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Original article

Simulation of Evacuation Route Scenarios Through Multicriteria Analysis for Rescue Activities

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Abstract

After a disaster happens in urban areas, many people need support for a quick evacuation. This work aims to develop a method for the calculation of the most feasible evacuation route inside buildings. In the methodology we simplify the geometry of the structural and non structural elements from the BIM (Building Information Modeling) to store them in a spatial database which follows standards to support vector data. Then, we apply the multicriteria analysis with the allocation of prioritization values and weight factors validated through the AHP (Analytic Hierarchy Process), in order to obtain the Importance Index S(n) of the elements. The criteria consider security conditions and distribution of the building's facilities. The S(n) is included as additional heuristic data for the calculation of the evacuation route through an algorithm developed as a variant of the A* pathfinding, The experimental results in the simulation of evacuation scenarios for vulnerable people in healthy physical conditions and for the elderly group, shown that the conditions about the wide of routes, restricted areas, vulnerable elements, floor roughness and location of facilities in the building applied in the multicriteria analysis has a high influence on the processing of the developed variant of A* algorithm. The criteria modify the evacuation route, because they considers as the most feasible route, the safest instead of the shortest, for the simulation of evacuation scenarios for people in healthy physical conditions. Likewise, they consider the route with the location of facilities for the movement of the elderly like the most feasible in the simulation of evacuation route for the transit of the elderly group. These results are important for the assessment of the decision makers to select between the shortest or safest route like the feasible for search and rescue activities.

Keywords : Pathfinding Algorithm, Evacuation Routes, Building Information Modeling, Multicriteria Analysis, Vulnerability Level

1. Introduction

In urban areas, hazards can happen any time and the risk will be stronger, if the level of vulnerability of the people is high. Therefore, it is required a fast evacuation of people to safe areas, particularly in large and complex buildings that at the moment of panic could turn into a maze when people try to find the emergency exits nearest. Currently, technologies offer us diverse sources from which information can be taken for indoor evacuation of the buildings towards safe places. For example, when the data is organized in a BIM (Building Information Modeling), they contain valuable information about the geometry and distribution of elements inside buildings. Likewise, the study of algorithms for generation of evacuation routes provide an alternative of navigation inside buildings in the short term and with greater precision. The

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purpose of this study is the calculation of feasible evacuation routes inside buildings for different simulation scenarios, which is performed through a method including the execution of a developed variant of the A* pathfinding. The algorithm uses geometric data validated and prioritized by the Multicriteria Analysis based on the security conditions and facilities location of the building. The method is divided in three stages, in the first step the simplified geometry of the building taken from the BIM is obtained. The geometry includes walls, doors, corridors and others facilities. This information with its basic attribute table is transferred in a spatial database. In the second step is applied the multicriteria analysis in the geometry. It considers the allocation of weights as heuristic data based on information of the security conditions of the building. Finally, the third step is the calculation of the most feasible evacuation route under the concept of AI (Artificial Intelligence). This is done through an algorithm developed as a variant of the A* algorithm, which uses additionally the heuristic data for its processing. The experimental results show the importance of the allocation of weights as heuristic data in the context of multicriteria analysis in which the conditions of the buildings like the wide of the routes, restricted areas, floor roughness, vulnerability of fixed elements and location of facilities were considered, and have a high influence on the processing of the developed A* algorithm variant, modifying the proposed feasible evacuation route, and does not consider the shortest, but the safest for the simulation of evacuation scenarios of vulnerable people in healthy physical conditions and for the elderly group. The results of this study are necessary for decision makers to have a tool that allows them to choose the most feasible evacuation route based on safety criteria, for search and rescue activities in buildings.

2. Overview

2.1 Related works

A number of studies have been carried out BIM and spatial database assessment. Karas *et al*. (2006) presented a model which automatically extracts geometry and topology of a building, computes the distances, records them into the geodatabase, and calculates the shortest path by using 3D network analysis and modified Dijkstra algorithm. Deng (2015) developed techniques and tools to allow bi-directional mapping between key schemes in the BIM and GIS domain. Regarding the use of pathfinding algorithms for evacuation routes inside buildings there are also studies that explore this topic. Hart *et al*. (1968) proposed a pathfinding algorithm using heuristic information from the problem domain that was incorporated into a formal mathematical theory, this algorithm was called A*. Lu (2006) evaluated the effectiveness between the linear programming algorithms and the A* algorithm, and explained that linear programming algorithms are computationally more expensive, require a large amount of memory and a prior knowledge of an upper-bound on the evacuation time, which affect the feasibility of this approach. Applications of the use of A* algorithm in vectors for simulation of routes for evacuation and guidance in different environments were shown by Xu and Doren (2011); Moon *et al*. (2016). A method for selecting the location of shelters using network analysis and genetic algorithm was presented by Yoo *et al*. (2018). Naderpour (2018) illustrated how algorithmic tools can be used to simulate human behaviors during the architectural design process to improve its performance. Park and Huh (2019) proposed a method for road network generalization that analyses maps using reverse engineering like the Töpfer's Radical Law and the logistic regression model. After this review, the difference of the related works with this research is that we propose the calculation of feasible evacuation routes inside buildings performed through a developed variant of A* algorithm and the Multicriteria Analysis. The geometric data are validated and prioritized by the Multicriteria Analysis based on the security conditions and facilities location of the building. The results are included as heuristic data in the developed variant of the A* pathfinding algorithm to compare feasible evacuation routes under different simulation scenarios that vary according to the prioritization of criteria and the classification of people by physical conditions.

2.2 Multicriteria analysis and pathfinding algorithms

The multicriteria analysis is a technique that allows identifying and prioritizing geographic elements based on the assignment of criteria expressed in numerical values (weights). In case of elements inside buildings, the data about the functional, structural, and design dynamics of them are organized using the BIM. The BIM format follows the rules of the IFC (Industry Foundation Classes) standard that guarantees easy conversion to other different formats and information management (Kuo *et al*., 2016). The geometry that have been abstracted from reality as a simplified model is stored in a spatial database. The pathfinding algorithms have been developed to simulate routes for movement from a point A to a point B. In its application for search and rescue activities, defining the feasible evacuation routes is essential. There are many methods under classic conceptions and AI. The standard AI algorithm for route calculation is the Dijkstra algorithm. This algorithm calculates the fastest route between two nodes as a function associated with the travel cost. The heuristic search algorithms have been developed that look for the shortest or optimal route in the direction of the goal node.

3. Methodology

The methodology describes a set of activities in order to generate the feasible evacuation routes inside buildings. It is divided in three stages, shown in process diagram of the Fig. 1.

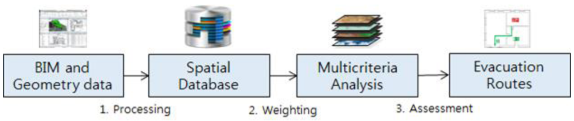

Fig. 1. Process diagram

3.1 Geometry processing and spatial database

In the first stage the BIM data of the building is organized and defined under the IFC standard. The BIM contain all the relevant information about the functional distribution of the building. These data include the location and dimension of the structural elements such as walls, columns, doors, hallways, etc, to recognize the distribution of the free and blocked areas, and the non-structural elements such as fixed and large furniture that are relevant as obstacles to the free walking of pedestrians. The geometry of the BIM is simplified as polygon vectors, preserving the georeferencing of its vertices and edges. Then, the simplified geometry with its basic attribute table is store in the database. Since the database has a GIS (Geographic Information System) concept it is possible to save the vectors linked to their table for each vector element. The tables are modeled under the entity - relationship scheme and they are created in the database manager system. For easy data management, the database uses standards of geometric elements as shown in Table 1.

Table 1. Standards for geometric elements

Element	Standard	Example
Object class	Tables with properties of vectors	Wall, Column, Furniture
Feature Class	Elements of the same type	Group of doors
Feature attributes	Properties stored as fields in a feature class table	Design, dimension, location
Feature dataset	Feature classes with the same spatial reference	All vector data
Relation-ships	Association between two objects	Furniture & rooms
Planar topology	Geometric relations shared between elements	Common borders

Table 2. Standards for data dictionary

Standard	Description	Example
V_NAM_LAY	General name	Furniture
V_NAM_STD	Standard name	V_FUR_BUI
V_KEY_ATR	Definition if column has key	PK, FK
V_NAM_COL	Standard Name of column	V_TIP_FUR
V_DES_COL	Description	Type of furniture
V_TYP_COL	Type of data	Varchar, Number
N_WID_COL	Number of characters	Total 6 & Dec. 2

Every table stores multiple attributes grouped by columns of the main characteristics of design, dimensions, location and security of the facilities. This attributes are organized in the database according to a standard data dictionary described in Table 2.

3.2 Weighting and multicriteria analysis

The multicriteria analysis is applied to the vector data in the second stage. The assignment of weights as a heuristic data $h(n)$ is made based on the information of the functional design and conditions of the facilities in the building. Fig. 2 shows its schematic process.

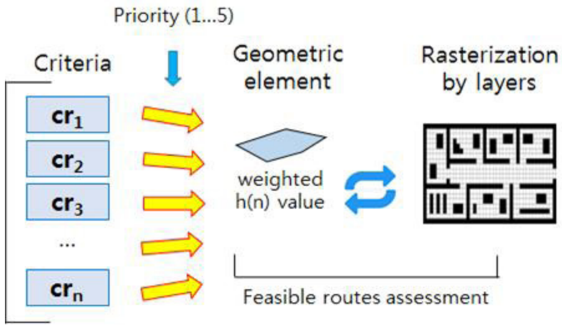

Fig. 2. Schematic process of the multicriteria assignment

The WLC (Weighted Linear Combination) is the multicriteria analysis used in this case. This method evaluates the importance of the cells by weighting and combining a series of criteria that have been considered in each one of them as is explained by Jiang and Eastman (2000). Every criterion is assigned by a range of numerical values to all the geometric elements. The range of numerical values for each criterion fluctuates between 1 to 5, having an inverse relationship to the concept of prioritization by weightings that is usually formulated in geographic information systems. The qualitative description of the range of numerical values assigned to the geometric elements is detailed as follows: 1 = Very high priority, 2 = High priority, 3 = Medium priority, 4 = Low priority, 5 = Very low priority. In the case that the criterion cannot be applied in the cell, for example areas totally restricted to pedestrians walking, the value to be assigned is 0 = Not applicable. The inverse relationship of the values and priorities is caused because the criteria will have analysis purposes as heuristic data $h(n)$, being interpreted by the algorithm A* that always selects the low values of $h(n)$ during its search process of the most feasible route.

To get the weight factors, we apply the AHP (Analytic Hierarchy Process) method developed by Saaty (1990). The AHP is a multicriteria decision making method that guarantees consistency between all the considered conditions. It organizes them into a hierarchical structure in which weights and priorities are derived on a ratio scale in order to do pair by pair comparisons to measure the level of importance of the criteria and sub- criteria and determine a normalized set of weights to be used. To apply the method a comparison matrix is constructed to establish the mutually important criteria. To define the consistency of the result of the matrix, the AHP calculates a CR (Consistency Ratio). The CR is the result of divide the CI (Consistency Index) of the matrix and a RI (Random Consistency Index) calculated previously also by Saaty (1990). The author suggests that, to be satisfactory data consistency, the result of the CR must be less than 10%, if it is higher there will be inconsistencies, and the method will not produce significant results. The results of the comparisons between pairs are organized into a matrix in which the weights of the factors are calculated and give the order of priority of the criteria.

For each criteria in the geometric elements, a rasterization process is applied that stores its data. The WLC multiplies the numerical values of the cells by the weight factor assigned to the corresponding criterion. The weight factor reflects the level of influence (%) of each group of criteria. Finally the WLC adds the weighted values to calculate the importance index as the result. The WLC model is described in Eq. (1).

$$S(n) = \sum w_{(n.i)} x_{(n.i)} \tag{1}$$

Where: $S(n)$= the importance index for every cell n; $w_{(n.i)}$= the weight factor of the criteria i for pixel n; $x_{(n.i)}$ = the numerical value of the criteria i for pixel n.

Because the range of expected numeric values is between 1 and 5, always the value of $S(n)$ >= 1. If $S(n)$ < 1, it means that one of the criteria cannot be applied in the cell. The criteria are mutually inclusive, therefore, the cells with value $S(n) < 1$ will not be considered as an alternative to the evacuation route. The results of $S(n)$ are stored as the additional heuristic data for the calculation of the evacuation routes with the algorithm.

3.3 Assessment of the evacuation route

In the third stage, the calculation of the most feasible evacuation route under the concept of AI is performed. The A* algorithm expands nodes based on their heuristic value $h(n)$. An example is showed in the Fig, 3.

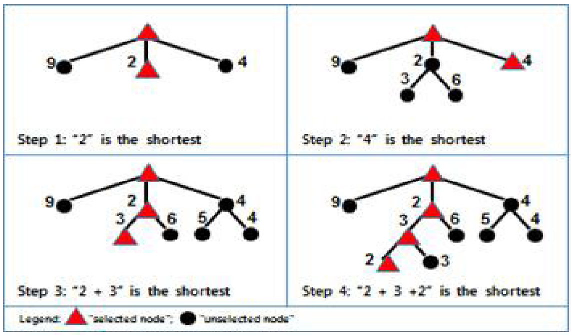

Fig. 3. A* algorithm

The A* Algorithm associates a cost function with a node. The cost function of node n is described in Eq. (2).

$$f(n) = g(n) + h(n) \tag{2}$$

Where: $g(n)$= the cost of the path (usually length) from the start node to node n; $h(n)$= the heuristic approximation provided by the user about the cost of traveling from node n to the goal node. At each step the node with lowest f value is selected to be expanded, and the previous node will be considered as parent of the current node. An algorithm generated as a variant of the A* algorithm was developed, that take the importance index $S(n)$ as an additional condition of the heuristic data and includes it within the function to calculate the f(n), determining the feasible evacuation route for vulnerable people in different simulation scenarios. According to the variant the Eq (1) will be added to the Eq (2) resulting in the Eq. (3).

$$f(n) = [g(n) + h(n)] * s(n) \tag{3}$$

In order to perform different simulation scenarios, the variables resolution of the grid, movement of people and evacuation time are also defined.

For the resolution size the floor plan is simulated by a two-dimensional grid. Each cell has an area of 40 cm x 40 cm, which represents the average space that an adult can occupy when there is a dense crowd around, as it was researched by Weidmann (1993). The distance between two adjacent pixels is directly related to the resolution size and classified in two types: d_1 = direct distance and d_2 = diagonal distance, the calculation of d_1 will be same than the spatial resolution of the pixel as is shown in Eq. (4), and for the calculation of d_2 is applied the Pythagoras theorem to get the diagonal measure, shown in Eq. (5).

$$d_1 = cell\,size \tag{4}$$

$$d_2 = \sqrt{(d_1)^2 + (d_1)^2} \tag{5}$$

The speed of movement of people is classified in two groups, s_1= speed of people in healthy physical conditions and s_2= speed of the elderly grouped from 55 years and proceeding towards greater ages up to 80 years that due to age-related problems, require more time to mobilize. The work has been done with the average speed for both groups, which for the case of s_1 is close to 1.34 m/sec and for the case of s_2 is close to 0.6 m/sec, as is detailed by Bandini *et al*. (2014). With the appropriate information on distance and speed, the evacuation time is calculated using the equation of movement, and the total evacuation time will be given by the sum of the calculated times between one cell and another throughout the proposed evacuation route. The Eq. (6) indicates the result.

$$et = \sum_{0}^{n-1} t_{xy} \tag{6}$$

Where: et = evacuation time; t = time to move from one cell to the neighbor cell; x = kind of movement of people by distance; y = kind of movement of people by speed; n = number of cells in the evacuation route.

Finally, with the application of the algorithm A* and considering the multicriteria analysis, the simulation scenarios are applied. As a result, the most feasible evacuation routes and evacuation times are obtained.

3.4 Pathfinding simulation software architecture

To develop the methodology including the programming of the variant of the A* algorithm and the simulation of the data, was used a group of open source software and free for educational purposes. The architecture for the processing in every stage of the methodology is shown in Fig. 4.

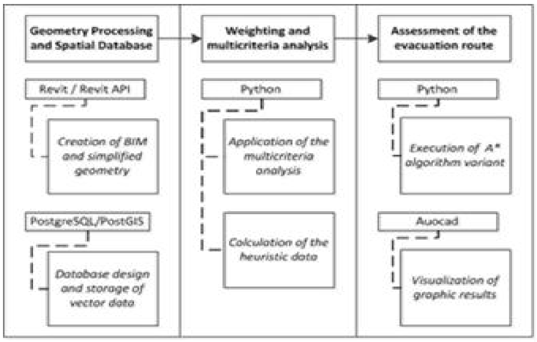

Fig. 4. Pathfinding processing architecture

The processing of the initial data and creation of the BIM was done with the Revit software, which is specialized in the analysis of structures in the construction field. The processing of the simplified geometry of the building was done through Revit API (Application Programming Interface). The spatial database was designed and implemented with PostgreSQL management system, and through the use of the PostGIS extension, it can support data tables containing geometry. The Python software was used for the application of the multicriteria analysis and the calculation of the heuristic data. Also the execution of the A* Algorithm for the generation of evacuation routes and the calculation of evacuation time was developed in this software. Finally, the graphical results are visualized through AutoCAD software.

4. Experimental Results

4.1 BIM processing and storage

For the development of the exercise a structure of an office floor of 40m x 24m has been built using Revit. The structural data belongs to the walls, columns, doors and room areas. Also basic furniture of fixed location has been included as cabinets, armchairs, tables, chairs and desks. The study case has big offices, meeting room and reception area. There is a wide corridor in the upper plane that has a handrail to help the elderly. In the lower left corner is located the main electrical power box, doing this area the most vulnerable. The starting point "S" for the simulation of the evacuation route is the desk located close to the lower left corner. Also, the exit of the place "G" is located close to the upper right corner. Fig. 5 shows the graphic distribution of the spaces, in top view and perspective.

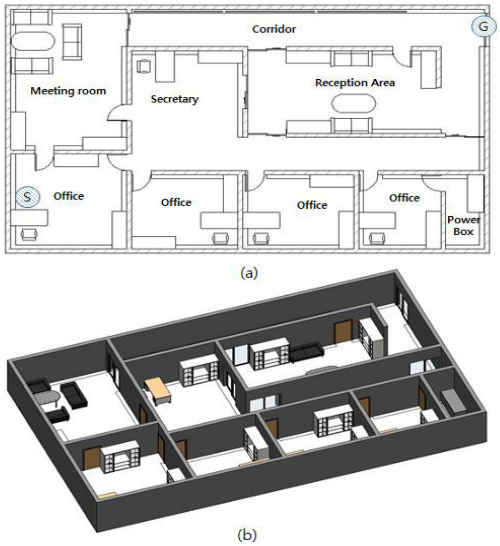

Fig. 5. Distribution of spaces in Revit: (a) Top view, (b) Perspective view

We propose an algorithm to select the geometry of elements of the BIM by using Revit API. The algorithm flowchart is shown in Fig. 6, where “*vector*” is the selected feature; “n” is the node; “xn”, “yn” are the coordinate pair of the node; “Mn”, “Ma” are the matrix for geometry and attribute data respectively. The result of the simplification of the geometry for the case of study is shown in the Fig. 7.

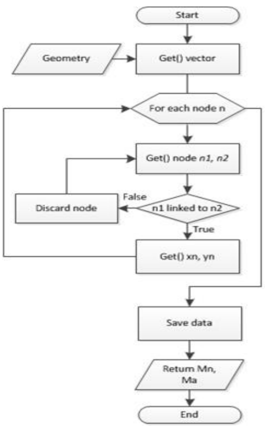

Fig. 6. Flowchart of selection of the geometry

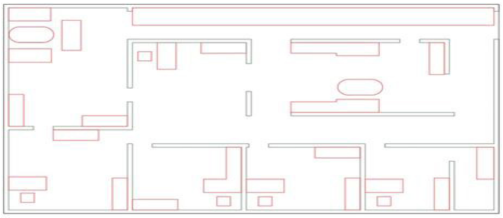

Fig. 7. Simplified geometry model

The simplified geometry is stored in the spatial database, a relational data model has been generated through the standards described in Table 1 and Table 2. In the Fig. 8 is shown the summarized logical model of the spatial database. Non spatial tables refer the elements that will later be used for the allocation of weights in the multicriteria analysis. The spatial tables also store the geometry information in the G_GEO_COL column as a consecutive set of coordinate pairs registered in the hexadecimal system.

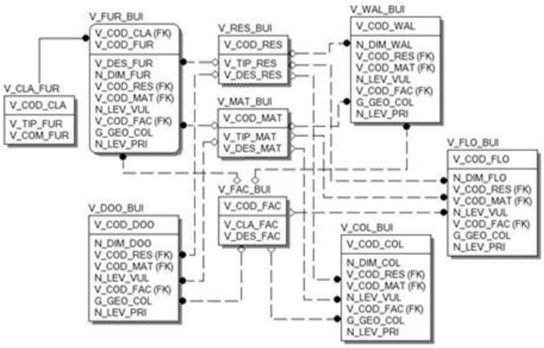

Fig. 8. Logical model of the spatial database

4.2 Analysis of conditions

For the purposes of this research the security conditions and distribution of the building's facilities are analyzed, therefore five criteria are considered, classified and detailed in the Table 3.

The geometric elements will receive the prioritization values within the range of 1 to 5. For the criterion cr_1, the widest corridor should be more than 2.285m to receive the best priority, All the divisions of this criteria were calculated following the Standards for Accessible Design, proposed by the Americans with Disabilities Act (1990). For criterion cr_2, it has been assumed that the electrical box room has the highest restriction for walking, so this area and the surrounding receive the lowest priorities. The classification of this criteria is based in the Building Vulnerability Assessment Checklist proposed by the FEMA (Federal Emergency Management Agency) of United States (2003). For criterion cr_3, the corridors with "stable surface" are more accessible for the walk of the elderly. According to the Standards for Accessible Design, "a stable surface is one that remains unchanged by contaminants or applied force, so that when the contaminant or force is removed, the surface returns to its original condition". For criterion cr_4, the vulnerability was divided by levels depending of the materials of the structural and non-structural elements, following also the Building Vulnerability Assessment Checklist. For criterion cr_5, the areas with facilities for the elderly located in the corridors have the best priority because they help the displacement of

Table 3. Criteria and reasons of priorities

		Classification and Scores					
ID	**Details**	**Highest (1)**	**(2)**	**(3)**	**(4)**	**Lowest (5)**	**Constraint (0)**
cr_1	Wide of the route	>2285mm	2285mm	<2285mm & >915mm	--	915mm	<915mm
cr_2	Walkable area	Walkable, totally free	Desig ned for walking	--	Walkable, furniture	Walkable but private areas	Closed to the transit of people
cr_3	Floor Surface	Stable surface	--	Surface: Carpet<13mm Opening<13mm Change level<6.4mm	--	Surface: Carpet =13mm Opening =13mm Change level =6.4mm	Surface: Carpet >13mm Opening >13mm Change level >6.4mm
cr_4	Vulnerability	Highly Safe	Safe	Slightly vulnerable	Vulnerable	Highly vulnerable	Totally unsafe area
cr_5	Facilities	Facilities for the elderly	--	General Facilities	--	No Facilities	

this human group. The classification of this last criteria was also made using the Standards for Accessible Design.

In the processing of the WLC, we have considered different weight factors (%) shown in the Table 4, that were calculated using the AHP method. The weight factors are applied to the five criteria for each simulation scenario proposed on the Section 4.3, in order to obtain the $S(n)$. It should be noted that the assignment of the values and the weight factors can be different between two buildings. Also, in the same place, it may vary based on the experience and knowledge of the person or group of people who will be responsible for the analysis.

Table 4. Weight factor by criteria

Criteria ID	Weight factor by criteria in SM2	Weight factor by criteria in SM3
cr_1	15%	10%
cr_2	10%	5%
cr_3	15%	10%
cr_4	35%	35%
cr_5	25%	40%
Total	100%	100%

We propose an algorithm by using Python for the multicriteria analysis of the vectors in order to find the importance index $S(n)$. The algorithm is executed based on the flowchart shown in Fig. 9, where "vector" is the feature selected; "vx" is the current node; "vy" is the exit node; "st" is the spatial table; "cr_1", "cr_2", "cr_3", "cr_4", "cr_5" are the criteria; "pr_1", "pr_2", "pr_3", "pr_4", "pr_5" are the prioritization values.

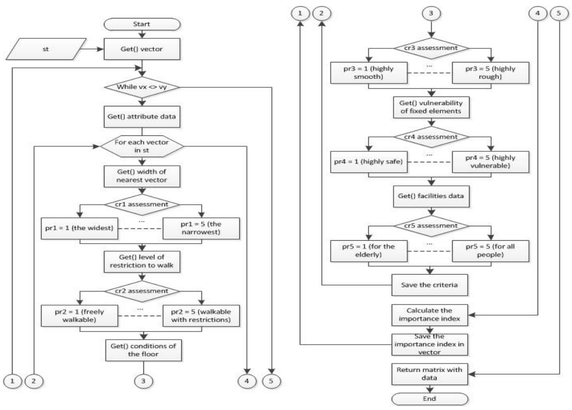

Fig. 9. Flowchart of multicriteria analysis

4.3 Simulation of scenarios

For simulation exercises, we are developed a variant of the algorithm A* which is able to read the information of the heuristic data $h(n)$ and the additional $S(n)$ resulting from the calculation of the multicriteria analysis on every pixel. Exercises have been done for 3 simulation scenarios:

- SM1 = Simulation of the feasible evacuation route without consider $S(n)$, applying the conventional A* algorithm.
- SM2 = Simulation of the feasible evacuation route considering $S(n)$, applying the variant of the A* algorithm for healthy people.
- SM3 = Simulation of the feasible evacuation route considering $S(n)$, applying the variant of the A* algorithm linked to the use of facilities for the elderly.

The data has been executed using the WLC process and the results are shown in Fig. 10. In the case of scenarios SM2 and SM3 include the importance indices $S(n)$, which are read by the variant of A* algorithm.

Fig. 10. Results of WLC for simulations: (a) SM1, (b) SM2, (c) SM3

The initial conditions of the cells for the calculation of the simulations are:

- Each cell contains two basic special markers: blocked and free. Blocked cells will be constant in all simulations because they represent the structure of the building observed from the floor view and also represent fixedly located furniture. Pedestrians can't walk in these areas. Free cells are all the walkable areas and have diverse classifications based on the criteria assessed in the simulation scenario.
- Two free cells are marked as "start cell" and "goal cell". Start cell, which indicates the point of location of the pedestrian (vulnerable person) in the scenario. Goal cell, which defines the possible goal of the pedestrian, usually the exit area of the building.
- The location of the start cell and the goal cell will be constant to compare the results of the simulations.
- All the cells that form the grid are assumed to be homogeneous and isotropic.

The proposed and developed variant of the algorithm which includes the data of $S(n)$ in its calculations, is executed based on the flowchart shown in Fig. 11, where "stn" is the start node; "cnd" is the current node; "end" is the end node; "sn" is the importance index; "im" is the matrix of the importance index; "*chil*" is the group to adjacent nodes to the current node, "*chi*" is the selected adjacent node to the current node, "ol" is the open list, "cl" is the closed list, "d" is distance and "t" is time".

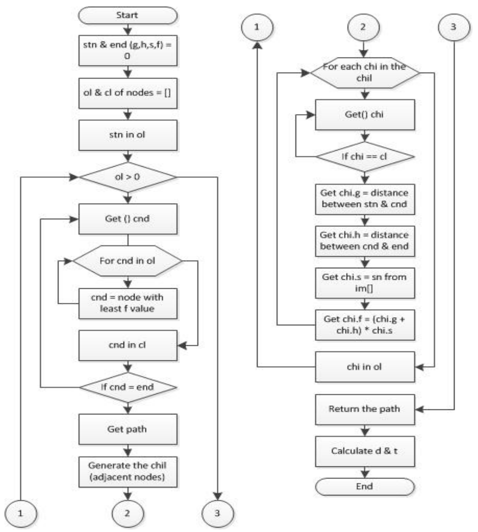

Fig. 11. Flowchart of variant of A* algorithm

After the execution of the conventional algorithm A* the result of the evacuation route for the simulation scenario SM1 is obtained. Furthermore executing the developed variant of the algorithm A*, the results of the evacuation routes for the simulation scenarios SM2 and SM3 are obtained too. These results are shown in Figure 12.

Fig. 12. Feasible evacuation routes: (a) SM1, (b) SM2, (c) SM3

The evacuation routes have been calculated based on the security conditions and distribution of the building's facilities evaluated by the multicriteria analysis. For this case of study, SM1 and SM2 shown shortest evacuation routes, but the main difference is that the route of SM2 follows the priority of the conditions assigned in the importance index $S(n)$ that are linked to the safety and security for transit of people, assessment in the multicriteria analysis. Therefore SM2 can be considered as the most feasible evacuation route (shortest and safest). In the case of SM3 the result of the evacuation route will be longer because the priority criteria assigned in the importance index $S(n)$ has a highest relationship with the location of facilities for the movement of the elderly, however no all spaces in the building have facilities. then the developed variant of A* algorithm will get the feasible route discarding areas without facilities.

In addition, the calculation of the evacuation time and distance were done, with the assumption that the speed of the pedestrian belonging to a certain age group is constant and similar. For simulations the spatial resolution of the pixel is 40 cm, using the Eq. (4) and Eq. (5) we can get the distances d_1 = 0.40m and d_2 = 0.57m for each pixel movement. The velocity values assumed for s_1 and s_2 are 1.34 m/sec and 0.60 m/sec respectively, then using the Eq. (6) we calculate the total of distance and time for simulations SM2 and SM3, shown in the Table 5.

Table 5. Total distance and time for simulation scenario

	SM2		SM3	
Speed (m/s)	s_1	s_2	s_1	s_2
	1.34	0.60	1.34	0.60
Distance (m)	44.80	44.80	48.48	48.48
Time (s)	33.4	74.7	36.2	80.8

According to the results, the distance on SM3 is 3.68m longer than the distance of SM2; the evacuation time increased from 33.4s to 36.2s, for the group in healthy physical conditions (using s_1), being a relatively moderate increase in emergency situations. For this reason, the SM2 route is selected as the most feasible. In case of the elderly group (using s_2), the decision of the feasible evacuation route must be made between the shortest generated by SM2 or the safest generated by SM3. In this result, although the difference in evacuation time between them is 6.1s, it should be considered that the distance for the study case is less than 50 meters, so in larger constructions, the time difference between the two simulation scenarios will increase proportionally. Therefore, the decision must be analyzed in more detail when choosing between the shortest route or the safest route. For this reason the results are essential for risk prevention actions and rescue plans, which are carried out by decision makers.

5. Conclusions

In this paper, we explained a methodology for the calculation of the most feasible evacuation route inside buildings. We proposed and developed a variant of A* algorithm that uses the multicriteria analysis as heuristic data to get the results. We have divided the methodology in three stages. In the first stage we got the simplified geometry of the structure and fixed elements of the building, taken from the BIM and stored them including their attribute table in a spatial database. In the second stage the multicriteria analysis was applied to get the importance index of the elements within the building based on their safety conditions. In the third stage the variant in the A* algorithm was developed and includes the results of the multicriteria analysis as a heuristic data for the processing of the evacuation routes. In the experimental results we used three simulation scenarios, the first one SM1, applying the conventional A* algorithm, the second one SM2, applying the developed variant of A* algorithm which consider the safety conditions of the multicriteria analysis, and the third one SM3, also applying the developed variant of A* algorithm but considering the safety conditions of the multicriteria analysis linked to the use of the facilities for the elderly. The simulation scenarios revealed that using the developed variant of the A* algorithm, the multicriteria analysis with the conditions inside buildings about the wide of the routes, restricted areas, floor roughness, vulnerability of elements and location of facilities considered for this study, had a high influence on the calculation of the feasible evacuation routes. The conditions of the multicriteria analysis modified the route results in every simulation scenario. The result of SM1 showed the shortest route, but, in SM2 was calculated a short and high priority route which is considered like the most feasible to use for healthy people. Also it was shown a longer but safer proposed route from SM3 for the displacement of the elderly. Although the increase of SM3 time compared to SM2 does not look considerable, the area of the study case is small, so in larger buildings, the time difference between the simulation scenarios will increase proportionally. Therefore, these results are important for the analysis in detail of the decision makers to choose between the shortest or safest route like the feasible for search and rescue activities.

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