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THE SIGNIFICANCE OF HUMAN INDIVIDUAL AND CROWD MOVEMENT RESEARCH IN BUILT ENVIRONMENT, WITH EMPHASIS ON ITS FUNCTION IN RETAIL SPACES

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Abstract: *Understanding the movements of crowds offers more and more opportunities in the field of architecture, in both active and passive methods of implementation.*
The study briefly describes crowd dynamics, the new field of research as well as the levels of investigation of human mass movements. Due to its expected large-scale spread, it particularly describes the need for and the possibilities of individual human body motion detection in retail facilities while emphasizing the architectural aspects of the rise of innovative commercial facilities. It details and compares the operational processes of modern-day queue-free "convenience" stores, Amazon Go with JWO technology, and Żabka Nano units operating according to AiFi, highlighting their architectural features.

Keywords: *crowd movement, architecture, built environment, human body motion detection, convenience store, innovative store, queue-free store*

1. INTRODUCTION

Crowd dynamics research is an extremely fast growing field. (Figure 1.) Although the SARS-COV-2 epidemic has somewhat slowed down the increase in the number of research in the past few years [1], the Web of Science (WoS) Core Collection application found 9289 scientific publications for the search term "crowd dynamics" in March 2023.

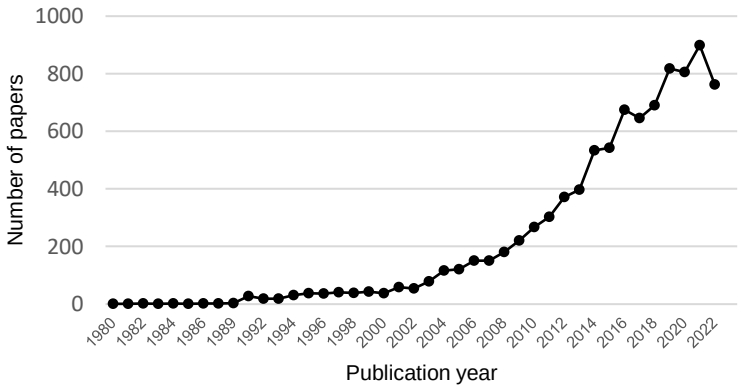

Figure 1. Number of appearances of the term "crowd dynamics" in scientific publications, 1980-2022, data source: Web of Science (WoS) Core Collection

The study of crowd movement is an interdisciplinary field of research aimed at developing such tools and management strategies that can improve the safety and comfort of crowds both in both normal and emergency situations [2].

It can be concluded that studies aimed at examining dense human masses - analyzing movements from the individual to the ever-larger mass, regardless of their methodology - usually use one of the following five approaches:

- nanoscopic (individual);
- microscopic;
- mesoscopic;
- macroscopic;
- mixed/hybrid.

Each approach chooses the observation or prediction points according to the chosen examination scale, which, by definition, also influence the framework of the created models [3].

In nanoscopic (individual) approaches, the movements of each individual that make up the human mass include at least the analysis of the position of their body parts (usually the head and the trunk) [4] [5]. Nanoscopic approaches can also be suitable for the description of movements that can be measured at an individual level, such as hand movements [6], facial expressions, eye movements and heartbeat. In addition, the detection of breathing can be traced back decades [7].

In microscopic approaches, individuals are usually identified with a one-dimensional geometric element: a point, or perhaps a smaller circle. However, they are still examined individually. The consideration of individual behavior in these models most often goes together with interactions with other pedestrians in the system [8].

Crowd studies on a mesoscopic scale mostly calculate with the average characteristics describing the crowd (e.g. density, the distribution velocity), allowing in many cases the effects of interactions between individuals occurring in the mass that affect the average.

The macroscopic scale of crowd examination is based on the average quantities describing the crowd. These definitions do not distinguish between individuals, describing the movement of the mass of people based on its density, average speed and flow patterns.

In mixed/hybrid crowd studies, at least two of the above discussed observation scales are combined in the same space and time [9].

2. THE CONCEPT OF HUMAN CROWD IN THE BUILT ENVIRONMENT

In order to examine high-density human masses, it is absolutely necessary to define the concept of crowd. For the construction of buildings, the relevant European national legislations most often determine values based on the individual risk classes and the provision of escape conditions according to fire protection regulations. According to them, stricter regulations or different provisions are typically used over a certain number of employees.

According to the definition often referred to in international literature, the crowd is: "A large group of individuals ($N \geq 100$ people) in the same space and time, whose movement for a longer period of time ($t \geq 60$ s) depends predominantly on local interactions "($k \geq 1$ person/m^2)" [10][11].

3. APPLICATION OF CROWD AND INDIVIDUAL MOVEMENT STUDIES IN THE BUILT ENVIRONMENT

The purpose of individual crowd movement studies can be very different in the built environment. For example, transport optimization, the organization of events, the planning of emergency escape or commercial purposes require different scales of investigation. The issue of temporality is also determined by the given goal. Crowd movement detections in the past can provide useful information in the theoretical research of movement phenomena. Real-time observations of crowd movements can help meet the current need for the regulation of pedestrian traffic or the safety of mass events. Mass movement modeling, on the other hand, aims to provide long-term predictions that anticipate future events, such as evacuation scenarios, and seeks to address them accordingly.

With the help of crowd movement studies, the function in architecture can be expanded with a new, more precise, quantified values. Indeed, not only spatial planning can be optimized, but also more economical energy systems for buildings can be designed. Knowing the exact position of users can often be vital in emergency evacuation.

Among the numerous areas of application, due to its expected spread and new architectural and safety issues, this study focuses on the novel applications of individual human body tracking in the context of the built environment, specifically in the commercial sector.

4. THE NEED AND POSSIBILITIES OF MONITORING INDIVIDUAL HUMAN MOTION DETECTION IN COMMERCIAL FACILITIES

Monitoring and recording customer habits are concepts as old as commerce. Keeping the inventory at the right level typically serves the mutual satisfaction of seller and buyer, for which the most thorough knowledge of the buyer's future needs is essential. In the past, this exchange of information was almost exclusively verbal. Nowadays, it has been recognized that there is a correlation between customer movements and habits.

Although monitoring customer habits in retail environment is quite an old practice, the first systematic methods only appeared in the United States in the 1930s, in the form of store

statistics, market research, radio advertisements, and customer interviews. It was then that the first market research specialists and researchers published articles and studies on this topic. *Ernest Dichter* (1907-1991) [12][13] *Paul F. Lazarsfeld* (1901-1976) [14] and *George H. Gallup* (1901-1984) [15] were the first researchers to use psychoanalytic theory to understand consumer behavior.

By the 1970s and 1980s, an increasing number of publications appeared that revealed the connections between the atmosphere and layout of the store and customer satisfaction, as well as more effective sales [16][17]. Non-sociological factors such as temperature, scents, noise, music and lighting were added to the marketing palette [18]. Since the 1990s, studies have been made on the active use and practical experience of these factors [19][20][21].

A term often used today, "customer experience" generally consists of the trinity of a pleasant environment, the satisfaction of individual customer needs, and a stress-free shopping experience. Maze-like store layouts that influence purchases, often considered a stressor, had narrow aisles in the stores that customers had to walk through to get to the products. Stores used this design solution to make the goods visible to as many customers as possible, thereby increasing sales. Although the method is still present in several types of stores and with certain brands, its use is increasingly declining.

The apparent contradiction of the connection between stress and shopping is well illustrated by two publications from the early stages of relevant research, from 1998 and 2000. A 1998 study by *Russell Aylott* and *Vincent-Wayne Mitchell* [22] traces the realization of the fact that everyday shopping puts a significant amount of pressure on most families to the increase in the number of dual-income families and longer working hours. In their study, they describe the stressors that occur while shopping for food based on their correlation and quantified effects. According to this, stress can be an important factor in our choice of particular retailers and can lead to a decrease in sales. Stressors act in a way that they destabilize the individual, who mainly tend to shop under the most satisfying and least stressful conditions. The study confirmed that more is needed than time-saving innovations, e.g. retailers ought to reduce transaction time and increase the convenience of customers during shopping. The research identified stressors that influence store design [22].

According to a study by *Yasuhisa Hama* in 2001, however, more than half of the people go shopping when they are under pressure. According to his research, "diversion shopping" is a kind of emotional coping strategy in which spending money is necessary for stress relief [23].

The above findings, i.e. shopping is a stressor, or, on the contrary, it has a stress-relieving effect, are seemingly contradictory. The ambivalence is resolved by recent research that examines customers according to personality types. According to this, for example, task-oriented consumers want to buy products effectively and make cognitively rational decisions. However, recreation-oriented consumers experience shopping as entertainment. In a more stressful shopping environment, task-oriented customers leave stores four times as often as recreation-oriented customers, therefore, they must be protected from situations causing high levels of stress [24].

The efforts of traders to make their sales strategy as effective as possible, nowadays, with the spread of store chains and store networks, are less and less able to provide traditional seller-buyer contacts. In the meantime, recognizing customer habits and needs and reacting to them as quickly as possible remained a primary requirement, for which, in addition to the relevant social and economic knowledge, the application of modern technology offers a number of opportunities.

The spreading of devices based on modern technology in commerce can be traced back to the 1950s, when the first bank card appeared. In the 1970s, automatic doors controlled by motion sensors became popular, and the use of cameras meant modern passive systems that primarily increased the security of property and comfort of use, but at the same time, their application to record products purchased at once can also be attributed to this period. The first personally registered loyalty card dates back to the 1980s, which, in addition to the fact of the purchase, also contained the consumer's individual data. Nowadays, active systems that not only function as a kind of beacon, but also provide significantly more information about movement processes, often with the possibility of interactions between the buyer and the seller, and their coordination, are widespread. New and innovative technologies suitable for the functions mentioned above appeared as examples:

- Wi-Fi beacons, which allow stores to obtain more accurate information about the movements and behavior of customers. Unlike optical sensors, these systems are independent of light conditions, dust, and coverage limitations [25][26];
- NFC (Near-Field Communication) technology, which in addition to bank cards and gate openers, often appears in other areas of use, goes back more than a decade [27][28][29];
- technologies developed for image recognition: Harris, Shi-Tomasi, BRISK, FAST, KAZE, SURF (Speeded-Up Robust Features), SIFT (Scale-Invariant Feature Transform); SLAM (Simultaneous Localization and Mapping) [30][31];
- RFID (Radio Frequency Identification) based on radio wave technology [32][33];
- Lidar (Light Detection and Ranging) systems based on laser technology [34];
- infrared cameras;
- RGB-D cameras [35].

As for the field of practical retail applications that follow the movement of customers the following have become popular in commercial circulation:

- iBeacon technology: Apple Inc. introduced iBeacon as a new location device in 2014, which is based on Bluetooth Low Energy (BLE) technology [36][37];
- artificial intelligence-based computer vision (AI-powered computer vision).

In parallel with the development of devices, software designed to model the possible movement of people and to predict it as far as possible appeared and became widespread. The use of special types of software suitable for emergency evacuation [38] is becoming more and more widespread; their expansion and development is continuous [39]. In the same way, human mass movement simulation software that helps urban planning, transportation, healthcare, and commercial facilities planning is also becoming more and more popular. In the area of commercial facilities planning, computer applications provide help not only in the appropriate layout of certain store types, services and community spaces of multi-unit facilities and shopping centers, but also in the optimization of product type placement and internal customer traffic [40] in certain store units. In addition to striving for realistic processes, more sophisticated visualization, development of validation procedures and making them more economical, are some of the most current research processes among the relevant directions of development [41][42][43]. The use of human mass movement simulations in the built environment not only helps to design a safer environment, but by depicting complex movement processes, it enables optimized and human-centered planning of buildings and cities.

5. ARCHITECTURAL ASPECTS OF INNOVATIVE COMMERCIAL FACILITIES

The quantified experiences gained from systems appearing in commercial establishments that monitor the movements of customers have been helping the work of designers for decades. The data-level feedback from usage not only provides feedback on necessary functional issues, such as congestion, but also provides specific information on the effectiveness of the selection of elements which affect the customer's mood, such as colour, lighting or decoration [44]. According to a survey conducted by EHI[1] in Germany, in 2017, 26% of retailers used video-based customer analysis, 10% used line-of-sight recording and eye-tracking, and 8% used other customer tracking technology based on 3D sensing.[2]

However, the new, innovative technologies do not only enable the analysis of statistics obtained from movement processes: with the help of AI technologies, a new framework for planning commercial facilities can also be formulated [45]. The new ways of communication with customers and the interactive solutions require a visual and functional design different from the traditional one. The increasingly active personal involvement of customers in the process of their own purchase requires new spatial designs and dimensioning principles.

In addition to their traditional stores, individual store chains are opening an increasing number of sub-type stores that use the latest technologies. Although these new-generation stores are made of traditional building materials, they are already based on technology. In addition to the usual "brick-and-mortar" and online store types, a third has undeniably appeared, which aims to combine the advantages of both.

5.1. A store without queuing

The new shopping system received its patent (US 2015/0012396 A1) in January 2015, according to which in January 2018 Amazon.com Inc. opened its first self-service Amazon Go convenience store in Seattle, Washington [46]. The 1800 square meter store sells food, beverages and toiletries. The company introduced a completely new shopping process in its store. The customer enters the shop with the help of an application installed on their phone. Their purchase is recorded by cameras that follow their movements in real time, as well as by sensors on the shelves where the products are displayed. After completing their purchase, they leave without using the cash register as the payment is made according to their bank account details recorded with the application. By using the system built with computer vision and deep learning algorithms, neither a traditional nor a self-service cash register is needed, so there are no checkout lines [47]. In terms of queuing processes, the store is 50-300% more efficient than a traditional store [48].

In the 5 years since the opening of the first store, the network has opened 44 stores worldwide, of which 29 are located in the United States and 15 in the United Kingdom.

Amazon Go is not the only and not even the latest store that uses modern technology to automate payments. However, in the five years since it was launched, quite a few publications and analyzes have been made which enable its ongoing study in operation [49] [50].

Regarding the type of store, consumers identify more advantages than disadvantages. The majority of customers identify automation and the lack of cash acceptance as advantages, and

[1] EHI Retail Institute, Köln

[2] source: Special Instore Analytics & Navigation, 2017, EHI Retail Insitute, Köln

link impersonality and the lack of human cashiers with speed. Disadvantages include the difficulty registering via the application and the violation of privacy [51].

Amazon Go stores are built from foundation to accommodate Amazon's high-tech cameras and sensors with a floor area usually around 2000 m^2. However, other developments appeared at the same time as the pioneering system, which allow for a more informal store design, adaptability to existing facilities, use independent of daylight conditions and on a larger floor area. Companies have entered the market with their individual developments to offer retail participants the opportunity of computer vision and machine learning in order to identify the products purchased by consumers. (Figure 2.)

The concept of a store without queuing has recently appeared in Europe and soon started spreading. Founded in 1998, Żabka operates 9000 traditional shops in Poland. In 2021, it opened its first state-of-the-art store called Żabka Nano, which was followed by another 50 in Poland in the last 2 years. (Figure 3.)

Figure 2. Amazon Go store [52]


Figure 3. Żabka Nano store [53]

5.2. Architectural aspects of queue-free stores

Compared with traditional solutions, stores without queuing represent a significant reduction in floor space requirements. In the present study, a comparison is made between the design of the consumer space (FOH, Front of House) of a traditional grocery store (Figure 4.) and one that records the tracking of customer movements (Figure 5.). In both cases, the same volume of stock was placed (refrigerator: 23.50 m^3, refrigerated showcase 18.57 m^3, cake cooler 1.50 m^3, shelves 58.97 m^3). In addition to self-service shopping, the traditional store also has a deli counter and a small buffet. In the modern store, the products of the latter are also sold in a self-service system. In the traditional store, the distribution of the customer area according to function is as follows: customer area 62%, service and checkout 24%, other (shopping cart storage, traffic area) 14%.

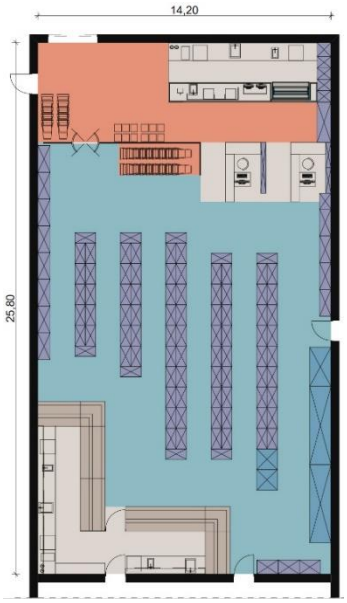

Figure 4. FOH layout of a traditional grocery store

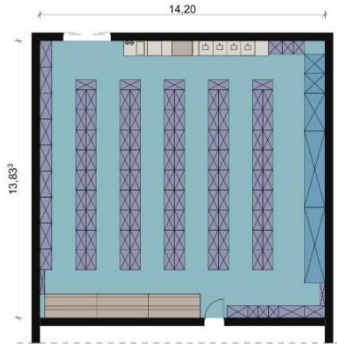

Figure 5. FOH floor plan design of a "queue-free" grocery store

In the case of a store using modern technology, the customer space makes up 100% of the FOH. In addition, a more economical use of the base area results from the simplification of traffic lines. Instead of a traditional store with a FOH floor area of 366 m^2, the same products can be sold in stores without queues in 196 m^2, which represents 53.5% of the former.

The self-service sale of locally made buffet products, primarily intended for take-away, is a characteristic of the examined store type (convenience store): in addition to food and household products, vending machines (Figure 6.) and food preparation robots (Figure 7.) add color to the product range.

Figure 6. Line of vending machines in a "convenience" store type [54]

Figure 7. Food preparation robot [55]

Among the conceptual issues affecting design, the prominence of technology has to be mentioned first, as it by now not only serves to support the function, but has become the center of the design of the particular store-type. Meanwhile, proprietary technologies complicate the processes of architectural design. The available data is different from what is usual in traditional design processes, and may be less well-known, which greatly reduces the

creative possibilities. The need for continuous innovation resulting from the nature of the particular business type makes it difficult to use the knowledge gained from deeper experiences.

The technology, which records the movement of customers and products, largely determines the interior of the stores. The virtual spatial mapping used to record individual movements and the optimization of the implemented technology require, in a number of cases, grids of a significantly larger scale than those of the traditional metric module system - which results in an extremely simplified interior space. (Figure 8. - Figure 11.)

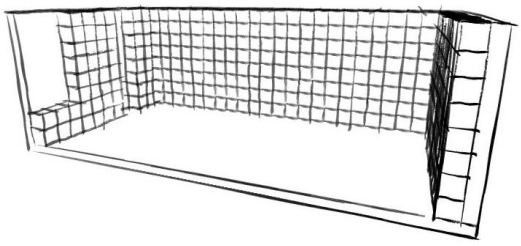

Figure 8. Sketch of the layout of a "C"-shaped store built from 50*50*50 cm blocks

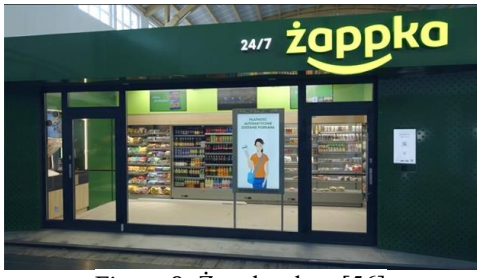

Figure 9. Żappka shop [56]

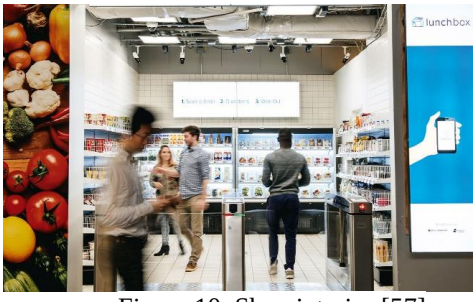

Figure 10. Shop interior [57]

Figure 11. Shop interior [58]

Nevertheless, the need for a view of the entire front surface of the shelves from several points from the direction of the ceiling can also result in wider than conventional shopping aisles, which can be beneficial both in terms of accessibility and in emergency evacuation.

Among development concepts, in several cases, there is an increased intention to gain customer trust. For example, on order to ensure the conditions of the greatest possible insight into the store, there appeared the absence of shop windows. The requirement causes a "C"-shaped internal product storage arrangement, especially for stores with a smaller floor area. In stores with large glass surfaces that are visually open to pedestrian traffic, the role of the shop window is taken over by the product line facing the portal front. (Figure 9.) Along with the elimination of the checkout line, the shop's consumer area increases. In the case of companies with an extensive network of traditional stores, another means of maintaining already gained customer trust is to stick to the old look when introducing new stores. The appearance, which is largely in line with the existing store stock of the given region and the existing image of the company, does not emphasize novelty, but rather has something to say about being "not expensive", "not different". The fewer and clearer communication points which feature these store interiors suggest an ease of use.

Shops without queues equipped with state-of-the-art technology contain significantly more power consumers compared to traditional shops, and according to the latest research, they use AI with a high energy demand [59]. Undoubtedly, the impact of these stores on the environment requires further detailed analyses.

The large number of electronic devices installed, automatic sliding doors and access gates (Figure 12. - Figure 13.) require special solutions to comply with the relevant fire protection regulations. Access, which is only possible after customer identification, can complicate and slow down rescue operations in a life-saving situation.

Figure 12. Entrance with gates [60]

Figure 13. Entrance with sliding doors [61]

Another aspect to be considered in the planning phase is the non-traditional queuing characteristics of cashier-free stores. In traditional shops, queues can be expected mainly at the cash register, which is typically located within the boundaries of the store. On the other hand, in stores without cash registers, a large number of customers may congest at the entrance due to the possible difficulty of entering, or due to a technical fault in the store. A crowd stuck on the pavement or directly on the street can make pedestrian traffic difficult. (Figure 14., Figure 15.)

Figure 14. Entrance to the store from the front [62]


Figure 15. Entering the Żabka store [63]

The technology used to record purchases results in a crowded ceiling. The majority of the existing stores use solutions without drop ceilings (Figure 16.), but there are also examples of cassette false ceiling solutions, which have been increasingly disappearing in retail interior design in the last decade (Figure 17.). Although more rarely, yet it is still possible to find a combination of latticed metal false ceiling (Figure 18.) and cassette and board false ceiling

(Figure 19.). The predominance of technological elements appearing on the ceiling foreshadows the need to expand their typical manufacturer's colour palette (white, black).

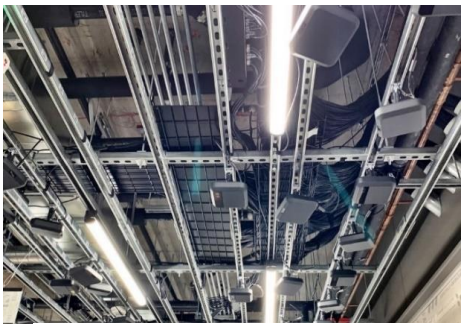

Figure 16. Ceiling design in Amazon Go store [64]

Figure 17. Ceiling design in Żabka Nano store [65]

Figure 18. Ceiling design in Continente Labs store [66]

Figure 19. Ceiling design, Nelson Hall Denver [67]

The solution of visual purchase detection with cameras along with the fact that the installed system is stationary, also affect the floor plan and furniture mobility. Instead of the free or partially unbound possibilities of equipment change in traditional stores, transformability is relatively bound, which can lead to the necessity of the transformation of technology.

Depending on the technology used, it may be necessary to achieve uniform light conditions, strong contrasts and outstanding color reproduction in the interior. The installed lighting fixtures accordingly create a cool and harsh atmosphere.

The placement of the self-service beverage vending machines typical of this type of store, the handling of food and drink leftovers from consumption in accordance with Regulation 852/2004/EC, and the provision of proper cleaning before using reusable cups in the interior require hygienic design considerations.

SUMMARY AND CONCLUSIONS

Human movements can be grouped into individual (nanoscopic), microscopic, mesoscopic, macroscopic and mixed/hybrid examination levels based on the number of people, interactions and form of movement examined. The past, real-time and predicted modes of human movements in the built environment are applied in the areas of accident prevention, planning and optimization as well as in the case of commercial purposes.

In the 1930s, the first systematic methods for monitoring customer habits in retail appeared in the United States. Today, new, innovative technologies allow not only the

analysis of statistics obtained from movement processes. With the help of AI technologies, a new commercial facility planning framework can also be formulated. The changed methods of communication with customers, the interactive solutions, require a visual and functional design different from the traditional one. The increasing personal involvement of customers in the process of their purchase, which requires activity, results in new space designs and dimensioning principles.

An increasing number of so-called queue-free shops based on the detection of individual human body motion detection can be observed in Europe. Grocery stores that typically use AI-based computer vision technology enable the sale of the same amount of goods in a nearly 50% smaller floor area than traditional stores. In general, the time spent shopping in stores is shortened. At the same time, shops without queuing create an impersonal consumer environment instead of units with buyer-seller interaction based on traditional human relationships. In stores without a salesperson, the interdependence of individual customers can result in a significant decrease in their sense of security and comfort. In the future, another important question to be examined is the unemployment caused by the type of store, as well as the need for changed employee qualifications. The new type of shops requires new, safe solutions in the areas of health and safety, the protection of life and fire security as well.

The authors aim to conduct a thorough examination of crowd movement phenomena and identify potential accident risks. As part of this objective, the present study focuses on the operation of novel retail units that rely on the detection of individual human body movements, with an emphasis on security aspects.

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