Do Drones dream of a Resilient and Sustainable Urban Distribution? A Literature Review

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Abstract: Over the last 20 years, the demand for transport services has grown thanks to increasing globalization and e-commerce exponentially. This led to the rise in externalities (e.g., air pollution, climate change, noise pollution, traffic congestion), an issue that is particularly relevant in urban contexts. The improvement of last-mile delivery processes comes as a natural necessity. The considerable pressure on urban systems was further pushed by the outbreak of COVID-19, which highlighted the need for a delivery system able to provide a fast, resilient and safe contactless solution to reach isolated or quarantined areas with ease. To cope with the abovementioned issues, many authors have been looking toward adopting unmanned aerial vehicles (a.k.a. drones) in logistics. Therefore, this work aims to identify how drones can improve last-mile logistics resilience and sustainability and understand the impact of drones on urban distribution. The following research questions will be answered to achieve these objectives: Which applications of drones to urban distribution have been researched? What is the impact of drones on urban distribution in terms of resilience and sustainability? This paper follows a Systematic Literature Review (SLR) approach. The SLR was conducted on the Scopus database and is based on 159 articles. This literature review provides insights into the current state of drone-enhanced urban distribution scientific literature, finds existing gaps and suggests future research opportunities to develop a resilient and sustainable urban distribution system.

Keywords: Drones, Urban Distribution, Resilience, Sustainability, Literature Review

I. INTRODUCTION

Over the last 20 years, the demand for transport services has grown thanks to increasing globalization and e-commerce exponentially. This led to the rise in externalities, an issue that is particularly relevant in urban contexts. The improvement of last-mile delivery processes is a natural necessity since it was defined as the least efficient stage of the supply chain [1]. The considerable pressure on urban systems was further pushed by the outbreak of COVID-19, which highlighted the need for a delivery system able to provide a fast, resilient and safe contactless solution to reach isolated or quarantined areas with ease [2]. To cope with the abovementioned issues, many authors have been looking toward adopting unmanned aerial vehicles (UAVs) in logistics. UAVs (a.k.a. drones) are uncrewed aircraft initially developed in the military. However, they spread to civil adoption in several sectors in the last years, such as "industrial monitoring, photography, disaster rescue and aid operations, parcel delivery, and agriculture" [3]. They can be autonomous or remotely piloted. This novel technology caught the attention of many researchers as it promised to offer incredible advantages such as decreasing operational transport costs [4], reducing traffic congestion and CO_2 emissions [5], as well as improving customer service [6, 7].

However, do drones represent the panacea to all last-mile delivery ills? Therefore, this work aims to identify how drones can improve last-mile logistics resilience and sustainability and understand the impact of drones on urban distribution. To achieve these objectives, the following research questions (RQs) will be answered:

RQ1 – Which applications of drones to urban distribution have been researched?

RQ2 – What is the impact of drones on urban distribution in terms of resilience and sustainability?

To answer the identified RQs, a systematic literature review was conducted. The rest of this work is divided as follows: section II is dedicated to the research background, the review methodology is described in detail in section III, findings are reported in section IV, conclusions to this work are drafted in section V, and ideas for future research are proposed in section VI.

II. Research Background

This paper is focused on last-mile logistics, which can be defined as "the final leg in a delivery service whereby the consignment is delivered to the recipient, either at the recipient's home or at a collection point" [8], specifically in urban areas, also called urban distribution. This sector is experiencing several issues which were caused by a significant growth in transportation over the last decades, such as an increase in externalities (e.g., air pollution, climate change, noise pollution, traffic congestion) and a rise in logistics costs (since the last-mile is considered to be the least efficient stage of the supply chain [1]). This is why academics and practitioners invest more effort into researching new sustainable and resilient solutions. Ahi and Searcy [9] analyzed the literature to analyze which definitions were given for green and sustainable supply chain management. In their study, the authors describe sustainability as "utilizing resources to meet the needs of the present without compromising future generations' ability to meet their own needs" [9]; following this definition, companies initially tackled only the environmental impact of their activities but as times changed they realized that sustainability involved more dimensions: economic, social, and environmental – also known as the triple-bottom-line.

A sustainable approach to urban distribution is undoubtedly essential, however, without improving the last-mile logistics from a resilience perspective – defined as "the ability to maintain critical functions during a disruptive event and at least return to the initial state by absorbing damage and recovering from disruption" [10] – all the economic, social, and environmental improvements will do very little to prevent or adapt to adverse events. COVID-19 taught this lesson to logistics practitioners the hard way. This unprecedented event which affected supply chains on a global level led academics to deepen their research in resilience practices, such as Queiroz et al. [11], who systematically reviewed the scientific literature to identify critical elements in improving supply chain resilience in the face of adverse events such as epidemic outbreaks.

COVID-19 further highlighted the need for a fast, resilient, and contactless delivery solution [2]. Among the novel technologies studied by academic researchers in this context, UAVs emerge as one of the most interesting. Even though drones were initially born in the military sector and served an entirely different purpose, in the last years, this technology entered the commercial industry to fulfill numerous needs, such as "industrial monitoring, photography, disaster rescue and aid operations, parcel delivery, and agriculture" [3]. In particular, drone parcel delivery entered the collective imagination as one of the most common applications for this novel technology. Since Jeff Bezos announced his plans for Amazon's Prime Air in 2013 [12], promising to "deliver packages up to five pounds to any customer within ten miles of a fulfillment center", many other companies followed suit: DHL's Parcelcopter [13], Alphabet's Wing [14], and more recently UPS Flight Forward [15]. Drones appear to have many advantages suitable to curb previously mentioned issues, such as being a practical step to zero-emission logistics [16], providing contactless delivery [17], being independent of transport infrastructures [18], and reducing acquisition and operating costs for package delivery [19].

III. Review Methodology

This SLR follows a "Partially Complete" Review strategy (Fig. 1):

- At first, Snowball Sampling is performed to get accustomed to the main research topics and identify the main keywords used in the extant literature.
- Then, a Search Protocol is developed to identify the most relevant papers and research streams in the scientific literature.
- Lastly, a Conceptual Review is performed. A Data Extraction Form was used to collect information in a structured way, which was finally analyzed through a Pattern Matching technique (ex-post approach).

Overall, this strategy allowed us to scan the literature and adequately understand the identified contents rigorously.

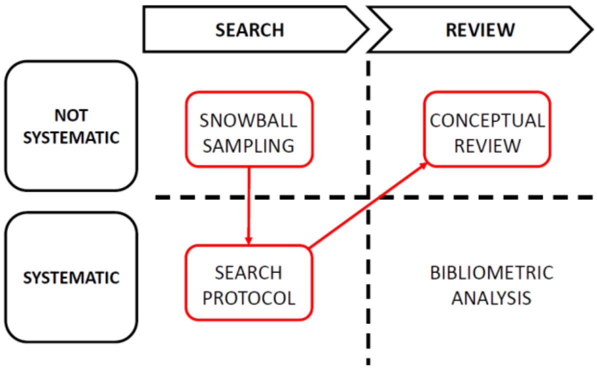

Fig. 1. "Partially Complete" review strategy.

The goal of the Snowball Sampling is to get accustomed to the research topics, which in this case are:

- Drones
- Last-Mile Logistics
- Resilience and Sustainability

To achieve this objective, once the seminal papers were identified, the following information has been collected:

- A clear definition of the topic.
- Main themes discussed for the topic.
- Main keywords used for the topic.

Once completed this first technique, it was decided to look into two intersections of the three topics systematically: on the one hand, "Drones and Last-Mile Logistics" and on the other hand, "Last-Mile Logistics and Resilience and Sustainability". The third intersection (Drones and Resilience and Sustainability) was not deepened because considered to be out of this research's scope: the main focus is on last-mile delivery. Therefore, it was not interesting to detail drones' resilience and sustainability aspects in other fields.

A search protocol was developed to find prominent papers and the most important research streams in the field. The whole search protocol, complete with a PRISMA chart, can be seen in Fig. 2.

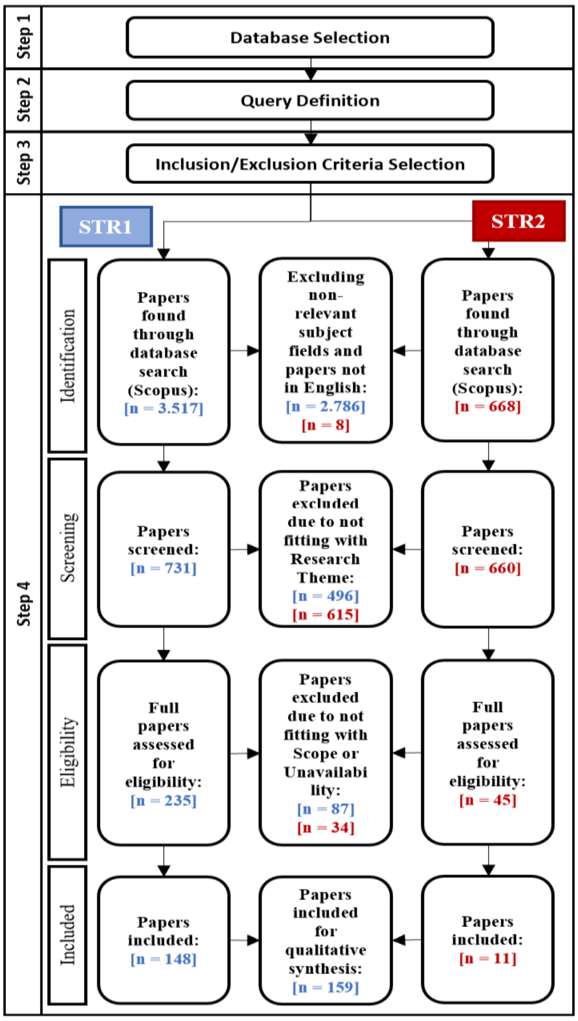

Fig. 2. Search protocol.

The database chosen for this SLR was Scopus since it is one of the most commonly used databases, and it has the advantage of having a coverage 60% larger than Web of Science's database [20].

Results on Scopus for the intersection between the topics "Drones" and "Last-Mile Logistics" were researched through the first query (STR1), which contains the most commonly used keywords and their declinations for those topics:

TITLE-ABS-KEY (("drone*" OR "aerial bots" OR "unmanned aerial vehicle" OR "unmanned aircraft*" OR "remotely operated aircraft*" OR "remotely piloted vehicle*" OR "remotely piloted aircraft*" OR "autonomous unmanned system*" OR "autonomous delivery robot") AND ("last mile" OR "last-mile" OR "logistics" OR "deliver*" OR "city logistics" OR "urban distribution"))

Results on Scopus for the intersection between the topics "Last-Mile Logistics" and "Resilience and Sustainability" were researched through the second query (STR2), which contains the most commonly used keywords and their declinations for those topics; in this case, for the topic of "Resilience and Sustainability," the words "resilien*" and "sustainab*" (with asterisks) were chosen to comprehend all their possible declinations:

TITLE-ABS-KEY (("last mile" OR "last-mile" OR "logistics" OR "deliver*" OR "city logistics" OR "urban distribution") AND ("resilien*" AND "sustainab*"))

The inclusion and exclusion criteria were created with the following objectives:

- Screening phase (i.e., reading title and abstract): minimization of false negatives.
- Eligibility phase (i.e., reading full text): minimization of false positives.

The inclusion and exclusion criteria for STR1 are summarized in table I.

TABLE I
STR1: INCLUSION AND EXCLUSION CRITERIA

Screening Phase		
Inclusion	Papers discussing drones and last-mile logistics.	235
Exclusion	Papers out of research theme (i.e., not including drones).	496
Eligibility Phase		
Inclusion	Papers focused on drones applied to last-mile logistics and urban distribution.	148
Exclusion	Papers out of research scope (i.e., papers not explicitly focused on drones in last-mile logistics).	87

The inclusion and exclusion criteria for STR2 are summarized in table II.

TABLE II
STR2: INCLUSION AND EXCLUSION CRITERIA

Screening Phase		
Inclusion	Papers discussing resilience or sustainability last-mile logistics or urban distribution.	45
Exclusion	Papers out of research theme (i.e., discussing resilience and sustainability in other sectors).	615
Eligibility Phase		
Inclusion	Papers focused on improving resilience or sustainability in last-mile logistics or urban distribution.	11
Exclusion	Papers out of research scope (i.e., just mentioning resilience and sustainability).	34

The number of papers initially identified for the first query (STR1) was too large to be manually screened (3,517 results). Therefore, two restrictions were added: language (English) and subject areas (Social Sciences; Decision Sciences; Business, Management, and Accounting; Multidisciplinary; Psychology – Psychology was chosen to include studies regarding social impacts and acceptance of drones; Multidisciplinary was selected to have studies that mix various disciplinary sectors as this theme is adept to this research; Social Sciences, Decision Sciences, and Business were chosen because they represent the central disciplinary areas of the managerial sector). While reading titles and abstracts, starting from the most cited works, 496 papers were excluded during the screening phase because they did not discuss drones. In the eligibility phase, 39 articles were excluded due to unavailability, and another 48 were excluded because they did not focus on drones in the last-mile sector.

The number of papers initially identified for the second query (STR2) was small enough to be manually screened (668 results). Therefore, only one restriction was added: language (English). While reading titles and abstracts, 615 papers were excluded during the screening phase because they discussed resilience and sustainability in other sectors. In the eligibility phase, 4 articles were excluded due to unavailability, and another 30 were excluded because they did not focus on resilience and sustainability in the last-mile sector.

Ultimately, a total of 159 papers were included in this SLR.

IV. FINDINGS

Vehicle routing optimization papers represent the most popular research stream on drone last-mile logistics (52 papers, representing roughly 33% of articles included in this SLR). Starting from one of the most used mathematical models to optimize last-mile vehicle routing, the so-called Traveling Salesman Problem, Murray and Chu [21] defined two new mathematical models, which they called Flying Sidekick Traveling Salesman Problem (FSTSP) and Parallel Drone Scheduling Traveling Salesman Problem (PDSTSP). By solving these problems heuristically, the authors aimed to optimize the routing of a truck and drone combination for last-mile parcel delivery while minimizing “the time required to service all customers and return both vehicles to the depot” in the FSTSP and “to minimize the latest time that a vehicle returns to depot, such as each customer is served exactly once” in the PDSTSP [21]. This paper, published in 2015, began the most prosperous and researched stream in the drone last-mile logistics field. Many authors improved the mathematical programming models or proposed more efficient heuristic methods to solve those models. Some examples include the work of Ha et al. [4], where the objective function is changed to minimize the operational costs of truck and drone delivery, Ferrandez et al. [22], where the efficiency of truck-and-drone in tandem was proved to maximize deliveries while minimizing time and energy, and Ham [23] where the PDSTSP was extended to include two drone activities: drop and pickup. This research stream, which considered only parcel or goods delivery as the last-mile delivery application, has received two literature reviews two years apart. In 2020, Macrina et al. [24] classified “research contributions on drone-aided routing problems”, including 63 articles obtained from several databases. Results highlighted four main categories of problems with the delivery time as the optimization function in most cases, thus missing contributions on other topics such as “environmental impacts, energy evaluation, realistic drone parameters, dynamic systems, and safety”. In 2022, Benarbia and Kyamakya [25] published a literature review on “drone-based package delivery systems,” which included a review of vehicle routing problems (as well as other operational-related issues such as “drone assignment”, “charging process and the location of recharging stations”, and “drone fleet dimensioning”). The final comment of the authors was that some of these mathematical models were tested only with generated data; therefore, feeding those models with real-world data would provide significant contributions for academics and practitioners.

As far as social impacts are concerned, on the one hand, many authors agree that drones would be able to offer better customer service due to their characteristics: fast and flexible delivery [6], as this technology is not constrained by roads infrastructure [7], and increased traceability so that customers could follow their orders [5]. Furthermore, drones could be an essential solution to the decline of drivers [26], which is an issue concerning many logistics companies. By decreasing the number of delivery vehicles on the road, problems related to traffic congestion would be curbed [27]. On the other hand, researchers also presented several concerns associated with the social aspect, such as increased air traffic congestion [28], possible accidents to people or damage to goods [6], concerns about safety, and noise [5]. Privacy is another concern that came up as the main issue according to a survey conducted in Pakistan [29]. These social impacts have been addressed from a psychological perspective in South Korea [26] and India [30], i.e., how these factors influenced the population’s social acceptance and perception of adopting another urban distribution application of this technology: drone food delivery. In 2019, Hwang, Kim, and Kim [26] published their first study to explore how motivated consumer innovativeness impacts customers’ attitudes and behavioral intentions about the use of drone food delivery services. The results showed that business owners employing this kind of service should focus on the functional (i.e., a better and faster service to the customer, as drones avoid traffic congestions and the ability to pre-order food while on the move), hedonic (i.e., it should provide a fun and enjoyable experience to customers), and social (i.e., decreasing the number of ground delivery vehicles would also reduce the number of accidents in which they are involved) aspects of this technology to tempt more customers in choosing this novel delivery method. Since then, the authors expanded their work by adding more details, such as the positive impact of perceived innovativeness and the moderating role of gender and age [31] (which showed the importance of focusing on a specific target market), the negative impact of perceived risk [32] and the positive impact of expected benefits [33].

Another essential aspect identified as having a positive influence on customers’ attitudes and behavioral intentions by the South Korean authors was drones’ green image and environmentally friendly characteristics [25, 26]. Several authors reported the environmental benefits of drones’ employment in last-mile logistics, such as being more energy-efficient than trucks [22] and having lower CO_2 emissions than traditional vehicles [5]. However, these statements seem to stem more from a common preconception than from scientific evidence in most cases. Two main works partially support these benefits. On the one hand, Goodchild and Toy [28] analyzed and compared the CO_2 emissions of traditional trucks and unmanned aerial vehicles. The results highlighted how drones have an advantage over trucks in cases where there are few recipients close to the starting depot. In contrast, the opposite is valid for a larger cluster of recipients far away from the home depot. The authors concluded that both vehicles would complement each other's weaknesses, resulting in more significant benefits rather than employing only one of them. On the other hand, Figliozzi [36] estimated the whole drone lifecycle emissions (i.e., including vehicle production and disposal, energy source, and infrastructure) and compared them to several ground delivery vehicles, both traditional (e.g., diesel vans) and novel (e.g., electric trucks). The results showed that, although drones may be more energy-efficient than conventional means of transport, they are not more eco-friendly than novel solutions such as electric trucks on delivery routes with more than ten customers. However, they can represent a practical solution in areas with sparse populations or densely congested urban areas still served by low energy-efficient vehicles.

Another aspect of drones that researchers have highlighted is their economic benefits. Authors generally mention drones to be low-cost [37], which is explained by reduced transportation costs (e.g., “having no driver or truck costs, eliminating congestion costs, having less missed-deliveries” [5]) and being less expensive than trucks [4]. Aurambout, Gkoumas and Ciuffo [5] studied the economic feasibility of this technology employment around Europe by optimizing the location of “drone-beehives” (i.e., warehouses specifically dedicated only to drone delivery service) and identifying the potential reachable population. In the most conservative scenario, it was estimated that 7.5% of the European population (roughly 40 million people) could benefit from this technology. In particular, the UK, France, Germany, and Italy would be the most probable adopters of drone delivery services thanks to the already existing infrastructures (i.e., online retailers’ warehouses).

Impacts on urban distribution resilience were not explicitly tackled in the scientific literature. However, some of the drones’ characteristics have been mentioned, which could prove to help improve last-mile delivery. Thinking back to quarantined areas during the first waves of COVID-19, when people’s movement was strongly restricted, the ability to deliver anywhere regardless of location [31] and offering a contactless service [38] would have proved highly beneficial. Following this logic, one sector, in particular, would benefit the most from these characteristics: healthcare. Rashidzadeh et al. [39] studied the feasibility of covering the last-mile delivery of the blood supply chain via drones. Their objectives were to minimize costs and CO_2 emissions while maximizing demand coverage. Krishna Varigonda et al. [40] developed an unmanned aerial vehicle focused on delivering medical supplies. The authors equipped the vehicle with controlled-temperature containers and a final recipient recognition system. Although they were not able to test their technological solution in a practical context due to urban airspace flight limitations, they proved the feasibility of their system in a shorter-range test and via simulation.

TABLE III
MAIN FINDINGS SUMMARY

Topic	Percentage
Vehicle Routing Problems	32.70% (52)
Social	25.16% (40)
Sustainability (Soc.+Eco.+Env.)	13.21% (21)
Resilience	10.06% (16)
Economic	9.43% (15)
Environmental	6.92% (11)

Sustainability and Resilience	2.52% (4)

V. DISCUSSION AND CONCLUSION

Concerning drones' application for urban distribution (RQ1), parcel and goods delivery is the most researched area. This is probably due to the practical implications of such technology employment, which has become quite famous in the collective image thanks to prominent logistics companies operating in this sector which announced their own drone last-mile delivery projects, such as Amazon's Prime Air, DHL's Parcelcopter, and UPS Flight Forward. Drone food delivery has been studied mainly from a psychological perspective on which factors most affected customers' attitudes and behavioral intention to choose this new service rather than a traditional delivery method. Lastly, healthcare was suggested as another important sector that could benefit from drone adoption since medical supplies and blood delivery requirements could take advantage of UAVs' speed and independence from roads and traffic congestions.

From a triple-bottom-line sustainability and resilience perspective (RQ2), unmanned aerial vehicles present several advantages for urban distribution, such as lower transportation costs, improved customer service, a solution to the decline in the logistics sector workforce, decreased traffic congestion, and more energy-efficient than trucks. Furthermore, they have some characteristics that offer an added resilience to the supply chain, such as being independent of road infrastructure and delivering their payload to any location while providing a contactless service. However, they do also present some limitations, such as being best suited only for specific cases (e.g., urban areas still served by low energy-efficient vehicles), drones would be economically viable to serve a small percentage of the population, and public acceptance (e.g., concerns about privacy, safety, and noise). As well as other potential issues such as accidents, damaged goods, and air traffic congestion.

Although drones currently represent an excellent potential for last-mile logistics and urban distribution, they do not represent the definitive solution to all last-mile logistics issues. However, they can become part of the solution. Drones provide attractive advantages with the potential to offer new kinds of services for specific contexts and fields of application. However, certain barriers and limitations will need to be surpassed first.

VI. FUTURE RESEARCH

Many authors mentioned the economic benefits of drone delivery in this SLR, but very few articles tackled this aspect in detail; further research on this topic would expand the extant literature. Psychological and social aspects have been researched, particularly for food drone delivery, without considering other drone applications. Therefore, factors affecting customers' attitudes and behavioral intention in adopting drone delivery for parcels or medical supplies could provide a general understanding of the public perception of this technology. Furthermore, most contributions mainly focused on UAVs implementation's operation and tactical problems. A more strategic approach to identifying influencing factors of companies' UAVs adoption would benefit practitioners and researchers alike.

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(The complete list of references for the papers included in this SLR is available upon request.)

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