDA”[1] OR “Multiple-criteria” OR “Multi-criteria”) AND (“last-mile”) AND (“historic*”));
- **SQ3:** ALL=((“last-mile”) AND (“historic*”));
- **SQ4:** ALL=((“MCDM” OR “MCDA” OR “Multiple-criteria” OR “Multi-criteria”) AND (“last-mile”));
- **SQ5:** ALL=((“MCDM” OR “MCDA” OR “Multiple-criteria” OR “Multi-criteria”) AND (“historic*”)).

How the results of these searches helped structure the model will be presented in the following Chapter 4.

(B) Semi-structured interviews

The model's evaluation relied on primary qualitative data collected from semi-structured interviews. As the research purpose of this work is exploratory, these

[1] Multiple-Criteria Decision Analysis (MCDA).

interviews are a good way to collect the required data, as it allows the researcher to further probe a participant's response or to build on their previous responses [131].

According to Saunders et al. [131], semi-structured interviews can be conducted under different approaches that range from face-to-face to focus groups. Face-to-face semi-structured interviews were conducted as there is a natural complexity in finding a common schedule for multiple participants, as in a focus group.

To conduct the interviews, the first step was inviting the participants via e-mail (an example of the invitation can be seen in Appendix B). Before each invitation was sent, most participants' availability and interest in contributing were probed. They were also given a short contextualization of the study before the actual invitation.

The participants were then engaged in conversations to schedule the interview. During these e-mail conversations, and prior to every interview, each participant received a document that clearly identified the academic context and the objectives, and characterized the phases of the participant's contribution. This document also contained the informed consent aimed at confirming the participant's collaboration in the research, listing the full information regarding the participation rights and use of data, namely regarding the comprehension of the study's objectives and mechanics, voluntary character, and data recording and analysis (Appendix C).

Due to the unresolved COVID-19 situation, technical simplicity and because it allowed a wider diversity of participants, every interview was conducted remotely via Zoom (in the interviewer's Zoom room). A presentation describing the aspects covered in the interview was shown to the participants during the interview.

The semi-structured interviews were planned with an interview guide that drove the entire interview. Ultimately, the interview guide is an auxiliary tool that assists the interviewer in collecting the desired data. Although it lists questions in a particular order, it differs significantly from a questionnaire, as not every question on it needs to be asked, new questions can be added to it during the interview, and the order of them can be changed. Therefore, the interview guide was simple and flexible in order to adapt to the interview context and the interviewees.

The developed interview guide (Appendix D) is composed of two main sections. The first section highlights the research objectives of the dissertation and the expected outcomes of the interview. This section helped to identify when the discussion was directed to other superfluous themes. Accordingly, the goals of each interview relied on the collection of expert insights regarding the hierarchical model proposed and the last-mile operations in historic centers. The expected outcomes were the evaluation of the model, with the eventual suggestion of improvements or corrections. Due to the nature of interviews and the studied topic, it was also expected to gather expert insights that further deepen the knowledge about the last-mile operations, specifically in historic centers.

The second section lists what was said to the participant at the start of the interview, as well as the planned questions. The interviewer started by thanking the participant for accepting the invitation, and by reminding the participant that the interview is being recorded exclusively for research purposes and that all the confidentiality and security precepts will be assured, according to the informed consent. Furthermore, the academic context of the research, the main objectives of the research, and the importance of the participant's contribution were described:

- Remind the participant about the consent for recording, transcription, analysis and reporting of findings;
- State that confidentially will be assured, the recording is only for research purposes and will be deleted after it;
- Present the academic context of the research;
- Present the research objectives and the research procedure;
- Justify the importance of the participant's contribution.

Recording the interviews allowed the interviewer to concentrate on listening to the participants; allowed the use of direct quotes; and helped the data analysis. The recordings were made using specialized software – Audacity – on the interviewer's laptop. Moreover, as a backup plan in case this method failed, the audio of the interviews was simultaneously recorded using the built-in app of the interviewer's smartphone. The combination of appropriate software and hardware provided a superior quality that aided the transcription process described in following paragraphs. Along with the recording, notes were taken during the interviews. Both the recording and the note-taking help to control bias and produce reliable data [131].

Following the suggestion of Saunders et al. [131], asking open-ended questions can encourage the participant to provide an extensive and developmental response, and to reply as they wish. Therefore, the only planned questions were:

- What do you think about this hierarchical model?
- Is there something you would like to mention regarding the last-mile operations in historic centers in general?

The first question was intended to be about the model in particular, thus answering RQ2. As expected, the participants also provided general insights about the topic i.e., not about the model in particular. Nevertheless, the second question was always asked in order to detect unexplored topics or to incentive these comments.

Although unplanned, other probing and follow-up questions were also present in the interviews. These questions increased the participant's engagement in the conversation, resulting in more detailed and complete answers, thus contributing to further explore the studied topic. For example, among those unplanned questions, there were questions about the generalizability of the model to different cities and countries, or questions to clarify some of the participant's answers. Moreover, the participants frequently asked questions, for instance, about the literature review methodology or the assumptions made for a particular sub-criterion.

The last component of the guide refers to the conclusion. Accordingly, the interview's closing questions were aimed at collecting suggestions for the study development, and a series of formal questions. A summary question was also posed when necessary:

- Is there something you would like to suggest for the study development?
- [After listing the key points] Is this an adequate summary?
- How would you like to be represented in the work in terms of position, specialty, and years of experience?
- Would you like to receive a copy of the concluded work?
- Remind the participants of the following stages of their contribution.

Each interview ended by thanking the participant's contributions.

After each interview, the recordings and notes were cataloged. The recordings were then transcribed into text, compared to the notes taken during the interviews, critically analyzed following adequate guidelines, and some extracts were translated to English in order to be reported in this dissertation. The files for the recordings and transcriptions were stored in a password-protected flash-drive and deleted after the entire research was concluded.

Table 3.2 lists the interview length and the interview date of each. The average interview length was 30 min 19 s, slightly above the stipulated 30 minutes.

Table 3.2: Interviews' characterization.

Alias	**Interview date**	**Interview length**
E1	06-09-2022	37 min 05 s
E2	06-09-2022	26 min 16 s
E3	06-09-2022	28 min 42 s
E4	07-09-2022	29 min 44 s
E5	09-09-2022	37 min 38 s
E6	09-09-2022	25 min 42 s
E7	09-09-2022	19 min 17 s
E8	12-09-2022	29 min 57 s
E9	13-09-2022	38 min 33 s

(C) Questionnaire

With the model evaluated, and in its final form, quantitative data is needed for its quantification. A method to collect quantifiable data is by employing standardized interviews based on a predefined set of identical questions and pre-coded answers. Usually, standardized interviews involve the use of questionnaires, which are better applied when linked with other methods, as is the case of this dissertation [131].

This work used self-completed questionnaires. In particular, using the web-questionnaire variant. This choice was based on the comprehensive benchmarking of different variants present in the work by Saunders et al. [131], which associated the use of web-questionnaires with attributes like the low likelihood of answer contamination or distortion, or high confidence that the right persons have responded.

Questionnaires were also distributed by e-mail to the participants, with the proper contextualization. Within this e-mail invitation, a presentation containing the revised hierarchical model; the criteria definitions; the alternatives and case study assumptions; and a description of the historic center case study, was attached in order to present the participants of the considered premises.

This questionnaire was performed using Google Forms and the provided answers were anonymous. This questionnaire allowed the application of the MCDM component of this dissertation and therefore had two sections: the first section is relative to the AHP, while the second is to the TOPSIS.

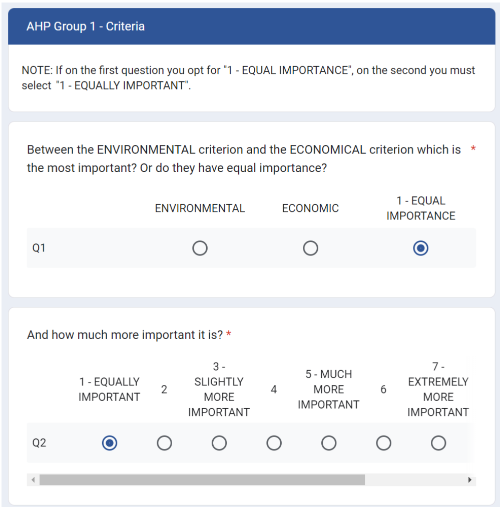
The AHP section is based on 12 pairwise comparisons to evaluate how much more important one element is over another. The scale that the experts used in the AHP section was based on the classic Saaty's verbal/linear 1-9 scale. However, the mathematical operations were conducted using a different scale, because there is no theoretic reason to calculate the AHP method with this linear scale, and because other scales have been proposed in recent papers that aim to solve some deficiencies of the linear scale. One of those scales was proposed by Salo & Hämäläinen [137]. These authors argued that the classic scale is unequally dispersed thus affecting the method's sensitivity, and proposed a balanced, evenly dispersed scale [138, 139]. A summary of the used scales is illustrated in Table 3.3.

Table 3.3: Used scales for the pairwise comparison [140, 137].

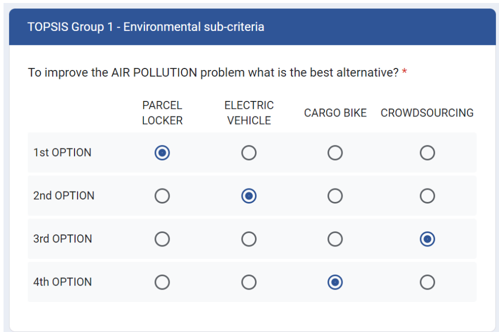
Verbal scale	**Linear scale**	**Balanced scale**
Equally important	1	1
Slightly more important	3	1.50
Much more important	5	2.33
Extremely more important	7	4
Absolutely more important	9	9
Intermediate values	2, 4, 6, 8	1.22, 1.86, 3, 5.67

The TOPSIS section is based on a set of nine rankings, where the participants ranked the alternative according to how well it meets each sub-criterion. In other words, the respondents selected as the first option the most desirable (and as the fourth option the least desirable) alternative according to that sub-criterion, and repeated this process for all sub-criteria. This ranking method is listed by Tague [141] as one of three possible methods to fill a decision matrix – an important part of the TOPSIS method that will be described in the next chapter.

Figure 3.2 presents translated extracts of the AHP-TOPSIS questionnaire, exemplifying how the experts did the pairwise comparisons and the rankings.



(a) Extract of the AHP pairwise comparison.



(b) Extract of the TOPSIS ranking.

Figure 3.2: Extracts of the AHP-TOPSIS questionnaire.

3.1.7 Data analysis techniques and procedures

The collected data from the literature, the interviews and the AHP-TOPSIS questionnaires needed to be prepared in order to be analyzed. This preparation took different forms as explained in the following subsections. In this subsection, the used techniques are presented, while their actual application is described in the next chapter.

(A) Systematic literature reviews

The data analysis of the systematic literature reviews was based on identifying every criterion, indicator and problem mentioned in the reviewed literature, as well as the sustainable last-mile solutions. Then, those most frequently assessed in the literature, that can be compared against others, and are adequate for the historic center, were selected to be part of the hierarchical model.

(B) Transcription, translation and thematic analysis

The data analysis of the interviews began with the transcription of the recordings into textual form. Because transcription is a very time-consuming process, there are different ways to simplify it [131]. Therefore, the audio was first converted into text using the Microsoft Word software and then some transcription errors found in pertinent sections were manually corrected. To assure that the transcriptions were faithful, each transcription was compared to the notes taken during the interview, and to the audio recording of the interview.

To report the findings in this dissertation, translation to English was needed, as the interviews and data analysis were conducted in Portuguese. Translations require additional care to ensure that the data in the original language is reproduced authentically in the translated language and, according to Saunders et al. [131], this process may be problematic, with issues like words or phrases that do not exist in the final language, or idioms or expressions that do not have the same meaning in the final language. Although aware of these potential issues, the author of this dissertation trusts in his ability to translate faithfully and accurately the Portuguese language to the English language. Moreover, online dictionaries were used as an auxiliary tool to further enhance the translation accuracy of some key terms.

In the literature, there are various qualitative analysis techniques such as discourse analysis, grounded theory, or narrative analysis. However, the selected technique was thematic analysis due to its ability to identify, analyze and report themes or patterns present in the data set, or in this case, the interviews. This was also the choice because, contrarily to other techniques, thematic analysis is a systematic and flexible approach to analyzing qualitative data, as it is based on orderly and logical processes, and it is not tied to a particular research philosophy or approach to theory development [131, 142].

Braun & Clarke [142] suggests a structure to conduct thematic analysis based on six steps:

- **Step 1:** Data familiarization;
- **Step 2:** Data coding;
- **Step 3:** Theme searching;
- **Step 4:** Theme review;
- **Step 5:** Theme defining;
- **Step 6:** Reporting.

The first step was concluded in the data preparation process described above, as the transcription and translation processes involved reading, re-reading, and note-taking, thus developing familiarity with the data.

This process also involves coding extracts of data within the interviews' transcripts with a code that reflects or summarizes that extract's meaning. The used codes were developed by the researcher based on the data – one of the three main types according to Saunders et al. [131].

Theme searching is based on collating the codes into potential themes. Consequently, a theme could be defined as a category that incorporates several codes that are related to one another [142, 131].

After defining the themes, it is necessary to review if the themes are well defined, as some themes might not really be themes, or some themes might need to be merged or unmerged [142]. This review is done at two levels, as it is checked if all codes within a theme are related and form a coherent pattern; and it is checked if all themes work in relation to the entire data set. At the end of this phase, a thematic map was generated (Figure 4.2), depicting the different themes and codes, and how they fit together within the data set.

After this review process, the themes were defined and properly named.

The last step of this guideline is producing the report. This should be composed of vivid, compelling extract examples, final analysis of selected extracts, properly framed within the research questions and extant literature. The reporting regarding this data analysis is included in Chapter 4.

(C) MCDM

With the model defined, evaluated and quantified by experts, followed the application of the MCDM methods. MCDM, also known as MCDA, is a branch of operational research that evaluates multiple conflicting criteria in order to help the decision-making. Several MCDM methods have been developed, but all have the same objective: to estimate the best alternative among different options, according to a set of predefined criteria.

In this work, two popular MCDM methods were used: AHP and TOPSIS. These methods have been applied to a myriad of research areas such as economics, environmental sciences, biodiversity, or geography [143]. Moreover, MCDM is quite suitable to assess research fields like construction and infrastructure, supply chain, transport and logistics, or energy, under sustainable perspectives [144]. Zyoud & Fuchs-Hanusch [145] found that research in supply chain management (i.e. supplier evaluation and selection, product design and customer satisfaction) frequently used AHP and TOPSIS, thus adding support to the appropriateness of using AHP and TOPSIS in this work.

AHP was introduced by Thomas L. Saaty in the 1970s, and is based on a hierarchical structure that breaks down a complex problem into simple components, and shows the relationships between the goal, criteria, sub-criteria and alternatives.

AHP uses pairwise comparison questions to construct matrices of judgments of the relative importance of each element.

TOPSIS was developed by Hwang and Yoon in 1981, and it is based on the principle that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest from the negative ideal solution. TOPSIS is a ranking-based method where each alternative is evaluated with respect to each criterion [146].

Because these two methods are reliant on human input, there is a case for imprecision due to the difficulty to assign an exact numerical value to their preferences, even if it comes from very knowledgeable humans. To handle this (potential) imprecision, scholars have adopted variants based on the integration of fuzzy sets within the classical MCDM [147].

Although these fuzzy variants have been widely applied in different research fields, the need for using fuzzy numbers is contested, especially by the creator of the AHP itself and its associates. Saaty [148] argued that in AHP "the numbers assigned to judgments are already fuzzy and making them more fuzzy does not help produce more valid outcomes", further stating that authors use fuzzy variants to give a "mystical" impression to their work. Saaty & Tran [149] demonstrated in several examples the invalidity of fuzzy AHP concluding that "one should never use fuzzy arithmetic on AHP judgment matrices" and that there is no evidence that Fuzzy AHP makes a decision more valid. Although criticism of fuzzy TOPSIS is nonexistent, the fuzzy TOPSIS process is more complex than the non-fuzzy TOPSIS [150].

For these reasons, and for sake of simplicity, comprehensibility and consistency of this dissertation and the MCDM method itself, both the AHP and TOPSIS methods were applied without the fuzzy variant.

This work combines these two methods. The primary reasoning for adopting this hybrid AHP-TOPSIS relies on the fact that, for quantifying the entire model using the single AHP method, it would need 66 pairwise comparisons, thus making it unbearable and not reasonable for the experts to answer.

In the AHP-TOPSIS process, the experts first weigh the criteria and sub-criteria using the AHP method. Then they rank the alternatives according to the sub-criteria with the TOPSIS method. Then, combining the weights derived from AHP with the ranks derived from the TOPSIS indicates the most favorable sustainable last-mile solution. The detailed AHP-TOPSIS process is described in Figure 3.3. Each step will be detailed in the following paragraphs.

The application of the AHP method was based on guidelines described by Saaty & Kearns [136].

After defining the problem and the goal, follows the creation of the hierarchical structure by defining the criteria, the different sub-criteria, and the considered

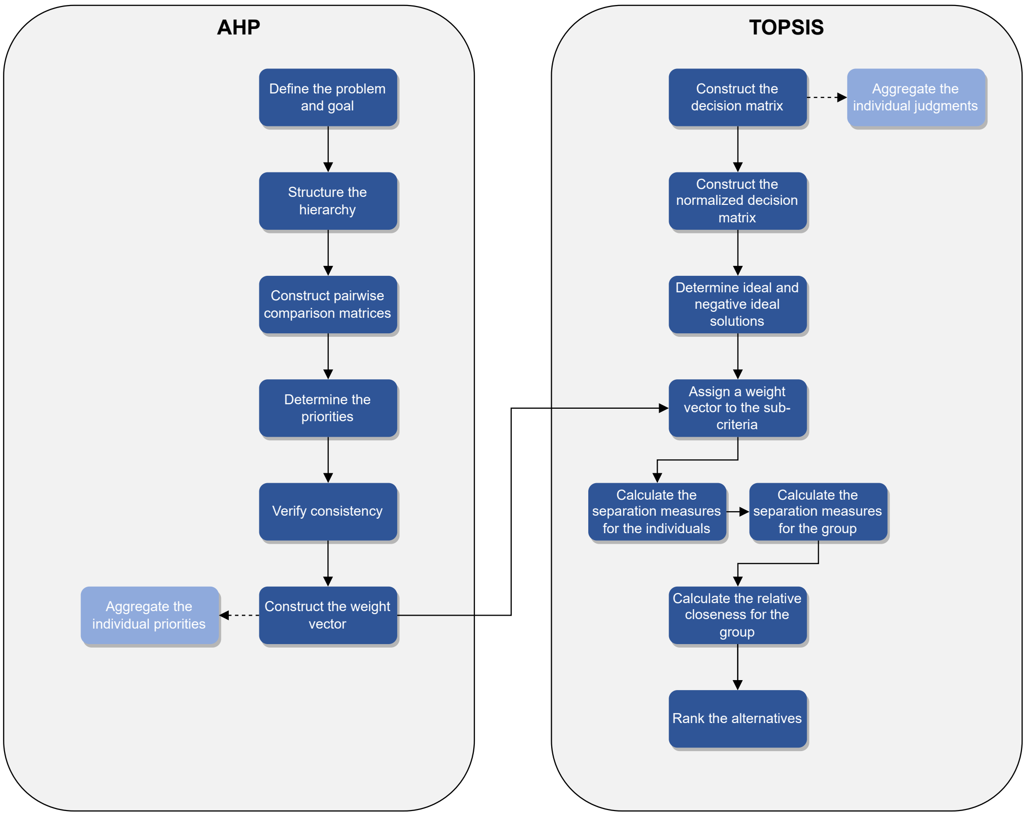


Figure 3.3: AHP-TOPSIS process.

alternatives.

Then, in the third step, the goal is to construct the pairwise comparison matrices (judgment matrices). To this end, a questionnaire was designed and distributed among the participants to collect their answers.

In the next step, follows the mathematical calculations of the AHP method that will return the weights of the criteria and sub-criteria.

Lastly, the validation of these AHP results is evaluated by calculating the Consistency Index CI with Equation 3.1:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3.1}$$

where λ_{max} is the eigenvalue corresponding to the pairwise comparison matrix and n is the number of compared elements.

Then, it is determined the Consistency Ratio CR with Equation 3.2:

$$CR = \frac{CI}{RI} \tag{3.2}$$

Where RI is the Random Index, which is related to the dimension of the matrix and is extracted from Table 3.4.

According to Saaty [140], an acceptable CR should be no higher than 0.10.

Table 3.4: Average RI values [140].

Size of matrix	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

With the weights provided, follows the application of the TOPSIS method that followed the guidelines by Shih et al. [151] that adapted the classic TOPSIS calculation to include multiple inputs of more than one decision-maker.

The first step of TOPSIS is to construct the decision matrix D^k for each decision-maker k ($k = 1, ..., K$). This matrix is composed of elements x_{ij} that represent the rating of each alternative i with respect to each criterion j.

Then, the decision matrix must be normalized i.e., transform the various dimensions into non-dimensional, between 0 and 1. This will result in the matrix R^k where the elements are calculated by applying Equation 3.3:

$$r_{ij}^k = \frac{x_{ij}^k}{\sqrt{\sum_{j=1}^{n} (x_{ij}^k)^2}}, \tag{3.3}$$

where $i = 1, ..., m$; $j = 1, ..., n$; and $k = 1, ..., K$.

Contrarily to the classic TOPSIS process, follows the identification of the (positive) ideal solution (V^{k+}) and negative ideal solutions (V^{k-}) i.e., the best and the worst alternative for each criterion. These solutions are defined according to Equations 3.4 and 3.5:

$$V^{k+} = \{r_1^{k+}, r_2^{k+}, ..., r_n^{k+}\} = \{(\max_i r_{ij}^k | j \in J), (\min_i r_{ij}^k | j \in J')\}, \tag{3.4}$$

$$V^{k-} = \{r_1^{k-}, r_2^{k-}, ..., r_n^{k-}\} = \{(\min_i r_{ij}^k | j \in J), (\max_i r_{ij}^k | j \in J')\}, \tag{3.5}$$

where J is associated with positive criteria, and J' is associated with negative criteria.

In the fourth step, each weight w_j^k of the vector W is attributed to each sub-criteria. These weights are derived from the AHP method. The next step is measuring the separation between each alternative and the positive ideal V^{k+}, and between each alternative and the negative ideal V^{k-}. This separation is measured by the Euclidean distance and given by Equations 3.6 and 3.7:

$$S_i^{k+} = \sqrt{\sum_{j=1}^{n} w_j^k (v_{ij}^k - v_j^{k+})^2} \tag{3.6}$$

$$S_i^{k-} = \sqrt{\sum_{j=1}^{n} w_j^k (v_{ij}^k - v_j^{k-})^2} \tag{3.7}$$

These results for each individual are then aggregated for the group via geometric mean according to Equations 3.8 and 3.9:

$$\overline{S_i^+} = \left(\prod_{k=1}^{K} S_i^{k+} \right)^{\frac{1}{K}} \tag{3.8}$$

$$\overline{S_i^-} = \left(\prod_{k=1}^{K} S_i^{k-} \right)^{\frac{1}{K}} \tag{3.9}$$

The final step of the TOPSIS procedure is determining the relative closeness coefficients of each alternative $\overline{C_i^*}$ to the ideal solution. The result is given by Equation 3.10:

$$\overline{C_i^*} = \frac{\overline{S_i^-}}{(\overline{S_i^+} + \overline{S_i^-})}, \tag{3.10}$$

where $0 \leq \overline{C_i^*} \leq 1$. The larger the value of $\overline{C_i^*}$, the better the performance of the alternative i.

Because there are different experts, aggregation is necessary. Following Saaty's [152] recommendation, because the participants are experts that act according to their own value systems, the aggregation was processed at the end of the AHP-TOPSIS method, thus maintaining the individuality of each expert. Therefore, the AHP-TOPSIS was computed individually and equitably (i.e., all experts have an equal weight) for each expert and then aggregated near the end with the geometric mean, as described in the above TOPSIS process.

However, only aggregating at this point of the AHP-TOPSIS limits important analyses regarding how the expert group prioritizes the criteria and the sub-criteria, and how the expert group prioritizes each alternative according to the sub-criteria. To this end, two parallel calculations to the AHP-TOPSIS were made: one referring to the AHP and one referring to the TOPSIS method.

The most fundamentally accepted procedures to do this aggregation in AHP are: Aggregation of Individual Judgments (AIJ) and Aggregation of Individual Priorities (AIP). In AIJ, the group of experts acts as a synergistic unit, while in AIP, the group of experts acts as a collection of experts [153]. This means that in AIJ the aggregation is done before AHP, whereas in AIP is done after. Like before, Saaty's [152] recommendation was followed and the chosen procedure was AIP. Therefore, the AHP was computed individually for each expert and then the resulting priorities were aggregated using the geometric mean – the uniquely appropriate way to do this aggregation [154]. Again, no distinction was made among the experts.

The aggregation in TOPSIS was made at the judgment level, therefore based on the principles of AIJ. In practical terms, the decision matrices of the experts were aggregated with the geometric mean and then normalized using Equation 3.3. Again, without expert's distinction.

The calculations behind AHP and TOPSIS can be simplified by utilizing adequate software. To this end, a Microsoft Excel document was developed for calculating the methods. The application of this hybrid MCDM approach will be detailed in the next chapter.

3.2 Research quality

Reliability and validity are the two classic criteria for establishing and assessing the quality of a research. Reliability refers to replication and consistency, as if a researcher is able to replicate an earlier research design and achieve the same findings, then that research would be seen as being reliable. Validity refers to the appropriateness of the measures used, the accuracy of the analysis of the results and the generalizability of the findings.

Both can be internal or external. Internal reliability refers to ensuring consistency during the research process, while external reliability refers to whether the data collection and analysis techniques would produce consistent findings if replicated by another researcher. Internal validity refers to the extent to which the results derive from the research subject rather than from methodological errors, while external validity refers to the generalizability of the findings to other contexts [131].

The questionnaire was only composed of the questions needed for the AHP-TOPSIS method. Therefore, the quality of the quantitative part of this research is intrinsically related to these MCDM methods.

AHP is based on pairwise comparisons. These make redundancy possible, that in turn improves the validity of the method. However, increased redundancy increases the inconsistency and therefore the unreliability of the process [155]. This redundancy happens in paired comparisons because when a judgment is made, a reciprocal judgment is also automatically made. To better illustrate this, consider an example where A is three times more important than B, and B is also three times more important than C. Logically, A must be nine times more important than C. However, even if the experts are highly qualified, due to human nature, this logical relationship does not always happen and therefore causes inconsistency. Common causes for this inconsistency are clerical errors, lack of concentration or inadequate model structure [156].

In fact, this inconsistency is exacerbated as the number of elements of the model increases, due to the human capacity for processing information [157, 155, 158]. This correlation between inconsistency, the number of elements, and the human capacity for processing information is evidenced by the developer of AHP – Thomas L. Saaty – and Özdemir in [157] as they proved the findings of cognitive psychologist George

A. Miller, who conjectured that the number of objects an average human can hold in short-term memory is seven plus or minus two. This limit was considered in the model definition, thus improving the consistency of the method.

Moreover, this referred consistency is included in the steps of the AHP method in the form of a CR. All judgment matrices where CR is higher than 0.10 should, theoretically, be revised or excluded from any calculation. Only two out of the 36 matrices (9 experts x 4 matrices) exceeded this threshold. However, these inputs were considered. The reasons for this decision are five-fold: (i) the respective CRs were only slightly above the stated limit (0.1016 and 0.1912); (ii) revision was discarded as asking the experts to revise their inputs was unfeasible; (iii) removing these theoretically inconsistent matrices would also imply the removal of the other six theoretically consistent matrices that these experts provided, thus significantly altering the overall results; (iv) excluding these inputs would lower the number of considered judgments, and consequently, the informative value of this research would be more limited; (v) Saaty & Kearns [136] state that CR up to 0.2 may be tolerated. On an additional note, the average CR for all experts and for all judgment matrices was 0.0207, therefore the consistency of the results is assured.

The external reliability of the quantitative methods, referring to the replication of the results, is assured in the present research by following well-regarded guidelines and steps for the application of the AHP and TOPSIS methods. In this case, the guidelines followed were based on the ones proposed by the methods' authors themselves. Internal reliability and validity are assured in this research by taking into consideration the principles described above, in specific, by using two respected MCDMs; by establishing a model with less than seven elements in each group; and by maintaining the CR low. These actions endow the model with replicability, consistency and accuracy.

The hierarchical model is not based on a particular real-life historic center, thus every conclusion derived from the interviews can (potentially) be generalized to other historic centers in various cities and countries. It is also believed that it can still be of interest in other urban contexts that are not historic centers. Nevertheless, the following quantification of the model was based on a specific case study of a real-life historic center as described later, thus the quantification's results could be perceived as limited or specific. However, the derived results of this quantification are believed to be valid for a wide number of cities with similar properties.

Measuring the quality of the qualitative parts of this research by assessing the concepts of validity and reliability, might be technically inappropriate. Therefore, it is difficult for researchers to justify that their research is of high quality and credibility [131]. According to Saunders et al. [131], there are different approaches to deal with this issue: adapting the concepts of reliability and validity to qualitative studies, or using alternative criteria.

The second approach is the one reflected in this research, by following the guideline proposed by Lincoln & Guba [159]. In this guideline, dependability is the parallel version of reliability, credibility is the parallel version of internal validity, and transferability is the parallel version of external validity. Lincoln & Guba [159] also add confirmability, related to the objectivity of the research.

Each criterion can be achieved by employing different techniques. The dependability and confirmability of the qualitative part of this research are achieved by presenting an audit trail, or in other words, a transparent, detailed and justified description of every research stage, so that the study could be externally reviewed and replicated (even if qualitative researches are not necessarily intended to be replicated) [159, 131].

According to Lincoln & Guba [159], triangulation is one of the means to achieve the credibility criteria. These authors define triangulation as "cross-checking of data and interpretations through the use of multiple data sources and/or data collection techniques" which accurately reflects this dissertation's methodology design, as data was triangulated between academic literature, semi-structured interviews and the AHP-TOPSIS method based on experts' insights. Lincoln & Guba [159] also mention a technique named member checks where the findings and interpretation are referred back to the data sources for correction or verification. Although with a different outline, the commitment to send the concluded dissertation to the experts (i.e., the data sources) can be representative of the level of credibility of this research.

Transferability is achieved through a technique called thick description that is based on the description of not just the perceptions and comments of the participants, but also the participants themselves and their context, thus justifying the relevance of adopting a purposive sampling [159, 160, 131]. As mentioned earlier, although it might be inappropriate to claim total generalization of the findings of this research, it is believed that the findings and the processes to obtain them can be transferred to other contexts of similar nature.

3.3 Research ethics

Research ethics concerns the researcher's behavior towards the study's development. In this context, Saunders et al. [131] list various ethical principles that have been developed to recognize ethical issues. Among these, there are principles about the integrity, fairness and open-mindedness of the researcher; principles about not harming the research participants; or principles about the privacy, consent, and confidentiality of their participation.

These principles were integral to the development of the dissertation and, although the researcher strove to maintain a fair, unbiased, open-minded, and truthful approach throughout the entire project, the ethical principles became more prominent in the data collection stage.

The invitations to contribute to this research were sent to the participants via academic e-mail. Alongside each invitation, a document that described the context of the research and contained the informed consent listing the full information regarding the participation rights and use of data was also sent to the participants.

Aware of the potential negative consequences that participating in a research may have for the participants, at the start of each interview, the interviewees were reminded of the premises declared on the informed consent, thus giving the interviewee the possibility of changing some of these premises. Moreover, the participants were given the option to choose how to be represented in this dissertation in terms of specialty area and years of experience. Nevertheless, because this data is listed in this dissertation; because the explanation behind the participants' selection is also present in this dissertation; and because the responses given by the participants are very likely based on their personal experiences, expertise and perceptions, there is a chance that some of the participants' identities could be revealed, thus affecting the anonymity premise. To this end, this research only used personal characteristics and other identifiable attributes that are strictly relevant to its purpose.

The fact that the interviews were recorded and then transcribed, contributed to the careful and rigorous analyses and interpretations that followed, thus improving the accuracy of the research. This also contributed to the not alteration or falsification of the data that the participants provided, including the data related to the participants themselves (e.g., years of experience).

Moreover, all participants collaborated voluntarily, and had legitimate rights to not answer any question(s); to alter the nature of their consent (including the consent to recording the interview); and to withdraw themselves and the data they have provided from the research.

All participants agreed to the offer to be sent the concluded dissertation. This was suggested for a few reasons. Firstly, the participant could attest if their contribution is accurately reported in the dissertation. Secondly, the participant could also verify that the premises agreed upon, namely the promise of confidentiality and the personal data (e.g., years of experience), were assured. Lastly, due to the urgency and importance of the themes discussed in this dissertation, as well as the belief that this dissertation can provide interesting insights about the topic, suggesting sending the concluded work to the participants was also done with the goal of raising awareness and motivate future research among those who are actively involved in the affected sectors.

3.4 Chapter summary

This chapter was devoted to detailing and justifying the adopted research methodology and was mainly based on the structure of the Research Onion and other guidelines proposed by Saunders et al. [131]. The present research followed a critical realism philosophy and was conducted under an abductive approach. It classifies as a mixed methods sequential exploratory research design, based on a case study and survey strategy, and a cross-sectional time frame.

The hierarchical model is derived from the systematic literature review, the evaluation of this model is a result of several semi-structured interviews, and the quantification of the model is derived from web-questionnaires self-completed by experts. The nine experts were the result of a purposive heterogeneous non-probability sampling approach. The interviews were arranged through e-mail and conducted remotely via Zoom. They were recorded with informed consent, and the transcriptions of these recordings were the basis for the data analysis. The questionnaires were deployed using Google Forms. The model was ultimately evaluated by applying a combined AHP-TOPSIS approach.

The research quality was assessed in terms of validity and reliability, and dependability, credibility, transferability, and confirmability, and the research ethics, discussing the principles like the open-mindedness of the researcher or the confidentiality of the participants.

Chapter 4

The hierarchical model

Although the reviewed literature addresses a myriad of themes, there is a lack of attention given to last-mile operations in different sectors within a city. These operations have different exigencies according to the city's sectors. Considering the various sectors, the historic centers stood out as the most critical to be examined.

To this end, a model was developed aimed at structuring last-mile operations in historic centers. This model was later evaluated and quantified by experts, and could be a unique tool for aiding the decision-making process by pointing out which criteria should be prioritized and which sustainable delivery schemes are better suitable within a historic center context.

This fourth chapter is devoted to the definition of the hierarchical model, and its consequent evaluation and quantification based on the experts' inputs.

4.1 Model definition

The first steps in the MCDM approach are the definition of the problem and goal, followed by the definition of the remaining hierarchical structure from the criteria to the alternatives. Note that the model and assumptions defined and detailed in the following paragraphs refer to the final model i.e., the model after being revised according to the experts' comments.

4.1.1 Problem and goal

In recent years, the concept of sustainable development has become increasingly more discussed among institutions and society. However, adopting a complete three-dimensional approach is particularly complex due to the multiple stakeholders and respective competing interests. Because the world is becoming increasingly urbanized, the sustainable development of cities is undoubtedly crucial, being considered one of the 17 Sustainable Development Goals listed by the United Nations [161].

A very sensitive sector within a city is the historic center, with the conservation of its historic heritage being an indispensable factor for sustainable development. To this end, there is a need for ensuring a balanced approach that integrates the conservation of the tangible and intangible components of the urban heritage, and the environmental, economic and social development of the city.

Consequently, activities such as the last-mile operations, which are already highly stressed and ineffective, become even more complex within the context of a historic center where problems like visual pollution, noise nuisance or damage to historical landmarks affect factors like the population's well-being or the economic returns of tourism.

Although various last-mile solutions that promise to alleviate these problems have been discussed in recent years, selecting the most advantageous has proven to be difficult due to conflicting criteria and because each solution carries disadvantages or restrictions.

In this context, the studied problem is selecting a sustainable distribution solution for last-mile operations within a historic context. In specific, the goal of the hierarchical model is the "Selection of a last-mile solution for historic centers".

4.1.2 Criteria

The design of the model was conducted based on the results listed in Chapter 2. Every indicator, factor, criterion, etc. present in this literature review was identified and counted. It should be noted, that the vast majority of these were not sourced from MCDM-based studies, as only four articles [68, 84, 121, 88] in the sample followed this approach.

Kijewska et al. [68] used AHP and Decision Making Trial and Evaluation Laboratory (DEMATEL) to evaluate distribution measures in Szczecin, Poland. Serrano-Hernandez et al. [84] used AHP to evaluate routes and transportation modes (van, tricycle, drone) in Pamplona, Spain. Rzesny-Cieplinska & Szmelter-Jarosz [121] used AHP to evaluate crowdsourcing logistics solutions. de Carvalho et al. [88] used AHP to evaluate UCC's locations in historical cities in Ouro Preto, Brazil. In fact, this is the only publication in the 102 articles sample that focuses primarily on historical cities.

Due to this very limited share of articles, four additional, more incisive literature reviews were conducted (SQ2, SQ3, SQ4, and SQ5). The first additional search query (SQ2) aimed at articles focusing on last-mile in historic centers using a MCDM approach, did not return any result. Therefore, the search query was divided into three. The second additional search query (SQ3), aimed at articles regarding last-mile in historic centers, resulted in 12 articles that, although all discuss the topics of last-mile, urban logistics and supply chains, most of the articles do not verse about historical cities, being included because the clause "historic*" in the search query referred to terms like "historical data", "historical information" or "historical delivery data". Moreover, those that superficially approach the target topic (≤ 10 "last-mile" or "last mile" hits per paper) were also excluded. Thus only two articles [162, 163] discuss last-mile operations in historic centers.

González-Varona et al. [162] proposed using the available newspaper kiosks in the historic district of the city of Valladolid, Spain as parcel lockers. The authors used simulations and comparisons. Urzúa-Morales et al. [163] proposed a new distribution system in the historical center of Santiago, Chile. The authors used optimization models for facility location selection and vehicle routing, and AHP for the selection of the most suitable vehicle (bicycle, electric vehicle, tricycle, small diesel vehicle, electric bicycle).

The third additional search query (SQ4), aimed at studies focusing on last-mile using a MCDM approach, returned 21 articles, that after excluding those that approached superficially the target topic; those that do not use a MCDM; or those that were repeated, 12 articles ([164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175]) that assess the last-mile topic and use a MCDM approach remained. The main conclusions drawn from reviewing these 12 articles were: (i) the researches' purposes are focused on evaluating/selecting a last-mile delivery company; a single or a combination of last-mile solutions from a set of different types of solutions (e.g., small truck, motorcycle, locker, drone, multi-modal); or a single last-mile solution from a set of the same type of solutions (e.g., four delivery drones); (ii) AHP and TOPSIS are the two most popular MCDM methods, but no article used AHP-TOPSIS; (iii) some studies focus on last-mile under a MCDM approach conducted in different countries (e.g., Vietnam, Brazil, Serbia, Germany).

The last additional search query (SQ5), aimed at papers focusing on historic centers using a MCDM approach, yielded 143 results that cover a wide spectrum of topics. Expectedly, no articles discuss the problem of urban logistics or last-mile operations in historic centers, but rather the problems related to the conservation, restoration or reuse of specific historical buildings such as religious spaces, pedestrian bridges, fortresses, or hospitals. Therefore, even if some criteria listed in these articles could be adapted to the research purpose, the results of the SQ5 were not considered enriching to the research, thus being discarded.

Therefore, the sample of academic literature that supported the model definition is composed of 116 articles (102 from SQ1; 2 from SQ3; 12 from SQ4). These literature searches not only provided a reference for the criteria selection but also pointed out the importance of the present dissertation in assessing this gap, as only three articles addressed the topic of last-mile in historic centers.

Besides the academic literature, another important reference was the World Heritage Committee administered by United Nations Educational, Scientific and Cultural Organization (UNESCO), in particular the initiative called Historic Urban Landscape [176, 177]. This initiative focuses on the need to frame urban heritage conservation strategies within the larger goals of sustainable development such as enhancing the livability of urban areas, and fostering economic development and social cohesion in an increasingly dynamic environment, hence is rooted in the classic sustainability principle of assuring the needs of the present and future generations. Therefore, this initiative seeks to increase the sustainability of these locations by not only taking into consideration the tangible and intangible components of the past urban heritage, but also the present and future social, economic, and environmental factors [176, 177].

Because of this definition by the UNESCO's initiative; because it is a common approach according to the literature; and because it maintains a cohesive approach throughout the entirety of this dissertation, the second level of the model is based on the "triple bottom line of sustainability", thus being composed of three criteria: Environmental, Economic, and Social.

It should be noted that various articles reviewed included a fourth dimension called Operational or Technical. Considering the close link between economic saving/profits and operational/technical effectiveness, the hierarchical model merged these two dimensions.

4.1.3 Sub-criteria

Each criterion includes three sub-criteria defined by taking into consideration the extensive literature reviews conducted. Note that, as previously discussed in Subsection 3.2, this number of sub-criteria follows the guidelines based on the human cognitive limitations proved by Saaty & Özdemir [157].

The most common criteria found in the analyzed literature were related to air pollution and climate change (e.g., "GHG emissions", "CO_2 emissions", and "PM emissions"), operational costs (e.g., "Delivery cost", "Handling costs", "Maintenance costs"), and operational speed (e.g., "Delivery speed"; "Lead time"; "Delivery time"). Other frequent criteria were related to congestion, noise, safety and security, failed deliveries, load capacity, operational distance, fleet size, acceptance, and investment costs.

Some of these made it to the hierarchical model, while others did not. The reasoning behind the sub-criteria selection was based on four principles:

- **i)** The sub-criterion is appropriate to all considered last-mile alternatives;
- **ii)** The sub-criterion is relevant to the context of historic centers;
- **iii)** The sub-criterion is comparable to the other sub-criteria;
- **iv)** The sub-criterion appears frequently in the reviewed literature.

Therefore, the Environmental criteria (C1) comprise Air pollution (SC1), Noise pollution (SC2), and Visual pollution (SC3); the Economic criteria (C2) comprise Operational costs (SC4), Load capacity (SC5), and Delivery speed (SC6); and the Social criteria (C3) comprise Congestion (SC7), Safety & security (SC8), and Acceptance (SC9).

A case could be made that some of the "discarded" criteria are also indirectly contemplated in the model. For instance, distance is closely related to the delivery speed and the operational costs, and fleet size is very dependent on the load capacity.

Air pollution is the contamination of the environment by any chemical, physical or biological agent that induces detrimental modification of the natural characteristics of the atmosphere [178]. Sectors like the industry; energy supply; residential, commercial and institutional energy consumption; and agriculture are all sources of air pollutants in Europe. The road transport sector is also a main source of polluting emissions that deteriorate the air quality, especially by increasing the levels of nitric oxide (NO_X) and PM [179].

Although air quality has considerably improved in past decades, it still continues to damage the environment and ecosystems through excess nitrogen pollution and acid rain. Moreover, air pollution is the number one environmental health problem in the EU, responsible for serious illnesses and premature deaths in Europe each year [178, 179, 180].

Because many of the air pollution sources like the combustion of fossil fuels are also sources of GHG emissions, thus reducing air pollution can benefit both the climate and health, lowering the burden of disease attributable to air pollution, as well as contributing to the mitigation of climate change [178].

Noise pollution is another major environmental problem in modern cities. It is related to the noise caused by industry, construction and transportation. Specifically, road traffic is the most prevalent source of environmental noise in Europe. The negative consequences of noise exposure include threats to wildlife, the productivity of workers, and health problems related to sleep disturbance, cardiovascular diseases, or the general well-being of citizens. In fact, the World Health Organization (WHO) classified traffic noise as the second most important cause of illness in Western Europe [181].

The last considered environmental aspect is Visual pollution, which refers to the distortion of the perception of the urban landscape, affecting the attractiveness of the city. This problem is difficult to assess but particularly important in historic cities. Furthermore, the visual impact is seriously affected by using public space for the infrastructures needed for economic activities such as last-mile delivery. This results in serious consequences for flora and fauna, as it reduces the natural areas [182]. The influx of vehicles operating in the historic center also disrupts residents and tourists.

Operational costs are the charges incurred related to labor salaries, fuel consumption, licenses, maintenance or other charges, while the Load capacity refers to the space available to accommodate the parcel(s). This factor affects the product range, and consequently the economic competitiveness of the delivery alternative. Moreover, a high load capacity can reduce the costs per delivery.

In the present competitive economy, the time between the purchase of an item and the reception of it is a differentiation point, with various companies offering extreme options such as same-day deliveries. The delivery speed has a direct influence on labor exigencies and on fuel consumption, as higher driving speeds lead to higher fuel consumption, therefore smaller profits [183]. However, not offering these "fast delivery" options can be a significant competitive disadvantage, making consumers select other shops. Additionally, higher driving speed of the logistics vehicles results in more potential accidents to citizens and property.

The social aspects are more difficult to evaluate but are crucial to the sustainability of a city. The first aspect considered is traffic congestion which is caused by an excess of vehicles on the road. Traffic congestion adversely impacts the quality of life in urban areas, in fact, a Eurobarometer survey indicated that congestion is the biggest challenge for daily mobility [184]. It also affects other aspects like energy consumption, operational costs or road accidents.

Accidents involving pedestrians and other road users, and feeling protected from these accidents, is an important social factor. These accidents are exacerbated by inadequate driving practices such as fast speeds and the influx of vehicles on a road. In fact, road traffic accidents are a leading cause of death, with approximately 20 000 Europeans dying in 2021 [185]. The reduction of the number of deaths and injuries from road traffic accidents by 50 % by 2030, is listed by the United Nations as one of the Sustainable Development Goals to ensure healthy lives and promote well-being [161]. Additional to the impact on people's health, these accidents can also cause property damage, either it being parcels or historical landmarks. Moreover, the concept of data security is increasingly important in a digital world. Accidents involving personal data like data leaks or piracy are also contemplated in this sub-criterion.

The perceptions of the population in terms of trust, willingness-to-use, reliability, etc. are the last considered sub-criteria. It is important because it not only considers the customer who bought the parcel and is waiting to receive it but also the other people that will be affected by this delivery operation.

These descriptions and assumptions for the sub-criteria are summarized in Table 4.1. To provide the necessary information for conscious evaluations, this data was presented to the experts in the interview and in the questionnaire.

Table 4.1: Descriptions of the criteria and sub-criteria considered in the model.

Criteria	**Sub-criteria**	**Description**
Environmental	Air pollution	Detrimental emissions of PM and NO_X
	Noise pollution	Noise level that a citizen is exposed to during the day (24 h)
	Visual pollution	Distortion of the urban landscape by the use of public space
Economic	Operational costs	Costs incurred related to labor salaries, fuel consumption, licenses, maintenance, etc.
	Load capacity	Available cargo space in the locker/vehicle
	Delivery speed	Time needed for the goods to reach the final recipient
Social	Congestion	Traffic delays experienced by the population
	Safety & security	Accidents involving people, personal data, goods and property
	Acceptance	Population perception in terms of trust, usability, reliability, etc.

4.1.4 Last-mile alternatives

Chapter 2 described a large array of last-mile solutions that have been discussed in the recent literature. The reasoning behind the selection is very identical to the sub-criteria selection:

- **i)** The last-mile alternative is appropriate to all the sub-criteria;
- **ii)** The last-mile alternative is relevant to the context of historic centers;
- **iii)** The last-mile alternative is comparable to the others;
- **iv)** The last-mile alternative appears frequently in the reviewed literature.

Therefore, the solutions that were selected to be part of the alternative level are Parcel locker, Electric vehicle, Cargo bike, and Crowdsourcing.

According to the selection principles listed previously, some solutions like the UCC, the use of technological systems, drones, off-peak delivery or regulatory measures like access restrictions, although discussed in the reviewed literature, were not considered to be part of the model as their comparison with the other solutions would be difficult, and their suitability inside a historic center is not clear. For instance, it would not be feasible to compare a regulatory solution like parking control with a solution based on cargo bikes, or compare a recent and still very unexplored solution like the autonomous vehicle with a more consolidated technology like the electric vehicle.

Defining the alternatives is particularly important as they differ from one another in several aspects. Parcel locker is a solution widely discussed in the reviewed literature and is based on delivering the parcels to a locker instead of delivering them to the consumer's residence. These parcel lockers are maintained by the logistical companies. The logistical company uses an Internal Combustion Engine (ICE) commercial van to deliver the parcels to the lockers where they are kept until the consumer retrieves them. The lockers operate 24/7 without a worker and are placed in a safe site.

The consumer's travels to collect the parcels to the lockers are neglected as it is assumed that the consumers do not collect the parcels at these points on purpose, but rather when they run routine operations such as commuting or shopping. To this end, the parcel locker is also assumed to be placed in a frequently visited place such as a commercial outlet.

Electric vehicles are the most discussed alternative vehicle in the reviewed articles. In this model, parcels are delivered to the consumer's home by electric commercial vans operated by specialized workers during the daytime. As mentioned in the literature, the battery of these vehicles is suitable for last-mile operations, therefore (preconceived) battery limitations are neglected.

The third alternative in the model – Cargo bike – is very similar to the previous alternative. The parcels are also delivered to the consumer's home by the logistics company's specialized worker during the daytime but the vehicle used is a non-motorized cargo bike.

Crowdsourcing is another popular emerging solution in the literature and is the last alternative considered in the model. In this solution, parcels are delivered to the consumer's home by a crowdshipper using preferably public transport and soft modes (e.g., walking, traditional bicycle). The crowdshipper is a non-specialized worker only operating during the daytime and within a restricted area, for instance, locations close to his residence.

Table 4.2 describes the delivery scheme and the assumptions made for each considered alternative in terms of the vehicle used, the type of worker, or the operation time.

Table 4.2: Descriptions and assumptions for each last-mile alternative considered in the model.

Alternative	**Description**	**Assumptions**
Parcel locker	Parcel is delivered to a locker by the logistics company, and kept there until the consumer collects it	• ICE commercial van • Consumers' travels neglected • Parcel locker without permanent worker • 24/7 operation • In a safe and commercial site
Electric vehicle	Parcel is delivered to the consumer's home by the logistics company via electric vehicle	• Electric commercial van • Battery limitations neglected • Specialized worker • Daytime operation
Cargo bike	Parcel is delivered to the consumer's home by the logistics company via cargo bike	• Non-motorized cargo bike • Specialized worker • Daytime operation
Crowdsourcing	Parcel is delivered to the consumer's home by a crowdshipper via public transport, complemented with soft modes	• Preferably by public transport and soft modes • Non-specialized worker • Daytime operation

There are eight assumptions common to the four considered last-mile alternatives, as listed in Table 4.3. The first two were included in the initial model. The first common assumption refers that the production stages are neglected so that the impacts caused during the building of the parcel locker infrastructure or the production of the electric vehicle components, for instance, are not considered. Only the impacts resulting from the operation are considered. The second refers to the assumption that all alternatives incorporate the latest technological advance for instance regarding the electric vehicle's battery capacity. The remaining six assumptions were included following the experts' comments and therefore their reasoning will be presented later in the following subsection.

Table 4.3: Common assumptions for all last-mile alternatives considered in the model.

Common assumptions	
• Production stages neglected	• Vehicles/locker with typical sizes
• State-of-the-art technology	• Same item to be delivered (t-shirt)
• UCC outside the historic center	• Same volume to be delivered
• Alternatives operate inside the center	• B2C (client living inside the center)

The graphical representation of the developed hierarchical model that structures last-mile operations in historic centers is presented in Figure 4.1.

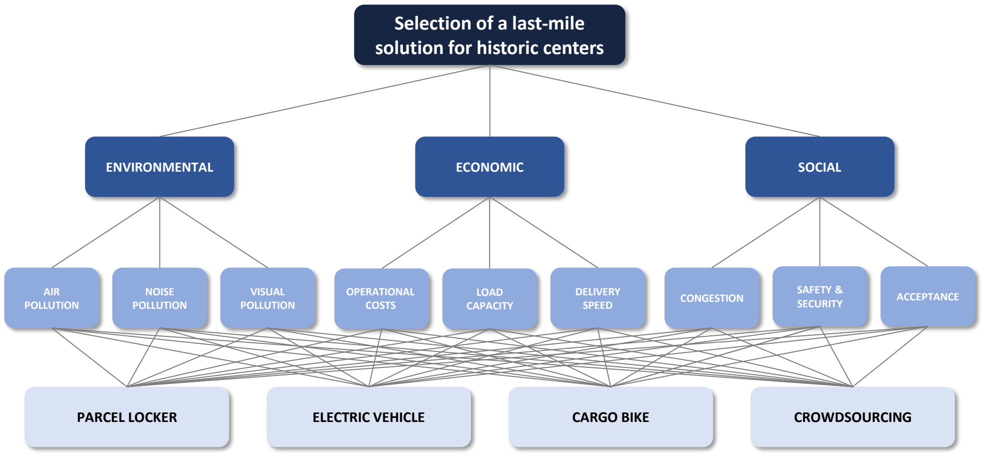


Figure 4.1: Hierarchical model proposed.

4.2 Model evaluation

The interviews provided very rich contributions to the structuring of the model. The interviews also contributed to further deepening the knowledge regarding the last-mile, in particular, the last-mile in historic centers. To this end, much contributed the heterogeneity of the sample and the level of expertise of the participants.

The analysis of the interviews was based on a thematic analysis. The identified themes were: (i) Importance; (ii) Goal & criteria; (iii) Environmental sub-criteria; (iv) Economic sub-criteria; (v) Social sub-criteria; (vi) Alternatives; (vii) Case study; (viii) Evaluation & generalization. The thematic map is presented in Figure 4.2.

Figure 4.2: Thematic map derived from the interviews.

4.2.1 Importance

The first theme approaches the importance of studying this topic. A clear finding was that the interviewed experts confirmed the urgency and significance of this study. To the expert E9, last-mile and urban logistics is a "very hot topic, on top of the table", remarking that with the "rising fuel prices, with the restriction in the city centers, with the brutal increase of e-commerce, this is something that is exploding. It has already exploded and is continuing to explode". This expert also mentioned that "in the next 8 years, the number of home deliveries will double". E4 said that this research "is very important" while E2 mentioned that "the area needs optimization" and "the country needs this, needs people thinking on the system". E2 further added that the "issue of urban logistics is very important and it is strangely an area where little is done" as "people talk a lot without doing much".

Furthermore, E9 mentioned that the last-mile in historic centers "is still not being worked on and it should, and for many years ago". This urgency is justified by the unique restrictions found within examples that the experts provided. E7 referred that "the delivery in the historic center is very chaotic" and "depending on the time, becomes very critical", while E2 mentioned restrictions associated with the "morphology of the pathways [or] the profile of the pathways". E9 exemplified that they are "very tight areas, very closed, with great mobility difficulties, few parking spaces" and where it is "urgent and fundamental to remove all large vehicles" to assure the "preservation of the buildings in the historic centers". E5 provided examples of zones where car access is restricted, zones with "very very much traffic", and zones "circumscribed" by physical barriers, while E8 mentioned zones where it is "super difficult to park, to stop".

4.2.2 Goal & criteria

The wording on the top level of the hierarchical model made E3 feel "intrigued", stating that finding "the best solution" is "a utopia", because "there will always be someone who comes from a completely different context, and maybe from a context that maybe has nothing to do with the population that will answer the questionnaires and will say that 'this best solution is not for me, it is inappropriate'". This comment led to a change in the top level of the model: "Best last-mile solution for historic centers" was substituted by "Selection of a last-mile solution for historic centers".

Regarding the following level, E9 stated that the three dimensions – Environmental, Economic and Social – are "clearly enough" as "we are no longer looking at the operation only in an economistic way, but [also] its environmental impact and the impact on the populations". E5 corroborated ("I [E5] would consider them [Environmental, Economic and Social] too") as these three are "common to all references" although some people suggest "adding a fourth or even a fourth and fifth dimension". This last comment is in line with the literature reviewed, where some articles included a fourth dimension related to operational or technical effectiveness.

E5 added that these additional dimensions "ended up being able to be merged into some of these [three dimensions]". In fact, the proposed model merges the operational/technical aspects into the Economic dimension. This merging is noticed and validated by E9: "the entire operational part is also already embedded in the economic part, so somehow I [E9] think it is fine".

E6 mentioned that "from the things I [E6] have seen in the literature I [E6] think this covers pretty much almost all the features and operational constraints" and therefore, could not "add anything else" to the model, stating the model already considered the "key features". E9, referring to the sub-criteria level added, "it seems to me [E9] that everything is correct".

4.2.3 Environmental sub-criteria

Referring to the Environmental sub-criteria, E3 said that "these three will be the topics to approach" while E9 stated that "the environmental part has an increasing impact on the operation".

Visual Pollution was the most frequently discussed Environmental sub-criteria, with experts like E5 agreeing on the importance of this sub-criteria, classifying it as "quite important", even if "it is not even that common". E2 suggested changing the name of this sub-criteria to "Public Space Utilization or eventually Visual Pollution/Public Space Utilization" because "in environmental terms, the utilization of the public spaces ends up being a relevant environmental/operational thing", giving the example that people like cargo bikes more than electric vehicles because "normally the minimum space needed to have a cargo bike is much smaller than for an electric vehicle". E1 expressed a similar thought about the problem regarding capacity and infrastructure needs from the perspective of the performed service. Based on these insights, the definition of the Visual Pollution criteria was changed to reflect this introduced factor related to the public space utilization.

E1 affirmed that "Air Pollution is very important, Noise [Pollution] too" but, although "logically agrees"; considers it "equally important" and "fine"; and exemplifies its importance using the historic center of Porto, suggested "eventually" exchanging the Visual Pollution sub-criteria with a sub-criteria related to the climate change impacts. The reasons behind this opinion towards Visual Pollution rely on its dependency on the "size of the fleet that will do this last-mile" and because it will differ "from historic center to historic center". Moreover, this expert expressed the importance of assessing climate change impacts such as "CO_2 and fuel consumption", noting that the considered parcel locker solution involves the internal combustion that causes these problems, while "electric vehicle, for example, supposedly does not have much noise pollution associated [...] nor air pollution", thus suggesting that some considered sub-criteria are "not so relevant" for some solutions.

An identical comment was made by E8. This expert said that the environmental sub-criteria "covers the dimensions reasonably well" but noted that it is "relevant to consider" the "high levels of fossil fuel consumption" as it is "a problem associated to transports in general, [and] freight transport in particular", referring to the CO_2 emissions and the impacts generated from the "process of extraction of fossil fuels". E8 also inquired if this factor was already incorporated in the model with the inclusion of electric vehicles.

Although assessing the climate change impacts such as CO_2 emissions is important on its own, it was decided that the model would assess a criterion like Air Pollution. Assessing this criterion could also contemplate the climate change impacts, because, as discussed previously in Subsection 4.1.3, they are closely interlinked, with many of the air pollution sources also being sources of greenhouse gas emissions like CO_2.

According to the assumptions made for the model, the only considered use of fossil fuels is during the travel that the logistic operator makes to drop the parcels in the parcel locker. Although an argument could be made that the travel that the consumer does to collect the parcels in the locker could generate fossil fuel burning, it is assumed that no dedicated travel will happen in this scenario, as the parcel lockers are located in frequently visited places like a grocery store. This is the reason why these consumers' travels were neglected. A similar situation in the crowdsourcing scenario, as there is the eventual use of conventional vehicles. However, the classic approach of this type of solution is based on the idea that the crowdshipper only delivers parcels within very a restrictive area, for instance, the neighborhood where the crowdshipper lives. Moreover, both electric vehicles and cargo bikes do not burn fossil fuel, thus making the climate change sub-criteria an ineffective comparison indicator.

4.2.4 Economic sub-criteria

The Economic dimension raised various comments regarding the perspectives and other important variables that could be considered. E3 suggested that "there should be multiple perspectives of this Economic dimension". These perspectives are: "the perspective of the receiver"; "the perspective of the deliverer"; and the perspective of who "manages the space or even who is there, like the police, to see if the rules are all followed". This expert stated that only the "company part" is being considered in the model. E4 also noted this: "there is a lot here [in the Economic dimension] from the point of view of the [...] companies that are participating". Moreover, E8 also identified the perspective of this model as being a "support to the logistical operator".

E3 alerted that this lack of consideration of other perspectives could induce a “big influence” on how the model is perceived and used, as “a model that only considers the companies, is a model that will always be applied within a more operational scope” thus making it less suitable within “more strategic scopes”, for instance, when “people from city councils or politicians [are] interested in implementing strategies or even implementing zones in city centers oriented towards this type of solutions”.

Although this dissertation’s author agrees that the model could be considered to be more adequate for the perspective of the logistical operator, the author does not find this limiting the suitability of the model to other perspectives. Assessing factors like Operational costs, Load capacity, and Delivery speed, even if from the perspective of the impacts they have on the operation, can provide key insights and be interesting to other stakeholders.

For instance, from the perspective of a politician, Operational costs are related to subsidies, taxes, and labor regulations; Load capacity will involve, either larger vehicles or larger fleet sizes, that will cause degradation of the urban landscape or generate noise, and therefore lower the economic returns of tourism; and Delivery speed will affect the productivity and general traffic conditions of the city. This stakeholder can then plan new city policies and regulations according to priorities, and therefore, opt to limit the access of big freight vehicles, rather than imposing speed limits.

These three indicators can also be assessed from the consumer and citizen’s perspective, as the operational costs will directly influence the shipping fee that the consumer pays; the load capacity will directly influence the size and the number of vehicles in the city; and delivery speed will directly influence the time between the purchase and the receiving.

Summing up, the model was developed without a specific perspective, so that it could be useful for the multiple involved stakeholders. This was (hopefully) clarified in the invitation for the questionnaire (see Appendix E). Asking the participants “to complete the questionnaire from an expert perspective” thus not specifying the perspective, aimed at getting the experts to adopt a general, equitable, and multi-stakeholder perspective.

Moreover, E3 expressed the importance of considering “variables of the customers [...] that, to the companies, will influence the delivery. A thought shared also by E4 that stated that ”it would be good to take into account the customer’s perspective, within the economic perspective“, pointing out the impacts that the ”consumer service, that is, the quality of service“ has ”from the point of view of the company”, as the company has “to meet some specific customer needs”. This expert also mentioned that it would be “difficult to quantify and place comparatively with the other [sub-criteria of the model]”. This customer’s perspective is framed within the Social sub-criteria Acceptance because aspects like trust or willingness-to-use are strongly related to how the customer's needs are met.

E7 suggested other possible economic aspects that could be considered such as "failure, the attempt of delivery" that "is important too", and the "pace that is happening in these deliveries" that is "a relevant criteria and factor". E8 evoked the costs that are "not really a function of the operation but are costs that are present" and are related to "the vehicles themselves" like the "existence of the fleet or the rental of a fleet" or "the facilities themselves". These suggested factors were also found in the literature but were ultimately not considered for the model as the other three seemed more relevant to assess.

To E8, Load capacity can also be a "restriction of the problem" on its own, as it has to do with the type of solution because "typically, the historic center conditions the type of vehicle [that operates there]". In fact, using the load capacity as a criterion to permit access to restricted areas of a city is mentioned in the reviewed literature. Using other characteristics of the vehicles as sub-criteria was discussed by E4. This expert said that "an important issue for historic centers would be the size of the vehicle" due to the vibrations that the "vehicle will cause when passing through the streets and roads [...] degrading the historic center, either directly through the streets it passes through or indirectly through historic buildings". E4 later agreed that this issue is contemplated within the scope of Noise Pollution and Safety & security.

E6 mentioned that the sub-criteria Load Capacity seems "much more specific" than Operational Costs, as this is "very widened" and "encompasses many more points inside", while E8 affirmed that these two are "associated". To E1, the three sub-criteria are "very important", with Load Capacity being important because it has "underlying the issue of routing that implies the issue of Congestion and Safety & security itself". E8 said that Delivery speed "also ends up conditioning the financial performance [...] but [also] the operation itself in general". These relationships between different sub-criteria are a reason for the difficulty in solving the last-mile problem, as improving one might worsen another.

4.2.5 Social sub-criteria

The Social dimension is also well perceived by the experts with E3 saying that it "looks good", and E9 saying that "the social life part also makes perfect sense"

The Social dimension of the model aims to consider two social perspectives: the impacts on the customers that are receiving the parcels, and the impacts on the "non-users" as called by E8. E8 and E3 both discussed this situation, but while E8 understood the intended duality of the criteria, E3 sees it as more focused on the "passive elements – who lives there but has nothing to do with that delivery, but has to put up with it because the vehicles have to pass".

E1 considered Safety & security as “extremely important, especially for the Cargo Bike as it has a more vulnerable user”; stated that Safety & security and Acceptance “ends up being quite important in Crowdsourcing, even more than in the others”; and that “Congestion ends up underlying almost all [alternatives]”.

The initial term of the Safety & security sub-criterion was only Security. This change derived from the remark made by E1 that claimed a “certain difficulty in calling it Security”, thus suggesting the term Safety. In fact, the term Safety & security is a better representative of this sub-criterion as it considers the state of being protected against accidents (Safety) and the actions taken to achieve this state (Security).

This sub-criterion was also highlighted by E9 as being “increasingly more on the table”, referring to the “data security and the package security itself, because there has been some trouble”. This commentary induced changes to the description of the Safety & security sub-criterion to contemplate the issues related to accidents involving personal data.

Similar to the Economic sub-criteria, some experts remarked that some Social sub-criteria could be included in other dimensions. However, including the issue of degradation of historical patrimony within the Social dimension, instead of the Environmental dimension, was a good decision according to E5. Moreover, E3 sees Congestion “as part of the Economic [dimension]”, but notes that the way it is described, it is a social issue.

4.2.6 Alternatives

The discussion regarding the alternatives level was heavily focused on the mention of other alternatives not considered in the model, and not actually debating the four considered alternatives. A probable reason for this was that the experts perceived the four as “very well placed”, as E4 said.

Interestingly, E6 remarked that is “not very evident” that the parcel locker is “as sustainable as people say” because this expert believes that “people leave the house just to pick up the order”. In fact, the generation of dedicated trips by customers to collect the packages can affect the sustainability premises of the parcel locker alternative. However, following a common approach in the literature, a model’s assumption was made that these dedicated trips are neglected as the lockers are placed in safe and commercial sites. This assumption was corroborated by this expert that claimed that ”that is how the people in this area defend themselves”. This assumption was also corroborated by E9 which noted that “the placement of these lockers in strategic zones of high flow of people [...] greatly simplifies” the process, as they can collect the parcels “in that movement of the person going home” without “even make a big detour”.

E8 mentioned that crowdsourcing is “often done with private solutions. They [crowdshippers] only use their own car to do this” thus being “a bit restrictive” to consider that the Crowdsourcing scenario only involved public transports and soft modes. Regarding the same alternative, E5 alerted that it would be “difficult” to use public transport in some historic centers whose public transports do not have “enough space for a person to enter with goods”, or do not have these systems at all. These comments led to the modification of the Crowdsourcing description to reflect that it could eventually involve the use of private means.

The inclusion of drones was discussed in the interview with E2 who alerted that “someone very tech-savvy [...] will soon ask if you [the researcher] are considering last-mile using drones”. E2 mentioned the associated technical and organizational problems such as the small cargo load, or the need for adequate legislation and delivery regimes, as well as their benefits: “drones, from a purely operational point of view, are highly efficient, as they are all-electric, because in most cases, they use direct routes, [...] and because they are effectively energy efficient”, before concluding that “in fact, drones are something that is missing here [on the model]”. E9, although not suggesting the inclusion of drones in the model, stated that even if “drones are no longer talked about because of all the confusion there is in legal terms because of the flights”, drones or other autonomous solutions could eventually be contemplated. E6 inquired about considering drones as another alternative, but understood their exclusion as “it is a very recent thing” and therefore is not on the same level of academic investigation and practice as the considered alternatives.

E7 introduced a new delivery scheme used in some historic centers in Brazil. This scheme consisted in delivering the parcels from the distribution center to “a specific place on the historic center” where a worker collects the parcels and distributes them using a sort of “shopping cart”. This expert also added that the “specific place” can be a mini-hub, that also operates as a parcel locker.

E9 mentioned the solution of mobile depots, explaining that “the truck stopped at the entrance of the town or neighborhood [...] and from inside, bikes or scooters or anything non-combustion came out to to the deliveries”. Furthermore, this expert used this example to suggest that some of the solutions that the model considered can be combined. Another example given was the combination of the concepts of parcel locker and crowdsourcing. E3 also pointed out “not having one solution, [but] a set of solutions”.

A popular last-mile solution discussed in multiple interviews is the establishment of horizontal collaboration schemes, aiming at load consolidation, that is, “partner logistics companies, [...] carriers, groups of stakeholders, work together to be able to consolidate the load to deliver in historic centers”, in order to “reduce the number of vehicles circulating”, as defined by E4. This expert addressed the fact that it “often happens that they [trucks entering the city] are only partially loaded”, and when companies collaborate, they can “consolidate this load, increase the load factor and decrease the number of vehicles circulating in the historic center”. E4 also mentioned that this consolidation can, not only be done by the logistic companies, but also by the suppliers. In this context, E8 mentioned a study conducted in Lisbon where “the small businesses [...] shared transport in vans when they went to the market to supply the small stores” so that “when one went, instead of bringing it just for himself, he brought for them and the competition”.

E9 also discussed this topic of horizontal collaboration, giving a B2B example in Lisbon where to a road that has three coffee shops, there will be three different trucks supplying three different brands of beverages, leading this expert to ask “but why is not a partnership between competitors created here?”. This expert further explored this topic by stating that “the difficult part is being able to create ‘coopetition’ here, that is, they are collaborating and at the same time competing. That allows that, instead of three trucks going there, only one go there”. Moreover, E9 also gave a B2C example with similar outlines, where three items purchased on Amazon, were delivered by three different carriers within a short time-frame, leaving the expert to say that “it is not efficient and it is not even practical for the customer because the customer has to wait all day for the products to be delivered”. E8 provided similar examples (e.g., “on the same day, five deliveries were made to my street [with] five different vehicles”) to illustrate this “quite considerable inefficiency”. E9 declared that there is “a lot to gain” with this solution but it “is going to be the big last-mile challenge” and therefore “it is necessary to think of models that enhance this ‘coopetition’” considering “not only the reality of packages but all the deliveries that are made, all the last-mile deliveries that are made within cities and in particular within the historic centers”.

According to E4, horizontal collaboration can be made through technology by sharing information like inventory or load factor, or through the creation of distribution centers. In fact, the discussions regarding collaboration schemes frequently led to the UCC and identical initiatives. “The concept is similar, only that in this case, some companies come together in a distribution center”, said E4. E2 also approached collaboration within the distribution center claiming that it “greatly optimizes the system but is very difficult to being able to have all agents accepting that the market has something like that” because “the manager of that space” “will have an obvious competitive advantage over the others”.

According to E4 and E2, the advantage of this infrastructure relies on the fact that companies “do the heavier truck transport” to the distribution center placed in the city’s entrance where “the cargo is stored and then they enter the city already consolidated” and “optimized”, knowing what and where to deliver “to reduce the number of trips, and to do the minimum number of traveled kilometers”. The first expert remarked that, with this consolidation, “it is even easier to think of other solutions that have less impact in terms of the environment and also for the society, like electric vehicles or bikes". The idea is that the consolidation center could manage "diverse companies, diverse brands".

E4, E8 and E9 mentioned that collaboration-based solutions are already being discussed and implemented in European countries like Italy, Sweden and Portugal. E4 stated that this solution "already exists, specially in Italy" as "Italy has many historic cities so they have a lot of concern in relation to that, so they put the consolidation center immediately [before] the entrance, and from that, to enter the historic center in order to attend small stores, business or restaurants, it has to be through consolidated deliveries" allowing the "public power" to "control the type of vehicles, the weight and the number of vehicles that are entering [the historic center] per day". E8 also mentioned that restricting the access "happens a lot in Italy", and also provided a personal example, in Portugal, where "it is only possible to load and unload until 11 a.m.". E9 mentioned that "creating consolidation centers in strategic zones of the city that would then supply the historic zones" was discussed "for many years" in Portugal but did not consummated because "companies do not understand each other; because they are competitors and do not want to share, and do not want the other to know what one sells", suggesting that these services have to be performed by "external entities, 'exempt' logistic operators", and that to be "effectively achieved" it requires to "change a lot [of] mindsets".

A similar thought was shared by E2 regarding the "very precarious logistics system" of Portugal, explaining that this gathering and regulation is "very difficult to organize" because the logistics system is "heavily reliant on non-professional distribution", that is, "a series of people that are not registered, and have their own means and distribute by themselves", which differs from the controllable "half a dozen of players that distribute everything". This expert added a unique point to this discussion by noting that implementing this collaboration scheme "on a macro level for the country" could be possible if the country had "many cities of roughly the same size". Moreover, E2 exemplifies that this is not the case for Portugal: "There is Lisbon and Porto, then there is Coimbra, Braga, Faro. Then there are not centers that are so interesting from the point of view of organization and commercial exploitation".

The UCC can also be an important mode to "control the flux inside the city" by restricting the entrance to "small vans and small automobiles", according to E4. This author, suggested a regulatory measure related to controlling the access to a historic center based on the size and quantity of vehicles, affirming that "in historic centers it is very important" because they are "places that involve tourists" and have a need to "preserve the heritage". This expert said that this control is "usually done through penalties or incentives to the companies that are participating", exemplifying with "creating a penalty [...] if very large vehicles enter, or even blocking their access", and the application of "some benefit from tax reduction or access at specific times that other companies do not have access".

This restriction of access to historic centers is also approached by E8 that added that it is "typical of urban areas" to, "in addition to condition the type of vehicle, also condition the delivery schedule", that is "limiting access to certain times of the day". "Therefore, there is a relatively short time window which greatly conditions the efficiency of this operation". This expert concluded by saying that "one of the biggest restrictions that this type of solution may have" is linked with the "problem of the transport peak", as "everything has to be on the street at the same time and it is not possible to smooth the peak because they cannot do the operation outside of that period of time". Interestingly, although E7 agrees that the historic center is a "complicated region" with "their difficulties [and] restrictions relative to delivery schedules", it is also a region "with a lot of speed", "where the time between deliveries is short" because it is "well concentrated, well consolidated", therefore "the productivity is much higher than when considering more interior regions".

Associated with these limited operation times "is the fact that people are not at home normally in the periods that the vehicles can deliver", constituting a "severe problem" and a "big dilemma", according to E8. This problem is also present in the reviewed literature, with authors suggesting delivering in alternative time schedules. This solution, often called off-peak delivery in the literature, was mentioned by E5.

Due to the restrictions of the historic centers, placing a UCC inside these areas is discarded, but, as E8 said, "not existing inside, they must exist outside. There is always the existence of some form of accumulation and separation in the vicinity". This expert added that "normally it is not inside because it is much more expensive to do so. But then the cost of transport increases ... it is all a matter of trade-offs". If moving the logistic infrastructures away from these centers causes impacts, moving the consumers also causes them. This was mentioned by E9 that referred that with the COVID-19 situation and "people able to work from home, [...] many people also saw an opportunity to not live in the city center and go to the outskirts, and that creates another challenge – the geographical dispersion – that creates additional costs to the last-mile". Therefore, another trade-off is pointed out, as this movement of consumers "leaving the historic centers, frees the cities from the confusion". The problem of geographical dispersion was also mentioned by E7. This expert stated that in the historic center there is "a little greater ease" to deliver than when considering a "region a little further away". These comments were reflected in the revised model, namely by stating that there is a UCC outside of the historic center.

In fact, drones, off-peak delivery, horizontal collaboration schemes, and access and time restrictions were all considered as possible alternatives for the model but were ultimately rejected, either because they are incomparable, unsuitable for historic centers, and not on the same level of investigation and practice as the others.

This decision was corroborated in comments like the one made by E6 which stated that these alternatives are “what is being talked about now in terms of sustainable transport”, or the one by E9, which referred to the Parcel locker solution as “what is growing now brutally, everywhere now starts to have it”, naming “two or three strategic places at the exit of Lisbon that already has these”.

4.2.7 Case study

The importance of defining the case study well was stressed by different experts. E6 mentioned that there are “many nuances that can make a difference” in the model evaluation, while E2 stressed that “there will be different answers depending on the inherent characteristics of each parcel” thus highlighting the importance of properly defining the case study, “because the case study will detail differences in the typology of the city: if it is more sloping; if it has wider or narrower street profiles, ...”.

E1 added that the evaluation could even vary according to different sectors of the historic center, pointing out the example of dangerous neighborhoods. Considering the historic center of Porto, this differentiation was not considered.

A common aspect highlighted by different experts is the importance of considering the type of parcel to be delivered. In fact, E6, E2 and E5 all stated the difference between delivering something “that has a giant volume and weights 2 t”; “pallets”; or “a washing machine”, and something like “a book that weights a few tens of grams and is relatively small in size”; “little products”; or “a t-shirt”. Considering these comments, the considered item for the case study was set, for all considered scenarios, on a t-shirt – an item with almost universal characteristics of volume and weight. The t-shirt is to be delivered in the same volume in all four scenarios.

Furthermore, E5 exposed the need to clarify if the case study referred to a B2B last-mile or a B2C last-mile, and following what E3, E4 and E8 said, E5 also discussed the issue of the perspective. The model was structured so that it could be suitable and interesting for both schemes and multiple perspectives. In fact, comments like: “This [the model] could be seen from various prisms. Can be seen from the business prism, the commercial, the consumer and the citizen that is passerby, the tourist, ...” made by E5, can be considered a proof that this multi-perspective characteristic of the model was achieved. Therefore, as explained earlier, no specific perspective was considered. Nevertheless, for the sake of a better definition, the case study (and consequent experts’ quantification) was focused on a B2C approach, where the customer lives inside the historic center.

A new assumption was included in the model because there were some doubts among participants regarding the location of the solutions, for instance, E8 asked whether the “parcel locker will be located in the same location [inside the historic center] or outside the historic area”. This assumption was “Alternatives operate inside of the center”.

The issue with the weight and size of the vehicle is “pertinent, but in this specific case [historic centers] it is much more pertinent” according to E4. This comment also led to revisions to the model in the form of a new assumption “Vehicles/locker with typical sizes”.

It is noteworthy that the interviews were conducted without using a particular case of a historic center, in order to enhance the generalizability of the results. Nevertheless, the above comments were crucial to improving the case study. Therefore, in conclusion, the case study was settled on a B2C last-mile delivery of a t-shirt to a customer that lives inside the historic center using vehicles or lockers of typical dimensions that operate inside the center with a UCC outside.

4.2.8 Evaluation & generalization

There is a consensus among the experts regarding the adequacy of the model. E6 considered the model “already quite complete”; E2 stated that the model “is touching on the points that matter” and is not “missing anything”; E9 classified the model as “well structured” affirming that “what is here [on the model] makes perfect sense”; E1 said that the model is “fine” and “looks good”; E7 said that the model is “very complete” and “very wide”, and that “in terms of selection criteria, [it] contemplated well the focus of the study”.

E5 corroborated the model and could not remember “anything [else]” to be added or altered. This last statement pointed out a potential limitation in this data collection procedure, because, although the specific topic of the interview was shared with all participants beforehand, the model was not. Two participants suggested that this preliminary sharing could improve their contributions. E6 said that “it would help if [the researcher] could send the presentation before” and E8 complemented that “maybe it would help because [...] looking for the first time at the model [...] is more complicated”. Moreover, E8 mentioned that “maybe the purpose of the work is also that”. In fact, a case could be made that this “almost on-time evaluation” as referred to by E8, contributed to the quality of the comments and insights, as providing more time to study the model beforehand could (eventually) lead to more comments but not necessarily more important ones.

The model’s appropriateness in other geographical contexts was also assessed. E9 justified that the model is generalizable because “the preoccupations that the cities, the municipalities, the companies must have are, in some way, transversal”. The international validity was assured by E4 and E7, that pointed out that the model is valid to European and South American countries.

E3 stressed that this geographical extension (“from one city to another, and even more from one country to another”) might imply a fourth dimension relative to the “cultural issues of the population”. When told that this dimension is contemplated in the sub-criteria Acceptance, E3 said that “in that case it is [contemplated]”. E5 mentioned that the model “may not be fully transmissible to other areas” as “historic centers usually have very specific restrictions”. E2 confirmed the generalizability of the model (“of course yes”).

4.3 Model quantification

The last part of the proposed methodology is the quantification of the model based on the decision-making capabilities of the AHP and TOPSIS methods. These methods took as inputs the answers provided by the experts in the questionnaires.

4.3.1 The historic center of Porto

The model definition and the interviews did not considered a particular historic center in order to increase the generalization of the model, making it more adequate for a wider array of contexts. As described by multiple experts, there is a real possibility that when presenting this model without any detailed case study, each would answer according to different historic centers. Therefore, a detailed case study was outlined.

This detailed case study is the real historic center of Porto, Portugal (Figure 4.3). Porto’s historic center is a UNESCO World Heritage Site since 1996, built along the hillsides of the Douro river, and the result of spontaneous and planned interventions made in different periods, from the Middle Ages to the Industrial Revolution [186, 187].

Figure 4.3: Photograph of the historic center of Porto [188].

The main characteristics of the historic center of Porto are [186, 187, 189]:

- 51 ha territory with around 5000 residents;
- Various monuments and historic buildings;
- Point of high tourist interest;
- Efficient public transport network with bus, metro, train and tram;
- Narrow streets and rough terrain with high slopes;
- Limited space for new technical infrastructure;
- Complex legal and institutional system with multiple stakeholders with authority.

The historic center of Porto is surrounded by the old Fernandina Walls. Accordingly, the inscribed area that UNESCO's World Heritage Convention considers is presented in Figure 4.4.

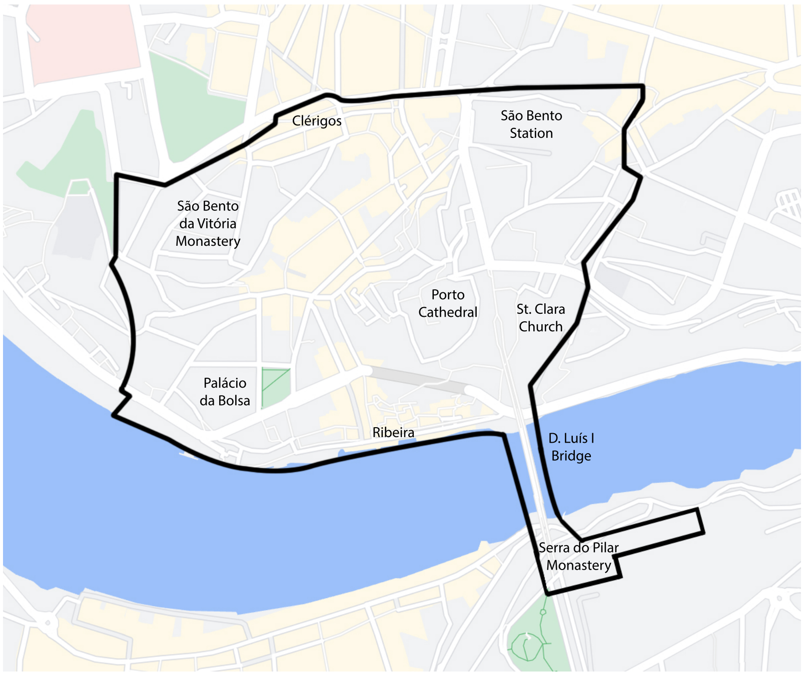


Figure 4.4: Map of the historic center of Porto (Adapted from [187]).

To note that, although the experts were all familiar with Porto's historic center, this inscribed area and the main characteristics were presented to them alongside the questionnaire.

4.3.2 AHP

The MCDM approach begins with the AHP method. This method will provide insights regarding the experts' priorities for the criteria and sub-criteria.

As mentioned in the previous chapter, the weights/priorities were computed for each expert and then aggregated with the geometric mean. The following calculations refer to one of the experts, serving as an example of how the weights/priorities were computed.

First, the questionnaire's answers that this expert provided were converted into a matrix, according to the balanced scale (Table 4.4).

Table 4.4: Pairwise comparison matrix for the criteria level according to one expert.

	Environmental	**Economic**	**Social**
Environmental	1.0000	1.0000	0.8182
Economic	1.0000	1.0000	0.8182
Social	1.2222	1.2222	1.0000

The matrix was then synthesized and the priorities according to this expert calculated (Table 4.5).

Table 4.5: Synthesized pairwise comparison matrix and priorities for the criteria level according to one expert.

	Environmental	**Economic**	**Social**	**Priorities**
Environmental	0.3103	0.3103	0.3103	0.3103
Economic	0.3103	0.3103	0.3103	0.3103
Social	0.3793	0.3793	0.3793	0.3793

Lastly, the consistency of this result was calculated according to the Equation 3.1, the Equation 3.2 and the reference Table 3.4. The consistency results are presented in Table 4.6.

Table 4.6: Consistency of judgments for the criteria level according to one expert.

	Value
λ_{max}	3.0000
RI	0.58
CI	0.0000
CR	0.0000

As the value of CR is not higher than 0.10, this judgment matrix is consistent. The same procedure was repeated for the remaining three judgment matrices of this expert. The final priorities for this expert are listed in Table 4.7.

Table 4.7: Individual priorities according to one expert.

Criteria	Priority	Sub-criteria	Priority
Environmental	0.3103	Air pollution	0.5691
		Noise pollution	0.2423
		Visual pollution	0.1886
Economic	0.3103	Operation costs	0.3984
		Load capacity	0.2305
		Delivery speed	0.3711
Social	0.3793	Congestion	0.2000
		Safety & security	0.6000
		Acceptance	0.2000

The exact same procedure was replicated for all remaining experts.

The average CR for all experts and for all judgment matrices was 0.0207 – below the recommended threshold.

4.3.3 TOPSIS

The TOPSIS part starts with the construction of the decision matrix D^k for the same expert as above (Table 4.8). Note that the option that this expert considered as the best option is converted into 4, whereas the worst option is converted into 1.

Table 4.8: Decision matrix according to one expert.

	Environmental			Economic			Social		
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**
Parcel locker	1	1	1	1	4	1	2	4	1
Electric vehicle	2	2	2	2	2	2	3	3	2
Cargo bike	4	4	4	3	1	4	4	1	4
Crowdsourcing	3	3	3	4	3	3	1	2	3

The elements of this matrix D^k were then normalized according to the Equation 3.3 to constitute the normalized decision matrix R^k for this expert (Table 4.9).

Table 4.9: Normalized decision matrix according to one expert.

	Environmental			Economic			Social		
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**
Parcel locker	0.1826	0.1826	0.1826	0.1826	0.7303	0.1826	0.3651	0.7303	0.1826
Electric vehicle	0.3651	0.3651	0.3651	0.3651	0.3651	0.3651	0.5477	0.5477	0.3651
Cargo bike	0.7303	0.7303	0.7303	0.5477	0.1826	0.7303	0.7303	0.1826	0.7303
Crowdsourcing	0.5477	0.5477	0.5477	0.7303	0.5477	0.5477	0.1826	0.3651	0.5477

Follows the calculation to obtain the ideal V^{k+} and negative ideal V^{k-} solutions for this expert, according to Equation 3.4 and Equation 3.5 (Table 4.10).

Table 4.10: Ideal and negative ideal solutions according to one expert.

	Environmental			**Economic**			**Social**		
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**
V^{k+}	0.7303	0.7303	0.7303	0.7303	0.7303	0.7303	0.7303	0.7303	0.7303
V^{k-}	0.1826	0.1826	0.1826	0.1826	0.1826	0.1826	0.1826	0.1826	0.1826

The priorities/weights given by the AHP and listed in Table 4.7 are now used. Multiplying the sub-criterion priority by the respective parent criterion priority gives the weights vector W (Table 4.11).

Table 4.11: Weights vector according to one expert.

	Environmental			**Economic**			**Social**		
	SC1	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**
W	0.1766	0.0752	0.0585	0.1236	0.0715	0.1152	0.0759	0.2276	0.0759

Then the separation measures from the ideal V^{k+} and negative ideal V^{k-} solutions were calculated with Equation 3.6 and Equation 3.7 (Table 4.12).

Table 4.12: Separation measures for one expert.

Alternative	$\overline{S_i^{k+}}$	$\overline{S_i^{k-}}$
Parcel locker	0.4445	0.3048
Electric vehicle	0.3209	0.2523
Cargo bike	0.3064	0.4355
Crowdsourcing	0.2687	0.3479

This procedure was repeated for the remaining experts. Then, the individual separation measures of every expert were aggregated according to Equation 3.8 and Equation 3.9 (Table 4.13).

Table 4.13: Separation measures for the group of experts.

Alternative	$\overline{S_i^{+}}$	$\overline{S_i^{-}}$
Parcel locker	0.2503	0.3498
Electric vehicle	0.3719	0.2772
Cargo bike	0.2900	0.3226
Crowdsourcing	0.3359	0.2813

At last, the relative closeness $\overline{C_i^*}$ to the ideal solution for the group of experts was computed according to Equation 3.10 (Table 4.14).

Table 4.14: Relative closeness to the ideal solution for the group of experts.

Alternative	$\overline{C_i^*}$
Parcel locker	0.5829
Electric vehicle	0.4271
Cargo bike	0.5266
Crowdsourcing	0.4558

4.4 Chapter summary

The previous paragraphs described how the model was developed, evaluated and quantified. The model's goal is the "Selection of a last-mile solution for historic centers" and is structured in three criteria (Environmental, Economic, Social). The Environmental criteria comprise Air pollution, Noise pollution, and Visual pollution. The Economic criteria comprise Operational costs, Load capacity, and Delivery speed. The Social criteria comprise Congestion, Safety & security, and Acceptance.

The interviews pointed out that there is a consensual opinion among the experts regarding the adequacy of the model. Moreover, the experts' comments, directly or indirectly, induced various modifications and additions to the model, like the change of the wording on the top level or the inclusion of more assumptions. As expected, the interviews also provided comments that deepened the understating of these last-mile operations.

Chapter 5

Discussion

The answers provided in the questionnaires allowed the application of the AHP and TOPSIS methods. These provided valuable insights about the topic of last-mile in historic centers. This chapter presents the results and their concomitant discussion.

5.1 Parallel AHP results

Before discussing the AHP-TOPSIS results, it is important to first address the two parallel calculations. The aggregation of the individual priorities derived from the AHP method allowed the investigation of how the experts prioritize the criteria and sub-criteria. Table 5.1 lists these parallel results.

Table 5.1: Aggregated AHP priorities.

Criteria	**Priority**	**Sub-criteria**	**Priority**
Environmental	0.3333	Air pollution	0.1568
		Noise pollution	0.0992
		Visual pollution	0.0772
Economic	0.3360	Operational costs	0.1416
		Load capacity	0.0892
		Delivery speed	0.1051
Social	0.3307	Congestion	0.1014
		Safety & security	0.1483
		Acceptance	0.0810

The experts consider the three dimensions to be on a very similar level of importance. This result was expected according to the comments made during the interviews and according to the experts' professional profiles, as most of the experts are researchers or professors and therefore have a wider perspective of the last-mile operations. For example, if the participants were consumers asked to evaluate and quantify the model from a consumer perspective, the social dimension would probably be more valued. Similarly, if the participants were more from the business/industry world (e.g., retailers, managers of logistics companies), the economic dimension would probably be more valued.

These results also confirmed that the experts understood that the model was developed from a multi-stakeholder perspective. Nevertheless, the experts valued the economic dimension slightly more than the environmental and social dimensions. This finding follows a completely equal trend from what was found in the reviewed literature, where the most considered was also the economic dimension, followed by the environmental and social dimensions.

The ranking of the economic dimension as the most important sustainability pillar should be highlighted. Three interpretations for this outcome can be made. First, the experts slightly valued the economic dimension more because they believe it is more urgent to be 'solved'. Second, the experts might have devalued the other two dimensions because they believe that 'solving' the economic problems of the last-mile could inevitably 'solve' the social and environmental burdens of the last-mile. Third, some experts might still have a profit-oriented mentality.

The prioritization regarding the environmental sub-criteria led to interesting results. The Air pollution sub-criterion is clearly more valued by the experts than Noise pollution or Visual pollution. In fact, Air pollution ranks first as the most prioritized criterion across all sub-criteria of the model. A justification could be that the experts understood that, although Air pollution refers to emissions of NO_X and PM, the impacts related to climate change are also indirectly contemplated, as taking action to reduce the emissions of NO_X and PM could indirectly reduce the emission of GHG gases like CO_2 that cause climate change.

Although the prevalence of Air pollution is valid, considering the particular vicissitudes of the historic center, the lower values given to the other two sub-criteria were surprising. The city of Porto is associated with good levels of air quality, thus the surprise [190, 191]. Moreover, due to the high touristic influx of Porto's historic center, the visual and noise problems were expected to be more valued.

The weights given to the economic sub-criteria depicted the Operational costs sub-criterion as the most important economic factor, according to the experts' inputs. The comment that E6 made in the interview regarding the specificity of these sub-criteria could explain this prioritization. E6 mentioned that the Operational costs sub-criterion "encompasses many more points inside".

Another possible justification for this result could be that Operational costs is the most evident and direct economic factor. In other words, Load capacity and Delivery speed could be considered technical criteria that are intrinsically related to the economic dimension but their impact is indirect. The load capacity directly affects the size of the vehicles/locker, and indirectly affects the economic viability of the solution because, for instance, a smaller van will move smaller volumes of parcels, thus its costs per parcel will be higher. Similarly, the delivery speed directly affects the service level, and a weaker service level leads to loss of customers or time windows failures which indirectly affect the profitability of the delivery service.

The social dimension's priority is Safety & security. The fact that this sub-criterion refers to the aspect of accidents that provoke damage to the historical property of the historic center is the most plausible justification for this result. In fact, considering the invaluable patrimony present in Porto's historic center, the prioritization of this sub-criterion is evident. The inclusion of the elements of road safety and data security could have also induced this prioritization.

Congestion in second place is also expected as the referred Eurobarometer [184] pointed out that congestion is the biggest challenge for daily mobility.

5.2 Parallel TOPSIS results

The second parallel calculation was the aggregation of the individual judgments for the TOPSIS method. This allowed studying how the experts evaluate the alternatives with respect to the sub-criteria. Figure 5.1 maps these results, comparing the aggregated normalized scores of each alternative according to each sub-criterion.

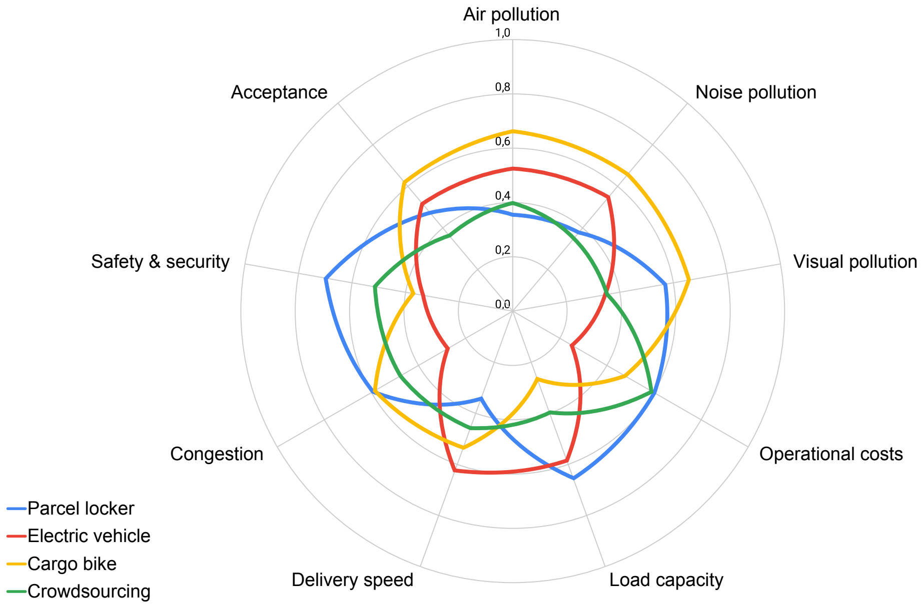


Figure 5.1: Visualization of aggregated TOPSIS judgments.

Several important relationships can be derived by analyzing the above figure, namely the identification of some potential advantages and disadvantages of the last-mile solutions.

The experts ranked the Cargo bike solution as the best in terms of air pollution. This is expected as the Cargo bike solution is the only alternative considered in the model that does not involve any air pollution. Electric vehicles do generate small amounts of air pollutants, and the Crowdsourcing scenario involved predominately public transport that also emits these pollutants. The less favorable solution was the Parcel locker – also expected as it is the only alternative that uses ICE vehicles.

The same two alternatives top the Noise pollution ranking. The experts perceive cargo bikes and electric vehicles as vehicles with little noise generation whereas parcel lockers and crowdsourcing are associated with more noise pollution. This result was also expected as the first two are known for their almost silent operation.

As expected, Cargo bike also tops the ranking regarding the sub-criterion Visual pollution. Although parcel lockers need adequate infrastructure, the existence of a parcel locker can retract the number of vehicles in the historic center and thereby reduce visual pollution – therefore being ranked second. Electric vehicle and Crowdsourcing imply the existence of large infrastructures (e.g., charging spots, metro stops) that can subtract the available public space and deteriorate the visual appeal of the city. Therefore, it makes sense they are not well regarded by the experts in this factor.

The Parcel locker scenario is the most optimal alternative in terms of operational costs. Factors like the reduced length that the logistics company travels, or the non-requirement of a full-time worker, were likely taken into consideration by the experts.

Nevertheless, the Crowdsourcing scenario is ranked almost identically to the aforementioned scenario, thus corroborating the reviewed literature. Because crowdsourcing does not require specialized workers, logistic companies can save money on labor costs. However, it is noteworthy to remind a situation raised in the literature by Bates et al. [39] that alerted that this advantage could lead to social problems, as precarious work is known for low incomes and lack of benefits or legal support.

Probably the most surprising result of this analysis is the fact that the experts considered parcel lockers the best alternative to improve load capacity problems. However, this could have to do with the assumed item to be delivered (t-shirt).

Not so surprising is the low prioritization of the Cargo bike solution, as they are smaller vehicles; and the Crowdsourcing solution, as it usually involves very limited space, for instance, a crowdshipper can only carry a small weight on its backpack.

The experts ranked electric vehicles as the best delivery alternative in terms of delivery speed. Expected result as the electric vehicle does not have any speed limitation. The Parcel locker scenario in last place is also expected as it involves more stakeholders to fully complete a delivery service, and it is dependent on the customer's habits like the food purchase patterns.

Furthermore, according to the reviewed literature, cargo bikes have driving speed and terrain limitations that undoubtedly affect the speed of the whole delivery operation. Considering the rough terrain of the historic center of Porto, these technical deficiencies were expected to be taken into higher consideration.

Solutions based on cargo bikes and parcel lockers are considered by the experts to be less prone and to better alleviate the congestion problems. In fact, this corroborated the reviewed literature, as cargo bikes are more flexible and smaller vehicles, and the parcel lockers reduce the number of trips and vehicles on the road. Electric vehicle ranked, distinctly, last is also expected because the electric vehicle is prone and contributes to the exact same traffic problems as the traditional vehicle.

However, the close link between delivery speed and congestion exposes an interesting dichotomy of the experts. On one side, Electric vehicle ranking first in Delivery speed and last in Congestion could mean that the experts consider that the time needed for the goods to reach the final recipient is more dependent on the actual vehicle attributes rather than on the traffic flow conditions. On the other side, the relatively high priority given to cargo bikes in Delivery speed and in Congestion could mean the exact opposite – the delivery speed is more dependent on the traffic flow conditions than on the actual vehicle attributes.

The experts considered the use of parcel locker the safest and most secure last-mile alternative. This could have to do with the assumption made that these lockers were placed in "safe and commercial sites". Moreover, because this solution involves less vehicle circulation, there are reductions in possible damages to the parcels and the historic landmarks.

The importance of preventing damage to historic property could also be the reason for the ranking of Crowdsourcing as the second best alternative, as the crowdshipper operates within areas familiar to them, and therefore understands the relevancy of these landmarks.

Cargo bike as the penultimate option is noteworthy. A case could be made that because cargo bikes are smaller and lighter vehicles associated with lower speeds, the probability of causing road accidents or damage to historical property is diminished. However, based on a thought shared by E1 in the interview, the results suggest that the experts do not consider cargo bikes to be safe or secure because the physical attributes of cargo bikes do not offer the same level of protection to the worker and the parcels.

Also noteworthy and expected, is the ranking of Electric vehicle as the last option. This could be due being heavier and faster vehicles, therefore increasing the chance of causing road accidents or damage to historical property.

Cargo bike and Electric vehicle lead the Acceptance ranking. Unsurprisingly, as the only major difference from the customer's perspective is the vehicle used.

The other two do induce palpable changes to the customer's habits. The two major changes are that, in a crowdsourcing initiative, the delivery is made by non-specialized workers; and in a parcel locker initiative, the customer needs to collect the parcel. According to the experts, these changes proved to be major setbacks to the acceptance of these solutions.

However, this goes against various authors in the literature that pointed out that there is general acceptance and willingness-to-use these solutions. In fact, as E6 remarked in the interviews, the viability of the Parcel locker solution is heavily dependent on the consumer's behavior.

5.3 AHP-TOPSIS results

Both parallel calculations and consequent analyses helped the understanding of the main objective of implementing this MCDM approach. This objective is the ranking of the four considered sustainable last-mile solutions, according to the relative closeness coefficient $\overline{C_i^*}$, that suggest the most advantageous solution. These results are summarized in Table 5.2.

Table 5.2: AHP-TOPSIS results.

Alternative	$\overline{C_i^*}$	**Rank**
Parcel locker	0.5829	1
Cargo bike	0.5266	2
Crowdsourcing	0.4558	3
Electric vehicle	0.4271	4

According to the AHP-TOPSIS results, the most advantageous last-mile solution for historic centers from the perspective of the experts is based on parcel lockers. Parcel locker ranked first with a closeness coefficient of 0.5829, followed by Cargo bike (0.5266), Crowdsourcing (0.4558) and Electric vehicle (0.4271).

Several conclusions could be made regarding these results. Firstly, because the TOPSIS' rankings are dependent on the AHP's weights, Parcel locker being the most prioritized is not unexpected. This result could be essentially attributed to the high prioritization of the Safety & security and Operational costs sub-criteria – sub-criteria where Parcel locker leads.

However, the Parcel locker solution is very closely followed by the Cargo bike solution. This result was also expected because the most prioritized sub-criterion by the experts was Air pollution, and the Cargo bike solution is the only alternative considered in the model that does not emit any air pollutants.

In fact, the results in Figure 5.1 could anticipate this result, as eight of the nine sub-criteria are either lead by Parcel locker (Operational costs, Load capacity, Congestion, Safety & security) or Cargo bike (Air pollution, Noise pollution, Visual pollution, Acceptance).

Nevertheless, the respective closeness coefficient of the Parcel locker and Cargo bike solutions are still significantly distant from the ideal solution (1.0000). This evidence corroborates a key finding of the literature review as every delivery solution proposed in the literature has limitations or disadvantages, thus making the literature fragmented and the decision-making more complex.

The last two last-mile alternatives are Crowdsourcing and Electric vehicle. The low rank of the Electric vehicle is expected as it is the worst alternative in four of the nine sub-criteria (Visual pollution, Operational costs, Congestion, Safety & security). In fact, these two solutions are closer to the negative ideal solution (0) that the ideal solution (1.0000).

Probably the most important conclusion is that the experts perceive all solutions with very identical expected benefits. These results might corroborate the comments made by the experts regarding the benefits of combining solutions.

5.4 Adequacy in the historic center of Porto

Considering the methodology behind this research, the above results are believed to be generalizable to other geographic contexts with similar attributes as Porto's historic center. Furthermore, adopting a last-mile delivery scheme based on any of the considered alternatives could potentially alleviate some of the experienced problems.

However, according to the results, two alternatives are better suited for this geographical context – parcel lockers and cargo bikes. Therefore, it is interesting to examine if this ranking would be practicable in Porto's historic center.

On one hand, the parcel locker scenario would imply the use of ICE vehicles which are the main contributors to the deterioration of the air quality. On the other hand, considering that Porto's air quality is currently very positive, an argument could be made that this externality of the parcel locker could be neglected, as its implementation would improve Porto's air quality status because it significantly produces less pollution than traditional delivery schemes.

Moreover, the air pollution generated from the last-mile operation would be completely eradicated as cargo bikes do not produce any sort of air pollutant.

The noise nuisance that the citizens and tourists are exposed to would also be severely decremented by using cargo bikes. The same is expected to happen in a parcel locker scenario but with significantly much more limited results.

Using parcel lockers implies the existence of infrastructures that can indeed affect the visual aspect of the city. However, although this historic center has limited space for new technical infrastructures, it has a lot of small and medium-sized commercial stores distributed across the center that can safely allocate these parcel lockers. With this, the parcel locker could remove delivery cars from the streets, without generating dedicated customer trips or impacting the visual aesthetic of the city.

Moreover, visual pollution could also be alleviated by adopting smaller vehicles like cargo bikes. This attribute makes them excellent alternatives to improve traffic fluidity and to operate through Porto's narrow streets.

It is noteworthy that Porto, and its historic center in particular, already have measures aimed at limiting these problems, like the implementation of zones with conditioned car access [192]. Nevertheless, adopting either solution can be another important measure to mitigate these problems.

All these positive factors could inevitably translate into acceptance by the population regarding such delivery schemes. Moreover, from a customer perspective, a scheme based on cargo bikes would be almost indistinguishable from the traditional one.

However, the biggest downside of the practicability of a parcel locker-based solution is that it induces major changes to the traditional scheme. Therefore its acceptance is dependent on the customer's behavior and preferences. Note that, according to various authors in the literature, there is general consumer acceptance towards a parcel locker solution.

The major downsides of cargo bikes in last-mile operations pointed out by the literature and by the experts can condition the suitability of this alternative. The literature classified cargo bikes as alternatives needing adequate road infrastructure and policies. Today, there are no dedicated bike paths in Porto's historic center. However, there are multiple bicycle parking stations scattered and one path along the Douro river is planned, which suggests that this solution will become more feasible in future years [193].

Furthermore, the academic authors and consulted experts also exposed some economic and technical disabilities of this vehicle. Considering Porto's rough terrain with a high slope, this could be the most severe setback to this solution. For example, Porto's topographical characteristics could make the delivery a more physically demanding job, thus implying higher labor costs.

Moreover, it is not clear that cargo bikes could lead to operational cost reductions. This is also associated with the speed and load limitations that imply a lower number of deliveries by travel and/or by round. The opposite happens in parcel locker-based scenarios that, by the reduction of the traveled distances and labor necessities, can lower the operational costs.

A common barrier is that any solution's feasibility is heavily dependent on the city's legal and institutional system. Porto's is known for being complex and with multiple stakeholders with authority, which can delay this shift away from the problematic *status quo* [189, 186].

As the results suggested, the combination of the alternatives can create a symbiosis environment where the cons of one solution are 'canceled' by the pros of the other. In fact, the combination of parcel lockers and cargo bikes was proposed by an article in the reviewed literature ([32]).

However, according to the reviewed literature; the experts' comments; and the particular vicissitudes of Porto's institutional system, any sort of collaboration necessary for the implementation of a combined approach will be extremely difficult to coordinate.

This combination could be for example made by placing a set of parcel lockers in zones with rougher terrain, and by doing the parcel distribution with cargo bikes only in the more plain zones. Another example could be using the parcel locker as a consolidation point from where cargo bikes would pick up the parcels and deliver them across the historic center.

5.5 Chapter summary

These results contributed to the understanding of an unexplored topic such as last-mile operations in historic centers. Several conclusions were drawn from the results. The most relevant were: (i) the Economic dimension is more valued than the Environmental or Social, thus corroborating the literature; (ii) Air pollution, Safety & security, and Operational costs are more valued than Visual pollution, Load capacity, or Acceptance; (iii) Parcel locker and Cargo bike top the rankings for most sub-criteria; (iv) all solutions are very closely valued, thus suggesting a combination of solutions; (v) the two best ranked are significantly distant to be considered ideal solutions; (vi) the adequacy of the results in Porto can lead to improvements to the historic center's sustainability, but their actual feasibility is arguable.

Chapter 6

Conclusions

The main objective of this dissertation was to provide a framework that may assist the involved sectors in further understanding the urgent problem that is the last-mile and its possible solutions. The research objectives are the characterization of the research field (RQ1); the structuring of last-mile operations in historic centers (RQ2); and the prioritization of criteria and solutions for these operations (RQ3).

Accordingly, this work's main contribution is threefold. The first contribution is the extensive systematic literature review that provides a holistic and wide overview of the fragmented research area of last-mile operations. This contribution depicts how the last-mile research field is characterized in bibliometric terms (e.g., who are the most relevant authors) and in thematic terms (e.g., what are the main disadvantages of cargo bikes).

The main conclusion of this first contribution is the confirmation that the research field is characterized by its multidisciplinary nature, as there is an increasing number of published studies conducted under perspectives that range from Environmental Sciences & Ecology to Transportation. This is further evidenced by the six thematic clusters identified, which encompass a multitude of concepts and solutions from very different perspectives, and the different methodologies followed. It is also noteworthy the fact that the economic dimension is the most considered, suggesting that the main driver for innovation in the last-mile and city logistics is (still) the generation of bigger profits. Moreover, the fact that more than half of the publications do not consider simultaneously the three sustainability dimensions, and the fact that the most polluting countries contributed little to the research should be stressed. This part of the work also showed that, although there are various last-mile solutions proposed in the literature that might alleviate some of these problems, most carry disadvantages or restrictions that complicate the decision-making.

Apart from being one of the contributions of this work, this systematic literature review also supported the remaining dissertation's development. Based on this search and on an additional set of literature, a hierarchical model that structures last-mile operations in historic centers was defined. This model was evaluated by nine interviewed experts.

The experts confirmed the urgency of studying this topic and the importance of this work. Moreover, the experts corroborated the adequacy and generalization of the model; discussed other criteria and delivery alternatives that could be considered; and suggested modifications to the model, most of which were followed.

The hierarchical model is this work's second contribution. The model provides a simple but complete way to structure these sensitive operations and thus aiding a decision-maker or another researcher in understanding the various dimensions to be considered. Moreover, the analyses made to the experts' comments can also be a valuable input to deepen the knowledge regarding this rarely discussed topic of last-mile in historic centers. The third contribution is the investigation of which criteria and solutions for last-mile operations in historic centers are prioritized by the experts, and if these results would be adequate and practical.

This quantification, based on a combined AHP-TOPSIS approach, referred to a particular case study – the historic center of Porto – and the obtained results depicted a variety of conclusions that can deepen the knowledge and aid decision-making. The experts considered the three sustainability dimensions to be all equally valuable. However, they maintained the same order evidenced in the literature (Economic > Environmental > Social). Air pollution, Safety & security, and Operational costs were the most valued sub-criteria, whereas Visual pollution, Load capacity, and Acceptance were the least.

Only the Parcel locker and the Cargo bike alternatives are closer to the ideal solution than to the negative ideal solution. Moreover, all sub-criteria, except Delivery speed, are either led by Parcel locker or by Cargo bike. However, all solutions have similar closeness coefficients therefore a combined approach might be the most optimal. Nevertheless, Parcel locker has a higher closeness coefficient and seems to be adequate in Porto's historic center. However, due to its dependability on the customer's behavior, and on the city's conflicting legal and institutional system, the actual feasibility is arguable and not clear.

Therefore, this work could be a good reference for other researchers, as its results and methodologies may be a starting point for other research projects; could assist politicians and other decision-makers (e.g., managers of logistic or e-commerce companies) in the urban and operational planning; could show managers of supermarket chains or public transportation systems how their sector can help in alleviating the last-mile burdens; and could also make consumers reflect, as they are part of the problem and can be part of the solution.

6.1 Limitations

This dissertation followed a rigorous, careful, ethical and critical approach throughout its development. However, some potential limitations can be listed, such as the potential exclusion of relevant contributions for the systematic literature review. Although the search query and keywords were adjusted several times, it is possible that some relevant articles were not included in the review sample, and therefore not analyzed. Another reason for this potential omission is the exclusion criteria defined. For instance, by excluding publications not written in English, some relevant contributions in other languages may have been omitted, or by excluding articles without a minimum number of citations, that may have excluded very recently published articles.

Some limitations could also have derived from the model definition, evaluation, and quantification. The participants' sample was closed when data saturation was expected to be reached, therefore there is a potential exclusion of relevant experts with relevant contributions. Moreover, the results are strongly associated with the criteria and alternatives selection, the assumptions made, and the experts' personal perceptions.

6.2 Future work

The literature review evidenced that a wide variety of concepts, themes, problems, and solutions are already being discussed under very different approaches by many authors. However, there are still various research avenues and opportunities remaining for deepening the knowledge on sustainable urban last-mile logistics. More research could be conducted, in particular real-life experiments, on the subject of drones or autonomous vehicles, as these are solutions with great potential, but whose impacts and application are still very unexplored.

Because the last-mile is such a diverse, ever-changing problem, a wide array of different adaptations and extensions to this work can be followed. First, evaluating other contexts like residential areas, megacities or industrial areas in different types of geographies or countries can further deepen the knowledge about this problem.

Establishing a participant sample more focused on city actors like logistics operators, politicians and citizens can provide a more holistic view and thereby generate a more complete evaluation.

The results suggested the great potential for creating a symbiotic delivery scheme that combines multiple last-mile solutions. Therefore, following this idea can lead to very positive alternatives to the *status quo*.

This research also uncovered a lack of studies focused on the last-mile operations in historic centers. An alarming finding due to the technical complexity and the socio-economic importance of these centers.

The practical effectiveness of the model and its results could also be explored in future research, for instance, by conducting field experiments on Porto's historic center.

Since it is believed that this research can be an important tool and/or a starting point for both academics and practitioners, spreading it and further developing it can inspire additional, more practical contributions to improve these complex operations. In this context, two academic publications derived from this dissertation:

- Silva, V., Amaral, A., Fontes, T. (2022) "Anticipation of new and emerging trends for sustainable last-mile urban distribution". Published and presented on *6th Conference on Sustainable Urban Mobility. Skiathos Island, Greece, 31 August - 2 September 2022.* The article was nominated for the CSUM2022 Young Researcher Awards.

- Silva, V., Amaral, A., Fontes, T. (2022) "Sustainable urban last-mile logistics: a systematic literature review". Submitted to *Sustainability*.

Further academic developments of this work are on the horizon. The two mentioned publications are attached in Appendix F.

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Appendix A

Methodology theoretical background

This work's methodology was designed according to the Research Onion framework proposed by Saunders et al. [131]. This framework can be graphically represented as presented in Figure A.1. According to Saunders et al. [131], the researcher needs to pass through these six layers of the onion, from outside to inside (i.e., from Research philosophy to Techniques and procedures).

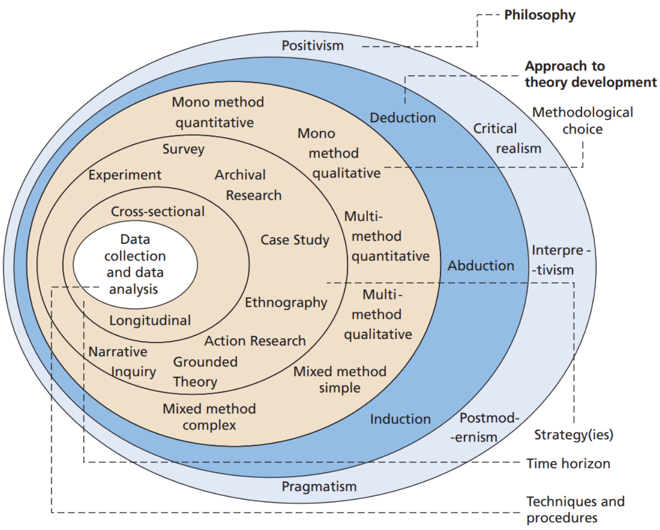

Figure A.1: Research Onion [131].

A.1 Research philosophy

The assumptions that an author will make during a research are ontological, epistemological, and axiological [131]. The ontological concerns the researcher's assumptions about the nature of the world and reality, determining what is researched, and how. The epistemological refers to assumptions about knowledge, determining what is considered to be satisfactory knowledge. The axiological refers to the influence of values and ethics within the research process, determining which researcher's values is incorporated into the study [131].

According to Saunders et al. [131], there are five major research philosophies: two classical positions – positivism and interpretivism – and three rather recent – critical realism, postmodernism, and pragmatism [131].

Positivism follows the rule that reality is objective, thus knowledge can only be sourced from empirical data based on observations and metrics, whereas interpretivism is a philosophy that considers that reality is socially constructed, thus knowledge and facts are subjective and relative to the people or the context [131, 194]. The other three positions emerged as alternative positions. Critical realism is a philosophy that sees observations and experiences, as a result of objective structures and mechanism. Pragmatism states that knowledge is only relevant when it enables action. Postmodernism seeks to find the knowledge that has been excluded or ignored.

To help researchers explore this topic, Bristow & Saunders [195] developed a reflexive questionnaire-based tool called Heightening Awareness of Research Philosophy (HARP).

A.2 Approach to theory development

There are three main approaches: deductive, inductive, and abductive [131]. In a deductive approach, the research starts with theory. In other words, the researcher will develop hypotheses based on existing theory (e.g., the extant literature) which will be tested by the following research (e.g., collecting and analyzing primary data), thus leading to either a confirmation or rejection of the theory. The contrary occurs in an inductive approach, as the research starts with the data collection. From the analysis of this data, the research will develop new theory. The abductive approach combines the previous two approaches, by moving back and forth between data and theory [131, 196].

A.3 Methodological choice

A research can be quantitative and/or qualitative. Quantitative research designs are focused on examining the relationships between numerical variables, which are measured and analyzed using mathematical techniques, while qualitative designs are focused on examining descriptive data that cannot be numerically measured like personal experiences or descriptions [131].

Both quantitative and qualitative designs can either be mono method or multi-method. A mono method is when only a single data collection technique is used, while a multi-method is when it is used more than one technique. There is also a third method, that integrates the use of both quantitative and qualitative research designs, known as mixed method [131].

Moreover, the research purpose can be exploratory, descriptive, explanatory or evaluative [131]. An exploratory research helps the development of deeper knowledge in a certain research field. Saunders et al. [131] argues that literature searches and unstructured interviews like interviewing experts, in-depth interviews or focus groups, are the ways to conduct exploratory research. Therefore, in exploratory research, data is likely to be qualitative. A descriptive research aims to gain an accurate representation of events, persons or situations, therefore only describing something, not developing or explaining any further. This approach is likely to be combined with a different approach [131]. Explanatory studies focus on establishing causal relationships between variables, thus expanding the descriptive approach, as it not only describes a situation but also tries to find the reasons behind it. The last type of research purpose is evaluative and aims to gain knowledge concerning the level of effectiveness of something.

A.4 Strategy

Saunders et al. [131] lists various research strategies: experiment; survey; archival and documentary research; case study; ethnography; action research; grounded theory; and narrative inquiry.

Ethnography traditionally involves describing and interpreting the social world through firsthand fieldwork, differing from contrived or artificially created settings such as is the case of an experiment strategy, that is rooted in natural sciences and laboratory-based research. Another strategy is archival and documentary research that is based on analyzing administrative records and documents. Accordingly, these three strategies were unsuitable for the research goals [131].

Action research is a strategy with a longitudinal nature, that associates research with practice by involving researchers and practitioners in a continued cycle of diagnosing, planning, taking action and evaluating. Therefore, the main focus of this strategy is to promote change within the organization [131]. Because this type of researcher-participant collaboration was not contemplated in this research, this strategy was inappropriate.

Grounded theory is a very time-consuming and intensive strategy that requires experience, and it is primarily used to develop theoretical explanations [131]. For these reasons, it was also not appropriate for this particular study.

Because it was believed that, for the research's purposes, it was better to collect "bits of data that flow from specific interview questions and which are then fragmented during data analysis", rather than collecting and analyzing the data as complete stories or narratives, narrative inquiry was excluded from consideration [131].

A.5 Time horizon

According to Saunders et al. [131], the decision here is between a cross-sectional study or a longitudinal study. The first answers a question at a certain point in time, while the second answers it repeatedly over an extended period.

A.6 Data collection techniques and procedures

There are two main classes of data: primary data and secondary data. Primary data is data that is collected by the researcher for his research purpose. This data can be collected through observation, interviews or questionnaires. Secondary data is data originally collected for other purposes, available in journal articles, databases, or large surveys like censuses of population [131].

The sampling techniques can be classified into two categories: probability and non-probability sampling [131]. Probability sampling is characterized by random sampling, meaning that each member of a population has the same probability to be in the sample, thus being indicated for a (large) survey and experiment research strategies [131]. Non-probability sampling is characterized by non-random sampling i.e., not all members of a population have the same probability to be in the sample [131]. Saunders et al. [131] lists quota, purposive, volunteer, and haphazard as sampling techniques associated with non-probability sampling.

The quota technique was excluded from consideration because the sample did not have to represent the population proportionally. The volunteer techniques were also excluded as no participants volunteered to be part of the research. The haphazard technique was excluded due to the lack of credibility of the findings. Therefore, purposive techniques were used in this process.

Saunders et al. [131] lists eight purposive sampling techniques: extreme case, heterogeneous, homogeneous, typical case, critical case, politically important, opportunistic, and theoretical.

A.6.1 Semi-structured interviews

Saunders et al. [131] differentiates interviews as non-standardized and standardized. Non-standardized interviews are either semi-structured interviews or in-depth interviews (also known as unstructured interviews). Semi-structured interviews are based on flexible settings as the questions and order of the questions may alter, and questions can be added in order to explore a particular subject. In-depth interviews are unstructured, informal interviews without a predetermined list of questions thus resulting in a free discussion concerning a particular theme.

A.6.2 Questionnaire

Saunders et al. [131] considers two questionnaire modes: self-completed where the respondents answers the questions themselves, and researcher completed where the researcher answer the questions based on the respondent's answers. Each mode can be conducted with various techniques (e.g., internet, postal, telephone, face-to-face, etc.).

Appendix B

Interview invitation and confirmation examples

B.1 Interview invitation example

Good morning,

Following the prior contact established by Dr. António Amaral / Dr. Tânia Fontes, I would like to thank you for your interest in participating, as an expert, in the evaluation of a model for the selection of logistics distribution strategies (last-mile) in historic centers.

The objectives of this interview would be: (i) Collection of insights from experts and (ii) Validation of a hierarchical model.

The interview would have a maximum duration of 30 minutes and would be carried out via Zoom.

Therefore, I inquire about your availability to schedule this interview.

Thank you for your collaboration,

Vasco Silva

B.2 Interview confirmation example

Good morning,

Excellent. Thank you for the collaboration.

The interview will be carried out via Zoom at the link: https://videoconf-colibri.zoom.us/j/*.

Please read the attached document describing the study and, if you confirm your participation, sign and send the informed consent to 1171000@isep.ipp.pt.

If there is a need for further clarification, you can contact 1171000@isep.ipp.pt.

Thank you,

Vasco

Appendix C

Study description and informed consent

C.1 Study description

This study is part of a master's dissertation at Instituto Superior de Engenharia do Porto (ISEP), being carried out in partnership with INESC TEC, within the scope of of the e-LOG research project. This dissertation is being developed under supervision of Tânia Fontes, researcher at INESC TEC, and António Amaral, assistant professor at ISEP.

This study is composed by two phases:

1) The first phase will consist of an interview carried out remotely, with a maximum duration of 30 minutes. This phase will contribute in a qualitative way to evaluate the model for the multi-criteria analysis, as well as gathering insights of experts. The entire session will be recorded for analysis purposes, being deleted after these. The personal identity of participant will not be disclosed in the publication of the results.

2) The second phase will consist of an online questionnaire lasting approximately 10 minutes. This phase will contribute in a quantitative way to quantify the referred model. This questionnaire consists of 12 multiple-choice questions referring to the AHP method and nine ranking questions referring to the TOPSIS method. The questionnaire is anonymous, as well as all data processing.

For any further clarification you can contact 1171000@isep.ipp.pt.

Thank you for your collaboration.
Porto, September 2022
[Digital signature of the researcher]

C.2 Informed consent

I, the undersigned, declare that I agree to collaborate in the study described previously, thus giving my consent for the processing of my data, under the commitment of anonymity and confidentiality.

I further declare that:

a) I was duly informed of the purpose and mechanics of the study;

b) I had the opportunity to inquire more information about the study;

c) I understand that my participation is entirely voluntary and that I may withdraw from the study at any time without penalty.

d) I accept that the interview is recorded;

e) All relevant data resulting from the interview will be collected;

f) All data resulting from the questionnaire will be collected;

g) All data collected will be processed for analysis purposes and duly stored during this analysis, being subsequently deleted.

Porto, September 2022
[Digital signature of the participant]

Appendix D

Interview guide

D.1 Research objectives and expected outcomes

D.1.1 Research objectives

- **RQ1:** How can the last-mile research field be characterized?
- **RQ2:** How can the last-mile operations in historic centers be structured into a hierarchical model?
- **RQ3:** Which criteria and solutions are prioritized for last-mile operations in historic centers?

D.1.2 Expected outcomes

- Model evaluation with eventual suggestion of improvements, corrections;
- Gain expert insights about the last-mile operations in historic centers.

D.2 Interview

D.2.1 Introduction

- Remind the participant about the consent for recording, transcription, analysis and reporting of findings;

- State that confidentially will be assured, the recording is only for research purposes and will be deleted after it;
- Present the academic context of the research;
- Present the research objectives and the research procedure;
- Justify the importance of the participant's contribution.

D.2.2 Planned questions

- What do you think about this hierarchical model?
- Is there something you would like to mention regarding the last-mile operations in historic centers in general?

D.2.3 Conclusion

- Is there something you would like to suggest for the study development?
- [After listing the key points] Is this an adequate summary?
- How would you like to be represented in the work in terms of position, specialty, and years of experience?
- Would you like to receive a copy of the concluded work?
- Remind the participants of the following stages of their contribution.

Appendix E

Questionnaire invitation

Good morning,

Firstly, I would like to thank the valuable contribution given in the interview to the evaluation of a model for the selection of logistics distribution strategies (last-mile) in historic centers.

As previously mentioned, after the evaluation and review of the referred model, the second stage aims to quantify it through a short questionnaire. This quantification will have as Case Study the historic center of Porto.

I enclose a file which presents the hierarchical model, the various assumptions to consider, and the main characteristics of the historic center of Porto.

The questionnaire will last approximately 10 minutes and consists only of the questions necessary for the application of the AHP and TOPSIS methods (previously presented in the interview).

Therefore, I invite you to complete the questionnaire from an expert perspective until September 30th (Friday)[1]. The questionnaire is available at https://forms.gle*.

The questionnaire is completely anonymous and all other confidentiality precepts will be maintained according to the informed consent.

If you need further clarification, please contact me via email 1171000@isep.ipp.pt.

Thank you in advance for all your collaboration,

Vasco Silva

[1] This deadline was later extended

Appendix F

Academic articles

Anticipation of new and emerging trends for sustainable last-mile urban distribution

Vasco Silva[1,2], António Amaral[1,2], and Tânia Fontes[1]

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[2] Polytechnic Institute of Porto, School of Engineering, Porto, Portugal
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Abstract. Globalization and the COVID-19 pandemic led to an increased number of consumers using e-commerce services. This trend has been raising the demand for logistic activities, especially on the last-mile. This part of the supply chain is expensive and ineffective, and a source of negative externalities such as air and noise pollution, traffic congestion and accidents. The anticipation of innovative solutions can help to mitigate these costs. In this context, this paper provides a systematic literature review of the existing literature regarding emerging solutions for last-mile parcel delivery. For guiding the development of more sustainable last-mile parcel distribution, and to provide some insights for future research, we identified and summarized the emerging concepts within this field domain. The results show that innovative solutions have been emerging at different levels: (i) definition of new crowdsourcing-based models, (ii) use of new types of vehicles, and (iii) development of optimization systems based on data collection and the combination of different technologies. Moreover, recent studies show that new strategies are being developed focusing on using consumers as active actors of delivery; non-road and autonomous vehicles are promising concepts in last-mile operations; and different logistic operations, such as vehicle routing, are being optimized with data analytics, cloud technology and mobile apps.

Keywords: systematic literature review, last-mile, parcel delivery, sustainability, business model

1 Introduction

The advent of globalization allowed consumers and businesses to trade in different countries, popularizing the development of e-commerce practices. According to Eurostat [13], EU consumers' interest in e-commerce grows each year, pointing out that 74% of internet users shopped online in 2021. With this trend, consumers' requirements change, as they start demanding more customization and more convenience [6].

The recent COVID-19 pandemic and subsequent restrictions also led to a significant change in consumers' and businesses' behaviour, increasing even more the adoption of e-commerce practices [22]. In this context, businesses seek to identify marketing and competitive opportunities by offering faster and cheaper deliveries to their customers [1].

All these factors increase the demand for logistic activities, especially on the last-mile, i.e., the last stretch of a parcel delivery service, from the last logistic center to the recipient's destination point [23]. This part of the supply chain is considered very ineffective and expensive, accounting for 13–75% of the total supply chain cost [16]. These costs can change depending on several factors like delivery failures or time windows. Last-mile operations also result in social and environmental externalities such as air and noise pollution, traffic congestion and accidents [26]. These impacts mainly affect urban areas where pressure has increased due to the growing population and consequent urbanization, as 60% of the world's population will live in urban areas by 2030 [43].

To mitigate these internal and external costs, private and public sectors are urged to reinvent themselves and explore innovative solutions. In this context, it is essential to anticipate those new solutions, studying their viability and impacts. Therefore, this paper aims to review the existing literature regarding emerging solutions for last-mile delivery.

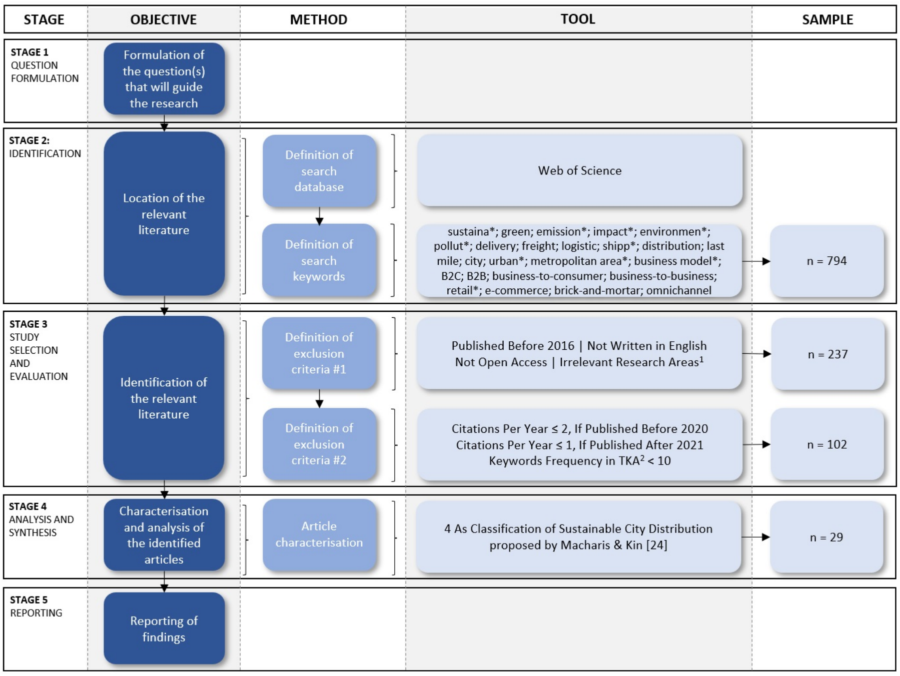
The remainder of this paper is organized as follows. Section 2 describes the methodology adopted for the systematic literature review. Section 3 presents the results of the review describing and synthesising the concepts and results of each contribution. Section 4 presents the discussion and Section 5 summarizes the paper and suggest new research avenues.

2 Methodology

A systematic literature review is a methodical process that aims to analyse the state of the art of a subject field [3], by following a strict set of guidelines, and by adopting a replicable, scientific and transparent process [41]. The systematic literature review presented in this document was based on the guideline proposed by Denyer & Tranfield [10]. Figure 1 illustrates the process followed.

First, we defined the scope of the systematic review. According to Thomas et al. [40], the most efficient way to do this definition is by formulating review questions. Therefore, the presented systematic literature review aims to answer the following research question: What are the emerging last-mile logistic concepts in the recent literature?

Then, a search in the Web of Science database was made to support the creation of a comprehensive list of documents relevant to the review purposes [10]. This database was used as it contains a wide collection of documents and most of the indexed journals are peer-reviewed [8]. The query was directed to the title, keywords and abstract of the available documents. This search query allowed the identification of publications that approach the subject of urban logistics of different business models, with a focus on sustainability. With this search, we obtained a preliminary sample with 794 contributions (done in March 2022).



[1]For example: Public, Environmental & Occupational Health; Food Science & Technology; Biodiversity & Conservation. [2]TKA: Title, Keywords and Abstract.

Fig. 1. Systematic literature review methodology (Source: Developed by the authors).

In the third stage, we defined two sequential objective screenings. These screenings were based on a set of criteria that aimed to select only scientifically and thematically relevant studies. Based on these criteria, articles are excluded if (a) published before 2016; (b) not written in English; (c) not open access; (d) classified with irrelevant research areas; (e) do not have a minimum number of citations per year; and (f) include less than 10 keywords in its title, keywords or abstract. After both screenings, we obtained 102 documents.

The following stages were based on the classification proposed by Macharis & Kin [24], which grouped city distribution solutions into 4 As: “Awareness”, “Avoidance”, “Act and shift”, and “Anticipation of new technologies”. Our paper only approached the last A: “Anticipation of new technologies”, which, according to Macharis & Kin [24], includes: “Full electric vehicle”; “Hybrid electric plug-in vehicle”; “Hydrogen vehicle”; “Gas-powered vehicle”; “Non-road technologies (i.e., drone, hybrid airship, pipelines)”; “Other (AFMS[3], RFID, GPS)”; “Big data analytics” and “Crowdsourced deliveries”. Documents that focused equitably on more than two As were excluded. Therefore, by following these criteria, our review was based on 29 articles.

[3] AFMS: Advanced Fleet Management Systems.

3 Emerging concepts

The presented literature review characterises the different concepts, objectives, methods and results stated in the papers included in the literature sample. This section is structured on the four main types of concepts identified in the literature: "Alternative vehicles", "Fleet management systems", "Emerging technologies and techniques", and "Crowdsourcing". The results are listed in Table 1.

Table 1. Concepts and sustainability factors studied

		Sustainability Factor		
Ref.	**Concept**	**Environmental**	**Economical**	**Social**
[2]	Alternative Vehicles	X	X	X
[4]	Alternative Vehicles	X	X	
[12]	Alternative Vehicles	X		
[20]	Alternative Vehicles	X	X	
[42]	Alternative Vehicles	X	X	
[31]	Alternative Vehicles	X	X	X
[25]	Alternative Vehicles	X	X	
[29]	Alternative Vehicles	X	X	X
[37]	Alternative Vehicles	X	X	X
[38]	Alternative Vehicles	X	X	
[39]	Alternative Vehicles	X	X	
[5]	Fleet Management Systems		X	
[9]	Fleet Management Systems	X	X	X
[11]	Fleet Management Systems		X	X
[34]	Fleet Management Systems	X	X	
[44]	Fleet Management Systems	X	X	X
[45]	Fleet Management Systems		X	
[7]	Crowdsourcing	X	X	
[14]	Crowdsourcing	X	X	X
[15]	Crowdsourcing		X	X
[18]	Crowdsourcing	X	X	X
[35]	Crowdsourcing	X	X	X
[36]	Crowdsourcing		X	X
[19]	Emerging Technologies and Techniques	X	X	X
[21]	Emerging Technologies and Techniques		X	X
[28]	Emerging Technologies and Techniques		X	X
[30]	Emerging Technologies and Techniques	X	X	X
[32]	Emerging Technologies and Techniques	X	X	X
[33]	Emerging Technologies and Techniques	X	X	X

3.1 Alternative vehicles

The adoption of green alternative vehicles in urban logistics is a concept well disseminated in the literature and gathering increasing academic interest, in specific in using alternative fuel transports like electric vehicles [29, 31]. Elangovan et al. [12] and Martins-Turner et al. [25] simulated and then compared, the performance of electric and traditional food distribution trucks using real-life data from New York City and Berlin, respectively. Both authors concluded that there is a significant reduction in energy consumption and greenhouse gases emissions when adopting electric vehicles. Similar comparative-based studies were conducted by Tsakalidis et al. [42], Siragusa et al. [39] and Brotcorne et al. [4] adding even more evidence that electric vehicles have lower operational and environmental costs than traditional vehicles.

Anosike et al. [2] conducted a systematic literature review and interviews with industry players to assess their perception and identify the main challenges in the adoption of electric vehicles in last-mile operations. These authors identified that operational barriers (e.g., limited driving range), battery issues (e.g., long recharge times) and cost implications (e.g., high investment cost) are among the most commonly associated obstacles to the use of these alternative vehicles. The limited driving range issue is refuted in the previously mentioned study by Martins-Turner et al. [25] that concluded that the battery duration of electric vehicles is suitable for most operations. Iwan et al. [20] conducted a real-life experiment in Poland that added evidence to the suitability of the electric vehicles' battery capacity in performing last-mile deliveries. Settey et al. [38] contributed by showing that electric vehicles' driving range could be enhanced if they are recharged during loading/unloading.

Emerging vehicular technologies have also been studied. de Oliveira et al. [29] and Patella et al. [31] conducted similar literature reviews that showed that drones, modular vehicles and autonomous vehicles are being studied by multiple researchers. The latter additionally stated that autonomous vehicles are the most promising and challenging solution for last-mile logistics. Serrano-Hernandez et al. [37] examined and compared different transportation modes based on Pamplona residents' priorities and concluded that residents prefer the usage of non-road vehicles such as drones in the last-mile operations over cargo bikes or traditional vans, mainly because residents associate this technology with better life quality, pedestrian safety, and reduced air and noise pollution.

3.2 Fleet management systems

Fleet management technological systems aimed at optimizing fleet derived operations such as routing or parking have been the subject of multiple studies. Rincon-Garcia et al. [34] introduced a time-dependent vehicle routing optimization model based on a large neighbourhood search algorithm that decreases the number of vehicles used, the travelled distance and the route duration. The authors also showed that imposing a time window substantially increases the cost and the CO_2 emissions. Cerrone et al. [5] demonstrated through a routing optimization model that in Milan, the routes' cost and total length are not affected by the application of street crossing penalties.

Two authors used genetic algorithms to develop models for fleet management optimization. The model proposed by Yang & Wu [45] optimized e-commerce vehicle routing and showed that the total route length increases as the time windows exigencies increase, while the model proposed by Wang & Bae [44] revealed that using fewer vehicles can reduce the operational costs, but the time windows failures will increase.

Another fleet derived operation whose optimization could have significant impacts is freight parking. Dalla Chiara et al. [9] designed a random utility model to optimize urban freight parking. Based on a simulation framework, the authors tested the model and concluded that reducing parking durations and parking in spaces reserved for passenger vehicles can reduce congestion, air pollution, accidents, delivery costs, street unattractiveness and illegal parking. Diana et al. [11] developed a GPS-based method to optimize urban freight loading and unloading area's examination. The method was evaluated for a real case study conducted in Turin and starts with the collection of geolocation data from the logistic vehicles, and then a clustering algorithm and a set of criteria (i.e., number of vehicles, congestion issues, street characteristics and retail locations) identify the most relevant locations for logistic operations.

3.3 Emerging technologies and techniques

Different publications have explored several emerging technologies and techniques, like the use of emerging data sources [30], tracking technologies [19, 21], the use of APIs or mobile applications [21, 28, 33], and cloud technologies [17].

Pan et al. [30] outlined a model based on data mining techniques to optimize last-mile operations of the perishable food product industry. The model uses electricity consumption data of customers' residences to estimate their absence. The results revealed that the model could reduce the number of failed deliveries and the total route length.

Hardware technologies like RFID, GPS, or cloud computing have been used to improve last-mile operations [17, 19, 21]. As concluded by Perboli & Rosano [32], RFID and GPS-based technologies are extensively used in European smart city projects, whereas the most used technologies in projects in USA and Canada are ICT-based models, databases and cloud computing. These hardware concepts are frequently combined with software solutions such as machine learning, simulation models, or databases [17, 19, 21].

Gutierrez-Franco et al. [19] proposed a data-and-model-driven framework for vehicle-related operations optimization. This framework relies on hardware (RFID, GPS); software (ERP, TMS, WMS, GIS); and optimization, machine learning and simulation models. Some of the advantages of the proposed system include reducing the number of vehicles in use, increasing the resource capacity utilization, and reducing the cost of fleet operations.

de Kervenoael et al. [21], based on independent delivery workers' practices, stated that using internal technological systems (e.g., parcel QR codes, logging data, tracking technologies) combined with external applications (e.g., Google Maps, WhatsApp) could lead to more sustainable logistics operations. These external applications can collect data from traffic and meteorological conditions, as well as improve communications. Mkansi et al. [28] examined how the use of mobile applications can optimize e-grocery logistics, namely managing demand and cooperation between competitors. Pronello et al. [33] adopted a different approach and analysed the stakeholders' need for freight optimization apps, and concluded that transport operators only value information about traffic disruptions, loading/unloading bays status, video surveillance and less polluting routes.

Giusti et al. [17] summarized the methods and results of the multimodality transportation project SYNCHRO-NET. This platform is based on cloud technology and a set of optimization and simulation software that can improve freight transportation and logistics management in real-time. Some of the most relevant results are the reduction of CO_2 emissions, route length and duration, and consequent transportation costs.

3.4 Crowdsourcing

Another emerging concept studied by various authors is crowdsourcing logistics i.e., the outsourcing of logistic services to a network of people, with benefits for all parties [27]. At this level, comparisons of different solutions [35, 36], a conceptual framework [18] and several models [7, 14, 15, 35] were proposed and studied.

Several of the crowdsourcing models proposed use public transport for the last-mile delivery operations. Chen & Pan [7] outlined a system that supports the application of a crowdsourcing model based on taxi drivers. Additionally, an analytical crowdsourcing model where commuters deliver parcels using the metro with parcel lockers located inside or near the station was proposed by Gatta et al. [14]. This model could lead to significant environmental benefits (on average, less 239 kg of particles per year), but could only achieve economical sustainability if public incentives and subsidies are applicated by the policy-makers. The same model was considered by Gatta et al. [15] but aimed towards the willingness to act as a crowdshipper (supply-side) and to use this service (demand-side). The results showed that the supply side prioritizes the parcel locker location over the remuneration per delivery; the demand side prefers flexible delivery dates and time windows over lower shipping fees or shipping time; and that younger people are more willing to act as a crowdshipper and to use this service.

To support the integration of crowdsourcing practices into a traditional delivery network, Guo et al. [18] proposed a conceptual framework based on five basic principles. According to these authors, the proposed integration could help reduce the environmental and economic last-mile costs, but needed a large number of participating workers and that an exclusive crowdsourcing system couldn't totally replace the traditional delivery system.

The identification of the best models is a difficult task. To overcome this issue, Seghezzi et al. [36] benchmarked the economic performance of a crowdsourcing-based model versus a traditional express delivery model. The results suggested that the average cost per delivery of a crowdsourcing model is lower for every number of workers and every vehicle mix (i.e., bike, motorbike, car and foot) except for a "100 % foot" model. The authors also concluded that a crowdsourcing initiative could lead to higher income for the deliverers. In addition, Rzesny-Cieplinska & Szmelter-Jarosz [35] contributed by developing a model for benchmarking various crowdsourcing solutions according to the needs of different stakeholders and concluded that the crowdsourcing initiative implemented by Amazon (AmazonFlex) had the most valuable characteristics.

4 Discussion

This paper is based on the classification proposed by Macharis & Kin [24], which clustered city distributions concepts according to 4 As ("Awareness", "Avoidance", "Act and shift", and "Anticipation of new technologies") with several concepts listed under each A. Macharis & Kin [24] listed under the A approached in our paper: "Full electric vehicle"; "Hybrid electric plug-in vehicle"; "Hydrogen vehicle"; "Gas-powered vehicle"; "Non-road technologies (i.e., drone, hybrid airship, pipelines)"; "Other (AFMS, RFID, GPS)"; "Big data analytics" and "Crowdsourced deliveries". Almost every concept was identified in the literature sample for our paper.

The results suggest that the new and emerging concepts for optimizing last-mile operations studied and proposed in our literature sample are strongly focused on alternative vehicles, as it represents more than a third of the considered articles. Vehicle-related operations such as routing or parking are also significantly represented. This could add evidence for the importance of transportation in improving the sustainability of city logistics.

An additional finding is that most articles do not consider the three sustainability pillars (environmental, economical and social), only considering one or two. In this context, the social factor is the least considered, being present in 62% of the articles, and the economical factor is the most considered, as it is present in 96% of the articles. This could mean that the main goal or motivation for introducing new and innovative solutions is the generation of higher financial profits and lower operational costs.

The adoption of sustainable alternative vehicles in urban logistics has gathered increasing interest from researchers, especially (full) electric vehicles [29,31]. Multiple authors compared the performance of electric vehicles and traditional vehicles, and concluded that there are significant operational and environmental advantages in adopting this type of vehicle [4, 12, 25, 39, 42]. The perceived obstacles related to the use of electric vehicles are also discussed and refuted, especially the limited driving range resulting from the battery capacity and the recharging needs [2, 20, 25, 38]. Other vehicular technologies such as autonomous vehicles and non-road technologies, namely drones have also been studied to examine their viability [29, 31, 37].

However, none of the studies included in this research approached hybrid electric plug-in, hydrogen or gas-powered vehicles. Hybrid airships, hovercrafts and pipelines were also not approached. This could suggest that these technologies and concepts were considered emerging or with great potential in improving the city logistics' sustainability when the 4 As classification was proposed in 2017. The most plausible justification for this change could be that the natural evolution of technology motivated researchers to shift their interest towards other concepts, namely (full) electric vehicles, as the technological advances led to higher battery capacity, lower recharging times and lower manufacturing costs (and consequent acquisition costs). Another possible interpretation for this change could be that the research of these omitted concepts did not led to satisfying results, thus being discontinued.

On the other side, the articles included in our research approached other alternative vehicles not clearly considered by Macharis & Kin [24] such as autonomous vehicles or modular vehicles. The reasoning could also be the technological evolution, as some of these concepts might not have been disseminated enough to be classified as "Anticipation" when the 4 As classification was published.

Advanced fleet management systems (AFMS) aimed at optimizing fleet derived operations such as routing or parking are also the subject of multiple studies. The routing optimization methods or models consider aspects like street penalties or delivery time windows and point towards the reduction of the number of vehicles used, the route length and the route duration [5,34,44,45]; while the parking optimization methods consider factors such as location and street policies, in order to reduce parking queuing duration or illegal parking, and consequent externalities such as congestion, air pollution or delivery costs [9,11].

Using other novel technologies (e.g., RFID, cloud computing) and techniques (e.g., (big) data analytics) is also approached in the reviewed literature. Authors suggest that mining electricity consumption data of customers' residences could reduce the number of failed deliveries and the total route length [30]; and the combination of hardware technologies with software techniques could reduce the number of vehicles in use, increase the capacity utilization rate, reduce route length and duration, reduce the operational costs and the CO_2 emissions [17,19]. On the other hand, the combination of logistic-specific technological systems with external applications could lead to more sustainable logistics operations [21], and using mobile apps can optimize demand management and cooperation between competitors [28].

Some technologies like cloud computing, WMS, QR code or open access platforms such as Google Maps or WhatsApp, are also not mentioned by Macharis & Kin [24]. The justification could be the same for the other omissions: these technologies might be very recent concepts among the research community.

The concept of crowdsourcing is also present in the considered sample. This concept was studied under different approaches, such as the examination of the integration of crowdsourcing into a traditional delivery network [18]; the benchmarking of different crowdsourcing initiatives [35]; the comparison of the performance of a crowdsourcing model versus a traditional model [36]; or crowdsourcing initiatives where public transport is used [7, 14, 15]. Results suggest that developing a crowdsourcing initiative could lead to environmental (e.g., less pollution particles), social (e.g., higher income for the deliverers) and economic benefits (e.g., less cost per delivery). However, these benefits are dependent on aspects such as the number of participating workers or the application of incentives or subsidies by the policy-makers [14, 18].

5 Conclusion

This paper provided a systematic literature review of the existing literature regarding emerging solutions for last-mile delivery, based on the classification proposed by Macharis & Kin [24]. Using the Web of Science database, a procedure was established resulting in 29 papers of interest.

The adoption of electric vehicles in urban logistics is well studied and could lead to improvements for sustainable logistics, while drones and autonomous vehicles are promising concepts in last-mile operations. Fleet management systems aimed at optimizing fleet derived operations such as routing or parking are also the subject of multiple studies and point towards the reduction of the number of vehicles used, the route length and duration, illegal parking, and consequent externalities such as congestion, air pollution or delivery costs. Adopting and combining novel technologies and techniques such as data analytics, GPS, APIs and mobile apps, cloud technology, or simulation methods is also approached in the reviewed literature and could improve logistics by reducing the number of failed deliveries, total length or CO_2 emissions, as well as enhancing cooperation between competitors and the load capacity rate. Crowdsourcing is also studied under different approaches that suggest there are environmental, social and economic benefits associated with this kind of initiative.

Some concepts (e.g., gas-powered vehicles, pipelines) listed by Macharis & Kin [24] were not found in the literature sample, suggesting that these technologies and concepts become outdated or did not led to satisfying results. On the other hand, the literature considered in this research approached other concepts not clearly considered by Macharis & Kin [24] such as autonomous vehicles, cloud technology or WMS, suggesting that new concepts have emerged in recent years.

Although electric vehicles, fleet operational optimization systems, technologies like GPS or data analytics, and crowdsourcing are covered with different approaches by many authors, various research avenues and opportunities remain for deepening the body of knowledge on sustainable last-mile urban distribution. Emerging vehicular technologies such as drones or autonomous vehicles could lead to revolutionising initiatives. Therefore, more research could be conducted in these domains, in particular real-life experiments. Another aspect that should be explored for future research is considering the so-called “triple bottom line of sustainability” i.e., considering environmental, economical and social aspects, as the majority of articles included in this review only focus on one or two aspects. The integration and combination of the multiple discussed concepts could also be the subject of relevant contributions. Another future research suggestion is conducting similar studies for the other three As (“Awareness”, “Avoidance” and “Act and shift”). Moreover, in future work, it might be relevant to explore the gaps/limitations previously disclosed, in order to propose a revised and extended version of the 4 As of sustainable city distribution.

Although the development of this paper followed a rigorous methodology, some limitations could be considered. The first limitation is the potential exclusion of relevant contributions. Although the search query and keywords were adjusted several times, it is possible that some articles could not be included. The same may have happened because of the exclusion criteria. For example, by only including publications written in English or with a minimum number of citations, some relevant contributions in other languages or very recently published thus no citations, may have been omitted.

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Review

Sustainable Urban Last-Mile Logistics: A Systematic Literature Review

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Abstract: Globalisation, urbanisation or the recent COVID-19 pandemic has been raising the demand for logistic activities. This change is affecting the entire supply chain, especially the last-mile step. This step is considered the most expensive and ineffective part of the supply chain and a source of negative economic, environmental and social externalities. The importance and urgency of this topic have recorded a significantly growth in academic interest. This article aims to characterise the sustainable urban last-mile logistics research field through a systematic literature review. The articles identified (n=102) discussed a wide variety of concepts, themes, problems, and solutions, under very different approaches. The review was organized into six thematic clusters: (i) Supply chain & channels; (ii) Delivery methods & attributes; (iii) Innovative vehicles; (iv) Logistic infrastructures & schemes; (v) Operational optimisation; and (vi) Emerging business models. From the concepts analysed, we found out that the so-called "triple bottom line of sustainability"; the integration and combination of multiple last-mile alternative concepts; the solutions' limitations; and the stakeholders' perceptions must be further explored.

Keywords: systematic literature review; logistics; last-mile; parcel delivery; sustainability

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1. Introduction

Globalisation induced significant changes in how consumers and businesses operate, either it being for facilitating trade in different countries or the possibility to buy products without leaving the house. In fact, more European consumers adopt e-commerce practices each year, with 74 % of internet users have shopped online in 2021 [1]. With this trend, consumers' expectations evolve as they begin demanding more from the e-commerce services in terms of customisation and convenience [2].

This change in consumer and business behaviour has been exacerbated by the recent COVID-19 pandemic and consequent restrictions, furthering increasing the acceptance of e-commerce practices [3]. In this dynamic context, businesses aim to identify competitive opportunities over their competitors by offering their customers faster and cheaper delivery options [4].

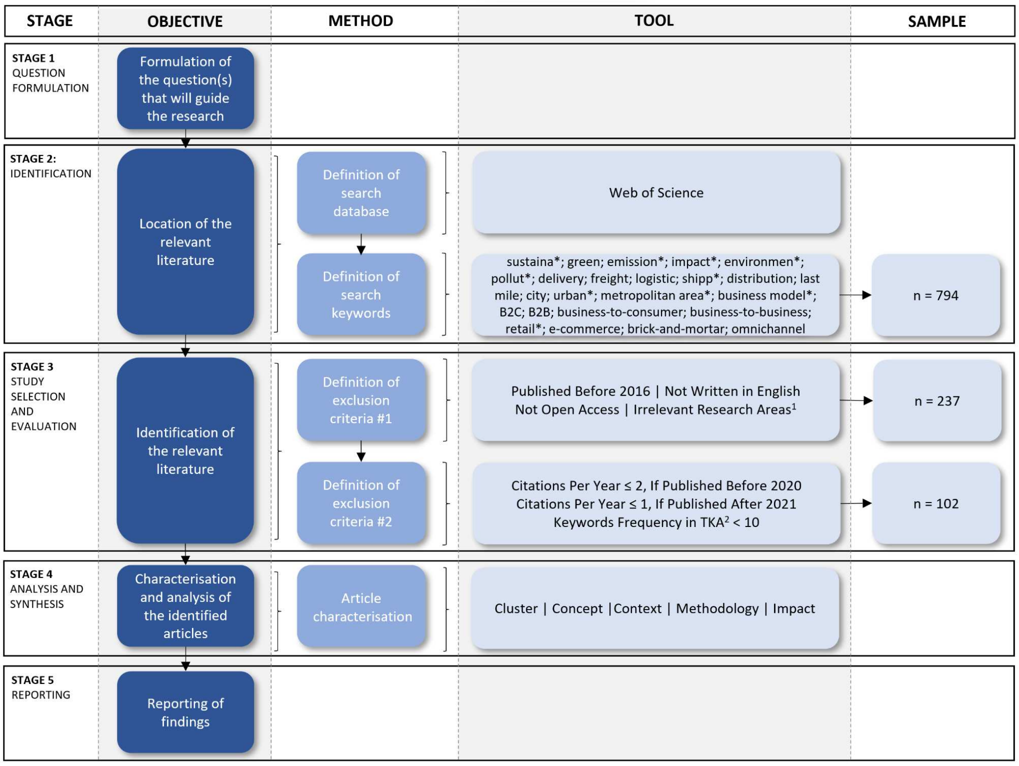
The impact of all these factors is reflected in the demand for logistic activities, particularly the last-mile, i.e., the last stretch of a parcel delivery service, from the last logistic infrastructure to the recipient's destination [5]. The last-mile part of the supply chain is considered very ineffective and expensive, accounting for 13–75 % of the full supply chain cost [6]. As expected, the last-mile operations also lead to environmental and social externalities such as air and noise pollution, accidents, and road congestion [7]. These impacts are more visible in urban areas where the pressure is high and will continue to increase due to the growing population and consequent urbanisation. About 60 % of the world's population will be living in urban areas by 2030 [8]. Therefore, there is an urgency to mitigate these internal and external costs.

Although changing the last-mile is not easy because of its multidisciplinary nature, the different academic sectors are studying the current problems of the last-mile logistics and exploring innovative solutions to reinvent the industry, thus optimising these problems. In this context, it is crucial to have a wide and holistic overview of this fragmented research area. Thus, the present paper aims to characterise the sustainable urban last-mile logistic research field through a consolidation and analysis of the existing literature.

The remainder of this paper is structured in five sections. Section 2 describes the methodology for the systematic literature review; Section 3 presents the thematic analysis, synthesising the concepts and results of the academic studies; Section 4 presents the characterisation of the research area according to the thematic cluster, the research methodologies adopted, and the sustainability dimension considered; and Section 5 summarises the article, suggest new research opportunities, and presents the limitations.

2. Methodology

A systematic literature review is a methodical, replicable and transparent process helpful in analysing the state-of-the-art of a research field [9,10]. The systematic literature review presented in this article was based on the guideline proposed by Denyer & Tranfield [11]. The process followed is illustrated in Figure 1.



[1]For example: Public, Environmental & Occupational Health; Food Science & Technology; Biodiversity & Conservation.
[2]TKA: Title, Keywords and Abstract.

Figure 1. Systematic literature review methodology followed.

The process begins by defining the scope of the systematic review with the definition of the review questions. They are:

- RQ1: What sustainable last-mile concepts have been studied in the recent literature?
- RQ2: What are the drivers and challenges associated with each last-mile concept?
- RQ3: How can the last-mile research field be characterised?

The second stage aims to search and create a comprehensive list of documents aligned with the review purposes [11]. The database used in this search was the Web of Science, as it contains a vast collection of publications and most of the journals are peer-reviewed [12]. The search query used was:

- TS=((“sustaina*” OR “green” OR “emission*” OR “impact*” OR “environmen*” OR “pollut*”) AND (“delivery” OR “freight” OR “logistic” OR “shipp*” OR “distribution” OR “last-mile”) AND (“city” OR “urban*” OR “metropolitan area*”) AND (“business model*” OR “B2C” OR “B2B” OR “business-to-consumer” OR “business-to-business” OR “retail*” OR “e-commerce” OR “brick-and-mortar” OR “omnichannel”)).

This search query was directed to the publications’ title, keywords and abstract. The search was conducted between February and March 2022, and resulted in a preliminary sample of 794 publications.

In the third stage, two sequential objective screenings were executed in order to only select scientifically and thematically relevant studies. The first screening consisted in the exclusion of articles: (i) published before 2016; (ii) not written in English; (iii) not open access; and (iv) classified with irrelevant Research Areas, for example, *Public, Environmental & Occupational Health*; *Food Science & Technology* and *Biodiversity & Conservation*. This first screening resulted in 237 publications.

Then, a second screening was applied to this sample. This screening excluded articles: (i) with an average citation number per year less than or equal to two, if published before 2020; (ii) with an average citation number per year less than or equal to one, if published after 2021; and (iii) where the keywords used in the search query appear less than 10 times in its title, keywords or abstract. This screening resulted in the 102 documents included of this review.

The following stages, based on a thematic analysis, provide qualitative insights about the studied field. In order to further characterise the studied topic, each publication was also classified according to the conceptual theme, the sustainability dimensions considered by the authors and the research methodologies adopted.

3. Results

Six thematic clusters were identified in the literature sample: (i) Supply chain & channels, (ii) Delivery methods & attributes, (iii) Innovative vehicles, (iv) Logistic infrastructures & schemes, (v) Operational optimisation, and (vi) Emerging business models.

3.1. Supply chain & channels

The supply chain requires a wide variety of activities to work fully. In this context, as stated in Table 1, various authors focus on different aspects of it, from examining the current practices and challenges, to comparing traditional and novel channels.

Table 1. Supply chain & channels literature summary.

Ref.	Concept	Country	Method[1]	Dimension		
				Env.	Eco.	Soc.
[13]	Practices	Australia	C, S			
[4]	Practices, Challenges	England	C, T		✓	✓
[14]	Challenges		T	✓	✓	✓
[15]	Practices	England	C, T	✓	✓	✓
[16]	Channels	Norway	S	✓		✓
[17]	Omnichannel, Challenges		T	✓	✓	✓
[18]	Challenges		T			
[19]	Practices	Belgium	M	✓		✓
[20]	Challenges	Europe	C	✓	✓	✓
[21]	Channels	Brazil	S			✓
[22]	Practices	Brazil	M, S		✓	✓
[23]	Packaging		T	✓		
[24]	Research community, Channels		T	✓		
[25]	Channels	China	M, S	✓	✓	✓
[26]	Practices	Indonesia	M	✓	✓	✓
[5]	Channels		T	✓	✓	✓
[27]	Channels	France	M	✓		
[28]	Challenges	Poland	C, M	✓		
[29]	Research community, Channels		T	✓	✓	✓
[30]	Practices	Sweden	C, M			
[31]	Omnichannel, Challenges		T			
[32]	Channels	England	M	✓		
[33]	Packaging		T	✓	✓	✓
[34]	Practices	Spain	C, M	✓		
[35]	Research community, Channels		T	✓	✓	✓
[36]	Omnichannel	Singapore	M, S			✓
[37]	Packaging	China	C, M, S	✓		

[1]C: Case study & interview; M: Modelling; T: Theoretical; S: Survey.

The characteristics and activities of the supply chain, especially the last segment of it, are studied by different authors. Loiseau et al. [27] compared the environmental performance of different food supply chains, and concluded that a very short supply chain where sales happen directly on the production site has more negative impacts than a national long supply chain or a short supply chain where sales happen via online or via a retailer. Aljohani & Thompson [13] studied the last-mile delivery practices of freight carriers operating in Melbourne, and found that light commercial vehicles are the most used type of vehicle, delivering to more than 65 stops per day, and that vehicles operate with about half of the full load capacity, mainly because of the time needed for "placing and readjusting" the parcels and the uncertain availability of on-street loading spaces. Comparable results in England were presented by Allen et al. [4] and Bates et al. [15] that used the same data source to identify that 34 % of the mileage performed by company-owned light commercial vehicles is in the goods transport segment, and there are 37 stops per round, 95 % of these being at the kerbside, causing conflicts and infringements. In fact, 62 % of the total round time, the vehicle is parked at the kerbside while the driver unloads, sorts and delivers the parcels by foot. A similar study conducted in different Brazilian cities added evidence that light commercial vehicles are the most utilised type of vehicles for goods distribution, especially vans [22].

Other researchers opted to develop tools and methods to deepen the knowledge and understanding of the supply chain. Sanchez-Diaz [30] proposed a method for quantifying freight transport trips. The method was applied to examine the freight needs and ordering behaviour of different sectors operating in Gothenburg, allowing to conclude that the retail non-perishable goods sector generated the most freight trips, surpassing other sectors such as the food, the perishable or the public services commercial sectors. Cardenas et al. [19] developed a calculation tool that estimates the associated external costs (congestion, accident, noise, air pollution and climate change) based on the travelled kilometres. The authors analysed the spatial distribution of e-commerce deliveries in Belgium concluding that, although urban areas generate more external costs, rural areas have higher external costs per parcel, due to their low customer geographical density. A causal loop model to understand how the externalities are generated through urban freight was proposed by Hidayatno et al. [26]. Their model depicts that factors like GDP, e-commerce orders, freight volume, logistics transport utilisation, CO_2 emissions, traffic congestion, transport costs and packaging are all related through reinforcement feedback loops.

The parcel's packaging was also highlighted by some authors. Zhang et al. [37] concluded that 32 % of all waste generated by food delivery services originated from excessive and disposable packaging solutions in Wuhan. In a more detailed study, Escursell et al. [23] point out the associated problems like using excessive packaging or non-renewable materials, based on a review of the current shipping packaging solutions for e-commerce deliveries. To avoid overpacking as solutions for more environmentally conscious packaging, they suggested using cellulose-based materials, 3D printing, adopting reusable shipping packages or the introduction of policies. 3D printing is also pointed out as a solution for reducing packaging waste by Taniguchi et al. [33].

The way that COVID-19 impacted the delivery activities of the supply chain was examined by Villa & Monzon [34] and Milewski & Milewska [28]. According to these authors, the lockdown led to a significant increase in e-commerce orders transported, that in turn, resulted in higher CO_2 emissions, but negligible when considering the global reduction. They further pointed out that the demand growth caused by the lockdown increased the efficiency of delivery operations [28].

Besides the COVID-19 pandemic and the challenges mentioned in the last subsections, other factors impacting city logistics are highlighted in the literature. Savelsbergh & Van Woensel [31] identified as factors the population growth and urbanisation, e-commerce growth, the desire for speed, the sharing economy, climate change and sustainability. Bosona [17] added the factor of globalisation as it facilitates good's trading around the world, increasing the transport distance, and factors related to geographical difficulties and the historical context of the cities. Complementary, Arvianto et al. [14] found out that fleet increment and inadequate loading/unloading spaces are predominantly challenges in developing countries. In contrast, education deficiency, regulation, the emergence of new business models, and network accessibility and capacity are developed countries problems. Urban growth, environmental challenges and traffic congestion are common challenges in both types of economies. Boysen et al. [18] included the ageing workforce is challenging innovation in physically demanding activities such as parcel delivery, while Allen et al. [4] added as the seasonal demand peaks. De Marco et al. [20] analysed and classified European city logistics measures identifying the level of pollution, the diffusion of e-commerce and GDP as important drivers of city logistics measures.

The way that the research community examines these challenges is also discussed. In a literature review, Viu-Roig & Alvarez-Palau [35] classified articles based on the type of impact covered, and concluded that the environmental impact is the dimension most frequently dealt with, followed by the social and the economic impacts. The technological impact is the least considered dimension but is frequently entailed with the other three dimensions. A similar review was conducted by Olsson et al. [29] that yielded disparate conclusions, as economic sustainability is the most covered dimension, followed by environmental sustainability and social sustainability. In a different tone, Feichtinger & Gronalt [24] developed a systematic literature review to identify the factors used for environmental impact assessments. The authors found that the most included factor is the modal split, while the most commonly used way to measure the environmental effects is GHG and CO_2 emissions.

The comparison of the various channels according to its impacts or the consumers' opinions is a topic frequently studied. Shahmohammadi et al. [32] compared three shopping models in the United Kingdom, in terms of GHG footprints and concluded that online shopping supported by physical stores reduces the GHG footprints when compared with traditional shopping, while online shopping not supported by physical store has the higher GHG emissions rate. The authors further showed that pure online shopping platforms could significantly reduce their GHG footprint by replacing delivery vans with electric cargo bikes, and by locating their logistical infrastructures closer to their customers. Bjorgen et al. [16] concluded that home deliveries render more environmental benefits than brick-and-mortar, because of fewer trips and reduced car use.

Examining the consumer's preferences is another way used by academics to differentiate the existing commerce channel modalities. Gatta et al. [25] and de Oliveira et al. [21] studied consumers' preferences on channel choices in Shanghai and Brazil, respectively. Both concluded that home delivery is the preferred mode over "click and pick" and brick-and-mortar. A different approach to compare these channels was followed by Lim et al. [5], as they reviewed and compared the commerce channel models, concluding that push-centric models (e.g., home delivery) favour time convenience over physical convenience; pull-centric models (e.g., brick-and-mortar store) prioritise order response time, order visibility, and product returnability performance; and hybrid models (e.g., parcel lockers) prioritise physical over time convenience.

An emerging commerce channel modality mentioned in the literature is omnichannel, i.e., reaching customers through various means of marketing and distribution channels [31]. According to Savelsbergh & Van Woensel [31] omnichannel may enhance the customer experience and increase the customer base, but introduces additional operational complexity for the organisations. Further findings by Bosona [17] identified as challenges associated with this strategy: the fragmentation of online orders, increased complexity of order fulfilment and high associated cost. In Singapore, Wang et al. [36] stated that the consumers do not perceive the current omnichannel system as a "seamless" system.

3.2. Delivery methods & attributes

The study of how deliveries occur is an important topic and has been studied from different perspectives, from proposing alternative methods to examining the consumers' perspective. Table 2 outlines the geographical context, the methodology and the sustainability dimension considered in the studies in this cluster.

Table 2. Delivery methods & attributes literature summary.

Ref.	Concept	Country	Method[1]	Dimension Env.	Eco.	Soc.
[4]	Parcel locker, Other	England	C, T		✓	✓
[38]	Parcel locker	Brazil	M	✓	✓	✓
[39]	Parcel locker	Belgium	C, M	✓	✓	✓
[17]	Parcel locker		T	✓	✓	✓
[18]	Other		T			
[40]	Delivery attributes	Norway	M, S	✓	✓	✓
[20]	Night delivery	Europe	C	✓	✓	✓
[41]	Off-peak delivery	Brazil	C, S	✓	✓	✓
[21]	Parcel locker	Brazil	S			✓
[22]	Off-peak delivery	Brazil	M, S		✓	✓
[42]	CDP	Brazil	M		✓	✓
[43]	Delivery attributes	Brazil	M, S		✓	✓
[25]	Delivery attributes	China	M, S	✓	✓	✓
[44]	CDP	Germany	S		✓	✓
[45]	Parcel locker, Other		T			
[46]	Parcel locker	Italy	M, S		✓	✓
[47]	CDP	New Zealand	C, M, S	✓	✓	✓
[48]	Off-peak delivery, Parcel locker	Poland	M, S	✓	✓	✓
[49]	Parcel locker	Australia	C			✓
[50]	24/7 delivery	Serbia	M, S	✓		✓
[51]	Parcel locker	Poland	S			✓
[28]	Parcel locker	Poland	C, M	✓		
[52]	Parcel locker	Poland	S	✓	✓	✓
[53]	Off-peak delivery	Canada	C	✓	✓	✓
[54]	Parcel locker	Italy	C, S		✓	
[55]	CDP	Finland, Netherlands	C, T, S	✓	✓	✓
[56]	Parcel locker		S		✓	
[31]	Parcel locker, Other		T			
[57]	Parcel locker	Germany	M	✓	✓	✓
[29]	Parcel locker, CDP, Other		T	✓	✓	✓
[35]	Parcel locker, CDP, Night delivery, Other		T	✓	✓	✓
[14]	CDP, Off-hours delivery		T	✓	✓	✓

[1]C: Case study & interview; M: Modelling; T: Theoretical; S: Survey.

Parcel lockers, pick-up points and similar collection and delivery points (CDP) are examples of alternative delivery solutions. Parcel lockers consist of unattended small lockers where parcels are delivered to and stored until the consumer collects them. This solution is widely discussed in the academic literature, as well as being highly implemented [45]. In their highly cited work, Savelsbergh & Van Woensel [31] considered this type of solution an opportunity to mitigate the negative effects of direct-to-consumer (attended) deliveries. Some of those adverse effects discussed in the literature are delivery failures and consequent repeated deliveries, and return deliveries, which exacerbate other externalities [4,17].

A key point for the viability of parcel lockers is their location. In a study conducted in five Australian cities, Lachapelle et al. [49] concluded that these lockers are frequently placed in commercial streets, sites with abundant parking, and near the post office or shopping centres. They also concluded that most are placed in safe sites and that should be placed more frequently in gas stations or shopping centres, so they can be combined with different purposes. Similar results were drawn by de Oliveira et al. [42] in Brazil as they concluded that supermarkets and shopping centres are located in high-income areas and in less costly locations for investors, thus making them more economically attractive, whereas post offices, gas stations and drugstores are located in highly populated areas, thus could serve almost the entire city population and stimulate active transportation modes. Kedia et al. [47] added that, although not the preferred location for CDPs due to consumers' low visit frequency, dairies (i.e., small convenience stores) could motivate consumers to walk or cycle to collect their parcels. This would reduce the impacts because they are densely located and operate for longer hours.

The location of parcel lockers is also studied based on consumers' preferences. Researches in Poland [51], Brazil [21] and New Zealand [47] showed that consumers' preferable locations for parcel lockers are in commercial outlets such as shopping centres or supermarkets, mainly because these places are part of their daily commute. According to Pronello et al. [54], Italian decision-makers working in the transport, environment and commerce sectors also prefer parcel lockers to be located inside strategic locations like supermarkets.

Several authors examine consumers' acceptance and priorities towards parcel lockers. The results of these studies shows that there is general acceptance and willingness to use these alternative delivery methods among New Zealanders [47], Italian [46], Polish [51,52], Brazilian [21] and German [44] consumers. Italian consumers are willing to pay more if the parcel locker is located within 500 m of their home and has 24 h accessibility [46]. The 24 h accessibility was even identified as the most attractive criteria in Poland [51,52], being prioritised over the price, the location and the delivery speed. Moroz & Polkowski [52], additionally concluded that environmental reasons were the least considered criteria for choosing parcel lockers. A similar study in Brazil returned alternative results by stating that the most important criterion is the traceability of the parcel, followed by the flexible delivery time and reduced cost. Moreover, this study stated that, although home delivery is the preferred option for parcel delivery, the use of parcel lockers is an option with high potential demand for the consumers [21].

The acceptance and willingness-to-pay towards a customer-driven central last-mile micro-depot model, that acts as a consolidation centre that delivers parcels to the consumers, and as a collection point where consumers pick up the parcels were studied by Hagen & Scheel-Kopeinig [44]. The results showed that the German consumers' would be interested in using it but not paying for it, making the micro-depot not economically viable on its own. A similar model was proposed by Rosenberg et al. [55], which introduced a conceptual shared micro-depot, driven by multiple logistics service providers. Based on existing initiatives, the authors proposed adding auxiliary business models to the micro-depot, such as providing charging stations for electric cars, or a library of small items to rent. They stated that the shared micro-depot solution mostly has advantages (e.g., reduction of monetary costs for all parties, noise, GHG and air pollutant emissions) but could have disadvantages (e.g., movement complexity, accidents trackability), and needs stakeholder's involvement for public acceptance.

Besides the opinion of consumers, the other city actors' feedback is considered by Russo & Comi [56], Kijewska et al. [48] and Pronello et al. [54]. The first pair [56] interviewed retailers/receivers, and transport and logistics operators to show that most stakeholders have a more positive perspective on measures related to pick-up points like parcel lockers than on measures related to environmental-friendly vehicles or Urban Consolidation Centres (UCC). In a multi-criteria evaluation of measures for sustainable urban freight transport from the perspective of Szczecin's logistical operators, Kijewska et al. [48] concluded that measures related to alternative delivery systems such as parcel lockers are perceived as positive in terms of implementation possibility and impact on the environment. Pronello et al. [54] found that retailers and most of the large goods transport operators are not interested in the service, but small goods transport operators like DHL, and the decision-makers see it as efficient.

Other parcel delivery alternatives, classified by Boysen et al. [18] as being emerging concepts, are the reception boxes in a consumer's home or an Amazon project for smart door locks that allow the deliverer to open the front door of a home with a smartphone app. Another possibility is to deliver into the trunks of private cars. In this area, partnerships have been developed between Volkswagen and DHL; Volvo and Ericsson; Audi, Amazon and DHL [18,31]. Delivering to the consumer's workplace could be a solution for reducing failed home deliveries [4]. Allen et al. [4] and He & Haasis [45] referred to the solution of mobile depots that can be used as parcel storage facilities as being in the testing and development phase by companies like TNT Express in Brussels.

Some authors opted to compare systems based on parcel lockers against traditional systems. In a simulation study, Milewski & Milewska [28] showed that adopting a parcel locker service can significantly reduce the fuel consumption per parcel, mainly because the number of parcels delivered increases when compared with traditional home delivery. Alves et al. [38] simulated different delivery and re-delivery schemes, concluding that the scenario where parcels lockers were used the most, led to reduced trip length and higher fuel, time, and external costs savings; more parcels delivered without re-delivery; higher profits and lower costs for customers. Arnold et al. [39] simulated and compared two different novel B2C delivery initiatives (parcel lockers and cargo bikes) against traditional home delivery (by van), based in the city of Antwerp. The results showed that using parcel lockers decreases operational costs at the expense of more (potential) external costs. Because the opposite occurs in the cargo bike scenario, the authors suggested an integration of both modalities. Similar results were obtained in Berlin for the parcel locker scenario [57].

A common concern pointed out by these researches is that the parcel locker solution might imply additional traffic generated by the customers' travel to these points, contributing to the external effects of last-mile delivery. However, according to some authors, these effects could be mitigated by implementing a wide network of parcel lockers near frequently visited places, so that the customers do not generate dedicated trips to these points, and to encourage customers to reach them using active modes [38,52,57]

Because delivery activities occur predominantly during the day (when customers are not at home), impacts like traffic congestion or failed deliveries are exacerbated [53]. Therefore, some authors studied the shift towards deliveries in different periods. Lazarevic et al. [50] proposed a 24/7 express delivery service and compared its impact versus a traditional express service. By surveying consumers and organisations, and by applying simulation tools, the authors concluded that in Belgrade, there is considerable interest in the service and that it could lead to lower diesel consumption and a consequent decrement in CO_2 emissions. Mousavi et al. [53] conducted a pilot for an off-peak delivery program i.e., parcels are delivered during the evening and overnight hours, that revealed faster delivery speed, zero noise complaints, and lower GHG and other air pollutants emissions. However, service times increased in the off-peak hours at the retail stores because it coincides with other activities.

de Oliveira & de Oliveira [41] took a different approach to assess the off-peak delivery alternative by surveying Brazilian stakeholders' preferences and perceptions regarding different city logistics solutions. The authors discovered that off-peak delivery was perceived as efficient by residents and administrators, but as not efficient by carriers and retailers. In another study, de Oliveira et al. [22], corroborated the Brazilian retailers' stance toward off-peak delivery. Different results were listed by Kijewska et al. [48], whose evaluation of Szczecin's logistical operators' opinions showed that alternative delivery systems like night deliveries are considered positive solutions by the respondents, as they view it as a solution with high implementation possibility and high environmental benefits. However, the practical implementation of this solution may not be that easy according to the findings of De Marco et al. [20], as they found that night delivery was not implemented in most studied European cities.

Several authors focused on examining the delivery attributes associated with delivery services like parcel lockers or home delivery [21,25,40,43]. Caspersen & Navrud [40] concluded that (female) consumers accept longer delivery time in return for a reduction in polluting emissions, and prioritise the traceability of the parcel over the delivery time, delays or emissions. In Brazil, sociodemographic characteristics such as age or income, and the type of product purchased influence which attributes are prioritised in a home delivery service, as found by Dias et al. [43].

Another Brazil-based study [21] stated that the most important criterion for Brazilian consumers is the information and traceability of the parcel, followed by the flexible delivery time and reduced cost, while Shanghai consumers' preferences assessment showed that factors like product price, service cost and product range are more important when choosing the channel than travel time, lead time or time window [25].

3.3. Innovative vehicles

The adoption of alternative vehicles in logistics is a concept well disseminated in the literature. Different authors analyse alternative fuel vehicles like electric vehicles or cargo bikes, but also novel vehicular technologies such as drones or autonomous vehicles (AV). Table 3 characterises the studies focused on innovative vehicles.

Table 3. Innovative vehicles literature summary.

				Dimension		
Ref.	**Concept**	**Country**	**Method**[1]	**Env.**	**Eco.**	**Soc.**
[58]	E-vehicle		C, T		✓	
[39]	Cargo bike	Belgium	C, M	✓	✓	✓
[14]	E-vehicle, Cargo bike, AV		T	✓	✓	✓
[15]	E-vehicle, Cargo bike	England	C, T	✓	✓	✓
[17]	E-vehicle, Cargo bike, Drone, AV		T	✓	✓	✓
[18]	E-vehicle, Cargo bike, Drone, AV		T			
[59]	E-vehicle, Cargo bike	Italy	C, M	✓	✓	
[20]	E-vehicle	Europe	C	✓	✓	✓
[60]	E-vehicle, Cargo bike, AV		T	✓	✓	✓
[61]	E-vehicle	USA	M	✓		
[45]	E-vehicle, Cargo bike, Drone, AV		T			
[62]	E-vehicle	Poland	C	✓		
[63]	E-vehicle	Germany	M	✓	✓	
[64]	Cargo bike	Poland	C	✓		✓
[65]	E-vehicle, Cargo bike, Drone, AV		T	✓	✓	
[31]	E-vehicle, Cargo bike, Drone, AV		T			
[66]	Cargo bike, Drone	Spain	M, S	✓	✓	✓
[67]	E-vehicle	Slovakia	M	✓	✓	
[68]	E-vehicle	Italy	M	✓	✓	
[33]	E-vehicle, Cargo bike,		T	✓	✓	✓
[69]	E-vehicle	Europe	M	✓	✓	
[57]	Cargo bike	Germany	M	✓	✓	✓
[48]	Cargo bike	Poland	M, S	✓	✓	✓
[29]	E-vehicle, Cargo bike, Drone		T	✓	✓	✓
[35]	E-vehicle, Cargo bike, Drone, AV		T	✓	✓	✓

[1]C: Case study & interview; M: Modelling; T: Theoretical; S: Survey.

Alternative fuel vehicles are an increasingly important part of the transportation system, with the potential to provide significant benefits [31,33]. Patella et al. [65] and de Oliveira et al. [60] showed that adopting green vehicles in urban logistics has gathered increasing interest, specifically in using vehicles powered by alternative fuels, such as electric vehicles. Multiple authors simulated and compared the performance of electric and traditional logistical trucks using real-life data from the food sector in New York City [61] and Berlin [63]. These authors concluded that adopting electric vehicles significantly reduces energy consumption and GHG emissions. Similar comparative-based studies [59,68,69] further added more evidence that electric vehicles have lower environmental and operational costs than traditional vehicles .

Several authors have discussed the challenges in the adoption of electric vehicles in last-mile operations. Anosike et al. [58] identified that operational barriers like the limited driving range; battery issues such as long recharging times; and cost implications such as a high investment cost are among the types of obstacles most commonly associated with the use of these alternative vehicles, while Bates et al. [15] and Bosona [17] identified as challenges against innovation, the infrastructural and financial complexity of replacing the vehicle fleet with a more sustainable one, namely due to the need for recharging stations and the high fleet acquisition cost. The limited driving range issue is refuted by Martins-Turner et al. [63] that concluded that the electric vehicles' battery duration suits most operations. A field experiment conducted in Poland by Iwan et al. [62] added evidence to the claim that the battery capacity of electric vehicles is suitable for last-mile deliveries. Moreover, Settey et al. [67] showed that electric vehicles' driving range could be enhanced if they are recharged during loading/unloading.

Cargo bikes are another popular vehicular mode in the literature. Field tests conducted in Stargard by Nurnberg [64], allowed the author to conclude that cargo bikes can help to decrease congestion, noise and air pollution, but needed adequate road infrastructure and policies, community approval, and have to be adapted to the terrain and tasks. The speed and capacity limitations of cargo bikes, and the need for new road infrastructure are also highlighted by Bosona's [17] literature review as the main disadvantages associated with cargo bikes. Brotcorne et al. [59] analysed the co-existence of traditional and green vehicles in urban logistics, from a managerial perspective, and concluded that cargo bikes are the vehicular mode associated with higher environmental and operational savings but correspond to a lower number of deliveries per hour.

In a simulation study conducted in Antwerp, Arnold et al. [39] found that cargo bikes resulted in an increase in operational costs but a decrease in external costs when compared to home deliveries using traditional vans. Because the opposite occurs in the parcel locker scenario, the academics suggested an integration of both modalities. Contradicting results by Zhang et al. [57] in Berlin, as the use of cargo bikes decreased both operational and environmental costs.

Some literature reviews showed that emerging vehicular technologies such as drones, autonomous vehicles, and modular vehicles are being studied by multiple researchers [17, 60,65]. In particular, Patella et al. [65] classified autonomous vehicles as the most promising and challenging solution for last-mile logistics. However, according to Savelsbergh & Van Woensel [31], their benefits for city logistics, how to effectively employ them, and how to integrate them with traditional vehicles are still unknown. In Pamplona, Serrano-Hernandez et al. [66] concluded that residents prefer unmanned aerial vehicles like drones in last-mile operations over cargo bikes or traditional vans. Complementary, in a literature review Bosona's [17] identified that drone-based delivery implies additional investments such as landing stations, while Savelsbergh & Van Woensel [31] cites Toyota, Amazon and Matternet as examples of companies investing in the use of unmanned aerial vehicles on parcel delivery.

Some of the alternative vehicular technologies were classified according to their academic investigation status and practical implementation status by He & Haasis [45]. Electric vehicles are on a high level of application and research; cargo bikes have received medium academic interest but high practical implementation; and drones, autonomous vehicles or modular vehicles are not highly investigated nor highly implemented. These results converge to the ones drawn by Boysen et al. [18] that classified electric vehicles and cargo bikes as "today's concept", drones and small autonomous robots as "near future" concepts, while autonomous vehicles as "farther future" concept. De Marco et al. [20] found that measures related to the adoption of low-emission vehicles are the most implemented type of city logistic measure, being present in more than 50 % of the 70 studied European cities. Moreover, according to Arvianto et al. [14], examining novel vehicular technologies like delivery robots, automated vehicles or electric vehicles as innovative solutions for city logistics is more common in developed countries than developing countries.

3.4. Logistic infrastructures & schemes

Logistic infrastructures like Urban Consolidation Centre (UCC) or parking areas are also examined by the research community, as summarised in Table 4.

Table 4. Logistic infrastructures & schemes literature summary.

				Dimension		
Ref.	**Concept**	**Country**	**Method**[1]	**Env.**	**Eco.**	**Soc.**
[4]	Parking	England	C, T		✓	✓
[70]	UCC	Sweden, Italy, Netherlands	C	✓	✓	✓
[17]	Parking		T	✓	✓	✓
[71]	UCC	England	C, S	✓	✓	✓
[72]	Parking	Singapore	C	✓	✓	✓
[73]	UCC	Brazil	M, S	✓	✓	✓
[20]	UCC, Parking, Road, Micro-depot	Europe	C	✓	✓	✓
[41]	UCC, Parking, Road	Brazil	C, S	✓	✓	✓
[22]	Parking, Road	Brazil	M, S		✓	✓
[74]	UCC		T	✓	✓	✓
[75]	UCC	Spain	M	✓	✓	
[76]	UCC	Luxembourg, France, Spain, Italy	C, M	✓	✓	✓
[44]	Micro-depot	Germany	S		✓	✓
[77]	UCC, Sprawl		T	✓	✓	✓
[78]	UCC	Sweden	C	✓	✓	✓
[79]	Parking	Poland	C	✓		
[48]	Parking, Road	Poland	M, S	✓	✓	✓
[80]	UCC	Belgium	M	✓	✓	✓
[81]	UCC	England	C, S	✓	✓	✓
[82]	UCC	England	M, S		✓	✓
[83]	UCC	England, Italy	C	✓	✓	✓
[54]	Parking, Road	Italy	C, S		✓	
[55]	Micro-depot	Finland, Netherlands	C, T, S	✓	✓	✓
[56]	UCC, Parking, Road		S		✓	
[31]	UCC		T			
[33]	UCC, Road, Sprawl		T	✓	✓	✓
[84]	UCC	England, Netherlands	C	✓	✓	✓
[29]	Parking, UCC		T	✓	✓	✓
[35]	UCC, Parking		T	✓	✓	✓
[14]	UCC, Sprawl, Parking		T	✓	✓	✓
[67]	UCC	Slovakia	M	✓	✓	

[1]C: Case study & interview; M: Modelling; T: Theoretical; S: Survey.

One of the most implemented and studied logistic infrastructures is the Urban Consolidation Centre (UCC). The UCC is one of the opportunities for improving city logistics, primarily by consolidating the fragmented deliveries, thus reducing the freight vehicle volume going into cities [31]. De Marco et al. [20] added that UCCs are implemented in 50 % of the 70 European cities they studied, making it the second most implemented city logistic measure, only below the adoption of low emission vehicles.

Different studies evaluated the pros and cons associated with the UCC from different perspectives. In a social cost-benefit analysis of an operational UCC conducted in Antwerp, Kin et al. [80] revealed that the UCC initiative has social and environmental benefits, but is not economically viable, mainly due to high initial costs. However, the authors calculated that the UCC becomes financially viable when the dealt volume increases significantly. Similar conclusions were drawn by other authors. van Duin et al. [84] designed an analysis framework to evaluate UCCs, and then applied it to describe three UCC city initiatives. Bristol-Bath UCC and Binnenstad Nijmegen UCC initiatives supported the thesis that, although there are social and environmental benefits, most UCCs are not financially attractive solutions, as they need public subsidies to "break-even" or generate small profits. However, the Regent St. UCC initiative claimed relevant profits. In another study by Bjorklund et al. [70], two of the five European UCC cases analysed are not financially viable. In a survey-based study of online shopping practices, Cherrett et al. [71] suggested that courier vehicle trips could be significantly reduced by using a consolidation scheme paid by university students and that students would respond positively to this service.

The previous authors also identified seven critical factors for viable business models, of which three stand out: scale up the operations, logistics competence and the use of advanced IT and information systems [70]. These authors stressed the importance of local authorities and municipalities engaging in the initiative. The scale of operations as a critical factor is also highlighted by Estrada & Roca-Riu [75] that analytically studied the necessary conditions for sustainable consolidation schemes, and concluded that a minimal retailer density is needed to ensure positive financial status whereas vehicle costs and other site-related parameters have minor impact on the financial viability of UCCs. The authors further found that consolidation strategies could alleviate the negative externalities, as well as provide cost savings for the carriers, as they exceeded the cost of participating in these strategies.

Guerlain et al. [76] showed that implementing consolidation centres in urban areas could improve other sectors, namely the construction sector. They simulated the implementation of this consolidation centre in four European cities and found benefits in terms of congestion, pollutant emissions, vehicle use and load factor. Interestingly, the results demonstrated that three of the four construction sector consolidation centres evaluated have a Payback period equal to 1 i.e., it takes one year to recover the investment cost. An alternative approach was followed by Deng et al. [74] that compared the performance of a UCC and a Peer-to-Peer platform (i.e., a capacity sharing-based platform) and found that the UCC is more profitable and more social-environmental efficient if the carriers' variable delivery cost and the number of carriers are both sufficiently high.

The perspective of stakeholders towards UCC initiatives is also the basis for some studies, like the ones led by Paddeu [81,82] based on the Bristol-Bath UCC, that pointed out that retailers are very satisfied with the overall service, and that most of them are unaware of what a consolidation centre is or how it works, while some retailers complained about the impossibility to set the delivery time and that some parcels were getting damaged. Russo & Comi [56] depicted that supply management measures like the implementation of UCCs are associated with average low benefits by the stakeholders. In Brazil, the UCC is perceived as efficient by carriers and administrators [41], and stakeholders consider criteria like the availability of parking spots, the use of technology or the service level more important in UCC planning in historical cities than insecurity, noise or traffic congestion [73].

In a research aimed at identifying the drivers and barriers associated with a UCC by analysing the perspective of retailers operating in the city of Bristol (with a UCC) and the city of Cagliari (without a UCC), the authors identified as drivers, aspects like the time savings or the pro-environmental principles, and as barriers, factors like the competitiveness or the public subsidies' dependence [83]. Johansson & Bjorklund [78] indicate that the most important driver to convince retailers to participate in UCCs is the possibility to outsource some services to the UCCs and thus gain economic advantages.

Hagen & Scheel-Kopeinig [44] and Rosenberg et al. [55] studied the viability of a micro-depot that acts as a consolidation centre and as a parcel collection point. The first academics found that, although consumers would be willing to use it, the micro-depot would not be economically viable because consumers would not pay for it, while the second authors remarked that the shared micro-depot solution that they proposed would have economic viability and social and environmental benefits, but could increase operational complexity.

Another pivotal urban infrastructure is freight loading/unloading parking spaces, an infrastructure particularly challenging to change in order to adapt to the increasing freight volume and changing distribution systems [17]. In fact, Dalla Chiara & Cheah [72] considered arrival rates, parking duration, queue waiting time and driver parking location choice to document evidence of congestion at these spots. These infrastructures were studied in the city centres of Poland [48,79], Singapore [72], Brazil [22,41], Italy [54] and multiple European countries [20].

To study these infrastructures, some authors considered the perspective of the main players. Kijewska & Iwan [79], found that inappropriate or unavailable loading/unloading space for delivery vehicles is the biggest obstacle pointed out by the Polish retailers, and de Oliveira & de Oliveira [41] found that Brazilian carriers classify exclusive loading/unloading locations as efficient while carriers, retailers and administrators perceive reservation-based loading/unloading systems as efficient. In another survey, de Oliveira et al. [22] added evidence that most retailers perceive the unavailability of loading/unloading parking areas as an impactful problem, therefore they are willing to accept the regulation of loading and unloading areas. Nevertheless, Pronello et al. [54] point out that, although the loading/unloading bays are perceived by stakeholders as obstacles to efficient delivery operations, their booking is not appreciated as it would increase the complexity of the deliveries. Parallel results obtained by Russo & Comi [56] and Kijewska et al. [48] showed that measures related to infrastructural delivery areas like loading/unloading areas are not considered by most stakeholders as very positive measures when compared to measures related to alternative delivery systems, collaboration schemes or the use of technological systems.

With a different approach, De Marco et al. [20] confirmed the lack of interest in parking-related measures such as monitoring, booking or dedicated roadside lay-by areas, as the authors found that this type of measures is implemented in less than 20 % of the considered set of 70 European cities.

The most omnipresent urban logistic infrastructure is the road. Therefore, some authors studied exclusive freight lanes or other mobility restrictions as a solution for improving road use. de Oliveira & de Oliveira [41] surveyed the Brazilian stakeholders' preferences and perceptions and stated that exclusive freight lanes are perceived as efficient by carriers, retailers and administrators. According to de Oliveira et al. [22] most surveyed Brazilian retailers agree with the restriction of vehicle circulation as a viable solution. Russo & Comi [56] found that stakeholders are interested in limited traffic zones. The pair also found that measures related to environment-friendly vehicles such as using the vehicle environmental performance as an access constraint are perceived as efficient by city users, but not by retailers or logistics operators, contradicting Pronello et al. [54] which presented that using the vehicle's emissions as a criterion to permit access to limited traffic zones is consensual among stakeholders while using criteria like the loading factor is not. Taniguchi et al. [33] wrote that applying direct road charging measures such as tolls can lead to more efficient utilisation of freight vehicles and avoid the need for additional warehouses. De Marco et al. [20] analysed European city logistics measures and found that low-emission zones are implemented in almost half of the studied cities, while dedicated freight lanes are the least implemented measure

Hesse [77] and Taniguchi et al. [33] approached the spatial context of logistics, discussing the logistics sprawl problem. This problem that can increase the travelled distance due to the lack of affordable logistics infrastructures in central and inner urban areas [4].

3.5. Operational optimisation

Different publications have explored how novel technologies and techniques can optimise last-mile operations like vehicle routing. These are listed in Table 5, which depicts the geographical context, method and sustainability dimension considered.

Table 5. Operational optimisation literature summary.

				Dimension		
Ref.	**Concept**	**Country**	**Method**[1]	**Env.**	**Eco.**	**Soc.**
[14]	Parking optimisation, Technology, Routing		T	✓	✓	✓
[17]	Technology		T	✓	✓	✓
[85]	Routing	Italy	M		✓	
[86]	Parking optimisation	Singapore	C, M	✓	✓	✓
[87]	Technology	Singapore	C		✓	✓
[88]	Technology		T	✓	✓	
[20]	Routing	Europe	C	✓	✓	✓
[89]	Parking optimisation	Italy	C, M			
[90]	Technology	Europe, Asia	C	✓	✓	
[91]	Technology	Colombia	M	✓	✓	✓
[92]	Technology	South Africa	C		✓	✓
[93]	Technology	USA, Colombia, Spain	M		✓	
[94]	Technology		M, S	✓		✓
[95]	Technology	Europe, Canada, USA	T			
[54]	Technology	Italy	C, S		✓	
[96]	Routing	Europe	M	✓	✓	
[56]	Technology		S		✓	
[31]	Technology		T			
[33]	Technology		T	✓	✓	✓
[97]	Routing		M	✓	✓	✓
[98]	Routing		M		✓	
[29]	Routing		T	✓	✓	✓
[35]	Technology, Routing		T	✓	✓	✓
[48]	Routing, Technology	Poland	M, S	✓	✓	✓
[4]	Technology	England	C, T		✓	✓

[1]C: Case study & interview; M: Modelling; T: Theoretical; S: Survey.

Urban infrastructures like freight parking spaces are intrinsically linked to fleet operations. Some academics study these operations as an optimisation problem. Dalla Chiara et al. [86] designed a random utility model to optimise urban freight parking. Based on simulations, the authors concluded that reducing parking duration, and parking in spaces reserved for passenger vehicles can reduce issues like accidents, congestion, air pollution, delivery costs, and illegal parking. Diana et al. [89] developed a geolocation-based method to optimise urban freight loading and unloading areas' examination using a clustering algorithm with criteria like the number of vehicles or the street characteristics, aimed at the identification of the most important locations for logistic operations.

Another fleet operation whose optimisation could have a significant impact is vehicle routing. Although measures related to routing or scheduling are among the least implemented measures in Europe [20], and are more relevant in developing countries [14], in the literature, there are different authors focusing on the Vehicle Routing Problem. Rincon-Garcia et al. [96] introduced a time-dependent vehicle routing optimisation model based on a large neighbourhood search algorithm that reduces the number of operating vehicles, as well as the route length and duration. Moreover, the authors found that the cost and the CO_2 emissions substantially increase if a time window is imposed. Cerrone et al. [85] demonstrated through a routing optimisation model that applying street crossing penalties does not affect the routes' cost and total length. Two articles used genetic algorithms to develop models for fleet management optimisation. The model proposed by Yang & Wu [98] optimised the routing of logistical vehicles and showed that the time windows exigencies affect negatively the total route length, while the model proposed by Wang & Bae [97] pointed out that a smaller number of vehicles can decrease the operational costs, but at the cost of an increase of time windows failures.

Different publications have explored the potential that emerging technologies and techniques like the use of emerging data sources, tracking technologies, APIs and mobile applications, or cloud-based technologies have on optimising logistical operations. Savelsbergh & Van Woensel [31] state that digital connectivity, big data and automation can drive city logistics innovations in order to decrease the negative effects on congestion, safety and the environment, while Bosona [17] writes that digitalisation and automation could result in more efficient, flexible and customer-focused supply chains, reducing externalities like delivery failures.

Pan et al. [94] outlined a model based on data mining the electricity consumption of the customers' residences in order to predict if they are at home. The results revealed that the proposed model could not only reduce the number of failed deliveries, but also the total route length of last-mile operations. Taniguchi et al. [33] contributed by describing other applications of big data systems and decision support systems found in the literature. de la Torre et al. [88] found applications of simulation techniques, machine learning and fuzzy-based methods in the optimisation of supply chains, transportation services, crowdsourcing logistics, autonomous and electric vehicles, among others. The authors concluded that, because of the different sustainability dimensions to be considered, it is unlikely that the transportation system can be improved using a single method.

Different hardware technologies have been used to improve last-mile operations. As concluded by Perboli & Rosano [95], RFID and GPS-based technologies are widely adopted in smart city projects in Europe, whereas ICT-based models, databases and cloud computing are the most used technologies in projects in USA and Canada. Giusti et al. [90] summarised and listed the outcomes of the multimodality transportation project SYNCHRO-NET. This platform is supported by cloud technology and a set of simulation and optimisation software that can improve freight and logistics management in real-time. Noteworthy results are the reduction of the route length and duration, and CO_2 emissions.

Hardware is frequently combined with software such as machine learning and simulation models. Gutierrez-Franco et al. [91] proposed a data-and-model-driven framework for vehicle-related operations optimisation. This framework relies on hardware (RFID, GPS); software (e.g., ERP, WMS, GIS); and machine learning, simulation and optimisation models. Reducing the number of vehicles in use, increasing the resource capacity utilisation and reducing the cost of fleet operations are some of the advantages the authors listed. The use of apps and APIs is also the subject of studies. Mkansi et al. [92] assessed the impact that mobile applications can have in the optimisation of e-grocery logistics, namely in managing demand and cooperation between competitors. de Kervenoael et al. [87] examined practices of independent delivery workers, and stated that the combination of internal technological systems such as parcel QR codes, logging data, or tracking technologies, with external applications like Google Maps or WhatsApp could make logistics more sustainable. Munoz-Villamizar et al. [93] proposed a model based on Google API to measure the effects of disruptions in last-mile operations. The model was computationally validated on a set of real data from different cities and allowed the authors to conclude that cities with larger sizes, limited road networks, and high customer concentration zones are more sensitive to disruptions.

With a different approach, Pronello et al. [54] analysed the stakeholders' need for freight optimisation apps, and concluded that the only valuable information for transport operators is information about traffic disruptions, the status of loading/unloading bays, video surveillance and apps that suggest less polluting routes. A similar approach was followed by Russo & Comi [56], as they found that the city stakeholders expect positive benefits from the use of information and communication technology and intelligent transport systems such as apps for booking delivery bays or traffic management.

3.6. Emerging business models

Emerging business models have been studied and proposed by various authors. These studies are focused on vertical collaboration schemes like crowdsourcing logistics or the combined transportation of people and freight, as well as horizontal collaboration, for instance, two companies sharing assets [99]. Table 6 outline the studies that explore these concepts.

Table 6. Emerging business models literature summary.

				Dimension		
Ref.	**Concept**	**Country**	**Method**[1]	**Env.**	**Eco.**	**Soc.**
[4]	Crowdsourcing, Collab.	England	C, T		✓	✓
[31]	Crowdsourcing, Collab., People/Freight		T			
[99]	Crowdsourcing, Collab., People/Freight		T			✓
[33]	People/Freight		T	✓	✓	✓
[100]	Crowdsourcing	China	M	✓	✓	
[101]	Crowdsourcing	Italy	M, S	✓	✓	✓
[102]	Crowdsourcing	Italy	M, S		✓	✓
[103]	Crowdsourcing	Italy	C, M		✓	✓
[104]	Crowdsourcing	Netherlands	C, M	✓	✓	
[15]	Crowdsourcing	England	C, T	✓	✓	✓
[105]	Crowdsourcing		M	✓	✓	✓
[18]	Crowdsourcing, People/Freight		T			
[106]	People/Freight	Spain	C, M	✓	✓	✓
[107]	People/Freight	USA	M		✓	
[108]	People/Freight		M	✓	✓	✓
[17]	Collaboration		T	✓	✓	✓
[109]	People/Freight	Netherlands	C, S	✓	✓	✓
[110]	Collaboration	Belgium	M	✓	✓	✓
[111]	Collaboration	England	M, S	✓	✓	
[112]	Collaboration	Netherlands, Canada	C	✓	✓	✓
[56]	Collaboration		S		✓	
[48]	Collaboration	Poland	M, S	✓	✓	✓
[14]	Crowdsourcing, Collab., People/Freight		T	✓	✓	✓
[29]	Crowdsourcing, Collab.		T	✓	✓	✓
[35]	Crowdsourcing, Collab., People/Freight		T	✓	✓	✓

[1]C: Case study & interview; M: Modelling; T: Theoretical; S: Survey.

Crowdsourcing logistics i.e., the outsourcing of logistic services to a network of people, with benefits for all parties [113], is the emerging initiative most present in the reviewed literature, being classified by Boysen et al. [18] as a "Near future" concept. Several of the crowdsourcing models proposed are based on exploiting public transport systems for the last-mile delivery operations. Chen & Pan [100] designed a system that supports the implementation of a crowdsourcing model using taxi drivers, data mining and algorithms to optimise routing and scheduling of tasks. Gatta et al. [101] designed a crowdsourcing logistics model where metro passengers deliver parcels using parcel lockers placed inside or near the metro station. This model could lead to environmental benefits, but could only be economically viable if public incentives and subsidies were applied. The same model was used by Gatta et al. [102] to examine the willingness to act as a crowdshipper and to use this service. The results demonstrated that the crowdshippers prioritise the location of the parcel locker over the remuneration per delivery, while the users prefer flexible delivery time windows over cheaper shipping fees or faster shipping time. This study also found that younger people are more willing to work as a crowdshipper and to use this crowdsourcing service.

Seghezzi et al. [103] benchmarked the economic performance of a crowdsourcing system and a traditional express delivery system. The results showed that the average cost per delivery of the crowdsourcing system is lower for any service level, number of workers and vehicle mix except for a "100 % foot" model. The authors further concluded that a crowdsourcing initiative generates a source of additional income for the deliverers. Guo et al. [104] proposed a conceptual framework aimed at supporting the integration of crowdsourcing practices into a traditional delivery network. According to these authors, even if an exclusive crowdsourcing system is not able to completely replace the traditional delivery system, the proposed integration could help reduce the economic and environmental last-mile impacts, at the expense of needing a large number of crowdshippers. This need is also pointed out by Savelsbergh & Van Woensel [31], that included crowdsourcing in their list of opportunities for improving city logistics, adding that the compensation for the worker has an impact on the effectiveness of the solution. Bates et al. [15] alerted that this type of initiative could lead to social injustices common with zero-hour contracts, such as low income and lack of benefits or legal support.

Rzesny-Cieplinska & Szmelter-Jarosz [105] contributed to the research field by benchmarking existing crowdsourcing services according to the needs of different stakeholders. The pair concluded that the AmazonFlex initiative implemented by Amazon had the most valuable characteristics, as the stakeholders associate it with social benefits such as security or creating a local community. Grabr and Nimber are other examples of crowdsourcing initiatives [18]. Allen et al. [4] stated that, although crowdsourcing is one of the initiatives that can improve last-mile operations by reducing vehicle activity, the emergence of crowdsourcing services by large companies like Uber and Amazon threatens to change the sustainable nature of crowdsourcing and result in dedicated vehicle trips specifically for parcel delivery.

Another "Near future" concept listed by Boysen et al. [18], and considered by Savelsbergh & Van Woensel [31] as having "enormous potential for exciting research" is the combined and integrated transport of people and freight. This solution takes advantage of the public transport infrastructures to deliver parcels and is already being implemented in countries like Switzerland and Japan [33,99].

This initiative is being considered, evaluated and compared by various authors. Villa & Monzon [106] assessed it by proposing a novel model for e-commerce parcel delivery based on Madrid's underground metro infrastructure. They compared two scenarios (combining people and goods, and using dedicated trains) with the status-quo scenario (delivery by road transit). The results demonstrated significant reductions in congestion costs, accidents, noise, and air emissions when adopting a metro-based delivery model, in particular, the shared train scenario. Beirigo et al. [107] modelled this integration using mixed-purpose compartmentalised autonomous vehicles. The simulation of various scenarios with different characteristics allowed to conclude that almost every scenario resulted in higher operational profits when compared to a model without people-freight integration. Cheng et al. [108] proposed two delivery methods (utilising the minimum and maximum amount of free capacity of each trip) based on the use of public transportation to move passengers and parcels. Analytical and experimental results showed that it was possible to distribute most packages, in under 1 hour in off-peak periods and with little impact on the passenger.

The free capacity of public transport is also studied by Van Duin et al. [109] that conducted a pilot project in the Netherlands to study the viability of using public buses to carry parcels and found that this solution led to lower CO_2 emissions, the creation of job opportunities and a sustainable business model. Moreover, Taniguchi et al. [33] stated that this initiative could bring benefits for public transport organisations as it can be an additional revenue stream; logistic organisations would benefit by reducing the transport costs and increasing the frequency and reliability of deliveries; and residents would experience less congestion, noise and air pollution. However, this solution involves extra transshipment costs, additional handling equipment and additional labour for loading/unloading and security tasks.

The idea of using the free capacity is also adopted when developing business models based on collaboration and sharing economy principles. Allen et al. [4] and Savelsbergh & Van Woensel [31] stated that fostering operational collaboration between carriers in order to reduce the number of operating vehicles or increase resource utilisation efficiency is one of the solutions to improve the parcel delivery operations, while Bosona [17] stressed the difficulty in addressing the different competing interests of urban freight logistics actors, and the difficulty in establishing coordination between these actors due to the uncertain and dynamic nature of freight operations. Kin et al. [110] simulated the operational feasibility of utilising the free capacity of cargo trucks to supply small independent stores and found that it potentially provides an additional revenue source as well as reduces the travelled distances and lead times, in specific, when adopting a centrally located logistic centre. Also using a simulation-based study, Zissis et al. [111] concluded that a collaboration model based on retailers sharing fleets and using micro hubs around residential areas, could lead to reductions in distance and operation time, by the use of fewer vehicles.

Enochsson et al. [112], explored the topic of sharing economy across different actors, segments and cities, affirming that municipal governments and organisations are, in general, supportive of sharing economy principles, as they could lead to sustainability benefits, as well as being a solution for the last-mile problem. Similarly, Russo & Comi's [56] assessment of city users, retailers/receivers and logistical operators' expected outcomes of a set of city logistics measures showed that public-private collaboration measures are expected to produce high benefits.

4. Discussion

Beyond the above analyses, the characterisation of the research area was deepened by classifying the literature sample according to the conceptual theme, the research methodologies adopted and the sustainability dimension considered by the authors. This classification is summarised in Table 7, depicting the number of articles, and the frequency of each type of method and dimension present in each cluster.

Table 7. Literature review summary.

		Method[1]				Dimension		
Cluster	**Articles**	**C**	**M**	**T**	**S**	**Env.**	**Eco.**	**Soc.**
(i)	27	30 %	41 %	44 %	26 %	70 %	44 %	59 %
(ii)	32	31 %	41 %	28 %	50 %	56 %	75 %	81 %
(iii)	25	28 %	40 %	48 %	8 %	84 %	76 %	52 %
(iv)	31	48 %	23 %	32 %	35 %	77 %	94 %	81 %
(v)	25	32 %	40 %	36 %	16 %	56 %	84 %	56 %
(vi)	25	28 %	48 %	40 %	24 %	68 %	88 %	72 %
TOTAL	102	38 %	51 %	22 %	29 %	71 %	74 %	64 %

[1]C: Case study & interview; M: Modelling; T: Theoretical; S: Survey.

The number of publications in each cluster is relatively similar, pointing out the diversity of areas of the studied topic, as well as, the effectiveness of the followed systematic literature review methodology in collecting a comprehensive array of the concepts associated with the last-mile. Nevertheless, the most represented cluster is (ii) Delivery methods & attributes, with 32 publications, closely followed by (iv) Logistic infrastructures & schemes, with 31 publications, while the clusters with the least associated publications are the (iii) Emerging business models, (v) Innovative vehicles, and (vi) Operational optimisation, each with 25 publications. It should also be noted that, because the city logistics and last-mile topics are characterised by their multidisciplinary nature, some authors adopt wider approaches, conducting studies that cover multiple concepts. Hence some publications and authors are classified with two or more clusters, thus being referred to in more than one subsection. These multi-cluster publications constitute 24 % of the sample and are mostly literature reviews, and evaluations of different measures based on case studies, interviews and surveys. The vast majority of the publications are classified with just one cluster (76 %).

Based on previously established methodology classification schemes [29,114], the 102 reviewed publications were classified according to the main research methodology adopted. Therefore, four classes were identified: Case studies & interviews (C), Modelling (M), Theoretical (T) and Survey (S).

Modelling is the methodology class with the most publications, constituting more than half of the sample (51 %). This methodology refers to studies conducted with various techniques, for instance, sensitivity analysis, data mining and exploiting APIs, heuristic algorithms, genetic algorithm, (mixed-integer) linear programming, cluster analysis, discrete choice modelling, Analytic Hierarchy Process, agent-based simulation model, Life cycle assessment, and economic-oriented models. The other two research methodologies classes are Theoretical studies and Survey-based methods, present in 22 % and 29 % of the papers, respectively. Theoretical publications mainly consist of classic narrative and systematic literature reviews. Surveys are predominantly quantitative studies based on a stated preference questionnaire on consumer's behaviour, satisfaction and preferences. Moreover, there are surveys focused on the perspective of the stakeholders and experts.

A significant share of publications (34 %) employ two methods, the most common combination being Modelling-Survey, either by using a survey as a data source for modelling techniques or by using a survey to evaluate the model proposed. A reduced lot of publications (3 %) adopt three research methodologies: Kedia et al. [47] used a modified p-median location-allocation model, surveyed consumers' shopping patterns and interviewed courier companies and dairy owners to study collection points; Zhang et al. [37] conducted a field study accompanied by a questionnaire survey, and used life cycle assessment modelling to measure the environmental impact of the food delivery sector; Rosenberg et al. [55] case studied shared micro-depots initiatives, surveyed future residents' behaviour and preferences, and theorised about possible extensions and evaluation metrics for these initiatives.

It is interesting to examine how the research methodologies are distributed by thematic cluster. Modelling is the leading methodology class in the clusters (vi) Emerging business models (48 %) and (v) Operational optimisation (40 %), because the articles included in these clusters are focused on predicting how novel models can be operationalised, or how the efficiency of the current models can be improved. Case studies and interviews are very frequent in articles of the (iv) Logistic infrastructures & schemes cluster (48 %), as the examination of infrastructures like UCCs or loading/unloading areas is mainly conducted by empirically assessing established initiatives and related operations. Theoretical methods are the most considered methodology in the (i) Supply chain & channels cluster (44 %) and in the (iii) Innovative vehicles cluster (48 %), as publications in these clusters are usually reviews aimed to consolidate the different aspects of the supply chain or the different vehicles. Surveys are the most common method in the (ii) Delivery methods & attributes cluster (50 %), but are very little considered in the clusters (iii) Innovative vehicles (8 %) and (v) Operational optimisation (16 %). A justification could be that, because surveys are largely employed to examine consumers' habits and perceptions, they are more important when examining solutions like parcel lockers, whose success is heavily dependent on consumer behaviour, whereas solutions like adopting electric vehicles or implementing routing optimisation systems are not.

Furthermore, the reviewed articles were classified according to the three dimensions of the so-called "triple bottom line of sustainability": environmental, economical and social. Factors like energy consumption, $PM_{2.5}$, CO_2 and GHG emissions, or waste are attributed to the environmental dimension; transport costs, delivery times, investment costs or profit margins are examples of economical factors; and security, traffic congestion, noise or quality of life are social factors.

In this context, the social dimension is the least considered, being present in 64 % of the articles, the environmental dimension is considered in 71 % of the articles, and the economical factor is the most considered dimension, present in 74 % of the reviewed articles. This could indicate that the main motivation for exploring and introducing new solutions is the generation of higher profits and lower operational costs.

57 % of the reviewed publications do not consider (simultaneously) the three sustainability dimensions. 50 % only considers one or two dimensions, the pair environmental-economical being the most common (present in 13 % of the sample). A small share of articles (7 %) consisting of four literature reviews and three case studies, do not clearly consider any of these dimensions.

Examining the distribution of the sustainability dimensions by thematic cluster yields that the economical dimension is the most considered in half of the clusters, being present in 88 %, 94 % and 84 % of the articles associated with the clusters (vi) Emerging business models, (iv) Logistic infrastructures & schemes, and (v) Operational optimisation, respectively, adding evidence for the importance of financial viability when proposing a novel system; when evaluating infrastructures like the UCC; or when calculating the cost savings returned by a routing optimisation model for instance. The environmental dimension leads in the clusters (i) Supply chain & channels (70 %), and (iii) Innovative vehicles (80 %), as comparing the pollutant emissions of traditional models (e.g., brick-and-mortar, combustion vehicles) against emerging alternatives (e.g., omnichannel, electric vehicles) is a popular way adopted by scholars. Lastly, the social dimension is the most considered in the cluster (ii) Delivery methods & attributes (81 %), mainly because there is a big focus on the consumers' acceptability and preferences towards methods like parcel lockers.

5. Conclusion

This paper provided a systematic literature review that aims to characterise the sustainable urban last-mile logistic research field through a consolidation and analysis of the existing literature (2016-2022). The review followed a methodology based on the Web of Science database and sets of objective exclusion criteria. This procedure resulted in

102 articles of interest. Each article was classified according to the thematic cluster, the sustainability dimensions considered and the research methodologies followed.

Six thematic clusters were identified: (i) Supply chain & channels that includes articles that range from examining the current practices to the development of tools to evaluate the supply chain; (ii) Delivery methods & attributes consists of articles focused on parcel lockers or the attributes of the delivery systems; (iii) Innovative vehicles is mainly focused on electric vehicles and cargo bikes; (iv) Logistic infrastructures & schemes refers to articles about structures like the UCC or parking spaces; (v) Operational optimisation groups articles about the use of technology in logistical operations; and (vi) Emerging business models clusters solutions like crowdsourcing logistics, the combined transport of people and freight, and collaboration between actors.

The research field is characterised by its multidisciplinary nature, encompassing a multitude of concepts and solutions from very different perspectives and methodologies. It is also noteworthy the fact that the economical dimension is the most considered, suggesting that the main driver for innovation in the last-mile and city logistics is (still) the generation of bigger profits. Moreover, more than half of the publications do not consider simultaneously the three sustainability dimensions.

Although the reviewed literature discussed a wide variety of concepts, themes, problems, and solutions, with very different approaches by many authors, there are still various research avenues and opportunities remaining for deepening the knowledge on sustainable urban last-mile logistics. More research could be conducted, in particular real-life experiments, on the subject of drones or autonomous vehicles, as these are emerging vehicular solutions whose exploration could lead to revolutionising initiatives. Another aspect that should be explored in future research is considering simultaneously the so-called "triple bottom line of sustainability", as the majority of articles only focused on one or two dimensions. The integration and combination of the multiple alternative solutions could also be the focus of relevant contributions. Reevaluating the stakeholders' perceptions towards off-peak delivery and parking-related measures could also be beneficial, as contradictory results were found in the literature. Moreover, because each solution has disadvantages, focusing on how to minimize them could lead to key research developments. For example, investigating if the technical deficiencies of cargo bikes can be suppressed by creating dedicated bike paths; studying the link between crowdsourcing initiatives and social inequalities; or proposing a horizontal collaboration scheme that pleases all involved stakeholders.

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Abbreviations

The following abbreviations are used in this manuscript:

API	Application Programming Interface
AV	Autonomous Vehicle
B2B	Business-to-Business
B2C	Business-to-Consumer
CDP	Collection and Delivery Points
ERP	Enterprise Resource Planning
GDP	Gross domestic product
GHG	Greenhouse Gas
GIS	Geographic Information System
GPS	Global Positioning System
ICT	Information and Communications Technology
QR	Quick Response
RFID	Radio-frequency Identification
TKA	Title, Keywords and Abstract
UCC	Urban Consolidation Centre
WMS	Warehouse Management System

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