1. INTRODUCTION
Nowadays, new forms of terrorist attacks directed against European citizens are witnessed. Explosives and weapons are no longer the only means of carrying out terrorist acts. A new form of terror has emerged, which is deliberate vehicle-ramming into crowds of people. Such tragic events have recently occurred in several major European cities: in London (22nd March 2016), Nice (14th July 2016), Berlin (19th December...
2016), Stockholm (7th April 2017), again in London (2nd June 2017) and in Barcelona (22nd August 2017). In those attacks, a total of 127 people were killed and 726 injured.

What makes it particularly difficult to prevent such attacks is the fact that they take place in a space of daily life, in places where pedestrian and traffic zones meet. The development of modern civilisation, in which the movement of people and goods is common and necessary, resulted in a vast expansion of vehicle traffic zones. Similarly, it is common for people to gather for entertainment, sports, cultural or religious events. Mass gatherings have always been a part of our culture and huge crowds of people are a particular target for terrorist attacks [1, 2].

Without going into further details concerning the causes of those tragic events, we can state as a fact that they are taking place in the real space, where both people and vehicles are present at the same time. The case in question is when a vehicle enters a pedestrian zone in order to cause as much damage as possible.

The point of reference for those events is the space and relations existing within it. The means of describing that space have been developed. The most important measure of articulating space is the modern form of a map – the Geographic Information System (GIS) [3]. The problem lies in the fact that vehicle traffic zones are commonly adjacent to pedestrian zones, and even when there is no such proximity, a threat of vehicle-ramming attack is still present. The following questions concerning the relations between these two zones should be studied:

• whether the existing state of space articulation in GIS is sufficient and what can be done to make it more efficient in order to protect the citizens,
• which of the GIS analyses can be helpful in order to prevent and eliminate risks,
• what new objects should be introduced to protect pedestrians from acts of terrorism.

As mentioned above, the problematic area is where the vehicle traffic zone and the pedestrian zone converge. The risk is higher in places where the pedestrian zone can be easily crossed by vehicles. In the language of GIS, the vehicle zone may overlap with the pedestrian zone. The highest risk arises when there is a crowd of people in the pedestrian area. Addressing this issue using the GIS tools can be the first step taken in order to improve the safety of citizens in Europe and other parts of the world. The main focus of technical problem-solving approach will be an analysis of the points of intersection between the two zones in question.

2. BUILDING LAYERS OF THE CONTACT AREA BETWEEN THE PEDESTRIAN AND TRAFFIC ZONE

Designating an adjacent line between pedestrian and traffic zones is possible on the basis of direct observation of the map. However, our task is to designate this line in the most effective way possible – in GIS, and what is more, to save this line in such a way that it can serve as a basis for further analysis. Our goal is to build layers of adjacent lines using the objects of geographical space as a background.

In large scale maps (for example, 1:500 scale), pedestrian and traffic zones are represented as surface objects. The condition for carrying out spatial analysis aimed at solving the issue of our interest, is to record the zones mentioned above as enclosed, unified areas. Thus, the records of the objects in the source layers in GIS, which will be the subject of further analysis, must be topologically accurate. Advanced GIS packages provide many toolsets for eliminating errors and creating topologically correct map images (Fig. 1).

![Figure 1. An example of a large-scale city map with colour-coded groups of objects of the same class. A topologically accurate map image is the source material for determining the junction line of traffic and pedestrian zones](image_url)

The input content for determining the adjacent lines are surface objects or groups of objects of the same class. The map shown in Fig. 1 is a part of a project created in the ArcGIS 10 system from ESRI (Environmental Systems Research Institute, Redlands, CA). All further analyses and presentations were made using these particular mapping tools [4].
ArcGIS offers a variety of tools for establishing relations between area objects, between area objects and linear objects, as well as point objects. In our case, however, the key is to define a line acting as a boundary between areas. That is why it is practical to examine relations between boundary lines, not between areas. For this purpose, the unified classes of pedestrian paths and streets (Fig. 1), consisting of surface objects, have been converted into linear object classes. By searching the contour border in overlapping section, we can find the adjacent lines of the two areas of interest.

However, the resulting lines may be unreadable in the map. Increasing readability can be achieved by changing the thickness of the lines and using a contrasting colour. Yet another way to achieve better results is building a narrow buffer on the output lines with such a radius that would provide sufficient readability of the analysis. The advantage of this method is that the buffer does not cover the contact line but surrounds it; provides a view, but does not obscure the actual result of the analysis.

The algorithm used to determine the contact line is shown in Figure 2 in the ArcGIS ModelBuilder visual language. Based on this algorithm, the adjacent line has been designated (Fig. 2).

3. THE ANALYSIS OF HIGH RISK AREAS AND METHODS OF PROVIDING SAFETY FOR PEDESTRIANS

Most large European cities incorporate hundreds of kilometres of contact zones between pedestrian and vehicular traffic in their infrastructure. Taking into account the current state of modern infrastructure and available financial resources, construction of safeguards along such a long contact line would simply be impossible. However, action should be taken to ensure safety in places of particularly high risk. The following are examples of such high risk places:

- pedestrian zones in enclosed engineering structures (bridges, tunnels) with reduced immediate evacuation potential,
- large public squares located in the immediate vicinity of vehicle traffic zones gathering crowds of people,
- public squares connected with the streets, which make them an easily accessible target for vehicles driving into the pedestrian area [5], [6].

The three cases require more consideration.

3.1. Pedestrian zones in enclosed engineering structures with reduced immediate evacuation potential

City bridges, besides carriageways, usually contain pavements, as well as cycling infrastructure. Bridges are engineering objects characterised by limited width, with no possibility of evacuation in the direction perpendicular to the axis of the bridge. Therefore, at the border of the traffic zone, architectural objects, such as crash barriers or bridge construction elements, separating vehicles from pedestrians should be used.

A very similar situation with limited evacuation possibility occurs in tunnels and structures that cross over another road (flyovers) or railway tunnels.

For analyses of pedestrian safety along the line adjacent to vehicular traffic, it is absolutely necessary that all existing technical objects separating the carriageway from walkways should be recorded in GIS. Building layers of pedestrian protection elements would allow objective assessment for citizen security services.

3.2. Large public squares located in the immediate vicinity of vehicle traffic zones gathering crowds of people

Huge crowds in open spaces such as public squares, can become an easy target for attacks. The threat grows if the open space is located within the immediate vicinity of vehicle traffic [7].

We deal with high concentration of people during sports and entertainment events, as well as religious
ceremonies. But even average daily traffic in pedestrian zones requires special protection. In this case, there are two sources of threat:

• the possibility of a terrorist attack using a vehicle that entered a pedestrian zone,
• panic – the second destructive factor in a crowd [8].

Open spaces such as city squares are generally deprived of any infrastructure which could provide shelter. The only effective means of safeguarding people gathered in an open space like that is blocking the possibility of a vehicle entering a pedestrian zone. It is a hardly achievable task to completely isolate pedestrian zones in the city centres filled with residents and tourists from the traffic, as public transport must function, goods must be delivered to shops, streets leading to city squares must be accessible to emergency services. One of possible ways to protect pedestrians is setting up a matrix-based network of barriers. Those barriers should be designed to prevent large vehicles from suddenly entering the pedestrian zone, as well as enrich urban space (by concealing their primary task).

This paper is aimed at finding ways to safeguard the perimeters of city squares with elements of landscape architecture, which could act as barriers against heavy vehicles. In this case, a grid based on Sierpinski fractal geometry – (Fig. 3, 4, 5 and 6) – was proposed. Sierpinski carpet consists of triangular elements and unlike regular rectangular or hexagonal meshes, it does not create typical “alleys”, which could weaken the blocking properties of the grid [9]. In addition, the Sierpinski grid creates a beautiful geometric pattern, which may serve as a substitute for an urban forest if planters with trees or greenery are used as elements of the matrix. Another advantage of that method is the fact that the grid may be modified by changing the location of landscape architecture objects (concrete planters). In the places of popular tourist interest, periodic variation of blockade grids could be implemented. Such variability could be an additional tourist attraction and at the same time serve as a further protection against terrorist attacks.

3.3. Streets leading to city squares – an easy target for fast unexpected vehicle-ramming into pedestrian zones

Squares in historic old town centres, larger commercial areas and market places have always been a distinguishing characteristic of European cities. Common feature of these places is the permanent presence of people – residents or tourists. This kind of places are most likely to be hit by attacks, if the square is adjoined by high traffic streets, whose geometric extensions cross the square area. In such streets, a heavy vehicle can move unnoticed and accelerate to ram into people in the area. Fig. 7 exemplifies this kind of street leading to a market square.

The purpose of this analysis is to identify the zone in the greatest danger of a vehicle ramming into the square from the adjacent street. To do so, a street buffer with a radius of several dozen metres was marked, which was then intersected with the pedestrian zone. In Figure 8, the resulting area was highlighted in red. This way of analysis does not differentiate the area which is potentially most vulnerable (on the extension of the street axis) from the rest of the
It seems that the most appropriate solution involves building a buffer on the extension of the street axis intersecting the square area. The only effective protection against the threat of vehicle ramming is cutting off the access to the square area in such a way that a heavy vehicle cannot get through, but it is still accessible to security services and small delivery trucks. Such a possibility is created by using a security system in the form of a labyrinth. An example of blocking the street exit is shown in Fig. 8, while various options of landscape architecture objects serving as street barriers are shown in Fig. 9.
4. SUMMARY AND CONCLUSIONS

So far the fight against terrorism has focused on safeguarding crowds of people in enclosed spaces such as railway and underground stations or auditoriums. Special services have been dealing with this issue for many years. These days there appear new forms of terror e.g. vehicle-ramming into crowds of people. Recent months have brought an increase in the number of such tragic events. So far, we have witnessed six attacks in European cities with 127 people killed and 726 injured.

The point of reference for these attacks is space and relations existing within it. The problem is that traffic zones and pedestrian zones are usually adjacent to each other and even the where there is no direct contact between the two, there is still danger of a vehicle-ramming attack.

The guiding principle we chose to solve this issue was an attempt at determining the area of convergence between pedestrian and vehicular zones. Based on this assumption, further GIS analyses have been carried out in order to identify the areas of highest risk for crowds.

To analyse pedestrian safety along the line converging with the vehicular zones, it is of primary importance to register all of the existing technical architectural objects separating carriageways from walkways in the Geographical Information System. Non-fixed technical equipment should also be periodically registered. Building layers of pedestrian protection elements would allow objective assessment for citizen security services.

This paper is aimed at finding ways to safeguard the perimeters of city squares with elements of landscape architecture, which could act as barriers against heavy vehicles. In this case, a grid based on Sierpinski fractal geometry was proposed. Sierpinski carpet consists of triangular elements and unlike regular rectangular or hexagonal meshes, it does not create typical “alleys”, which could weaken the blocking properties of the grid.

In order to safeguard city squares against unexpected vehicle-ramming attacks from the adjacent streets, we have suggested using barriers in the form of a labyrinth, built up of landscape architecture objects. Each large European city incorporates hundreds of kilometres of contact zones between pedestrian and vehicular traffic in their infrastructure. It is not possible to safeguard pedestrian zones along such a long contact line, however, we can protect large groups of people. GIS can provide basic tools for activities aimed at safeguarding people against this new form of terrorist acts. The method we have proposed using landscape architecture objects can be effective in protecting people in cities, in everyday situations and also at the time of large gatherings in public squares.

REFERENCES