Sustainable City Logistics Concepts – Elements and Conceptualization

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Defining and the application of sustainable city logistics concepts is a prerequisite for achieving sustainability in urban areas. The scientific literature is abundant with research that highlights individual technologies, initiatives, measures and approaches as indispensable elements of sustainable concepts. Although a relatively large set of city logistics concepts is analyzed in the literature, there is no generally accepted set of guidelines for defining sustainable city logistics concepts. This article tries to fill that literature gap. The main contribution of this article is, on basis of the review of relevant literature in the field, to demonstrate how potentially sustainable city logistics concepts could be conceptualized by combining different building elements (technologies, initiatives, measures, and approaches).

Key Words: *sustainability, city logistics, concepts*

1. INTRODUCTION

In order for society to return to a path of sustainable development, in 2015, the United Nations defined 17 sustainability goals to be achieved [1]. Particular attention was paid to goal 11 – “Sustainable cities and communities”, as cities are the areas where unsustainable development is most visible [2]. Inadequate logistics planning [3] has made a significant contribution to urban unsustainability, which leads to emissions of harmful gases, traffic congestion, creating noise and vibrations, threatening traffic safety, increasing production and service costs, rising logistics costs, the occupancy of public space, ineffective resource and energy consumption, etc.

Luckily, there is a whole branch of science that deals with the sustainability of logistics in urban environments - city logistics. The importance of planning sustainable logistics systems at the urban level has long been recognized, and the number of studies in this area is increasing year by year. Existing research agrees, that the traditional approach to logistics planning, particularly in cities, is unsustainable [4]. A large number of concepts, technologies and solutions have been analyzed in the scientific literature however, there is no widely accepted set of guidelines on how to define sustainable concepts of urban logistics.

The aim of this work is to provide a brief overview of the most commonly analyzed elements of sustainable city logistics concepts in scientific literature, and to illustrate possible ways of conceptualizing (defining) a wider set of potentially sustainable city logistics concepts. In the next chapter, a detailed review of the current scientific literature is given. Chapter 3, demonstrates how different elements (technologies, approaches, initiatives) can be combined to define a diverse set of potentially sustainable city logistics concepts. In chapter 4, final considerations and recommendations for future research are given.

2. CURRENT RESEARCH ON SUSTAINABILITY IN CITY LOGISTICS

The issues of sustainability of logistics systems in urban environments have been approached in practice and scientific literature through various city logistics initiatives, as well as integrated planning, identification of factors affecting sustainability and fundamental sustainability criteria of solutions [5]. There are many

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initiatives in the field of city logistics and various ways to structure them [6]. Works [7, 8] provide an overview of all city logistics initiatives, which are classified in relation to the urban environment context. The study [9] was focused on evaluating the sustainability of basic categories of initiatives. The results of that research have shown that the development of different categories of logistics centers, intermodal transport application and fostering cooperation between participants represent elements with the highest potential in developing sustainable city logistics systems.

Logistics centers are often the subject of analysis or at least one of the key components of solutions analyzed in existing literature. In a spatial sense, logistics centers can be developed on the periphery of urban areas and thereby enable macro-consolidation of cargo flows [10] through urban consolidation centers (UCCs) or in delivery zones in order to achieve micro-consolidation of cargo flows [11] through micro-consolidation centers (MCCs). The possibility of defining various system structures and the eligibility of combining them with different transport technologies and other city logistics initiatives justifies the place of logistics centers in scholarly literature as one of the most frequently analyzed categories of initiatives.

The article [12] is focused on selecting the most favorable city logistics concept for Brussels, while in the article [13] the selection of the concept is carried out for the city of Belgrade, and for the central business district of Belgrade in the article [14]. In those articles, different configurations of logistics centers and their combinations with different categories of delivery vehicles and different political initiatives (road charges and measures of access restrictions) are taken into account. The selection of the most favorable model of horizontal cooperation between peripheral logistics centers for the city of Bucharest is carried out in the article [10], while the article [15] deals with the sustainability of a logistics center on the periphery of Copenhagen by considering different scenarios that differ according to the applied measures and the participation of the public sector in financing. The article [16] deals with the selection of the most favorable concept of the last mile delivery, in which concepts are based on different categories of logistics centers, alternative modes of transportation and modern technologies that are the subject of analysis in recent literature. In the consolidation of flows on the periphery of urban areas, approaches can be classified as those that consider the development of only one UCC [12, 17] and those that define more complex structures based on multiple UCCs [10, 13, 14, 18, 19].

The catchment area of a MCC is usually limited to a narrow area in the delivery zone (most often in the central urban area). This means that city logistics concepts based on micro-consolidation of flows imply the development of a larger number of MCCs [11]. Special solutions based on micro-consolidation of flows, which are increasingly the subject of analyses, relate to e-commerce, home delivery and the use of parcel lockers in cities [20]. Logistics service providers deliver the goods to parcel lockers, after which they notify customers that the requested package is located in close proximity [21]. The parcel lockers are available to users 24/7, which eliminates the occurrence of failed deliveries, which is a common case in traditional models [22]. In the article [23], solutions for the last mile delivery based on parcel lockers and electric-powered cargo bikes were analyzed for the city of Hanover.

The development of logistics centers and consolidation of cargo flows at multiple levels expands the range of practically implementable city logistics concepts. Spatial and temporal consolidation of flows justifies the use of smaller delivery vehicles and alternative transportation modes for deliveries as a competiton to truck-based transportation. With increased awareness of the sustainability issues in urban areas, the number of researched alternatives to traditional delivery vehicles has also risen.

The application of small delivery vehicles and emission-free vehicles in delivering goods is one of the key elements for achieving sustainability in cities. Alternative-powered vehicles such as electric [24], hydrogen [25], hybrid [26], etc. have been analyzed. High purchase cost and weaker performance compared to traditional vehicles are the main reasons why logistics service providers rarely opt for alternative-powered delivery vehicles [24]. The efficient use of these vehicles requires high-quality, sustainable city logistics concepts, which inevitably implies some form of flow consolidation through logistics centers.

The development of new technologies enables the possibility of defining new, potentially sustainable city logistics solutions [16, 27]. Technological advancements, especially those in the 21st century, directed the attention of scientific research towards autonomous vehicles as elements of potential concepts of future city logistics. The application of autonomous vehicles, ground and aerial (drones), in specific scenarios of last mile delivery could positively affect urban sustainability [28, 29]. Regardless of the great enthusiasm in the scientific community regarding autonomous vehicles, a wider practical application mostly depends on regulatory policy support (that has yet to be done) [30] and public acceptance [31] as well.

In city logistics concepts, intermodal transportation is based on the utilization of alternative modes of transportation, with a focus on rail and water-based transportation. The primary challenge encountered with railway transportation of goods in urban environments is its lack of competitiveness with road-based transportation for shorter distances [32]. This issue can only be addressed through the consolidation of flows [33] and the establishment of regular rail connections between consolidation centers and delivery zones, or between the consolidation centers themselves [13]. Aside from the successful projects utilizing railway transportation, such as those in Dresden and Zurich, some (such as those in Amsterdam and Vienna) have been abandoned due to insufficient participation of the public sector in financing and legal support [34]. Intermodal transportation in urban logistics can be highly efficient when integrated with underground logistics systems [35].

In light of the growing demand for transportation of both people and goods, some authors argue that the development of new integrated rail systems for the transportation of both people and goods in urban environments is justified [36]. Some studies have examined the potential of using existing passenger transportation systems for the transportation of goods to the delivery zone [37]. Solutions that combine passenger and cargo flows, referred to as cargo-hitching, have also been proposed in the literature [38].

Inland waterways are utilized in several cities in Western Europe in the realization of the last mile delivery [39]. A concept that uses barges as mobile depots [40] which carry smaller delivery vehicles (such as bicycles, motorcycles, and drones) for the final stages of delivery, has been proposed as a way to combine efficiency and sustainability in urban logistics operations.

Historically, the majority of European and world cities have emerged along significant rivers, providing the basic prerequisites for the development of sustainable city logistics concepts based on inland waterways [41]. While such concepts are considered to be feasible only in cities with a dense network of inland waterways (such as Utrecht, Amsterdam, Venice, etc.), there are examples of their effective implementation in regions with weaker waterway networks, such as Paris and Lille [39].

In addition to the engagements of logistics service providers in all phases of delivery, concepts that involve the participation of ordinary people in performing specific logistics activities (such as home delivery, transportation, or storage of goods) are becoming increasingly popular in literature and are known as crowdsourcing [42]. The advantages of crowdsourcing include parallelism (the ability to perform multiple tasks simultaneously) and reduced negative impact on the environment (reducing the number of delivery vehicles required) [43]. The application of this concept contributes to achieving sustainability goals in urban and rural areas alike [44], bringing numerous economic, environmental and social benefits. Crowdsourcing deliveries provide greater flexibility and require less capital investments when compared to traditional delivery approaches [45]. Intelligent transportation systems and multi-agent models provide a significant support for crowdsourcing [46].

It is obvious from the literature review that there is a certain set of elements that could compose city logistics concepts however, no research article has explained the ways of combining those elements and what some typical city logistics concepts could be the product of those combinations. Exactly that is the main contribution of this article. The next section illustrates in what way could a wide set of city logistics concepts be defined from a relatively narrow set of building elements.

3. A FRAMEWORK FOR DEFINING SUSTAINABLE CITY LOGISTICS CONCEPTS

The various initiatives, technologies, and approaches previously discussed constitute the foundational elements for the development of sustainable city logistics concepts. The conceptualization of these potential solutions involves the integration of individual components into one cohesive concept. Once conceptualized, a thorough examination of the defined solutions must be undertaken to assess their potential impact on achieving sustainability.

According to the findings of [9], the conceptualization of sustainable city logistics solutions should rely on the establishment of appropriate logistics centers, the utilization of intermodal transportation, and the fostering of collaboration among stakeholders. By considering these three key city logistics initiative categories in conjunction with various transportation technologies, a wide set of practically viable city logistics concepts can be defined.

Although the number of elements that constitute city logistics concepts is limited, a diverse array of potentially sustainable concepts can be formulated. As highlighted in the literature review presented in the preceding section, different types and roles of logistics centers, system structure, cooperation model, applied transportation technologies, transformation degree of logistics flows and modal redistribution are considered as main building elements of city logistics concepts.

Considering flow macro-consolidation at the periphery of urban areas and micro-consolidation in the delivery zone, three main types of city logistics concepts could be defined. These types differ in the system structure (Figure 1).

The figure depicts four different system configurations. The subplot a) illustrates a system without the consolidation of deliveries. Subplots b) and c) depict two distinct variations of a two-echelon city logistics concept. Subplot b) illustrates a concept type featuring flow macro-consolidation through an UCC located on the periphery of urban areas, while subplot c) represents a concept that employs flow micro-consolidation through the utilization of MCCs within the delivery zone. Subplot d) illustrates a three-echelon concept type that combines both flow macro- and micro-consolidation.

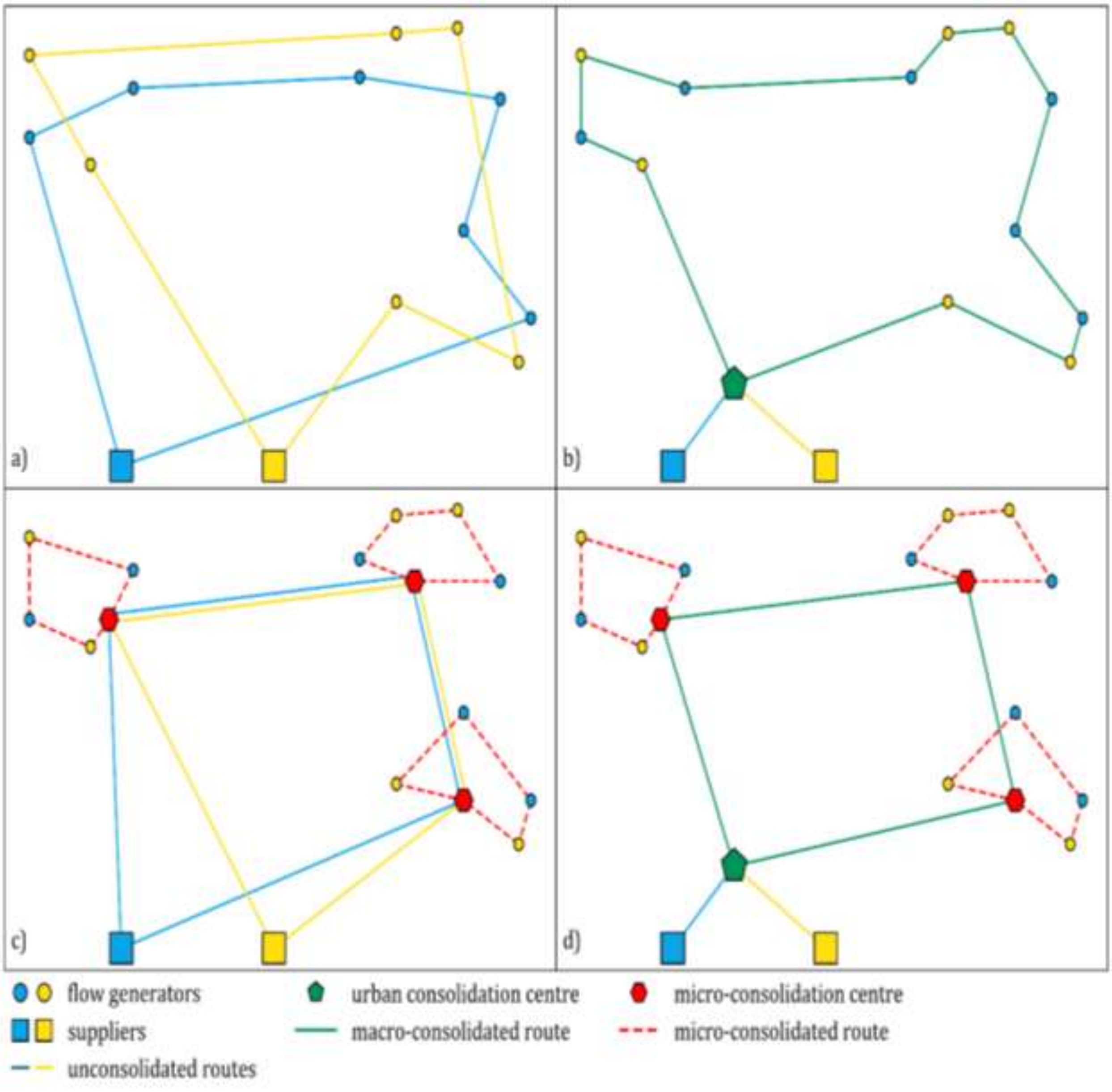

Figure 1 - Different city logistics concept types according to system structure: a) without flow consolidation; b) consolidation through a UCC; c) consolidation through MCCs; d) consolidation through UCC and MCCs

By taking into account various system structures and available transportation modes, a wide range of potentially feasible city logistics concepts can be formulated (Table 1). For instance, concepts that center on the establishment of UCCs can be further developed into different variations that vary in the transportation mode employed for the delivery of goods to the UCC, such as road, rail, inland waterways, and sea. Variations utilizing rail and inland waterways can be advantageous in cases where the UCC has direct access to the regional intermodal network, while the sea transportation variant may be suitable for urban areas in coastal cities. These sub-variations can be further refined based on the transportation mode used in the final phase of delivery, from the UCC to the end customers.

Table 1. A theoretical elaboration of different city logistics concepts according to the system structure and the applied transportation modes

City logistics concept	System structure	Transportation - phase I	UCC	Transportation – phase II	MCC	Transportation – final phase	Coverage of generators
CL-C01	two-echelon	road, inland waterway, rail, sea	yes	/	no	road	theoretically maximal
CL-C02	two-echelon	road, inland waterway, rail, sea	yes	/	no	rail	generators that have acces to rail infrastructure
CL-C03	two-echelon	road, inland waterway, rail, sea	yes	/	no	inland waterway	generators that have acces to inland waterway infrastructure
CL-C04	two-echelon	road, inland waterway, rail, sea	yes	/	no	air	generators in the drone delivery zone
CL-C05	two-echelon	road	no	/	yes	road	theoretically maximal
CL-C06	two-echelon	rail	no	/	yes	road	theoretically maximal
CL-C07	two-echelon	inland waterway	no	/	yes	road	theoretically maximal
CL-C08	two-echelon	road	no	/	yes	air	theoretically maximal
CL-C09	two-echelon	rail	no	/	yes	air	theoretically maximal
CL-C10	two-echelon	inland waterway	no	/	yes	air	theoretically maximal
CL-C11	three-echelon	road, inland waterway, rail, sea	yes	road	yes	road	theoretically maximal
CL-C12	three-echelon	road, inland waterway, rail, sea	yes	road	yes	air	theoretically maximal
CL-C13	three-echelon	road, inland waterway, rail, sea	yes	rail	yes	road	theoretically maximal
CL-C14	three-echelon	road, inland waterway, rail, sea	yes	rail	yes	air	theoretically maximal
CL-C15	three-echelon	road, inland waterway, rail, sea	yes	inland waterway	yes	road	theoretically maximal
CL-C16	three-echelon	road, inland waterway, rail, sea	yes	inland waterway	yes	air	theoretically maximal

The final delivery phase could utilize road (light delivery vehicles or vehicles with alternative energy source) (CL-C01), rail (CL-C02), inland waterway (CL-C03), or air transportation mode - drones (CL-C04).

Variations utilizing rail and inland waterway transportation modes in the final delivery phase are restricted to delivery zones that have direct access to the corresponding infrastructure, while the variant incorporating air transportation (by means of drones) for delivery from the UCC is limited by the technical capabilities of the drones in terms of delivery zone coverage.

City logistics concepts can be made two-echelon through the implementation of MCCs within the delivery zone. The variations differ in the applied transportation mode from suppliers to MCCs, which may include road, rail or inland waterway mode – CL-C05-10. The application of rail and inland waterway modes in the transportation from suppliers to MCCs is possible only when the suppliers have direct access to the coresponding infrastructure.

The catchment area of concepts that utilize MCCs is theoretically unrestricted given the sufficient development and distribution of MCCs throughout the entire delivery zone.

The final delivery phase – from MCCs to the generators – could be performed through road or air transportation. The catchment area of an individual MCC is primarily determined by the technical capabilities of the vehicles employed in the final delivery phase.

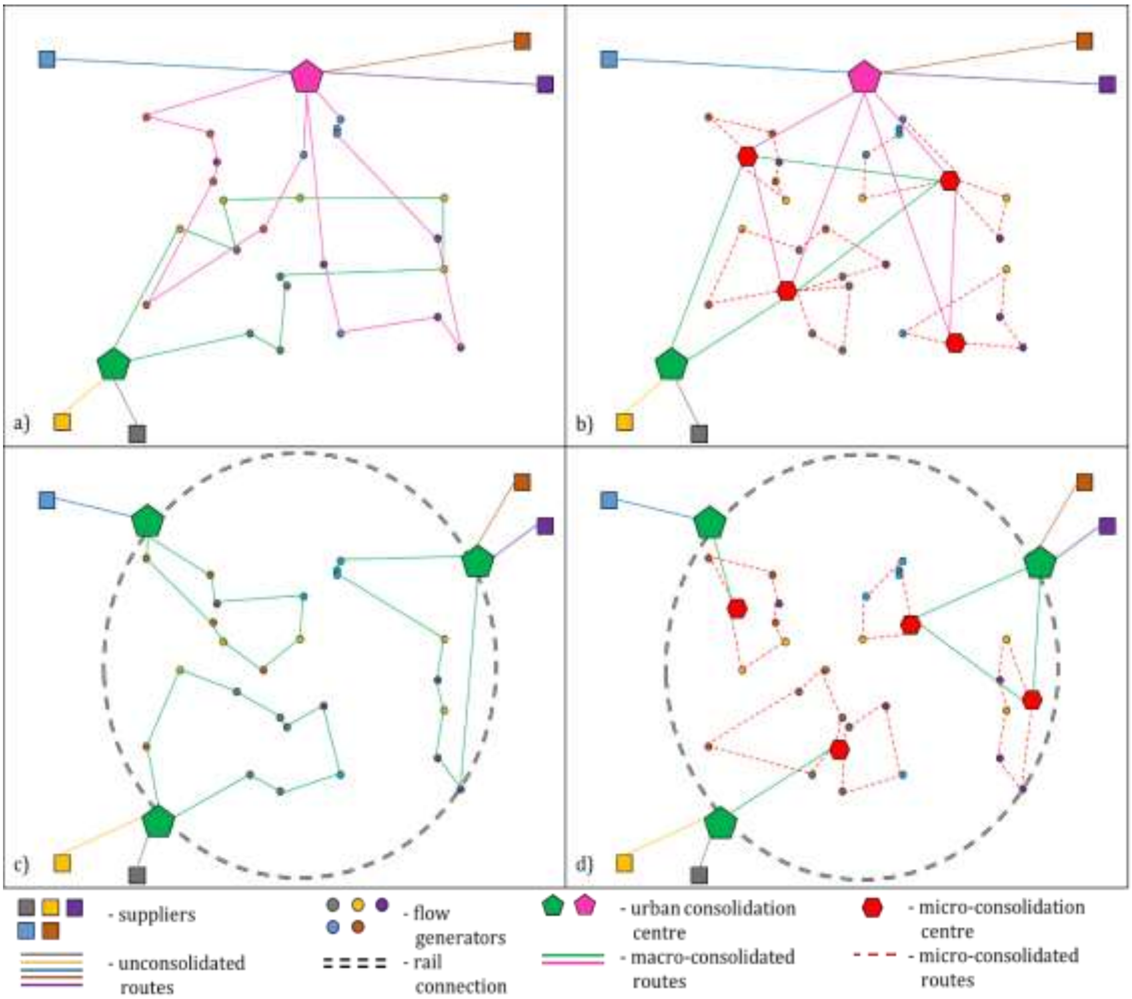

Figure 2 - Different city logistics concepts according to the system structure: a) independent UCCs; b) independtent UCCs and MCCs; c) interconnected UCCs; d) interconnected UCCs and MCCs

Ultimately, three-echelon city logistics concepts can be developed by combining the utilization of UCCs and MCCs (CL-C11-16). In addition to the transportation mode employed for delivery to UCCs and the final delivery phase, these concepts may also vary in the transportation mode utilized for delivery between UCCs and MCCs, which may include road, rail, or inland waterway transportation. Such concepts effectively leverage the advantages offered by rail and inland waterway modes, however, they may pose significant operational challenges during implementation. In some cases, the development of a single UCC may not be sufficient to meet the specific characteristics and functions of a given urban area. In such instances, the consideration of the establishment of a greater number of UCCs allows for an increased diversification of the set of potential city logistics concepts (Figure 2). UCCs can be developed independently, or could be interconnected through rail transportation for example for better redistributing transportation work in the urban area. The previously described concepts can be further refined into a multitude of variations, particularly when different technologies and their respective areas of application are taken into account. The Industry 4.0 technologies, such as artificial intelligence (AI), advanced robotics (ARo), blockchain, Internet of Things (IoT), augmented reality (AR), and cloud computing (CC), add an additional dimension to the formulation of city logistics concepts.

As outlined in [47], it is possible to develop „smart“ city logistics concepts by combining different Industry 4.0 technologies, transportation modes and technologies, and consolidation types. In the article, all defined concepts include flow consolidation and cooperation through an UCC at the urban periphery, the application of ARo in the processes of goods manipulation, order picking, labeling, sorting, etc., with decision support systems and the blockchain technologies as an integral part of all concepts as well. The difference between the defined concepts is in the carrier of logistics activities, the applied transportation modes and technologies, and the system structure (Figure 3). For a more detailed explanation of those concepts, the reader is encouraged to see [47].

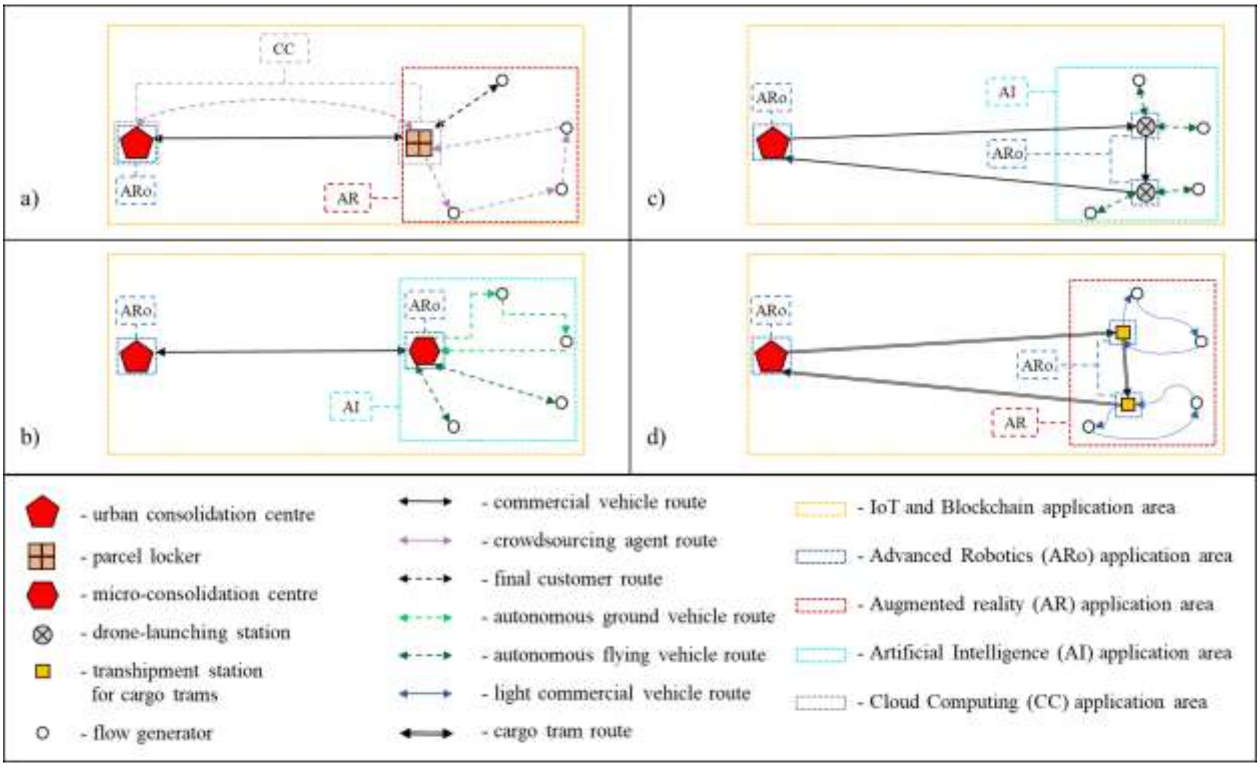

Figure 3 - Smart city logistics concepts – some examples (adapted from [47])

This section demonstrated a conceptual approach in defining potentially sustainable city logistics concepts. Although the defined concepts are conteptually universal, their application is not. The sustainability of city logistics concepts depends on the urban characteristics and the inclusion of all stakeholder groups and their goals. Therefore, it is imperative that the concepts be further developed in accordance with the characteristics of the particular urban area under consideration. Additionally, it is crucial to establish a dedicated sector within local authorities with a mandate to address city logistics issues. This sector should play a key role in the development of regulations that support the sustainability of city logistics solutions. To achieve this, the sector should be composed of experts in the field of city logistics [5].

4. CONCLUSION

The academic literature in the field of city logistics recognizes the pressing need for addressing the sustainability of urban areas. To plan logistics systems that are sustainable, it is essential to develop and implement sustainable city logistics concepts that incorporate a variety of technologies, measures, initiatives, and approaches.

The core initiatives upon which sustainable city logistics concepts are built include the development of logistics centers, the utilization of intermodal transportation, and fostering collaboration among stakeholders. By further integrating various technologies, measures, and approaches, an extensive set of potential city logistics concepts can be formulated.

Since the literature lacks a generally accepted set of guidelines for defining sustainable city logistics concepts, the aim of this article was to try filling that gap. The article presents various approaches for defining potentially sustainable city logistics concepts and demonstrates how they can be further refined for specific case studies. It is crucial to take into account the characteristics of the urban area and the goals and interests of stakeholders during the whole process. Furthermore, local authorities have a great influence on the development of solutions. To contribute to sustainability, it is necessary to establish a sector within the local authorities that would focus on solving city logistics problems and promoting collaboration and sharing of knowledge and experiences. That sector should be involved in defining of regulations that would support the sustainability of city logistics.

Future research should focus on the evaluation of individual typical city logistics concepts defined in this article to demonstrate that as a good initial step in defining sustainable city logistics systems. The analyisis of such concepts in real case studies is an always ongoing topic, therefore it can be another direction for future research. Some more complex concepts that are explained in this article are underrepresented in the existing literature and deserve more attention. A good addition to the existing literature would be a more in-depth elaboration of such concepts and the development of appropriate models for their evaluation and planning.

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REZIME

ODRŽIVE KONCEPCIJE CITY LOGISTIKE – ELEMENTI I KONCEPTUALIZACIJA

Definisanje i primena održivih koncepcija city logistike je preduslov postizanja održivosti u urbanim sredinama. Stručna literatura obiluje istraživanjima koja ističu pojedine tehnologije, inicijative, mere i pristupe kao neizostavne elemente održivih koncepcija. Iako je istražen relativno širok skup koncepcija city logistike u literaturi, ne postoji opšteprihvaćen skup smernica za definisanje održivih koncepcija city logistike. Ovaj rad pokušava dopuniti taj nedostatak. Osnovni doprinos rada je da na bazi sprovedenog pregleda relevantne literature u oblasti demonstrira na koji način je moguće konceptualizovati potencijalno održive koncepcije city logistike kombinovanjem različitih gradivnih elemenata (tehnologija, inicijativa, mera i pristupa).

Ključne reči: *održivost, city logistika, koncepcije*