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APPLICATION OF INDUSTRY 4.0 TECHNOLOGIES IN HOME DELIVERY: A REVIEW

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The development of the Internet has accelerated the development of electronic commerce, which has led to changes in the management of supply chains and logistics. Unlike traditional shopping trips, there is a need for home deliveries and appropriate logistics systems for their implementation. To overcome new challenges and achieve process efficiency and the quality of home delivery service, there is a need for individual or integrated application of various Industry 4.0 technologies such as the internet of things, additive manufacturing, autonomous vehicles, blockchain, big data, data mining, artificial intelligence, virtual and augmented reality, etc. Accordingly, this paper aims to provide a comprehensive overview and description of the application of technological solutions of Industry 4.0 in home delivery. This goal is achieved through a comprehensive literature review on the topic. The results indicate that although a large number of studies in the literature dealt with the application of individual or integrated Industry 4.0 solutions in home delivery or last-mile logistics, a comprehensive review of the application of existing solutions in home delivery has not been carried out so far. This is thereby the main contribution of this paper. Overview of the technologies application provides a basis for identification of those that have the widest possibilities and generate the most positive effects, and should thus be the focus of future studies and development plans.

Keywords: last mile, home delivery, industry 4.0, Logistics 4.0, technologies

1 INTRODUCTION

History was marked by numerous revolutions, which changed its course in the political, social, economic, and cultural context. Some of the most significant changes in the world in recent centuries were brought about by industrial revolutions. The peak of industrial and technological innovations so far is the emergence of the Internet and, subsequently, technological solutions of Industry 4.0, such as the Internet of Things (IoT), additive manufacturing, drones, etc. The appearance of these technologies greatly influenced everyday life, trade and logistics. The development of the Internet has accelerated the development of electronic commerce, which has led to changes in supply chain management and logistics. In fact, in contrast to traditional shopping trips, there is a need for home deliveries and appropriate logistics systems for their implementation. The new challenges require the application of adequate technologies, which will enable the efficient implementation of logistics processes and activities. It is precisely in this context that Industry 4.0 technologies play an increasingly important role.

The efficiency of the process and the quality of the home delivery service could be achieved both individually and through the integrated application of various logistics 4.0 technologies: e.g. IoT and Big data [1], IoT and blockchain [2, 3], IoT, Global Positioning System (GPS) and Transport Management System (TMS) [4], IoT and cloud computing (CC) [4] etc. Although a large number of papers deal with the application of individual or more integrated Industry 4.0 solutions in home delivery or last mile logistics, a comprehensive overview of the application of existing solutions in home delivery has not been found in the literature.

This paper offers a thorough examination and explanation of how Industry 4.0 technologies are applied in home delivery, thereby accomplishing the primary objective and contribution of the study. The paper is structured as follows. An introduction is presented initially, followed by an explanation of the concepts of Industry 4.0 and Logistics 4.0 in the second section. The third section delves into the application of Industry 4.0 technological solutions in home delivery. Finally, concluding remarks are provided, along with suggestions for future research directions.

2 INDUSTRY 4.0 I LOGISTICS 4.0

The term "Industry 4.0" appeared in 2011 at the Hanover fair as the name of a joint initiative for business, science and politics to promote the competitiveness of Germany's industry [5]. Nowadays, this term is commonly embraced and has the same meaning as the term fourth industrial revolution. There are different definitions of Industry 4.0, but they all have in common that it implies the integration of computing, networks and tangible physical processes, thus creating a cyber-physical system that represents the foundation for the emergence of novel business models and solutions [6].

Industry 4.0 consists of all the elements needed to facilitate smart production and logistics processes [7]. In this context, the concept of Logistics 4.0 is gaining growing importance. Logistics 4.0 is considered an important component of Industry 4.0 and encompasses the implementation of diverse technologies that embody the principles of Industry 4.0 in the domain of logistics [8]. In the literature, this concept is frequently synonymous with the term "smart logistics" [9].

The significance of qualities such as adaptability, self-organization, proactivity, flexibility, and is growing in the field of logistics, and their attainment relies on the integration of emerging advanced technologies [10]. They are especially important in e-commerce, last mile and home delivery logistics. Namely, a divergent distribution structure, a large number of smaller orders, heterogeneous and changing customer requirements represent major problems for delivery service providers [11, 12, 13, 14, 15]. Technological solutions of industry 4.0, i.e. logistics 4.0, can play a significant role in overcoming these challenges.

Industry 4.0 technologies are applied in various areas of logistics [9, 16, 17, 18] and contribute to the transformation of logistics chains and systems. They are of increasing importance in reverse logistics [19, 20, 21], but also in the development of modern logistics centers [22, 23, 24], smart city logistics [25, 26], etc. Many research studies examine how these technologies contribute to the realization of a circular economy within the logistics sector. [27, 28, 29, 30, 31, 32]. Although the impact of certain Industry 4.0 solutions on last-mile deliveries has been discussed in many studies, very few papers comprehensively consider the impacts of the development of Industry 4.0 technologies on this part of logistics and supply chains [33, 34].

3 METHODOLOGY

The search for sources was performed using Google Scholar, by systematically entering combinations of two or more terms from two or three groups shown in the table 1. Thus, some of the entries were: "last mile industry 4.0 technologies", "last mile transport smart technologies", "home delivery internet of things" etc. Papers whose title contains the mentioned combinations were analyzed, as well as those where they are not highlighted in the title, but fully or partially deal with this topic. Apart from this way, the authors came to the source by searching the cited sources (fig. 1). In both cases, a selection of relevant and useful sources for the given topic was made.

Table 1. Groups of search keywords

I group of keywords	II group of keywords	III group of keywords
home delivery, last mile, last-mile, last mile delivery, parcel delivery	logistics, transport, storage, warehouse, package, inventory, order	technologies, new technologies, 4.0, industry 4.0, smart, *names of technologies and corresponding abbreviations* (Internet of things, IoT, automated guided vehicles etc.)

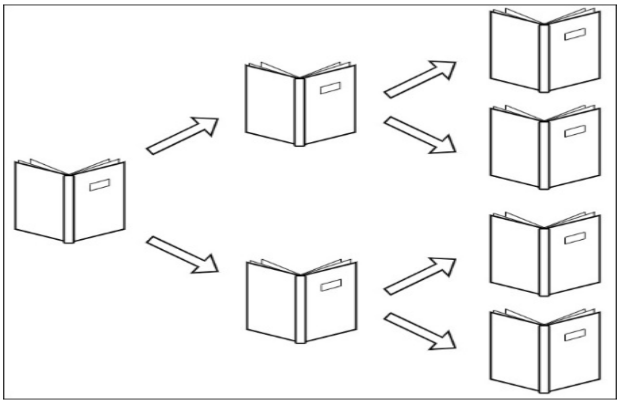

Fig. 1. Divergence of research by searching cited sources

4 TECHNOLOGICAL SOLUTIONS OF LOGISTICS 4.0 IN HOME DELIVERY

The process of home delivery involves the transportation of goods to the user's residential address, by the retailer, manufacturer or third party [15]. The complexity of the distribution of goods in the last mile requires the development of modern technological solutions. By reviewing the literature, the following technological solutions have been identified that are applied or have the potential to be applied in home delivery: internet of things, augmented reality (AR), automated guided vehicles (AGVs), drones and AVs, AI, big data, data mining, management and control support systems, CC, E-marketplace and M-marketplace, blockchain, additive manufacturing, advanced robotics. The importance of these technologies for home delivery will be described below.

4.1 Internet of things

IoT is a communication paradigm that implies that various objects are equipped with microcontrollers, transceivers for digital communication and the appropriate protocol, which allows them to communicate with each other and with users, becoming an integral part of the Internet [35, 36]. The advantages of IoT architecture are scalability, extensibility and interoperability [37]. IoT technology has been most widely applied in the logistics system [38, 39, 40, 41]. It enables the visibility, monitoring and management of goods throughout their entire life cycle [1], but also to other entities (logistics units, transport means, manipulative equipment, etc.) in the entire supply chain, including its last mile. The connection of vehicles (Internet of vehicles - IoV) is particularly important. IoV can provide real-time various information (e.g. fuel consumption, tire wear, etc.) [4], as well as intelligent vehicle scheduling and management [42].

IoT is applied in various home delivery models from the perspective of endpoint (customer address, collection or delivery point - CDP), executor (logistics provider, shipper, crowd worker), delivery technology (different transport means of different transport modes) etc. (table 2) A special contribution to the efficiency of the process and the quality of the delivery service can be realized by integrating IoT with other logistics 4.0 technologies: AVs, drones and intelligent robots [42], Big data [1], blockchain [2, 3], GPS and TMS [4], Intelligent Transportation Systems (ITS) [42], CC [4] etc.

Table 2. Fields of application of IoT in home delivery

Field of application	Literature sources
real-time track and trace, collection of data about the vehicle	[1], [4]
intelligent vehicle scheduling and management (integration with unmanned vehicles)	[42]
collection of data about the goods and safety monitoring (in integration with blockchain)	[2]
delivery assurance (in integration with blockchain)	[3]
virtual user addressing	[45]
connecting unmanned CDPs with the systems of delivery company	[49]

Although there are different options in terms of the endpoint of delivery, most users prefer delivery to home address [43, 44]. One of the main operational problems of this type of delivery is the impossibility of finding the user's address, due to the lack or inadequate marking of street data, number, etc. and consequent delivery failure. This problem can be solved by implementing an IoT-based virtual user addressing system [45]. In addition to information about the target location, this system could also provide information about the users who can receive the package, in case the recipient is not at home. Also, the system can automatically update the address of the user in case of his relocation.

IoT can also be applied in deliveries to CDPs. CDPs form a network of sites where suppliers aggregate and deliver requested products, while customers make payments, collect items, or initiate returns [46, 47]. There are two types of CDPs: manned or unmanned [48]. The IoT is used to connect unmanned CDPs (automated stations, parcel lockers) with the delivery systems of companies [49].

By applying IoT in home delivery, shippers or logistics providers ensure [4]: higher service quality for users (the user is enabled to track the shipment in real time), and thus their satisfaction, a more efficient refund process and lower insurance premiums in case of disputes and user dissatisfaction with goods, network optimization (costly bottlenecks and places where certain incidents with goods occur can be easily identified and eliminated), decision support, reduction of late deliveries, improved capacity planning and allocation, greater storage efficiency, etc. Also, the application of IoT can bring significant benefits in the case when the crowd worker performs the delivery [42].

IoT can be applied in various delivery models in terms of transportation technology. This technology contributes to the efficiency of the process both in traditional (using passenger vehicles, light trucks, etc.) and in innovative delivery models, which can also be performed without drivers (using autonomous vehicles, drones, intelligent robots, etc.) [42].

4.2 AGVs and AVs

AGVs and AVs offer potential for home delivery [50] (table 3). AGVs, whether self-driving or remotely controlled, follow predetermined paths using technologies like magnets, lasers, cameras, radio waves, for guidance [51]. From the aspect of delivery time, AGVs are adequate for various delivery models except for instant delivery [50, 52]. In home delivery, AGVs with lockers can serve as mobile unmanned collection and delivery points (CDPs), transporting goods from the initial location to nearby user destinations [53]. Drones, as AGV variants, can also be employed for home delivery, carrying goods in mini-containers and depositing them near the user [54]. Drones can operate independently or in conjunction with road transport [25, 50]. There are numerous advantages (avoidance of congestion, faster delivery in urban areas, time and cost savings, efficiency of deliveries in rural areas, etc.), but also disadvantages, problems and challenges of applying this technology (technical challenges: payload limitations, battery power, interference, unreliable location data, access issues, etc.; security challenges: risk of injury and death due to a drone accident, risk of privacy, terrorism, etc.; requirement for advanced IT systems and qualified workforce; legal limitations of application; insufficient social acceptance, etc.) [9]. The utilization of drones for home delivery holds significant importance for urban areas, i.e. city logistics [55, 56].

AVs are vehicles that can adapt and learn, enabling them to perceive their surroundings and navigate safely with minimal human intervention [57]. They have the capability to autonomously execute entire home deliveries or assist delivery personnel in the final leg of the delivery process [50]. AVs can improve efficiency, contribute to cost savings and reduce negative environmental impacts [58]. In the foreseeable future, in technologically advanced nations, AGVs, AVs, and drones have the potential to emerge as the primary transport technologies for home deliveries. However, the timeline for their widespread implementation hinges upon factors such as cost, regulatory frameworks, and public acceptance of these technologies [52]. Additionally, it is imperative to address various technical problems, establish suitable infrastructure, and provide training to personnel responsible for overseeing the operation of AGVs [50].

Table 3. Fields of application of AGVs and AVs in home delivery

Field of application	Technology	Literature sources
delivery and using as unmanned CDPs	AGVs	[52, 53]
complete delivery	drones	[50, 52]
performing part of the delivery		[25, 50, 55, 56]
complete delivery	AVs	[50, 52]
assistance to delivery person for last part of the delivery		[50]

4.3 Artificial intelligence and augmented reality

AI represents the automation of activities associated with human thinking, such as learning, decision-making, problem-solving etc. [59]. This technology has enabled a boost in productivity and provided support for economic expansion [60].

There is growing number of examples of AI applications in logistics and supply chains, and the most immediate impact is on the end of the supply chain [61] (table 4). AI enables precise management of even the most complex data set, enables the use of systems to create data sets that are used to control patterns and various phenomena, produces data models that focus on predictive analytics [60]. Therefore, in e-commerce, last mile and home delivery logistics, it is applied in various fields: for delivery time forecasting [62], demand forecasting [63], inventory planning [61], routing optimization and shipment tracking [60]. It is most often applied in city logistics, but also for planning the distribution of electronically ordered goods in rural areas [64].

The advancement of AI has paved the way for the emergence of innovative technologies, one of which is AR. AR represents a combination of the physical and digital world, i.e. the addition of virtual elements, objects or information to the physical world in real time [65]. It is created using different types of AR-devices, most often smart glasses, helmets, head-up displays and hand-held devices (tablet computers, smartphones, etc.). There are numerous attempts to apply AR in last mile delivery and home delivery [66, 67] (table 4). AR can be applied in logistics, distribution centers, as well as in the distribution process.

There are numerous potentials for the application of AR in operations related to logistics centers and warehouses: receiving, storage, ordering, shipping [65], as well as warehouse planning [68]. Smart glasses, helmets and handheld devices are mostly used in these operations. Trials of AR indicate a significant improvement in productivity in warehouse operations. Thus, the integration of this technology with the Warehouse Management System (WMS) enables the automatic updating of data on the inventory level and the reduction of picking errors by as much as 40% [68]. Also, AR can play a significant role in replacing printed waybills and instructions for loading and unloading goods and speeding up these processes.

AR can contribute to the efficiency of transportation and other distribution operations. The use of head-up displays is particularly important for the execution of transport. These AR-devices are based on projecting information about the movement (speed, time, navigation, etc.) on the windshield of the vehicle, thus ensuring the concentration of the driver on the management of the means of transport, without directing his sight to its interior. One of the problems in home delivery is finding the target building or entrance, especially when street names and house numbers are not clearly visible or there is no well-structured network of streets and buildings. GPS (Global Positioning System) devices that are most often used for navigation have interference in receiving signals when vehicles move through densely built-up areas, and AR-devices can also be used for this purpose with appropriate adaptation [68].

Research shows that a significant part of the working time spent outside the distribution center is not spent by delivery people driving, but rather searching the cargo space for a shipment intended for a specific user [68]. They perform this procedure by recalling the loading process. In the future, AR-devices could provide suppliers with information about each shipment (type of goods, weight, customer address, goods characteristics, specific logistics requirements, etc.). Based on information about shipments and currently free space, the device will be able to determine where they should be positioned during loading, taking into account the planned route. More efficient loading and virtual marking of the required cargo unit with an AR-device will certainly speed up and facilitate home delivery. Also, drivers will no longer have to drop the cargo units on the floor or hold them with one hand to close the vehicle doors when extracting the desired shipment, thereby risking damage to the goods, but will give the instruction for automatic door closing by voice or gestures [68].

Augmented reality technology can also be used for more secure user identification. During the delivery of the goods, the AR-device takes a video which, based on facial recognition technology, compares it with the user's face, which is saved in the database.

Table 4. Fields of application of AI and AR in home delivery

Field of application	Technology	Literature sources
dynamic data analysis and intelligent delivery scheduling and recommendation	AI	[61]
precise management of complex data set and producing data models that focus on predictive analytics		[60]
demand and delivery time forecasting		[62, 63]
inventory planning		[61]
distribution optimization and shipment tracking		[60, 64]
in warehousing (receiving, storing, picking, shipping) and logistics (distribution) centers	AR	[65]
warehouse planning, automatic updating of data on the inventory level (integration with the WMS)		[68]
registering and tracking the parcels inside the truck and projecting the location in the user's field of view		[66, 67, 68]
projecting information about the movement on the windshield of the vehicle during transport		[68]

4.4 Big data and Data mining

Big data techniques are used in home delivery in real-time optimization of delivery vehicle routing, as well as in the planning and implementation processes of crowd delivery [69] (table 5). In the first case, fast processing of a large amount of data enables more efficient routing of the delivery vehicle, optimization of the fleet operation, saving time and costs, a higher level of service, etc. Namely, vehicle routing is continuously adjusted, taking into account information about traffic conditions, geographical factors, and the user, which are updated in real time. Another area of application of this technology is crowd deliveries, which are carried out by individuals, with the help of their own resources (vehicles, walking, public transport, etc.) [70]. This delivery model allows the daily flows of employees, students, pupils, taxi drivers and tourists to be used for home deliveries. The large amount of information about supply and demand for crowd delivery services makes this area suitable for the application of big data techniques.

Table 5. Fields of application of big data in home delivery

Field of application	Literature sources
real-time optimization of delivery vehicle routing	[69]
planning and implementation processes of crowd delivery	[69]

Process of examining extensive volumes of data to uncover concealed patterns and correlations is denoted as "Big data analytics". These technologies serve as a means to discover, gather, transform, analyze, and visualize data, making them applicable for efficient decision-making while optimizing resource consumption such as time, finances, and energy [72]. Collectively, these technologies are often referred to as data mining and are applied in various areas and subsystems of logistics [9, 73], so in the future they may play a significant role in home delivery.

4.5 Blockchain

Blockchain is a computer technology that represents a distributed database or ledger shared among a computer network's nodes. Transactions are recorded in blocks, which form a linear, chronologically ordered chain. The conceptual origins of blockchain technology can be traced back to the paper [74], but its practical implementation and the name by which it is recognized today were established in 2008. During that time, a group of authors operating under the pseudonym Satoshi Nakamoto [75] utilized this technology to develop the Bitcoin cryptocurrency.

Blockchain technology is most often used in home delivery in integration with other technologies (e.g. drones, IoT, CC) [76] (table 6). By itself, it is not an effective driver in solving last mile problems and improving performance, but after implementing a strong last mile logistics management system, its performance can be strengthened by applying this technology [77]. Using blockchain technology can increase sustainability and the speed of problem identification, reduce waste, possibility of fraud, delays in paperwork [78], as well as overcome problems of mistrust in cooperation and data exchange between courier, express and parcel services [79].

Table 6. Fields of application of blockchain in home delivery

Field of application	Literature sources
collection of data about the goods and safety monitoring (integration with IoT)	[2, 77]
delivery assurance (integration with other technologies)	[3, 76, 77]
horizontal collaboration of carriers in the context of micro-hubs	[79]

4.6 Management and control support systems and Cloud Computing

Management and control support systems encompass software designed to aid in overseeing and managing the execution of diverse activities and processes across all logistics subsystems [9]. When it comes to home delivery, several systems can be employed, including electronic data interchange (EDI) systems, enterprise resource planning (ERP), TMS, inventory management systems (IMS), WMS, package management systems (PMS), ITS, telematics systems and among others. The application of these software in last-mile logistics (table 7) can contribute to the efficiency of logistics processes [80], but also to the achievement of sustainability and environmental protection goals [81, 82, 83].

Table 7. Fields of application of management and control support systems in home delivery

Field of application	Technology	Literature sources
digitalization and monitoring of all activities in the logistics system (in integration with oher technologies)	EDI	[33]
optimization of the total delivery time and the distance traveled (in integration with an algorithm for the optimization and planning of fleet usage and routes)	ERP	[81]
crowd last mile delivery	ITS	[82]

While many of these solutions have been implemented long before the advent of the Industry 4.0 concept, they are experiencing a resurgence in the Industry 4.0 environment, primarily due to their widespread availability and user-friendly applications facilitated by the cloud computing (CC) paradigm [9]. CC entails broad and convenient network access, enabling the utilization of shared computing resources (e.g. software, servers, applications, storage capacities, services etc.) that can be swiftly provisioned and released with minimal reliance on service providers [9, 84]. The key characteristics of CC include on-demand service provision (where users independently select and initiate computing resources as needed), widespread network access (enabling resource accessibility from any location using various devices connected to the network), resource pooling (aggregating resources from multiple providers and users across different locations), elasticity (allowing for swift and effortless adjustment of resources to meet user requirements), and service metering (measuring resource utilization for billing and broader application purposes).

4.7 E-Marketplace and M-Marketplace

E-marketplace and M-marketplace are platforms for electronic commerce, which has a direct impact on the development of home delivery. In fact, although home delivery can be generated by different systems of ordering goods (in person, by phone, mail, fax, interactive TV, etc.), it is most often preceded by ordering via the Internet [53]. E-marketplaces facilitate automated transactions, trade, or collaboration among partner companies [84]. These platforms can vary based on a range of criteria [9]: mechanism of sales, ownership, number of owners, core business, type of goods or services and method of organization, but the most important criterion is the participants, which can be individual or legal entity. The most important models of electronic commerce are Business-to-Business (B2B) and Business-to-Customer (B2C). Although there are other ways for goods ordered electronically to reach the user (electronic delivery of intangible products, pick-up in a store), home delivery is the most common form of B2C transaction. Moreover, it is most often an integral part of the online shopping service, which often decides customers to use this service.

The development and mass use of smartphones and other mobile devices (tablets, portable computers, etc.), with which electronic commerce can be carried out, led to the evolution of the e-market and the emergence of the m-market. Mobile applications are especially often used for ordering goods that require instant delivery (most often delivery of fast, prepared food).

In addition to e-commerce, the Internet and mobile applications play a significant role in the development of crowd delivery. This concept implies that delivery to users is carried out by individuals, most often during daily trips (shopping trips, trips to work, etc.). Delivery contracting is performed through applications and social media.

4.8 Additive manufacturing

Additive manufacturing, also known as 3D printing, encompasses the fabrication of three-dimensional objects by layering materials in accordance with virtual models. Its origins can be traced back to the development of stereolithography in the mid-1980s [86]. The process of additive manufacturing relies on three key elements [87]: 3D printer, materials used for printing and design/3D model of the product. According to some authors (e.g. [88]), this technology heralds a new industrial revolution. There are examples of additive manufacturing in many fields (aviation, automotive, construction, medicine, etc.) [89].

The development of additive manufacturing can also significantly affect supply chains and logistics, especially city logistics, last mile delivery and home delivery (table 8). The impact on home delivery can be particularly pronounced from the aspect of the starting point, i.e. the delivery organizer, the type of goods, freight or material and the performing of return flows [53]. These delivery features depend on the location and additive manufacturing provider.

Additive manufacturing can be implemented in different places, from the aspect of the supply chain (at the producer/seller or the user) or in the geographical sense (at locations that are at different distances from the user). Manners-Bell and Lyon [90] state that the development of additive manufacturing can lead to significant changes in the relationship between manufacturers, wholesalers and retailers. Hence, within specific sectors of retail, stores have the potential to vanish entirely or undergo a metamorphosis into showrooms devoid of inventory or direct sales of goods [9]. In this case, the manufacturer, in addition to production, would also carry out direct sales and delivery of finished products to the user's home address.

One of the main expectations related to the development of additive manufacturing is the transition from centralized to decentralized production and supply chains [87, 91], which would also significantly affect logistics. By decentralizing and geographically bringing production closer to the user, an increase in the efficiency of logistics systems and processes and a reduction in logistics costs can be achieved. In fact, in this case, the flows of raw materials would have a greater importance and share in the total flows in the supply chain than the flows of finished products, which can contribute to better utilization of means of transport, reduction of tonne-kilometers traveled, reduction of packaging material, etc. Therefore, efforts are being made to make the location where additive manufacturing takes place closer to the end users. In this context, the development of the concept of local "fab shops", places for additive manufacturing in urban areas, from which finished products can be delivered to the user's home address, is significant. Some companies have already developed this concept, but for now it is aimed at small businesses and not end users [86].

Finally, additive manufacturing can be performed in the households of end users [14]. In this case, 3D printers and printing materials are delivered to the home address, which the user uses for the production of goods, which can optimize logistics processes in relation to the delivery of finished products. This concept contributes to the optimization of transport processes, the reduction of inventories of finished products in stores and warehouses in urban areas and the release of commercial space for other uses [92], because the storage of materials for additive manufacturing takes up less space than conventionally produced finished products. Mass individualization, intensification and diversification of consumption encourage the development of this concept. In fact, the user can perform additive manufacturing of different goods based on their own needs, desires and affinities. In this way, the percentage of goods returned due to customer dissatisfaction can be reduced, and thus the volume and frequency of return flows. This concept is still very rarely applied [86], but its development and expansion is expected [87, 93]. However, Cutting et al. [94] indicate that only certain types of goods will be produced in this way, while other goods will be purchased by customers in the usual way.

Expectations regarding the dynamics and effects of the development of additive manufacturing are twofold. Despite the mentioned positive effects that it can bring, there are numerous challenges that affect the uncertainty of the development and effects of the application of this technology (high costs, limited range and quality of products, technical shortcomings and limitations, etc.) [86, 87, 94, 95].

Table 8. Fields of application of additive manufacturing in home delivery

Field of application	Literature sources
development of local "fab shops", as places for additive manufacturing and delivering	[86, 94]
manufacturing in the households of end users	[14, 92, 93, 94]

4.9 Advanced robotics

Advanced robotics is applied both in home delivery itself, and in operations in logistics centers that are carried out before or after it (table 9). Self-driving robots are of special importance in delivery, which are most often used in the "last yard" of delivery, while the driver simultaneously serves other users nearby. The use of these robots can ensure flexibility and timeliness of delivery, better protection of drivers and customers by minimizing contact, which is especially important in the context of the current pandemic [96]. Currently, many companies are testing the application of these robots in home delivery [97].

Within logistics centers, advanced robotics have predominantly been implemented for storage and warehouse operations [69]. Prototypes exist for robots that handle the loading and unloading of transport units and assets, as well as stationary and mobile robots that carry out a range of value-added logistics (VAL) services, including processing, packing, repacking, palletizing, depalletizing, finishing, labeling and more [9, 69]. Furthermore, conceptual solutions are being explored for fully automated systems in distribution centers and cross-docking terminals [69].

Table 9. Fields of application of advanced robotics in home delivery

Field of application	Literature sources
operations in logistics (distribution) centers for delivery	[69]
complete delivery	[96, 97]
performing part of the delivery	[98]

5 CONCLUSION

Industry 4.0, as the backbone of technological development in the first decades of the 21st century, has changed, is changing and will change the way of production, work, communication, and life. Digitization, automation, robotization and other transformations it brings are also evident in logistics and supply chains. Distribution in the last mile, especially home delivery, as one of the most challenging logistics processes, can be an area for the implementation of technological solutions of Industry 4.0. They can be applied individually or in combination both in home delivery processes and in the operations that precede it (in previous stages of the supply chain, distribution centers, etc.) or are performed after it (return flows). Their application contributes to the efficiency of logistics activities, the productivity of logistics systems, and in some cases even to their aesthetic appeal.

In this paper, the technologies of Industry 4.0 and the possibilities of their application in home delivery are identified and described. This achieved the main goal and contribution of the paper and created the basis for future research in this area.

The selection of an appropriate Industry 4.0 technology for home delivery can be the subject of multi-criteria decision-making in future research. In addition to home delivery, as a household supply model, other areas and subsystems of household logistics (inventory management, storage, packaging, etc.) can be areas of application of Industry 4.0 technologies, which should be analyzed in future research. Finally, bearing in mind the evolution of technological concepts and technological development trends, the focus of researchers' attention will inevitably be the implementation of Industry 5.0 solutions. Therefore, it is necessary to analyze the possibilities of applying these solutions in home delivery.

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