

# Smart Lockers: Approaches, Challenges and Opportunities



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**Abstract:** This survey focuses on the benefits of smart lockers and their potential contribution in the last mile problem. It first introduces the related concepts. Then, categorizes existing solutions and identifies the similarities and differences. Further, their strengths and limitations are discussed. Finally, it presents key challenges in the field, and discusses envisioned future research directions that must be factored in by researchers, implementers, and manufacturers to increase the acceptance of smart lockers and to improve their security.

**Keywords:** Smart Lockers, Parcel Delivery, IoT, Survey, Tutorial, Security.

## I. INTRODUCTION

In 2020, according to the CTT e-Commerce Report 2021 [1], e-commerce in Portugal grew 46%, which means that the Portuguese people spent near 4.4 billion euros. This study supports future previsions that indicate a continuing growth of this market [2].

Therefore, when customers buy items online, the typical expectation is that they will have five different delivery methods. These are home shipping, in-store click and collect, in-store reserve and collect, parcel store, and smart lockers [3]. The first method involves online payment with delivery to the customer's home. The second method, on the other hand, still includes online payment, but delivery is made at the physical store. In-store reserve and collect enables a reservation on the website with payment at the time of pickup in the store. A little different, the parcel store, allows online payment and a variety of delivery points.

These can be gas stations or other stores with more flexible schedules. The last method is smart lockers, which involve an online payment. Smart lockers are usually found in public places such as train stations, streets, or shopping centres. The customer can choose the most convenient location for himself, where the delivery will take place. However, smart lockers can serve for much more than parcel delivery. One example of their versatility is laundry smart lockers [4]. These allow customers to leave their laundry in lockers. Employees access these lockers, wash, iron, and fold the laundry. Then, the customer receives a notification that his laundry is ready and can collect it from the smart locker. Another example is smart lockers applied to offices [5]. These enable a more dynamic workspace, where employees can store their items where it is most convenient for them. Whether on a specific floor or in a room, smart lockers allow greater security and proximity to people. Furthermore, these are not the only scenarios where smart lockers can be found. They are getting a huge hype these days on a wide range of application scenarios, which will be covered in this survey.

The Covid-19 pandemic increased the interest in smart lockers. With all the malls physically closed, shopping online was the only option to get basically everything. Customers got used to this way of buying. But sometimes there was no one at home to accept the parcel, making smart lockers an indispensable tool for delivering goods. But this is not the only factor responsible for their growth. In fact, with the rise of e-commerce also came the need for secure places to store packages [6]. Something like traditional mailboxes was missing, which did not meet the customers' needs. This is where smart lockers started to gain momentum, with an increasing interest from customer, postal companies, and society in general.

This paper surveys the different approaches to smart lockers, the associated challenges and the opportunities that can lead to the massification of their use. The remainder of this document is organized as follows. Section 2 introduces the concept of smart lockers and their areas of application. Section 3 presents related projects, commercial products, and provides a discussion on authentication and opening methods. Research trends, challenges and open issues are discussed in Section 4. Finally, Section 5 presents the conclusions.

Manuscript received on January 24, 2022.

Revised Manuscript received on February 22, 2021.

Manuscript published on February 28, 2021.

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Retrieval Number: 100.1/ijeat.C33740211322

DOI: 10.35940/ijeat.C3374.0211322

Journal Website: [www.ijeat.org](http://www.ijeat.org)

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Fig. 1. Process from Ordering To Delivery To A Smart Locker.

## II. SMART LOCKERS

Smart lockers take advantage of today's technologies to automate activities related to parcel delivery [7]. They are storage units whose main objective is to notify the customer when a package arrives and keep it safe until the customer can pick it up. In addition, they allow administrators to monitor how many lockers are being used, which times of the month are the busiest, and so on. This usage analysis can be useful in shopping malls and stores, for example, to understand the effectiveness of smart lockers and to determine whether a future investment in them is worthwhile. Fig. 1 illustrates the steps from the customer order to the parcel delivery when a smart locker is used.

One of the biggest advantages of smart lockers is that they allow delivery without the presence of the customer. Moreover, smart lockers can help reduce parcel theft. When a package is delivered, only the customer can pick it up [7]. Plus, they may offer a contactless and individual way to interact, increasing hygiene and reducing time lost in queues. Fig. 2 shows the usual design of smart lockers, commonly called a smart locker bank [8]. This specific solution includes compartments that will only open after customer authentication.

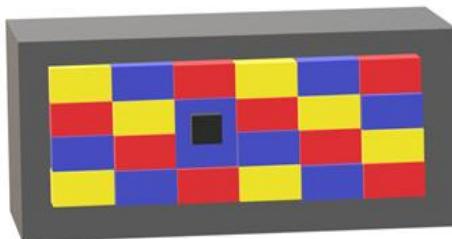


Fig. 2. Example of a smart locker bank.

Smart lockers have been used in a wide range of areas. One of those areas is the health sector [9]. Smart lockers can be used in hospitals to store medicine, vaccines, belongings of the staff or patients, and even to charge mobile phones. In pharmacies, they can be used to store the customers medicines, preventing them from waiting in line unnecessarily.

Smart lockers are also used in banking [10]. They improve efficiency due to quick and secure processing and prevent human errors. Perhaps one of the handiest applications of smart lockers is in condominiums since it is the closest to the customer's house [11]. Residents may acquire or pay a monthly fee to facilitate parcel delivery or to access a temperature-controlled locker for food delivery.

Offices use smart lockers to provide personal storage for their workers or visitors [5]. Some of these lockers can also serve as desks. This design offers a discrete and cleaner look and may be space-saving. Workers can store items they are not using and still have them in a close hand. Smart lockers

can be deployed in schools and universities, replacing old locker types [12]. They help to avoid the problem of lost keys and are a safer option to store valuable items.

The commerce sector uses them on retail companies and logistics [13]. For example, customers may settle a smart locker address as their delivery address. On retail companies, smart locker banks adapt to the individual needs of customers through time. Moreover, they may provide various sizes of compartments depending on the parcel size. More importantly they contribute to help solve the inefficiencies of the last mile delivery problem for retailers and logistics – i.e., the need for multiple stops with low drop sizes. This is the most expensive and time-consuming part of the delivery process [13][14]. With fixed drop points where the packages can be stored and kept safe, to be collected by customers later, the retailer and logistics companies can cut costs and help the environment too.

## III. APPROACHES

The popularity of smart lockers increased the interest of companies and researchers. This section presents examples of solutions and projects divided into the categories outlined on Fig. 3: health, banking, condominiums, education, offices, and commerce.

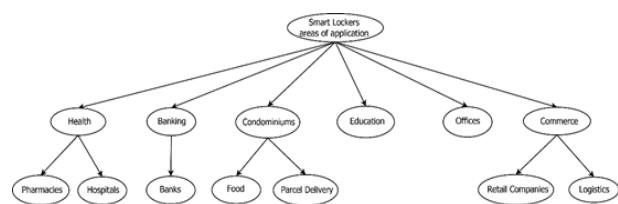


Fig. 3. Smart lockers areas of application.

### A. Solutions and Projects

#### Health

The concept of smart lockers can be applied in pharmacies and hospitals for patients and staff. Bloq. It, Aituo IoT and Gantner are some examples of companies that provide solutions for this sector. Bloq. It [15] a Portuguese start-up together with Glintt [16], developed a smart locker bank solution for medicine delivery called g-Pharma Collect shown in Fig. 4. It is a pharmacy locker used in some cities of Portugal. When the patients' medication arrives, a text message is sent to their mobile phones, acknowledging that it is ready for pick up, and containing a safe numeric key code to open the locker. They can also be applied to other stores and offices. Bloq. It provides an app to locate nearby lockers, for payment management, and to easily send items to someone else.



The approach used by this company can generate real-time data about the smart locker usage. These lockers can also have multiple compartment sizes for big-sized parcels and be installed indoors or outdoors.



**Fig. 4. g-PharmaCollect.** Source: Adapted from [17]

AituoIoT Smart Lockers [18] shown in Fig. 5 were found in various areas like health, laundry, phone charging, and parcel delivery. They offer various ways for customers to open the lockers, such as Quick Response Codes (QR Codes) [19], tracking numbers, customer's credentials, and Radio Frequency Identification (RFID) [20]. A helpful feature of AituoIoT lockers is the temperature control which provides continuous information about the temperature inside the smart locker. They can be very handy at hospitals, by keeping the patient's belongings in a safe spot until they leave or to store medicines or other medical equipment.



**Fig. 5. AituoIoT laundry smart locker.** Source: Adapted from [21]

Gantner [22] developed an indoor smart locker shown in Fig. 6 in cooperation with Lista Office [23] (a furniture manufacturer) that has had great success in a hospital in Switzerland. It has GAT NET Lock 7000 [24] that are systems with alarms, automatic opening for cleaning purposes and monitoring. This solution improves security and key losses since the opening method uses a Near Field Communication (NFC) [25] medical keycard that all the employees carry. These lockers can detect when an employee

leaves work by switching a Light-Emitting Diode (LED) [26] color that indicates the locker is now available. Besides that, it has real-time monitoring for occupancy levels and an alarm for security matters.



**Fig. 6. Cantonal Hospital St. Gallen smart locker solution.** Source: Adapted from [27]

#### *Banking*

Banking requires maximum security. Armários Inteligentes [28] is a company that provides solutions for this area. They developed a variety of indoor smart lockers solutions that support different opening modes such as via app, numeric code, QR code, and Barcode. A particular model called Armário Conectado [29] shown in Fig. 7 uses the IoT concept to make it possible to control the lockers using a mobile application or a remote application programming interface. Moreover, they have LED lights to indicate the availability of the compartment. The application distinguishes customers into separated categories: manager and customers. The manager can allocate/deallocate lockers, define usage periods and change the mode of operation. All these features are particularly useful in the banking sector, allowing easy and real time monitoring.



**Fig. 7. Armário Conectado.** Source: Adapted from [29]

#### *Condominiums*

Smart lockers can be placed in condominiums like mailboxes. Parcel Pending and I-Box propose interesting approaches.



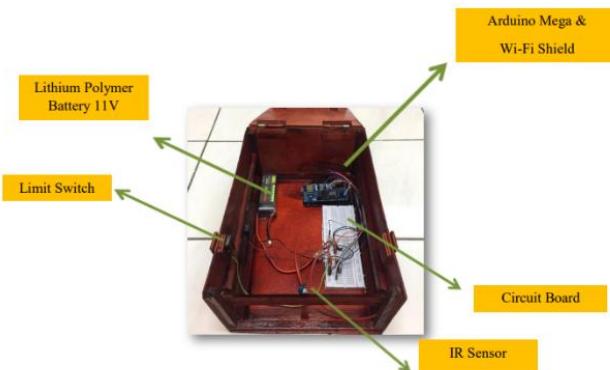
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Parcel Pending [30] shown in Fig. 8 has different indoors and outdoors solutions with surveillance and access control features. The outdoor solutions have mechanisms to control and maintain temperature levels to keep items in good conditions. The opening modes can be via application or QR code, improving speed and personalization. According to their website, their solutions contribute to package delivery time reduction up to 78%.



**Fig. 8. Parcel Pending outdoor smart locker.** Source: Adapted from [31]

I-Box [32] is an intelligent mailbox solution developed by Malaysian students shown in Fig. 9. This proof-of-concept prototype based on an Arduino platform has some interesting points. For instance, it uses an infrared sensor that detects when a letter is inserted in the box. Then, the owner receives an alert in the application. This avoids the necessity to open the mailbox to check for any mail. This solution still uses a physical key to open the locker like a classic mailbox.



**Fig. 9.I-Box.** Source: Adapted from [32]

### Offices

Smart lockers are the perfect solution to safely store the employees' personal items. In addition, they are a good choice for dynamic workspaces.

AirLocker [33] shown in Fig. 10 is an indoors and outdoors solution for offices, commerce, health, condominiums, and even military or governmental complexes. Each one of these sectors requires specific features. For example, for offices they provide mechanisms

that allow checking the locker usage, the information about the content and even sending codes to other personnel to remotely control the allocation and dispatch. These lockers use different opening modes, such as RFID, biometric data, and numeric codes sent by e-mail. One of their biggest clients is Cisco, which has implemented AirLockers in an office in Munich. AirLocker can easily personalize its products according to the activity area. One example is the Refrigerated Smart Locker, which is similar to a fridge and that can be used in grocery stores. This specific model of smart locker enables temperature control and a system of different baskets for groceries.



**Fig. 10. Air Locker smart locker.** Source: Adapted from [34]

### Education

Smart lockers can be implemented in schools to ensure the safety and security of students, staff and their belongings. Some examples are LockerSwarm and TZ SMArt Lockers.

LockerSwarm [35] shown in Fig. 11 is a solution developed by a team of academic researchers to help students dealing with excess weight in backpacks. This locker can store multiple items or food. The back-end allows monitoring the smart lockers providing information about the occupancy rates and the customer's data. A mobile application that generates a QR Code is used to open the locker. The application uses a LINE chatbot to unlock the locker, find new lockers, share it with another customer, and to get help for faulty devices.



**Fig. 11. LockerSwarm smart locker.** Source: Adapted from [35]



TZ SMArt Lockers [36] developed by TZ, is a solution for universities shown in Fig. 12. The smart lockers can be unlocked using different modes, such as RFID, QR Code, numeric code, or via application. TZ's software includes a Locker Manager Portal, which allows it to connect various lockers, providing remote access and monitoring. A customer application is used to interact with the smart locker. Some relevant features are the USB phone charging option, and the braille keypad and speakers embedded, allowing people with disabilities to use them.



**Fig. 12. TZ SMArt lockers. Source: Adapted from [37]**

#### Commerce

Smart lockers are particularly useful in commerce for delivery services. PUDO, KePol CL and AmazonHub Locker are some examples of these solutions.

PUDO, a Portuguese company, in cooperation with Correios de Portugal (CTT) [38] and Dynamic Parcel Distribution (DPD) [39], created solutions focused on parcel delivery shown in Fig. 13. They can be applied either indoors or outdoors. An interesting feature of these lockers is the maximum parcel weight, which goes up to 20kg. When buying items online, the customer only needs to set the locker's address as the delivery address. When the parcel arrives, the customer receives a text message in an application, containing the locker's number and a numeric code. Then, the customer can open the locker and retrieve the package using that information.



**Fig. 13. CTT24H smart locker. Source: Adapted from [40]**

KePol CL [41] is another indoor or outdoor solution shown in Fig. 14 that can be deployed in public locations such as shopping malls or apartment buildings for parcel

delivery. It is easily customizable with roofs and video cameras to prevent graffiti or vandalism. 1D or 2D barcodes are the opening methods.



**Fig. 14. KePol CL outdoor solution with an optional roof. Source: Adapted from [41]**

Amazon presented the AmazonHub Locker [42] shown in Fig. 15. This locker allows retail and logistic companies to store parcels that customers requested to be delivered at that location. To use this solution, customers must register at the Amazon website or application. If desired, it is possible to link an AmazonHub Locker's address to the customer account so that in the next order the default address will be the locker. When the package arrives, the customer receives an e-mail containing a 1D barcode and a numeric code to pick up the parcel. AmazonHub can be found either indoors or outdoors. It provides a touchscreen for easier management and to guarantee that the customer can still get his parcel in case of application failure [42].



**Fig. 15. Amazon Hub Locker. Source: Adapted from [42]**

## B. Authentication and Opening Methods

The authentication and opening methods used by lockers are a security issue that may lead customers to distrust these solutions. These methods should guarantee the authenticity of customers, preventing third parties from taking possession of goods that do not belong to them. This section describes and discusses the different methods to authenticate customers and open the lockers.

### Numeric code

The numeric code [4], used in [15], [16], [28], [33], [36], [38], and [42], is simple and easy to use, and it is one of the most popular modes. Usually, the deliverer enters the parcel's tracking number on the screen to open the locker. As soon as the deliverer closes the door, the customer receives a notification via email or message informing the unique code that unlocks the locker. Then, the customer only needs to go to the smart locker location, insert the code and collect the package.

### Tracking number

A tracking number [43], used in [18], is a unique identification number assigned to a parcel once it is shipped. It is usually printed on the parcel's label and transformed into a barcode for easier and quicker identification. In this case, both the deliverer and the customer use the parcel's tracking number to open the locker. When a package is delivered, the customer receives a notification containing the number and informing the parcel is ready for pick up.

### Customer Credentials

Most e-commerce websites require customers to have an account to interact with them and to buy their products [44]. Smart lockers can be configured to connect to a database that stores information about customers' accounts. So, every time a customer buys products, it sets the delivery address location to the smart locker's address. To open the locker, the customer only needs the login credentials of his account. This opening mode is used for example in [18].

### Barcodes

Barcodes [45], used in [28], [41] and [42], are a set of vertical parallel bars with variable width and quantity. Barcodes are read by optical laser scanners, and the computerized system receives the data and processes it. In smart lockers, the customer can receive the barcode via email and use it later to authenticate. If there is a match, the door opens.

### QR Codes

QR Codes [19], used in [18], [28], [30], [35], [36] and [41], are 2D barcodes. They store data in the form of a matrix. In comparison with the older barcodes, QR codes can store much more data since they store it horizontally and vertically. This technology is an interesting choice since they are fast to generate and to read and has a great capacity to encode data. It is necessary that the smart locker has a QR code scanner. So, when customers need to get a parcel from the locker, they receive a message containing the QR code and scan it to open the door.

### NFC and RFID

NFC [25], used in [22], is the technology present in contactless cards and some smartphones. To better

understand this concept, it is essential to know that RFID is a technology that uniquely identifies items through radio waves. An RFID system [20], used in [18], [33] and [36] comprehends a reader, a tag, and an antenna. On the other hand, NFC devices are both readers and tags, even though they use RFID protocols. When applied to smart lockers, the customer can have an NFC card associated with his locker. To open the smart locker the customer needs to hold the card close to the sensor.

### Biometric data

Biometric data [46], used in [33], is a group of characteristics or physical features that make a person unique among others. With this technology, only one specific person can open a smart locker since others do not share the same characteristics. Some common examples of this type of technology are eye scan, fingerprint scan, and voice or face recognition. Unlocking a smart locker using biometric data brings many advantages, such as not requiring passwords or codes (which are easy to forget) and safer and quicker interactions. On the other hand, some disadvantages are related to data breaches, making the person unable to use their biometric data.

### Mobile Application

Perhaps one of the most popular methods is via application [47], which is used in [28], [30], [35] and [36]. When picking up a parcel, the customer starts the smart lockers' application and, with a few clicks, the compartment opens, and the parcel can be picked up.

## C. Summary

Table 1 summarises the above-described projects. It presents a clear comparison and analysis of existing smart lockers solutions and their main characteristics.

The main characteristics under evaluation on Table 1 are described as follows:

- Areas of Application: project/solution area of application.
- Smart Locker Bank: whether the solution is a smart locker bank (centralized solution) or not.
- App: if it supports or requires a mobile application.
- Indoor and Outdoor: where it can be placed – indoor, outdoor, or both.
- Touch Screen: If it provides a touch screen for customer interaction.
- Additional Features: Unique features/characteristics provided by the solution.
- Authentication and Opening Methods: how it can be unlocked.

## IV. CHALLENGES AND OPPORTUNITIES

This section discusses challenges and opportunities that should be factored in by researchers, implementers, and manufacturers to increase the acceptance of smart lockers and improve their security. Following is a list of some open issues and important details related to the implementation of smart lockers.

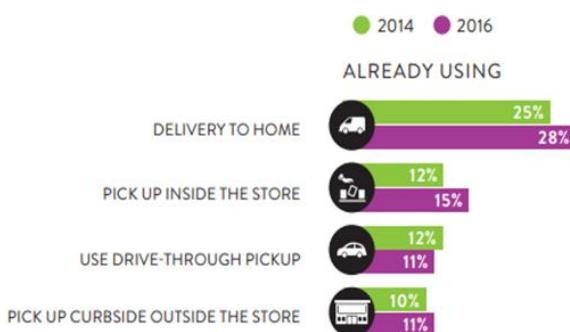


Published By:

Blue Eyes Intelligence Engineering  
and Sciences Publication (BEIESP)

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One of the topics addressed in this survey is the different application areas of smart lockers. All the smart locker solutions presented focused on one specific area of use only. A possible challenge would be to combine several application areas into a single smart locker. For example, if a person needs to receive a package and send some clothes to the laundry, it could be much more comfortable to do both operations in a single smart locker. One of the problems is related with their acceptance by customers. Even though people are turning less reluctant technology, most of them still prefer current delivery methods. According to [48] and [49], customers prefer home delivery to any other possible solution, as shown in Fig. 16. To the best of our knowledge, there is not a dedicated smart locker solution with a single compartment to be installed at customer's home. Although there are smart locker solutions for condominiums, it may be that not all residents agree with their installation, leaving this as an open issue.



**Fig. 16. Customers still prefer home delivery. Source:**  
**Adapted from [49]**

Another challenge is the locker's storage size. Although most companies offer various sizes of smart lockers, the most common ones are medium-sized. This becomes a problem when a customer wants to use a smart locker for a large order. In fact, the customer will have trouble finding lockers large enough. An additional problem emerges if the customer wants to pay only at delivery to check the parcel in front of the courier. In these cases, smart lockers cannot be used. Furthermore, there is no way to guarantee that the parcel delivered is legal, thus creating problems with prohibited goods [48]. To enable advanced authentication and opening methods on a smart locker, a stable Internet connection is necessary, which can be a problem in some places [48]. Therefore, if the location where the customer wants the smart locker does not satisfy this requirement, then it cannot be installed. Also, the device must be as secure as possible. Not

only physically but also in terms of software. It must be prepared against hackers and failures, guaranteeing that, at the end of the day, only the customer can pick up his parcel or good. Single-factor authentication methods attempt to provide security to smart lockers, but none of them is problem free [50]. Thus, security can be enhanced by using two-factor authentication or multi-factor authentication. Multiple authentication methods should be provided to prevent service authentication failures. In addition, different application scenarios may require different authentication methods. For example, it does not make sense to have a laundry smart locker with biometric data, since it is likely to be used by multiple customers. However, this method is likely to be applicable on a condominium locker allotted to a single person. Remote monitoring of smart lockers also allows to quickly detect faults, to plan maintenance and better system availability. At the beginning of the Covid-19 pandemic, when countries were starting to fully lockdown, Agcom, an Italian governmental agency, initiated a study about smart lockers for secure parcel delivery [50]. Their goal was to minimize face-to-face contact between couriers and customers, promoting contactless deliveries. Based on this study, it was possible to conclude the clear advantages in terms of health and safety precautions. Thus, there is a need to motivate the widespread adoption of smart lockers.

The existing smart lockers are developed with the main goal of reducing the costs of last-mile delivery. This delivery is a lot more expensive than deliveries to a single public location. However, people still must travel to pick up the package. Yet, all people have a mailbox at home, so an idea to explore is an individual smart locker that could be placed at people's addresses.

## V. CONCLUSIONS AND FUTURE WORK

Smart lockers are intelligent storage units that can be applied in many areas of application helping recipients to store their personal belongings or collect their parcels and packages of different sizes. In an increasingly technological world, smart lockers contribute to help solve the inefficiencies of the last mile delivery problem for retailers and logistics. This survey first introduced the concepts related to smart lockers. Next, an analysis of existing solutions was presented discussing their main characteristics. Key challenges and opportunities were identified as well as perspectives on future developments expected to contribute to their widespread use.

**Table 1: Smart Lockers Solutions and Their Main Characteristics.**

Name	Areas of Application	Smart Locker Bank	App	Indoor and Outdoor	Touch Screen	Additional Features	Authentication and Opening Methods
Bloq.it & Glint [15], [16]	Health, Commerce, Offices	Yes	Yes	Both	Yes	Multiple compartment sizes	Numeric code
Aituo IoT [18]	Commerce, Education, Health	Yes	Yes	Indoor	Yes	Phone charging lockers, temperature control	QR code, tracking number, Customer credentials, RFID
Gantner [22]	Health	Yes	Yes	Indoor	No	LEDs for availability	NFC card

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<b>Armários Intelligentes [28]</b>	Health, Condominiums, Commerce, Offices, Banking	Yes	Yes	Indoor	Yes	Different privilege modes	Application, Numeric code, QR code, Barcode
<b>Parcel Pending [30]</b>	Condominiums, Commerce, Education	Yes	Yes	Both	Yes	Video surveillance, temperature control	Application or QR Code
<b>I-Box Project [32]</b>	Condominiums	Yes	Yes	Indoor	No	More like a mailbox that detects letters	Physical key
<b>AirLocke r [33]</b>	Commerce, Condominiums, Offices	Yes	Yes	Both	Yes	Temperature Control	RFID, Biometric Data
<b>Locker Swarm Project [35]</b>	Education	Yes	Yes	Indoor	No	Back-end system to control all lockers	QR code
<b>TZ Smart Lockers [36]</b>	Education, Condominiums, Commerce	Yes	Yes	Both	Yes	Braille keypad, speakers	Application, RFID, QR Code, numeric code
<b>PUDO [38], [39]</b>	Commerce	Yes	Yes	Both	Yes	Up to 20kg deliveries	Code received by message
<b>KePol CL [41]</b>	Condominiums	Yes	No	Both	Yes	Anti-graffiti coating	QR code or simple barcode
<b>AmazonHub Locker [42]</b>	Commerce	Yes	Yes	Both	Yes	Linked to an Amazon account	Numeric code, barcode

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