DATA SOURCES AND ACQUISITION METHODS FOR 3D INDOOR NETWORK ANALYSES*

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Abstract

Building interiors are areas to which capabilities of network analyses have not been so far widely applied. Building environment is significantly different from other places where network analyses are used. The main difference is the introduction of the third dimension (3D). This requires both adaptation of algorithms and overcoming difficulties associated with visualization of data and obtained results. The problem, which also cannot be missed is the availability of relevant data needed to perform the analysis. Traditionally, architectural plans are stored in the form of vector drawings made in CAD (Computer Aided Design) software, whose applications, beyond presentations, are very limited. Therefore, more and more three-dimensional models are created, built of interconnected objects, having not only geometric properties, but also other characteristics, and even possibilities to register behaviours. However, even complete information about the structure of building does not allow routing in its interior. This requires collection of point objects – nodes, that represent rooms and edges – linear objects linking pairs of nodes. Despite the introduction of IndoorGML standard defining the structure of navigational graphs in buildings, at this moment there are no widely available tools for automatic generation of networks necessary for carrying out the analysis. Therefore, the paper analyses presented by other authors and proposes its own algorithms for automatic determination of network elements on the basis of information about the structure of the building. Basing selected methods on the functionality of the existing tools of GIS software will allow for easier implementation and will give a chance for their faster dissemination.

Key words: *routing, building interior, GIS, algorithm, node, edge*

Introduction

Network analyses belong to a group of tools available in geographical information systems. The basis of their operation are data, consisting of two sets: edges and vertices, so called network. In practice, one has to do with a network in case of street network, sewerage system, transportation network, and so on. In the group of network analyses one can find variations of analyses such as finding the shortest and/or the fastest route, determination of service areas, a solution to the travelling salesman problem (CICHOCIŃSKI, DĘBIŃSKA, 2012).

Interiors of buildings are areas where network analyses has not been widely used. This is because the building environment is significantly different from other places where network analyses are used. The main difference is the introduction of third dimension (3D). This requires both customization of algorithms and overcoming complications related to visualization of data and results of performed analyses (CICHOCIŃSKI, DĘBIŃSKA, 2016).

A problem that cannot be overlooked is the availability of relevant data required for analysis. Currently digital information about the structure of buildings (architectural plans) is usually collected in the form of vector drawings made in CAD (Computer Aided Design) software, consisting of simple geometric elements such as lines or arcs (DOMINIGUEZ, 2012). Optionally, blocks can be created as assemblies of these simple elements and other blocks, allowing representation of repetitive elements such as doors and windows. Additionally, CAD software allows dividing information into layers that group together related items and can be turned on and off as needed. However, the use of data in this form beyond presentation function is very limited. Therefore, one can now observe the rapid development of the field referred to in short term as BIM, where drawings are replaced by three-dimensional models consisting of interrelated objects, not only with geometric features, but also other properties, and even having the ability to record behaviours (DENIS, 2015).

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Recently, the topic of collection and processing of data describing the internal structure of buildings is also the subject of research in the field of geographic information systems. Pioneering works in this area were led by the creators of the CityGML standard (OPEN GEOSPATIAL CONSORTIUM, 2012) being an XML application for registration and exchange of three-dimensional urban models. CityGML then became the starting point for formulating the 3D building data model for the Infrastructure for Spatial Information in the European Community (INSPIRE, 2013), which guarantees popularization of this subject. Attempts can also be seen to use tools and data structures offered by GIS software for building management (SŁOWIKOWSKI et al., 2014, HARRIS, 2015).

However, even complete information on the structure of the building does not allow for determination of routes in its interior. Therefore, it was necessary to define data structures suitable for navigation in buildings. The result was IndoorGML standard (OPEN GEOSPATIAL CONSORTIUM, 2016).

This standard specifies the structure of navigable spaces in buildings. It describes in detail the abstract data model as well as characterizes the XML schema for spatial information. IndoorGML does not duplicate CityGML schemas, but only uses them as the background of the navigation space. The main idea behind IndoorGML is to represent closed spaces (corridors, rooms) as cells that are linked by relationships. This is accomplished using point objects – nodes, that represent rooms, and edges – linear objects connecting pairs of nodes. Such information is already sufficient to carry out network analyses in buildings.

Description of proposed solutions

Despite the adoption of the IndoorGML standard, there are still no universally available tools to automatically generate the necessary network for analysis. Although proposals of algorithms to automate the process of acquiring navigation data are formulated (JAMALI et al., 2017, KARAS et al., 2006, LI et al., 2016, XIONG et al., 2016), but so far they have not been implemented in popular software. It would seem that the only solution would be to manually add individual elements to the database, using existing drawings as a base (PU, ZLATANOVA, 2005).

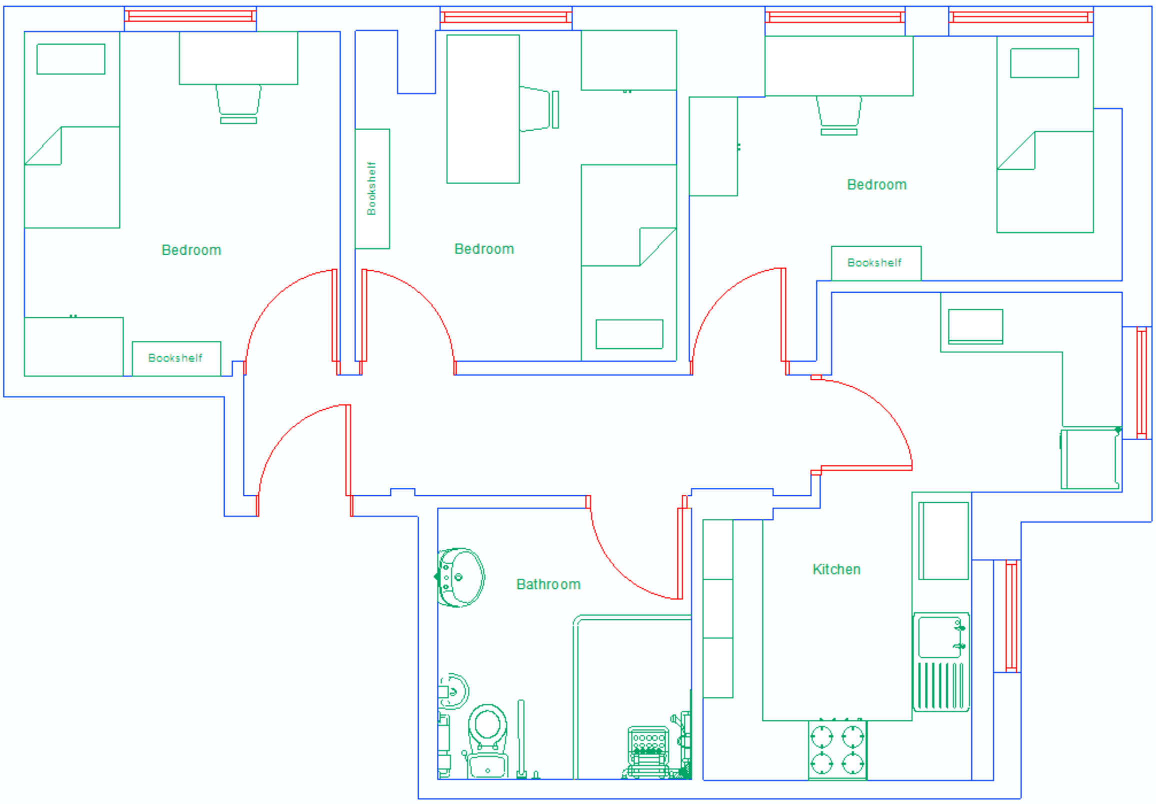

Fig.1. Sample CAD drawing used as the data source for verification of proposed solutions. *Resource: http://www.cadblocksfree.com*

But according to the author, GIS software has a ready-made functionality that could be used to generate a network. One of them is the Euclidean Distance tool, which describes each cell's relationship to a source or a set of sources based on the straight-line distance. The proposed method is based on the assumption that the raster of Euclidean distance from walls may be treated as terrain model. Then "valley floors" will be located in the center of the rooms and corridors, and network of streams "flowing" in these valleys should form the navigation network. In the arsenal of GIS tools, at least two tool sets can be found, application of which should allow to determine "watercourses" that will represent axial lines of rooms. One of them consists of Flow Direction and Flow Accumulation tools (ESRI, 2017). The first tool takes a terrain surface as input and outputs a raster showing the direction of flow out of each cell. On this basis, the second tool calculates accumulated flow as the number of upslope cells flowing into each downslope cell in the output raster. Cells with a high flow accumulation are areas of concentrated flow and may be used to identify stream channels. By applying a threshold value to the results of the Flow Accumulation tool, a stream network can be delineated.

The second proposal is to use Topographic Position Index (TPI) tool, which calculates an index that expresses whether a given cell is higher or lower than its neighbours (WEISS, 2001). For this purpose it compares the elevation of each cell in a raster terrain model to the mean elevation of a specified neighbourhood around that cell. Positive TPI values represent locations that are higher than the average of their surroundings – ridges. Negative TPI values represent locations that are lower than their surroundings – valleys. TPI values near zero are either flat areas (where the slope is near zero) or areas of constant slope (where the slope of the point is significantly greater than zero).

Verification of Euclidean distance method

Verification of the assumptions was made on the basis of the drawing *Student halls of residence flat.dwg* (Fig. 1) downloaded from CADBlocksFREE site (http://www.cadblocksfree.com) which offers a library of free 2D and 3D CAD drawings. Inspection of drawing elements allowed to determine that relevant to the task are *wall_01* and *door_01* layers, containing respectively walls and doors of the analysed rooms. Before proceeding further, unnecessary elements such as door leaves were removed from these layers and minor imperfections were corrected.

Further actions and essential analyses were carried out in ArcGIS software, which has the required functionality in terms of vector data geoprocessing, including in particular data import from CAD drawings and converting linear features to polygons. It also has a wide array of raster analysis tools available through the Spatial Analyst extension (ESRI, 2017).

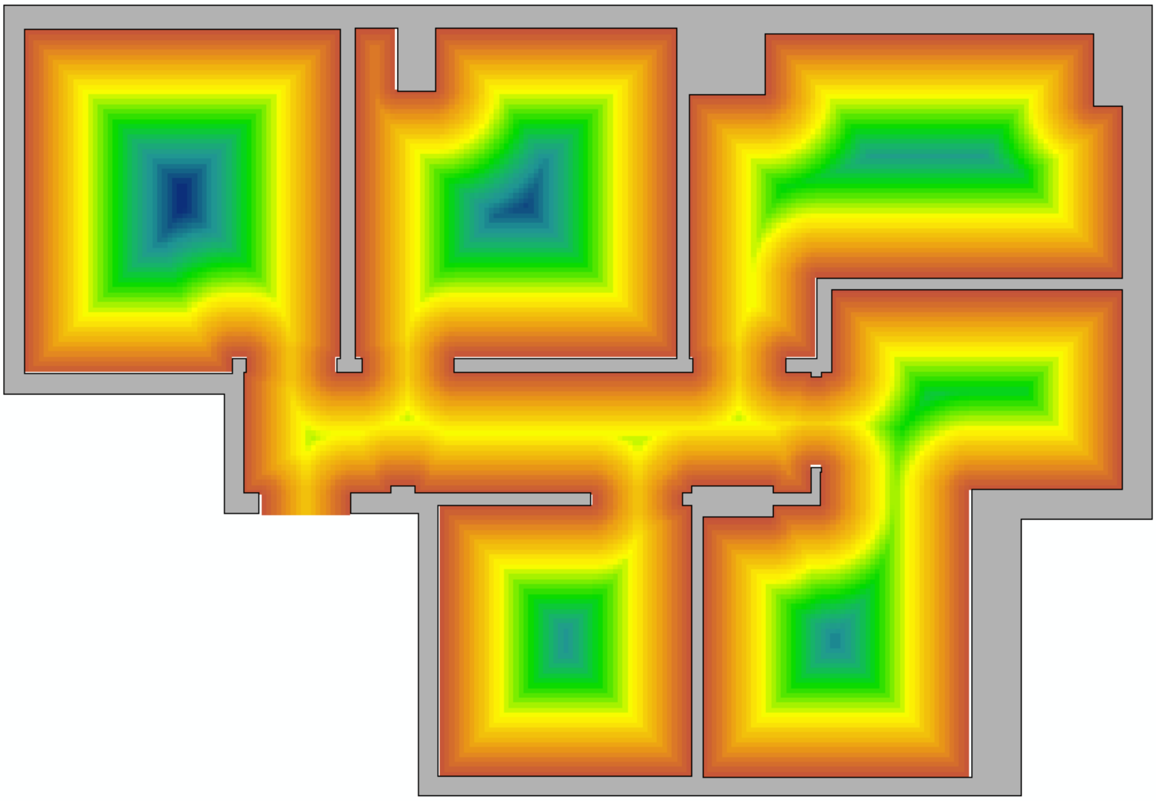

Fig. 2. Map of Euclidean distance from walls. *Resource: own work*

First, drawing elements located on *wall_01* and *door_01* layers were selected from the CAD drawing and saved in *wall_L.shp* dataset. Then polygons representing walls were created (*wall_A.shp*), which are obstacles to moving people. Using Dissolve tool internal wall divisions were removed to obtain *wall_AD.shp* file. Subsequently, raster representing each cell's Euclidean distance to the closest wall was calculated (*EucDist.img*).

By "closing the entrance door" (simply drawing one line) a collection of lines was obtained (*wall_L2.shp*), which allowed for the creation of a polygon representing the interior of rooms (*floor_A.shp*), subsequently converted into raster form (*floor_R.img*). Multiplication of *EucDist.img* and *floor_R.img* rasters allowed to obtain a "terrain model" (*EucDist_F.img*) only in areas where people can move (Fig. 2).

Unfortunately, in Figure 2 it is easy to see that a mistake was made in formulating the assumptions of the method. It was not taken into account that narrowings formed by the doors would result in "sinks". A sink is a cell or set of spatially connected cells with an undefined drainage direction – no cells surrounding it are lower. In typical hydrologic analysis sinks should be filled to ensure proper delineation of basins and streams. If the sinks are not filled, a derived drainage network may be discontinuous. Sinks in elevation data are most commonly due to errors in the data. Naturally occurring sinks are rare (TARBOTON et al., 1991), except in glacial or karst areas, that is why GIS software often offer the possibility to automatically fill them. However, in this case, it caused too much flattening of the "valley floors", negating the sense of further actions.

That is why the search had started for alternative solutions to the problem of avoiding "sinks", while maintaining clear "valley floors". Finally, it was proposed to use the *EucDist_F.img* file as the cost surface for Cost Distance function, which determined the least costly path to reach entrance for each cell location. The Cost Distance tool is similar to Euclidean Distance tool, but instead of calculating the actual distance from one location to another, the Cost Distance tools determine the shortest weighted distance (or accumulated travel cost).

The author came up with the assumption that a surface would be created that would have lower values closer to the entrance, and higher farther from it, which meant that "water flow" would be provided. Additionally, lower cost (lower "height") of "valley floors" should also translate into "valleys" in the resultant surface. In the first approach this second effect was not evident, which had prompted the author to consider the issue of magnitude of "valley slopes".

It turned out that this direction of reasoning was right, because the tenfold increase in value scale (multiplying *EucDist_F.img* ten times) had made the "valleys" visible on the *CostDis.img* surface.

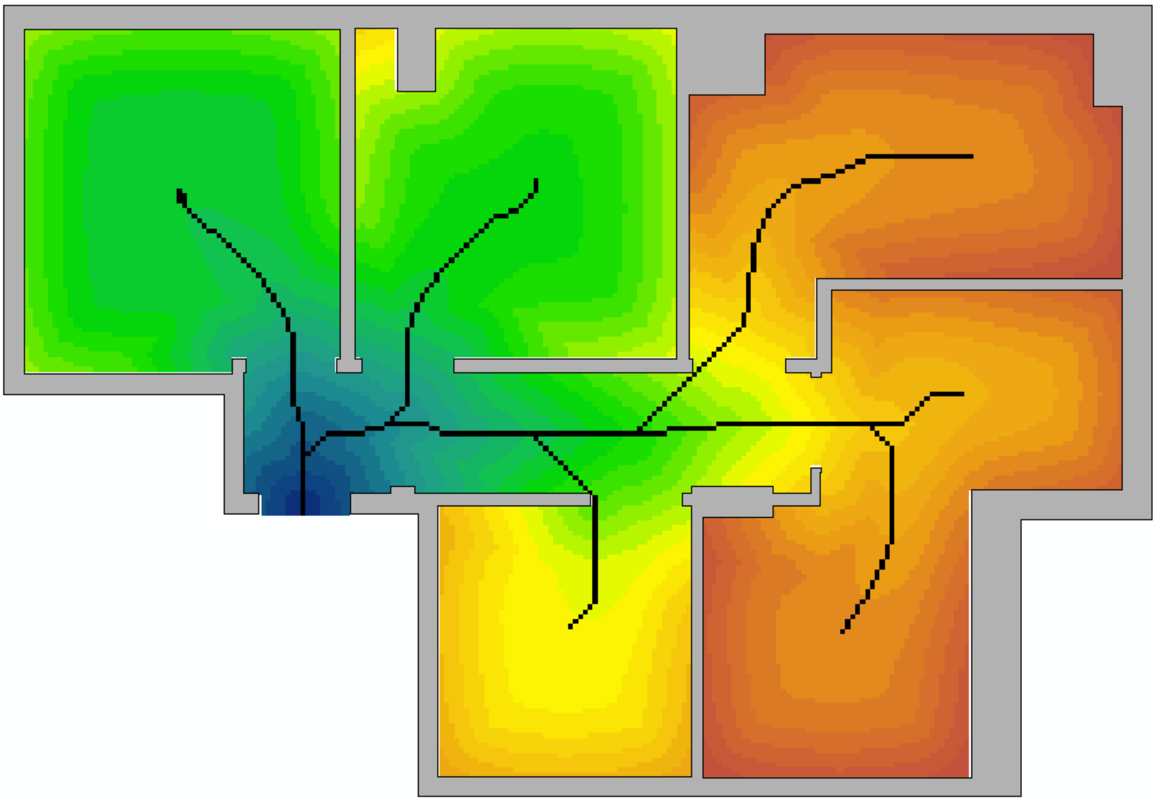

Fig. 3. The result of Euclidean distance method. *Resource: own work*

The sequential application of Flow Direction and Flow Accumulation functions to so prepared surface gave satisfactory result, which is presented in Figure 3 after the reclassification of the raster causing the distinction of "stream network".

Verification of Topographic Position Index method

For TPI calculation Topography Tools for ArcGIS (DILTS, 2015) were used, a toolbox containing variety of topography and terrain-related tools. According to the author's statement, that TPI is scale dependent, this tool was run multiple times on *EucDist.img* raster, examining how the results change depending on the size of the analysed neighbourhood around each cell. Regardless of the value of this parameter, the result (*TPI_ED.img*) each time was similar and unsatisfactory. The algorithm detected not only absolute bottoms of "valleys", but also any other places where the analysed cells were located below their neighbours (Fig. 4).

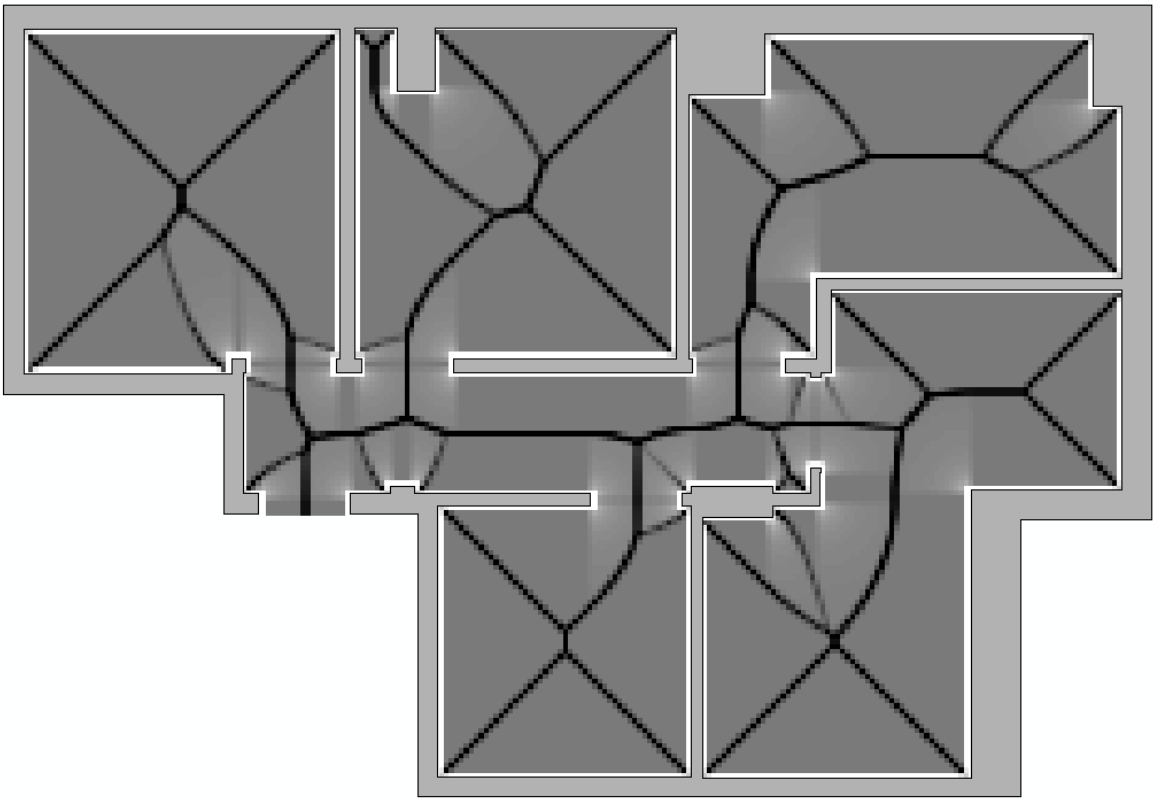

Fig. 4. Topographic Position Index. *Resource: own work*

Like before the author decided to use the *TPI_ED.img* file as the cost surface for Cost Distance function This time even stronger image of valleys was obtained in *CostDis_TPI.img* file. Reapplying Flow Direction and Flow Accumulation functions to this surface gave, in author's view, more satisfying result than using Euclidean distance method. It is presented in Figure 5 after reclassification of the raster causing the distinction of "stream network". Raster linear networks obtained by both presented methods can be accurately converted to feature data with the Stream to Feature tool.

Conclusions

Conducted research shows how often assumptions that look good in theory do not work in practice. However, failure can motivate to seek alternative solutions that one sometimes finds.

Presented attempts to apply hydrology and topography tools to generate navigation network for 3D indoor routing finally allow to propose the Topographic Position Index method involving sequential use of the following tools: Euclidean Distance, TPI, Cost Distance, Flow Direction and Flow Accumulation. Basing this method on the functionality of existing tools of GIS software should allow for easier implementation and gives a chance for its faster dissemination.

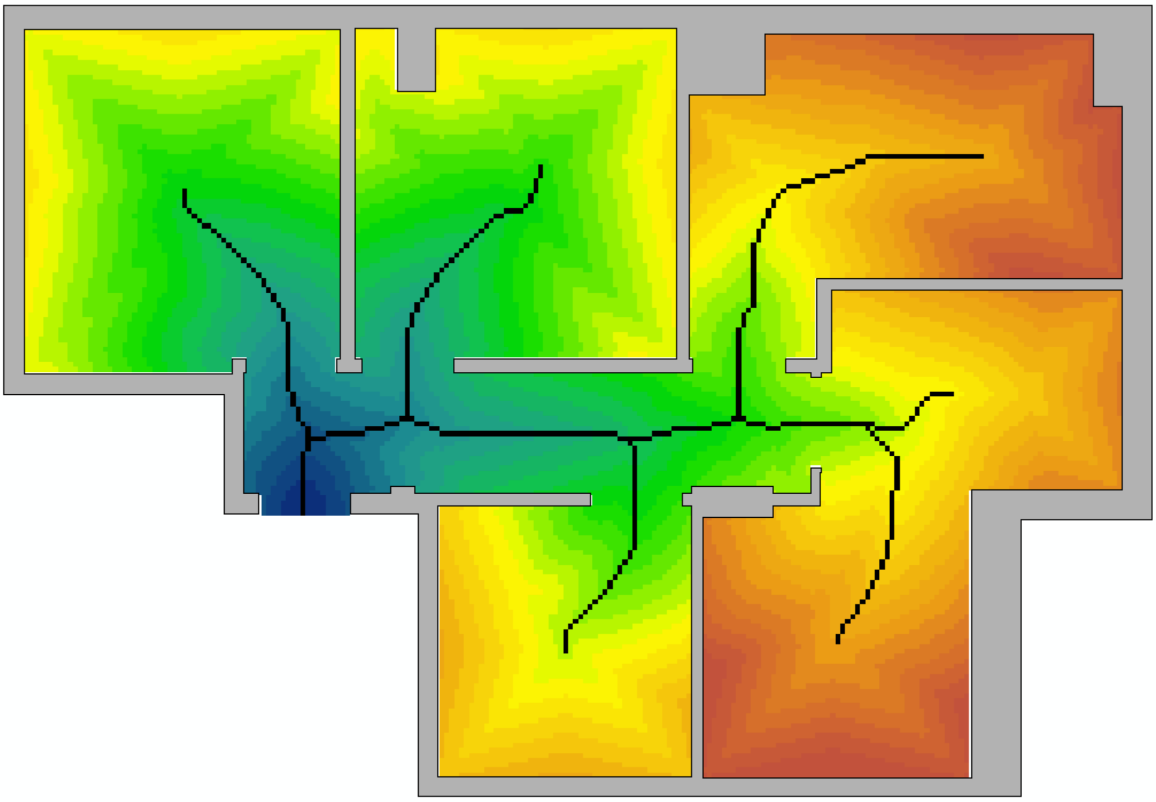

Fig. 5. The result of Topographic Position Index method. *Resource: own work*

The results obtained by Euclidean distance method can be considered as worse. In particular, it can be seen that the designated paths do not pass centrally through the doors and generally they were run differently than a man (operator) would do. However, this solution also has the advantage that it directs towards the exit, that is, shows close to the actual trajectory of evacuee movement. One can suspect, that in this way, the problem of determining the shortest routes to reach emergency exits or collection points is solved. However, this requires further detailed research, which the author intends to carry out next. It also seems necessary to test the proposed solutions on a larger number of objects, which should help to determine either the universal values of the parameters of the tools used or propose separate sets of parameters for some specific case groups. In particular, the coefficient of "slope steepness" in Euclidean distance method may require an adjustment.

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