THE CONCEPT OF CREATING RASTER ACCESSIBILITY MAPS FOR MULTI-STOREY BUILDINGS

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Abstract

The paper presents proposals for solving the problem of carrying out a comprehensive analysis of the evacuation process running on many storeys of buildings. The difficulty arises from the use of raster model, which as an extension of the concept of occupancy grid used in mobile robotics allows modeling of movement on the entire surface of rooms, but is limited to one storey. The raster model has replaced here the graph usually used in applications related to evacuation and, also, navigation. Due to the location of staircases, in many cases in places surrounded by other rooms, it is often impossible to connect, even with paths of cell, individual floors into a single raster, which was the author's first idea to cover the entire building. Finally, it was proposed to introduce "common points", that could be identified on two adjacent storeys. On the lower floor it would be a place where a person descends from the upper storey, while on the upper storey it would be place of leaving it during the movement towards the exit. At the same time, such a point on the upper storey would be the starting point of the analysis, playing the same role as the exit from the building on the ground floor. This allowed transferring information about the distance of reaching the evacuation exit to the next floors covered by the analysis. Thus, it would be possible to take full advantage of the benefits of the raster model, such as possibility to consider obstacles that impede movement.

Key words: building interior, cost distance, evacuation, GIS, occupancy grid

Introduction

For evacuation purposes, but also navigation, the space inside buildings is usually modeled using a graph defining interrelations between rooms, in which point objects – nodes represent rooms, and edges – linear objects, connect pairs of nodes (CICHOCIŃSKI, DĘBIŃSKA, 2016). This approach has been formalized in the form of the IndoorGML standard (OPEN GEOSPATIAL CONSORTIUM, 2016), defining the structure of navigable spaces in buildings. It is focused on interconnections between rooms and moving from one room to another and in this respect it can be compared to the road network model. However, unlike in the case of roads, where vehicles must move along sections of the network (CURTIN, 2007), pedestrians are free to move around the entire available space (TANEJA et al., 2016).

Therefore, the interest of researchers dealing with applications of geographical information systems (GIS) for navigation in buildings has turned towards models of reality used in mobile robotics. In addition to the topological representation, which can be compared to the graph network models used in GIS, a metric representation is also used (AMBROSZKIEWICZ, 2006). It involves the decomposition of the space into a grid of cells, taking into account their occupancy in a binary form (KUŁAKOWSKI et al., 2008).
Such occupancy grid was adopted by LI et al. (2010) as the basis for their solution. As in the case of IndoorGML, it is a vector and graph approach, but (just like in a raster model), the nodes arranged at regular intervals fill the entire available space. So it still registers the structural properties of space, but at the same time it takes into account its geometrical properties. Positive verification of this model, carried out by analyzing the shortest routes using the hotel plan, was presented in (SUN, LI, 2011).

An important issue when generating a grid is its density. Due to the computational efficiency, the number of nodes should not be too large, but at the same time it is important to accurately reproduce the geometry of the analyzed object. LI et al. (2016), adopting the grid size of 0.2 x 0.2 m, made it dependent on half of the width of the narrowest door in the building. In their experiments, LI et al. (2010) came to the value of 25 cm, resulting from the minimum width of the occupied parts of the space, i.e. the thickness of the walls.

However, it must be emphasized that, despite the use of the grid, presented models are in fact vector models. However, spatial analysis does not have to be done only on vector data. Regular grid can also be stored in a raster model. Indeed, individual applications of the raster model for the analysis of movement in the interiors of buildings can be noted, but considerations boil down to attempts to achieve results similar to those of the vector model (for example, finding the shortest route) (HONG, MURRAY, 2016, CICHOCIŃSKI 2017a). However, the whole wealth of algorithms in GIS is related to the raster model. One of the areas of their applications is the creation of accessibility maps (BIELECKA, FILIPCZAK, 2010, CICHOCIŃSKI 2017b), which can be used in the case of evacuation planning.

Examples presented above, as well as studies on the use of grids described in the available literature, are limited to one storey. However, public buildings usually have more than one floor. Therefore, the author decided to investigate whether there are any possibilities to perform accessibility analyses in a raster model that would cover all floors of buildings.

The thesis was made that by appropriate transformation of source data, or by using appropriate algorithms, it is possible to carry out complex spatial analyses on raster data covering many storeys of buildings. This thesis has been proved by a series of experiments on data representing the real object, which is building C-4 of the AGH UST campus, which is the seat of the Faculty of Mining Surveying and Environmental Engineering.

Two programs: ArcGIS and QGIS, were used to carry out the activities described in the paper and drawing up illustrations. Thus, the secondary objective of the work was a comparison of the functioning of these two tools.

AGH UST employees and students may use Esri's ArcGIS for Desktop Advanced commercial software under the Site license purchased by the University. An element of this advanced version of the program is the Spatial Analyst extension, which offers wide spectrum of tools for processing raster data. QGIS (previously known as Quantum GIS) is a free and open-source cross-platform desktop geographic information system (GIS) application that supports viewing, editing, and analysis of geospatial data. It is licensed under the GNU General Public License, which guarantees end users the freedom to run, study, share and modify the software. QGIS can be adapted to one's special needs with the extensible plugin architecture. A core plugin for QGIS is the Processing Toolbox – a set of geo-spatial algorithms (QGIS DEVELOPMENT TEAM, 2018). In most cases they are standardized wrappers around functions of external applications, such as SAGA or GRASS GIS, the most important elements of which are extensive sets of spatial data analysis tools, mainly raster ones.

Data acquisition

Vector data describing the C-4 building was acquired by students from the Scientific Circle of Surveyors „Dahlta" as part of the AGH UST geoportal development (PARKITNY et al., 2013). On the basis of a set of lines depicting construction elements of the building, a set of polygons was generated for each storey corresponding to the floors, i.e. representing surfaces on which people stay and move. Then these data sets were converted to raster form. Cells representing walls received the NoData value which excluded them from analyses. Like the other researchers mentioned above, the author of this paper recognizes the issue of the cell size of the resulting raster. In his opinion, the main determinant of this size should be objects in the building with the smallest at least one dimension. Walls are such objects in this case, whose width is smaller than the next potentially small objects, such as the door. The cell size should be adjusted in this way to the width of the walls, so that they create in the raster model a real barrier separating rooms from each other. This means that there should be at least two cells in the wall width, i.e. the size of the cell should be less than half the width of the narrowest wall. Therefore, 10 cm (0.1 m) was assumed the optimal cell size.

In such a way defined raster lacks one more feature, in order to be able to perform an accessibility analysis based on it, specifying the distance of each place on a given floor from the points representing the exit from this storey. It is the value of the cost – resistance, which must be overcome when moving through individual cells. It should be noted, that in ArcGIS the cost is referred to a distance unit and therefore does not depend on the size of the cell. Therefore, all cells of the raster representing the floors had to be given a value of 1 (the cost of overcoming a distance of one meter is one). Based on a raster defining the cost surface, the *Cost allocation* tool identifies, for each cell, the least accumulative cost distance over a cost surface to the user-specified source locations (ESRI, 2017), in this case, determining the distance of each place in the building from the nearest exit (Fig. 1). In addition, it generates another two data sets: raster specifying the zone of each source location that could be reached with the least accumulative cost (Fig. 2), thus indicating to which exit one should go from a specific location and back-link raster containing values of 0 through 8, which define the direction or identify the next neighboring cell (the succeeding cell) along the least accumulative cost path from a cell to reach its least cost source.

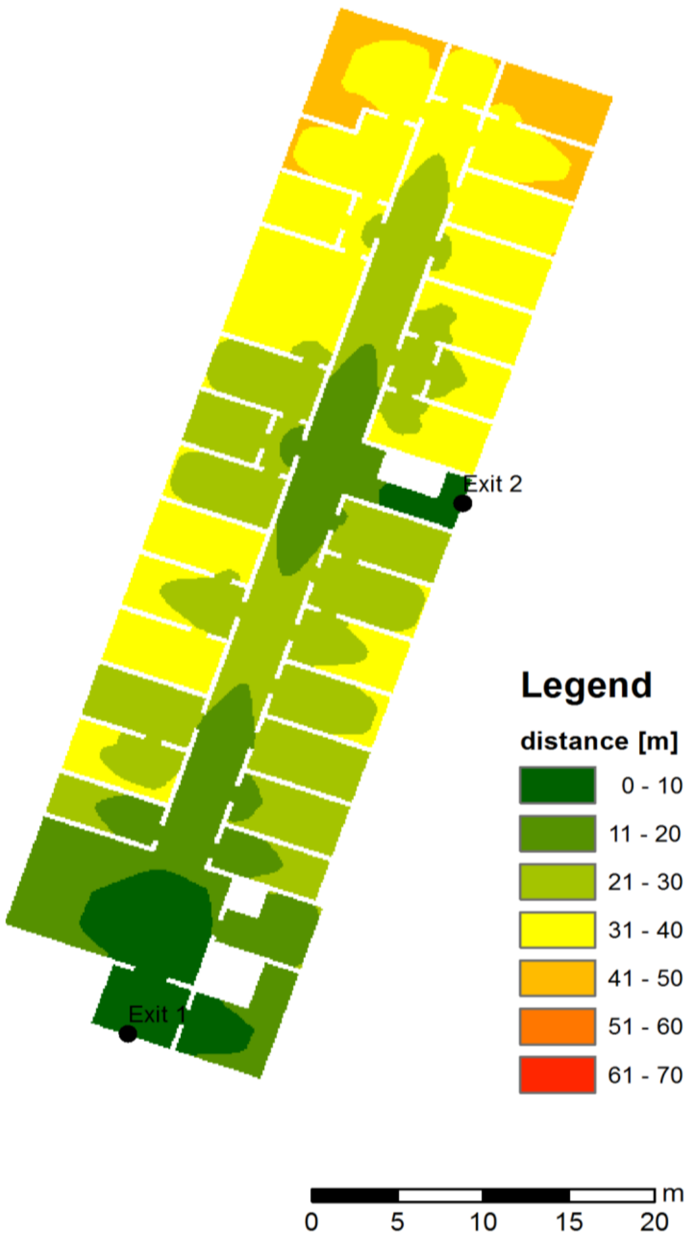

Fig. 1. The result of *Cost allocation* analysis – the least accumulative cost distance over a cost surface to exits.
Source: Own work.

Such analysis can be performed simultaneously only for one floor of the building. In order to be able to include at the same time more floors, it was necessary either to combine them in one raster or to automate repeating the cost allocation for subsequent floors.

Proposal no. 1

The first of the proposed solutions to the problem of running raster spatial analyzes on many storeys of buildings consists in placing all of them next to each other in a single raster. Because this way they will create unconnected fragments of space, each place of departure on one floor should be connected with the corresponding place of entry to the next floor. The author proposes to do this with the help of "paths of cells". Giving 0 (zero) to these cells means that regardless of the path length, they will not artificially increase the cost of movement. It turned out, that in ArcGIS cost raster cannot contain values of zero since the algorithm is a multiplicative process (ESRI, 2017). That's why it was decided to use QGIS. Paths were obtained by drawing their axes as vector linear objects, then making a buffer around them. Still functioning in the vector model, paths were combined with the surface of floors and only the result of this operation was converted to raster.

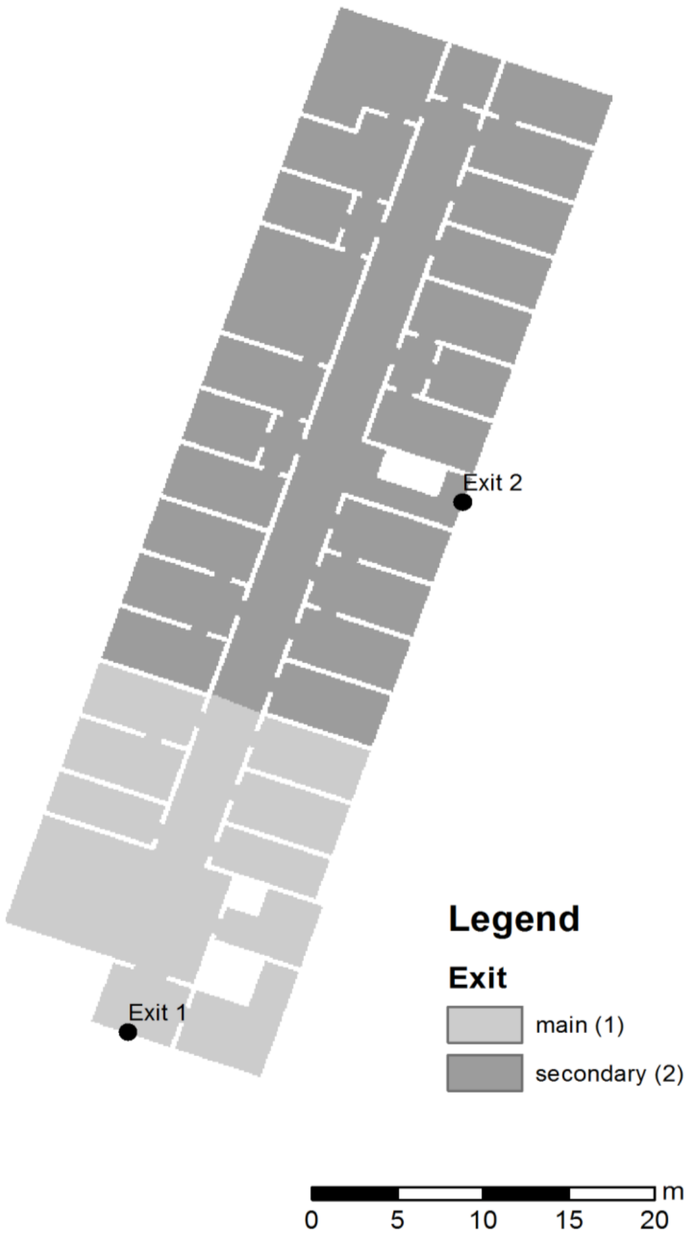

Fig. 2. The result of *Cost allocation* analysis – the zone of each exit that could be reached with the least accumulative cost.
Source: Own work.

In the Processing Toolbox there are two functions for determining the cumulative cost of moving to each cell on a cost surface from other user-specified locations: *Accumulated Cost* provided by SAGA GIS and *r.cost* provided by GRASS GIS.

Attempts with the *Accumulated Cost* tool have shown that it is poorly optimized. Analysis on a 3000x2500 cell raster took about half an hour. The *r.cost* tool (which was finally chosen), generating the result within several seconds, turned out to be incomparably faster. Both of these tools required a cost raster to be prepared differently than for ArcGIS: each cell contained a value which represented the cost of traversing that cell.

The result of the *r.cost* analysis consists of three rasters (GRASS DEVELOPMENT TEAM, 2018): *Cumulative cost* – in which each cell contains the lowest total cost of traversing the space between each cell and the user-specified points (Fig. 3), *Cost allocation map* – presenting for each cell its nearest starting point based on the minimized accumulative cost while moving over the cost surface (Fig. 4) and *Movement directions* – showing the movement direction to the next cell on the path back to the start point.

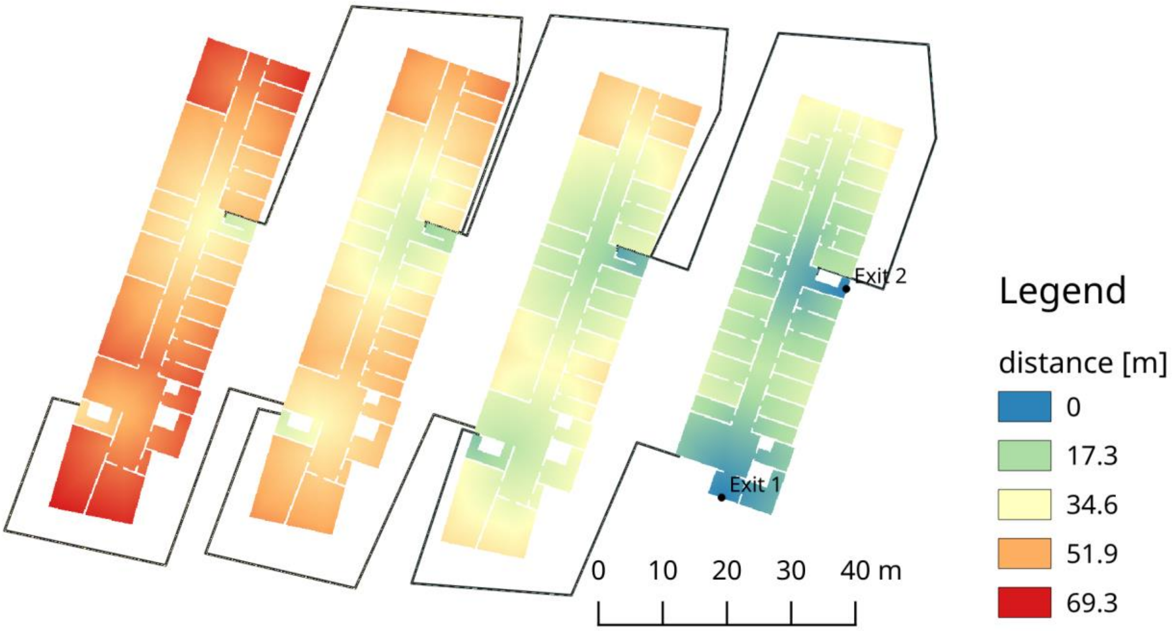

Fig. 3. The result of *r.cost* analysis – *Cumulative cost*.
Source: Own work.

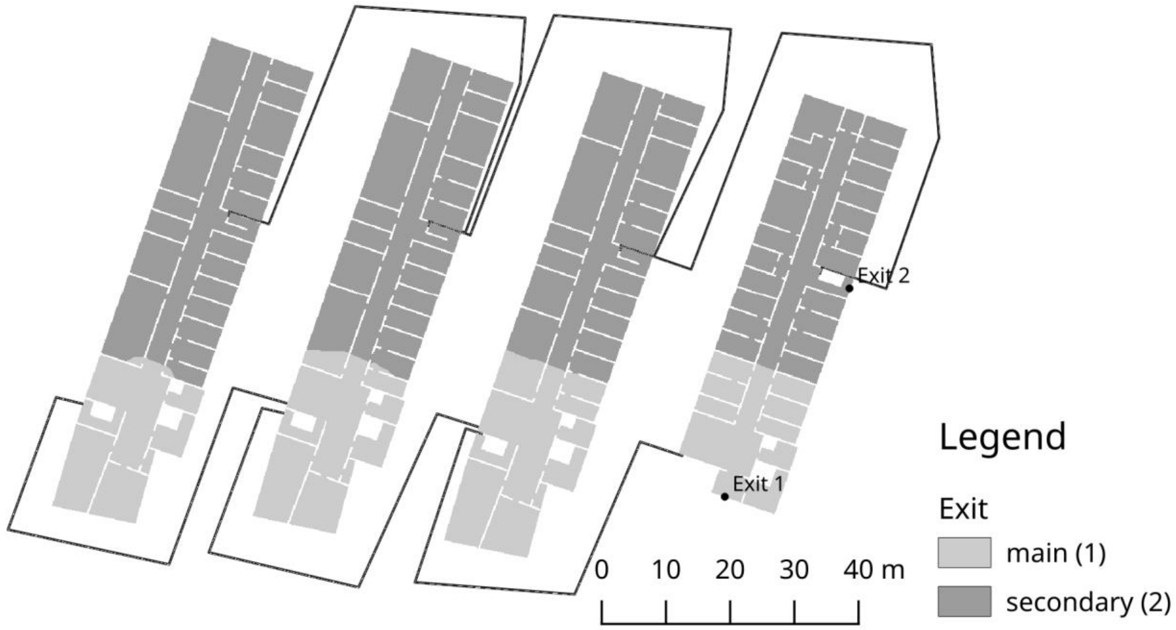

Fig. 4. The result of *r.cost* analysis – *Cost allocation map*.
Source: Own work.

Closer look at the paths on the resulting Cumulative cost raster reveals that they have a uniform color, which means that, despite significant length, they did not affect the cell values, transferring them "safely" between floors. Reading the values of cells on subsequent storeys, it can be stated that these values do not start from zero, but from the number corresponding to the distance to the emergency exit from the place where the floors meet.

It may be difficult or even impossible to use this approach if the locations of places connecting the floors are inadequate. In the described example, the author managed to use the space of walls to guide the lines (fig. 5). This, however, may not always be feasible, for example in the case of staircases located in the interior of the building. This forced the need to increase the resolution of the raster (reduce the cell size) to 3 cm (0.03 m), so that two lines fit inside the wall.

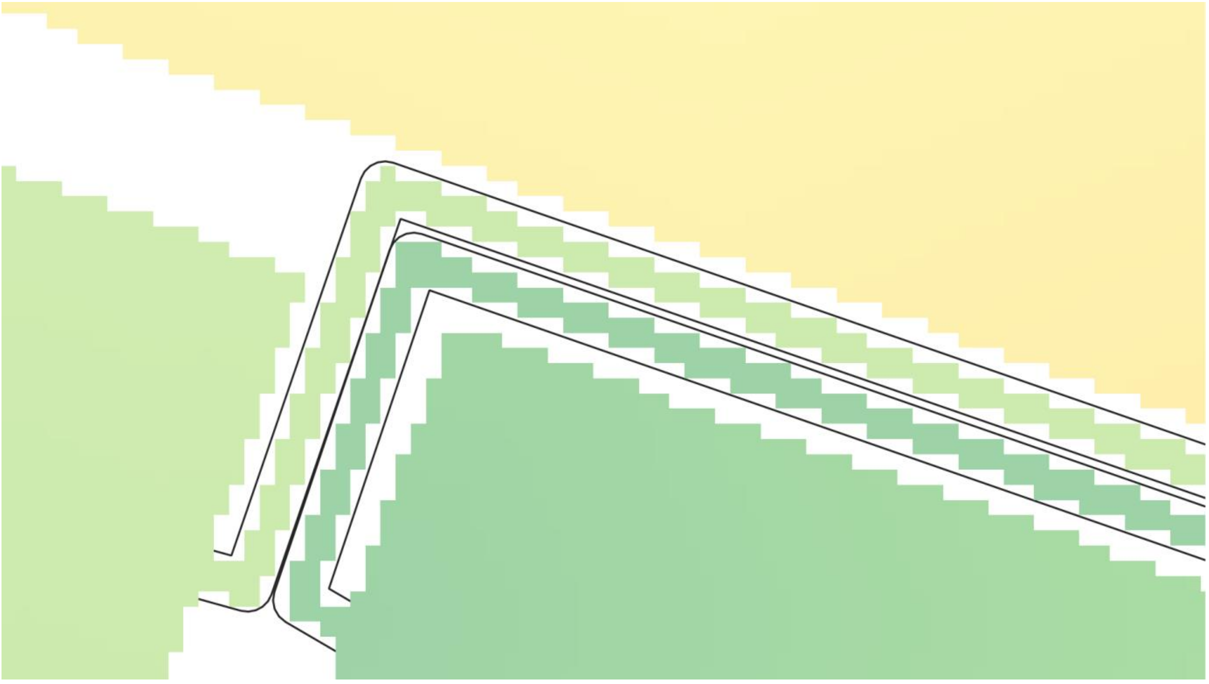

Fig. 5. Paths of cells "inside" walls.
Source: Own work.

Proposal no. 2

Due to the location of staircases, in many cases in places surrounded by other rooms, it is often impossible to connect individual floors in a single raster, which was the author's first idea to cover the whole building. This inconvenience was resolved by introducing "common points" ("links") that can be identified on two adjacent floors. On the lower storey it is a place where a person descending from the upper storey appears, while on the upper storey it is a place to leave it during the move towards the exit. At the same time, such a point on the upper storey will be the starting point for the analysis, playing the same role as exit on the ground floor. Of course, because such a starting point on subsequent floors is not an exit, determining the distance to such a point is not the end of the analysis. But, acting iteratively and starting from the ground floor, it is possible to determine its distance from the exit for each point connecting with the next storey, reading the value of the cell identical with its location. This value can then be added to all cells resulting from the cost distance analysis from this point on the upper storey. This complicates the operation a bit, because for each common point the value may be different and it is not possible to carry out such an analysis on a higher floor at the same time from all points. They must be done independently for each link, and then obtained results must be combined. This join must be based on selecting the lowest value from all the cells (coming from all rasters) in a given location. In ArcGIS, the Cell statistics function with the Minimum parameter is used for this purpose. In this way, the length of the shortest route is selected from the place represented by the given cell, although not directly, because it is not possible to determine which raster the selected smallest value was from. The Lowest position function comes with help in solving this task, determining on a cell-by-cell basis the position of the raster with the minimum value in a set of rasters. For each cell in the output raster, the value represents the position of the raster with the lowest value.

Finally, information about evacuation is carried (independently for each analysed floor) by two rasters: one defining the distance to the nearest exit (Fig. 6) and the second indicating the nearest exit (Fig. 7). By reading cell values presented in Figure 6, it can be concluded that these values do not start from zero but from the number corresponding to the distance to the emergency exit from the location of the common point on the lower storey (Fig. 1).

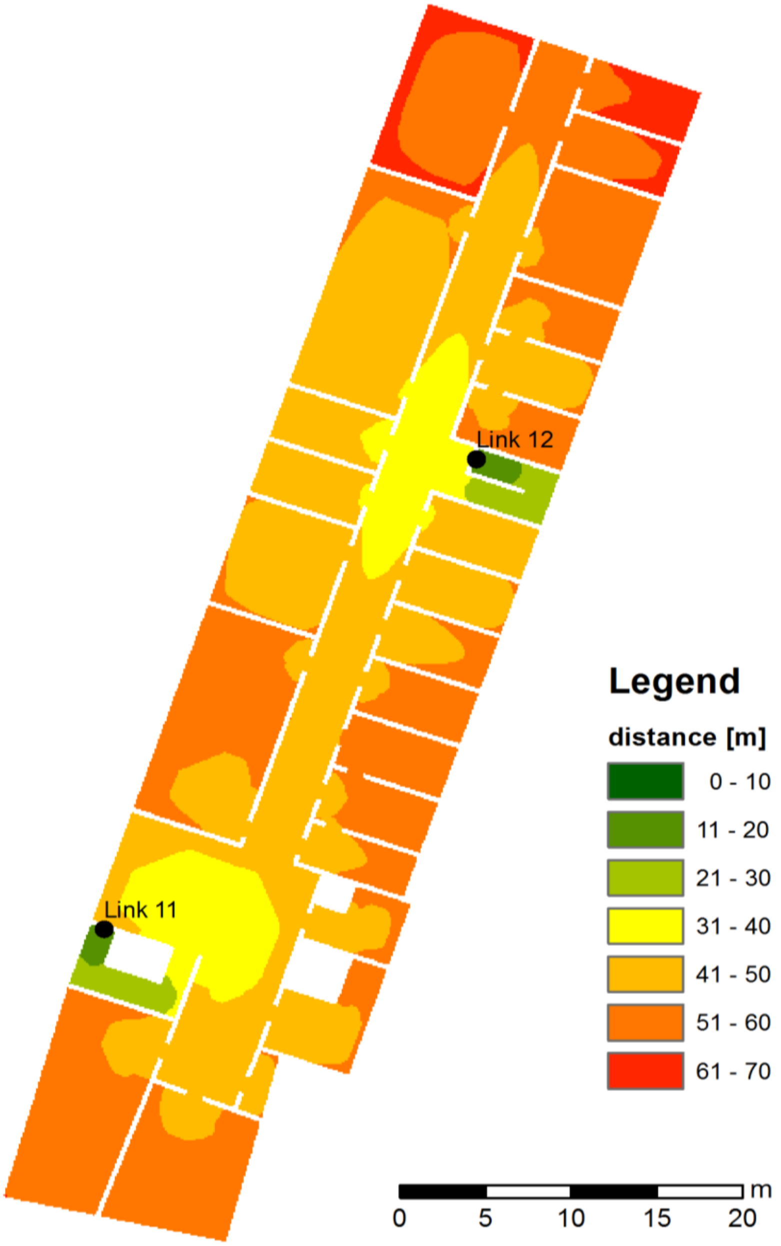

Fig. 6. The result of *Cost allocation* analysis on the second floor – the least accumulative cost distance over a cost surface to common points.
Source: Own work.

Conclusions

Expanding the concept of occupancy grids used in robotics, the paper proposes the use of raster data and tools operating on such data for modeling the evacuation from buildings with a complex layout of rooms and many storeys. In particular, concepts of solving the problem of carrying out comprehensive analysis on many storeys were presented. Two solutions have been proposed that allow the transfer of information on the distance to the emergency exit to the subsequent floors covered by the analysis: the use of common points (links) and paths of cells. Unfortunately, none of them is perfect: the use of common points is not easy to automate – it requires programming the process of transferring values resulting from the analysis on the lower floor to a higher floor, while combining analysed floors in one raster (if at all possible due to the location of staircases) requires careful and thoughtful routing of connecting lines.

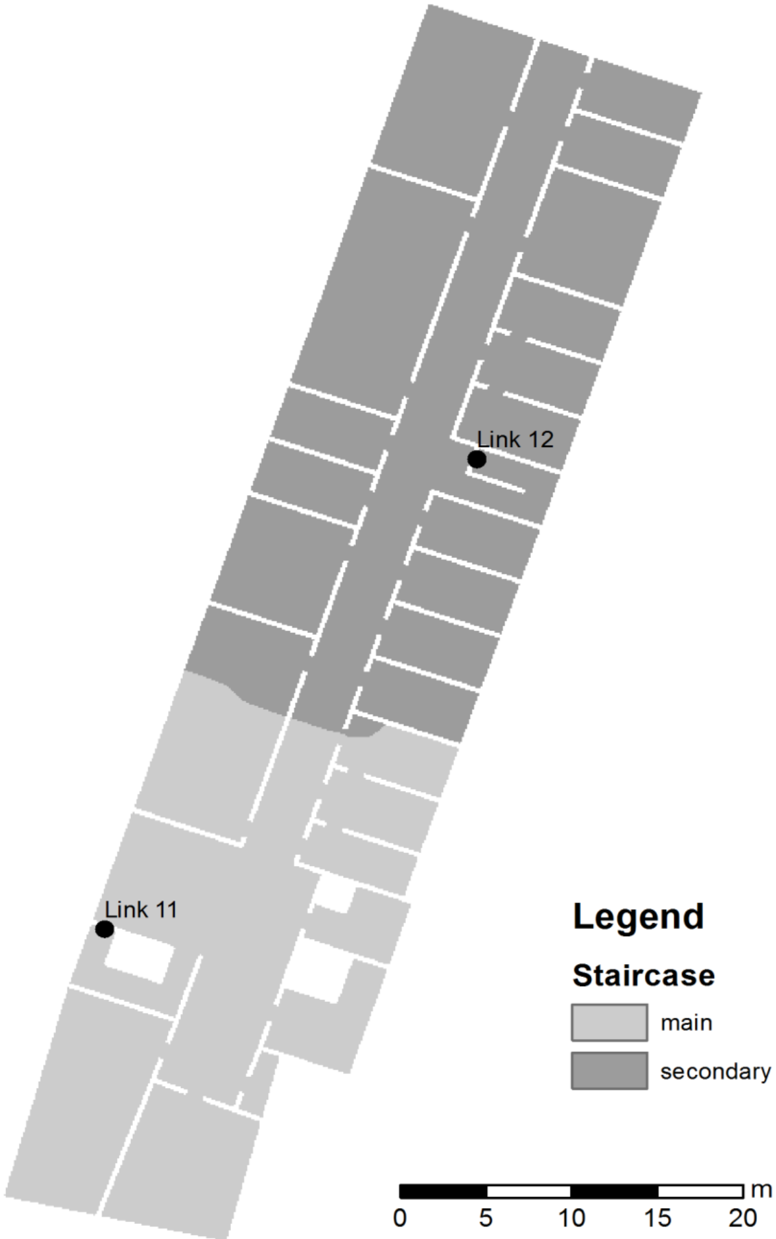

Fig. 7. The result of *Cost allocation* analysis – the zone of each common point that could be reached with the least accumulative cost.
Source: Own work.

However, according to the author, conducted studies, the results of which were presented in the form of examples of analyses, confirm the thesis put forward at the beginning, that by appropriate transformation of source data, or by using appropriate algorithms, it is possible to carry out complex spatial analyses on raster data covering many storeys of buildings. Thus, it will be possible to take full advantage of the benefits of the raster model, such as: availability (easily obtainable from architectural plans), possibility to determine the distance between every location in the building and the emergency exit and, also, possibility to consider obstacles that impede movement.

In addition, it can be concluded that both used programs: ArcGIS and QGIS fulfilled their role by providing reliable results. One just have to remember when preparing the data for analysis that different approaches to the interpretation of the cost surface were used in these programs. In addition, QGIS often has many tools performing the same task, which means that selecting one of them for use should be preceded by at least a short test of all similar ones.

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