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Silesian University of Technology, **Poland****INTRODUCTION**

There are different types of car parks in urban spaces, and we divide them based on their size, the type of space they occupy, and the construction technology itself. Due to the growing interest in the topic of parking in urban centres, the categories of car parks are widely described by many researchers (Vikram and Ayesha, 2017). The literature addresses their design (Jog et al., 2015), principle of operation (Bukowski et al., 2018), environmental impact (Chester M., Horvath A., and Madanat S., 2010), and potential for automation (Idris et al., 2009). The decision to build the most optimal car park in a city is not an easy one, as it depends on many factors, including construction cost, safety, functionality, location, occupancy size, residents' expectations, aesthetic value, etc. In order to make the most optimal decision, it is necessary to analyse many options and choose the best one for a given location (Faheem et al., 2013).

This article attempts to describe and compare selected car parks operating in the centres of Polish cities.

**METHODOLOGY OF RESEARCH**

In order to describe selected types of car parks, an analysis of scientific and industry literature was carried out, and the method of field observation was used. The article presents data from secondary sources such as: statistical offices, Internet information published by branch institutions, promotional materials of city offices. The evaluation of the selected parking solutions was carried out by means of a comparative analysis taking into account the following criteria:

- surface area occupied,
- safety of parking and entering traffic,
- safety of property left in the car park,
- cost of construction,

- aesthetics.

## TYPES OF CAR PARKS

The most common car parks in the city centre are surface car parks. Based on the type of space occupied, one can distinguish among them on-street parking, off-street parking, and the so-called space-separated parking ((Vikram and Ayesha, 2017).

On-street car parks are lane-side parking spaces where parking by driving directly off the lane and exit by joining traffic in the adjacent lane is possible. They are usually located in city centres, along the main traffic routes and in most cases have pay parking zones (European Parking Association, 2013). One example of "On street" parking is parking "at an angle" to the traffic lane in dedicated parking spaces. Typically, an angle of 45 or 60 degrees to the traffic lane is maintained (Fig. 1). Such parking spaces are organised on streets that are relatively wide because the parking spaces themselves take up a lot of space (Vikram and Ayesha, 2017).



**Fig. 1** Cars parked "at an angle" to the traffic lane

Source: own study

On-street car parks, where parking spaces are organised perpendicular, i.e. at 90 degrees to the traffic lane, are among the most popular car parks (Fig. 2). The main reason for the high popularity of car parks is the large number of cars that we can park in a relatively small area (European Parking Association, 2013).



**Fig. 2** Cars parked perpendicular to the traffic lane

Source: own study

Parking spaces parallel to the traffic lane are organised on narrow streets or streets where it is not possible to place spaces at a different angle for reasons of road user safety (Fig. 3).



**Fig. 3 Cars parked in spaces parallel to the traffic lane**

Source: own study

Parallel parking does not block traffic in the bordering lane, and joining traffic is relatively smooth, unlike park and ride spaces that are perpendicular or at 45 and 60 degree angles to the lane. This type of parking does not take up much space, however, it accommodates the least number of cars (Vikram and Ayesha, 2017).

“Off street” car parks are parking spaces organised literally off the road. Depending on the owner of the spaces (whether they are privately owned or belong to the city), charges may apply. These types of car parks are usually located at commercial and service points such as shopping malls, food discounters, airports, community centres, etc. (Vikram and Ayesha, 2017).

Car parks set aside in a given urban space are a common type of car park, which are most often seen next to retail outlets with a smaller built-up area or where the construction of an underground car park was not possible (Fig. 4).

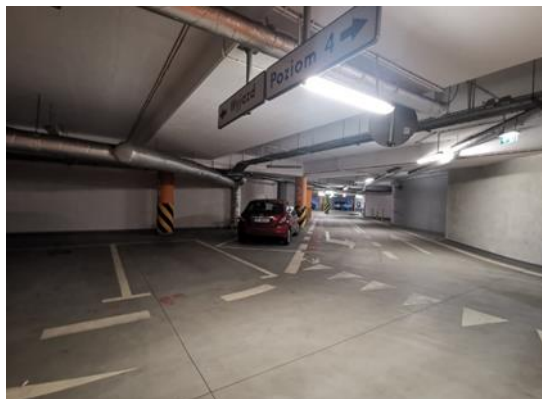


**Fig. 4 Separated parking in urban space in the vicinity of retail and service outlets and a housing estate**

Source: own study

These car parks cover a large area and the cost of building one space is relatively high, which is determined by the cost of land (Bankier.pl, 2019). In addition to surface car parks, the category of 'off street' car parks also includes

underground car parks, which are most often built under large shopping malls and other service and retail buildings (Fig. 5).

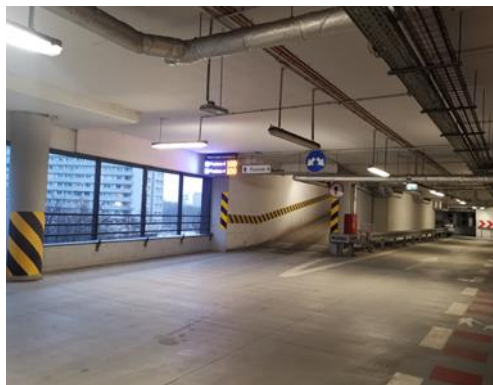


**Fig. 5 Underground car park built under the shopping mall**

Source: own study

The biggest advantage of this type of car park is its large capacity and its visual appeal (in modern buildings it is often used so that the architecture of the building can be seen instead of rows of cars). However, they are not applicable everywhere due to the type of soil or, for example, post-mining damage. They are also relatively expensive to build (money.pl, 2019).

Due to the increasing number of car owners, there is a need for multi-storey car parks (Fig. 6).



**Fig. 6 Multi-storey car park built over a shopping mall**

Source: own study

Multi-storey car parks can occur in several variants: as a stand-alone structure, as car parks on the floors of buildings or underground multi-storey structures (Walach et al., 2017). They are usually used at large commercial and retail outlets or in modern residential buildings (Mahalakshmi et al., 2018). Standalone parking structures can be seen, for example, at airports, where the demand for parking spaces is very high and drivers are mindful of the safety of property when leaving their car for the duration of their trip. One of the newer parking solutions, vertical car parks (Fig. 7), are becoming increasingly popular with the growing problem of parking space shortage.



**Fig. 7 Vertical parking system manufactured by Wiromet**

Source: (Wiromet, 2021)

This type of solution is used both at service and retail outlets and in city centres, mainly because of the high space savings (up to about 70% compared to surface parking), safety and reduction of exhaust fumes and thus improvement of air quality (Pashte et al., 2016).

### **TECHNOLOGIES SUPPORTING PARKING MANAGEMENT**

In view of the ever-increasing suburbanisation, the demand for parking spaces in city centres is also increasing (European Parking Association, 2013), where the main service and retail outlets are usually located, which are often the workplace for hundreds of people, including those from outside a given city (Górniak J., 2016). Many engineers are intensively researching the possibility of optimising parking policies in city centres and solving a daily problem for hundreds of drivers. Due to the increasingly dynamic development of Industry 4.0, data analytics and the Internet of Things, we highlight several modern solutions used in parking management that could significantly impact parking comfort (Srikanth et al., 2009). These can include RFID, QR technology, GSM and PGI systems, among others (Polycarpou et al., 2013). The use of RFID technology is expected to allow parking spaces to be found more quickly and paid for later. Solutions based on QR codes are designed to allow spaces to be booked in advance, so that drivers get to them more quickly and do not waste time searching for a free parking space, and are guaranteed a free space when they arrive at their destination. SMS and GSM-based systems make it possible to reserve a parking space temporarily. The driver sends an SMS to the GSM module in the car park and receives a password and the number of the temporary reserved space. Upon entering the car park, LED signage directs the driver to a pre-booked space (Jog et al., 2015, Lin et al., 2017). PGI systems are parking guidance and parking information systems that, through the use of dynamic information, indicate to the driver the free space in controlled areas and show him the way to the desired location. Integrated with traffic monitoring, they can vary parking charges according to traffic volumes and parking demand (Kotb

et al., 2017). In the next steps it is possible to develop the technology both in the direction of simplifying the payment of parking fees, the reservation of parking spaces and, thanks to in-car sensors, cameras and data analysis and dynamic information, finding free spaces located in the area of interest. It is currently estimated that the annual revenue generated from smart parking systems reached approximately \$356.5 million in 2020, indicating the growing demand for such solutions and their huge potential (Jog et al., 2015).

### **COST OF CONSTRUCTING SELECTED CAR PARKS**

The cost of building a parking space depends on the location of the space and its type. In large cities, land reaches very high prices, so the price per parking space is higher than on the outskirts of the city. Analysts of an industry portal found that the price of a ground parking space starts at around PLN 7,000 and ranges up to PLN 20,000, depending on the location and quality of the space in question (constructionmarketexperts.com, 2020). Underground car parks are much more expensive. The price of one space in an underground car park varies between PLN 80,000 and 100,000. Hence, in the case of developers who set the cost of a space between PLN 25,000 and 60,000, a practice has arisen of redirecting the remaining costs to all buyers of flats or offices in a given building, as the prohibitive price deters potential investors (RynekPierwotny.pl, 2020).

According to developers' offers, the steel structure alone for one parking space in a multi-storey car park costs approximately PLN 22,000, and to this price must be added the price of the land on which the car park is built (abh-investments.pl, 2021). For comparison, the estimated value of one parking space in a vertical car park is PLN 50,000-60,000. Detailed data on construction costs of selected car parks are presented in Table 1.

**Table 1 Data on construction costs per parking space by type of parking space**

<b>Parking space type</b>	<b>Average price per parking space</b>
Ground level	PLN 13 000
Underground	PLN 90 000
Double-storey (construction)	PLN 35 000
Vertical car park	PLN 55 000
In a residential area (underground)	PLN 35 000
In a residential area (ground level)	PLN 18 000

Source: own research on abh-investments.pl, 2021, Wiromet., 2020 and constructionmarketexperts.com, 2020

### **DISCUSSION**

Each type of car park has advantages and disadvantages (Table 2). It is difficult to identify a single best solution, as the decision to choose the type of car park is determined by the expectations of buyers and drivers themselves, i.e. later users of parking spaces (Górniak, 2016).

When analysing the construction price of individual sites, land-based parking spaces are among the cheapest (Table 1). They are the cheapest to build and

their sale usually brings the highest profit to developers when considering inputs and labour costs vs. the final sale price (RynekPierwotny.pl, 2020).

**Table 2 Comparison of different types of car parks providing space for 16 cars**

Parking type	Area occupied	Property security	Aesthetics	Construction costs
„On street”	-	🔒	👁️	💰
Pararell parking spaces	191.36 m <sup>2</sup>			
Perpendicular parking spaces	180.32 m <sup>2</sup>			
At the angle of 45°	180.32 m <sup>2</sup>			
At the angle of 60°	198.72 m <sup>2</sup>			
Underground car park	-	🔒 🔒	👁️ 👁️ 👁️	💰 💰 💰 💰
Multi-storey car park	-	🔒 🔒	👁️ 👁️	💰 💰
Vertical car park	35 m <sup>2</sup>	🔒 🔒 🔒	👁️ 👁️	💰 💰 💰

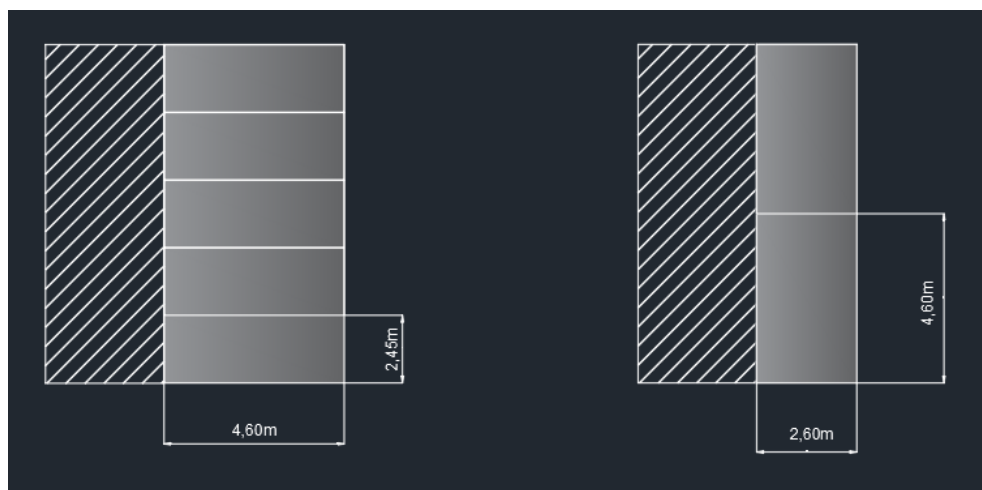
Source: own research

Although ground-level spaces are the cheapest, they occupy the largest area, accommodating the smallest number of cars. In addition, on-street parking significantly narrows the traffic lane by approximately 4.60-5.40 metres (Table 3, Fig. 8, Fig. 9), which can cause chaos, traffic jams and reduce road safety (Kyung Dong T&P Co., 2015).

**Table 3 Data on the width of the lane occupied by on-street parking**

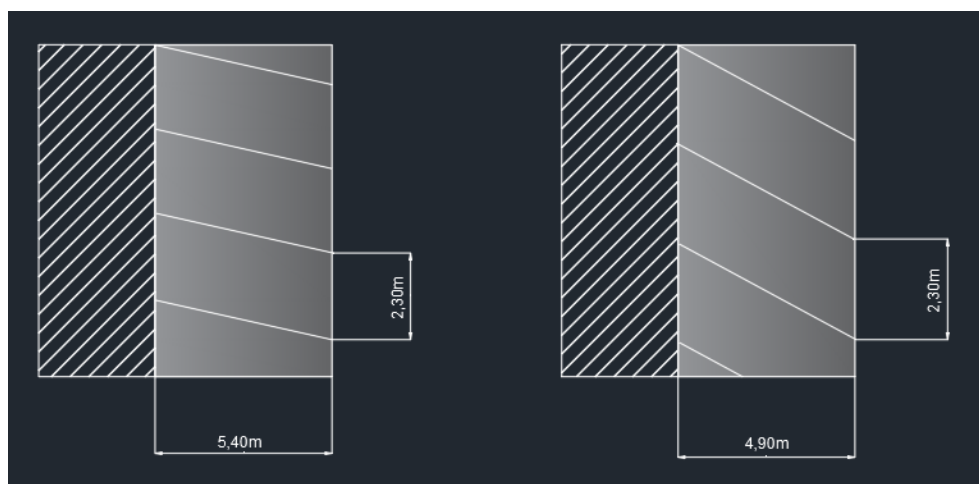
Place rotation angle [°]	Space width [m]	Width of lane reserved for parking [m]
0	2.60	2.60
45	2.30	4.90
60	2.30	5.40
90	2.45	4.60

Source: own study



**Fig. 8 Variants of arranging parking spaces "On street" – perpendicular and parallel to the traffic lane**

Source: own study



**Fig. 9 Variants of arranging parking spaces "On street" – "at an angle" of 60° and 45° to the traffic lane**

Source: own study

In view of the area occupied, vertical car parks are the most optimal and can accommodate up to 16 cars in an area of approximately 35 m<sup>2</sup> – equivalent to 2 standard parking spaces (Wiromet, 2020). In addition, vertical car parks provide the highest level of security for the parking itself and for the protection of property. In the case of standard car parks, various types of collisions, damage to cars (caused not only by inattentive driving but also by weather conditions) or even theft and pedestrian hits are commonplace. Choosing vertical car parks largely eliminates these risks as we leave our car in a secure parking structure and unauthorised people cannot access it. When analysing traffic safety among on-street parking, the safest for all road users is parking in spaces parallel to the traffic lane. The lane is not blocked and the subsequent joining of traffic is safe due to full visibility of the lane. Parking in spaces perpendicular to the lane is the most problematic, as it requires the largest amount of space to perform the manoeuvre, and it is often necessary to block traffic in one or even both directions (Polycarpou et al., 2013). Angled spaces are optimal because parking is relatively convenient and does not block traffic, while exiting the space requires extreme caution and also generates the need to block a lane (Nirwan et al., 2016).

An additional aspect to pay attention to is the aesthetics of car parks. It is most desirable for car parks not to be visible, which can be achieved by building underground car parks (however, this is not possible in all areas) or by building vertical and multi-storey car parks which, with a well-chosen facade by architects, can be perfectly integrated into the surrounding environment and architecture (Ślęzok and Łuczak, 2015).

Due to the increasingly discussed issue of environmental protection, we can also divide car parks into those that are more and less harmful to the environment. Vertical car parks allow parking spaces to be found relatively quickly, as do underground and multi-storey car parks. LED signs are a great help in this respect, so that the driver immediately knows in which direction to



go in order to take up an available space. Surface car parks generate the most congestion and the need to drive into every nook and cranny to check for available spaces, which translates into exhaust fumes and increased air pollution levels in city centers (Brzezinski and Rezwow, 2007).

## CONCLUSION

On the basis of the conducted analysis, it can be concluded that the answer to the growing problem of parking space deficit in cities is a vertical parking solution, i.e. an innovative system of so-called smart parking. The constant increase in the number of vehicles, high land prices, small parcels of land or the high cost of building an underground car park make smart parking an alternative to traditional, large-scale solutions.

## ACKNOWLEDGEMENTS

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**Abstract:** Statistics from the Central Statistical Office (CSO) state that the total number of motor vehicles and mopeds in Poland in 2019 was 31,989,313 units. According to the Central Register of Vehicles (CEPiK) maintained by the Ministry of Digitalisation, the number of motor vehicles registered in Poland in 2019 was 23,878.8 thousand units. Among them, 18,302.4 thousand passenger cars were registered. The constantly increasing number of vehicles on the road has a significant impact on the deterioration of road capacity and drivers' frustration with parking, especially during rush hours in the centres of large cities. Hence, urban logistics, including the country's parking policy, is extremely important to a significant proportion of citizens. Unfortunately, citizens have different perspectives on parking issues. Most drivers expect to be able to leave their car as close as possible to their destination, while some residents, especially non-motorised ones, are against the conversion of free city space into car parks. In response to the presented issues, a comparative analysis of selected types of car parks was carried out. This analysis was one of the stages of the project entitled: "Analysis of the environmental impact of a vertical parking solution using life cycle assessment at the design stage" carried out at the Silesian University of Technology.

**Keywords:** parking areas, vertical parking areas, horizontal parking areas, on-street parking areas, off-street parking areas