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## THE ANTHROPOMETRIC CRITERION IN THE MODELLING OF EVACUATION

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## KRYTERIUM ANTROPOMETRYCZNE W MODELOWANIU WARUNKÓW EWAKUACJI

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**Abstract:** The article presents a sample study on the use of anthropometric criteria in modelling evacuation conditions. Formal evacuation models differ in the level of detail they offer in reality mapping. The key parameter determined with their use is evacuation time. The basic data inputs in such modelling are the speed of human movement. Numerous research papers offer examples of such speeds for people of varying ages who wear various clothing (that is more or less restrictive of movements) and footwear. As opposed to movement-based and behavioural models, the models that reflect the basic evacuation parameters fail to account for the number of evacuees. Where human traffic is denser, causing congestion, it is equally essential to consider body dimensions. The article outlines analyses of the impact of changes in anthropometric dimensions in a selected building. Models are rendered using the Pathfinder software. Recommendations are offered on how to assess evacuation conditions for various building types and various occupants.

**Keywords:** modelling, evacuation, anthropometry, Pathfinder, human motion simulator, evacuation simulation models.

**Streszczenie:** W artykule zaprezentowano przykład badania wpływu uwzględnienia kryteriów antropometrycznych na proces modelowania warunków ewakuacji. Formalne modele ewakuacyjne różnią się szczegółowością odwzorowania rzeczywistości. Podstawowym parametrem ustalonym za ich pomocą jest czas ewakuacji. Do podstawowych danych wprowadzanych podczas modelowania należy prędkość przemieszczania się osób, a liczne prace

badawcze zawierają przykłady wartości dla osób o różnym wieku, ubraniu (mniej lub bardziej ograniczającym ruchy) i obuwiu. Przy zastosowaniu modeli umożliwiających uwzględnienie podstawowych parametrów ewakuacji nie bierze się pod uwagę liczby ewakuowanych. W modelowaniu z użyciem modeli ruchu lub behawioralnych konieczne jest uwzględnienie liczby ewakuowanych. Przy większym natężeniu ruchu, powodującym zatory, ważne jest uwzględnianie wymiarów osób. W artykule przeanalizowano wpływ zmian wymiarów antropometrycznych dla przykładowego obiektu z użyciem programu Pathfinder. Wskazano zalecenia co do postępowania podczas analizowania warunków ewakuacji dla różnych grup budynków i różnych użytkowników.

**Słowa kluczowe:** modelowanie, ewakuacja, antropometria, Pathfinder, symulator ruchu człowieka, modele symulacyjne ewakuacji.

## 1. Introduction

Evacuation conditions can be simulated with a range of formal models. The authors of such models are aware of the diversity of populations that vary in age, body dimensions, mobility and their personalities. Many models are developed for specific population categories such as adult male, adult female, children, the elderly, and data median (Pan, Han, Dauber, and Law, 2006). Such classifications focus primarily on movement speed differences (Robbins and Buckett, 2014; Kholshchikov and Samoshin, 2010).

The most accurate simulation models account for a range of behaviour (Santos and Aguirre, 2004), such as non-straight-line movements (Peng and Ruihua, 2010), differences in the movement of small groups and independent individuals (Zou, Xu, and Gao, 2010), various modes of behaviour exhibited under time pressure (which reduces the ability to perceive and process information volumes), limited mental resources, the impact of evacuation drills and familiarity with relevant procedures (Kuligowski, 2008; 2013), crowd density, familiarity with the building, physical and cognitive abilities, role and responsibility, commitment to the task, and prior evacuation experience (O'Connor, 2005). Most simulation models ignore panic behaviour although many studies show that asocial or antisocial behaviour during evacuations are a myth (Henein and White, 2010). The basic parameter determined through calculations is evacuation time. To arrive at such time, it is necessary to map (Kuligowski, 2013; Pathfinder Verification and Validation, 2020):

- the lengths of the routes to the emergency exit,
- the widths of the communication routes (corridors, stairwells, etc.),
- the widths of the doors in the passages to the emergency exits,
- the number of evacuees,
- the speed of movement (down corridors, staircases, etc.).

Many computer applications have been developed to model evacuation conditions, e.g. AnyLogic PLE, CrowdMaster, Evacs, EvacSim, building Exodus, maritime Exodus, Legion Simulator, Massive, MassMotion, Panic, Pathfinder, Pedestrian Dynamics, Simulex, Simwalk, Social Distances, Steps, Wayout and many

others (Kuligowski, 2013). In such software, individuals are visualized in the form of (Helbing, Farkas, and Vicsek, 2000; Pathfinder Verification and Validation, 2020):

- circles,
- disks,
- spheres,
- cylinders,
- cuboids,
- phantoms and
- realistic 3D characters.

In the calculation of human flows, the figures of individuals shown in top view are represented as (Figure 1):

- circles (Pathfinder Verification and Validation, 2020),
- ellipses (Zou et al., 2010),
- a combination of three movable, flexible circles (Chooramun, Lawrence, and Galea, 2012; Korhonen, Hostikka, Heliövaara, and Ehtamo, 2010; Thompson and Marchant, 1995).

The maximum sizes of such geometrical figures are usually described as shoulder width (Pathfinder User Manual, 2020). In her doctoral dissertation, Still (2000, p. 32) used the term “shoulder breadth”. Pheasant (2003, p. 37) offered two definitions of shoulder breadth:

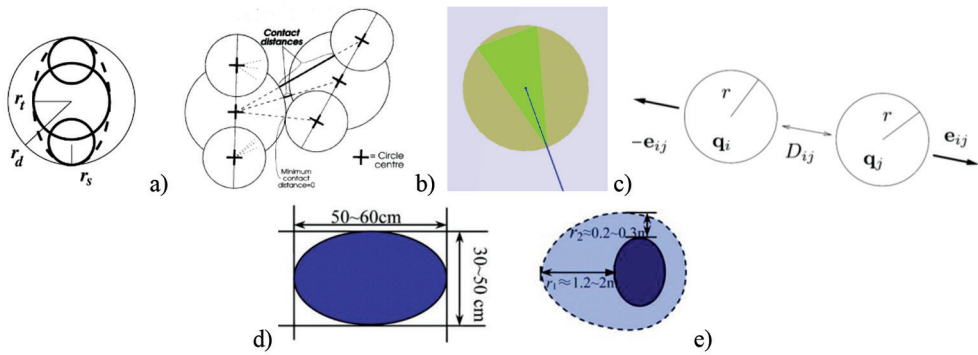
- shoulder breadth (bideltoid) – maximum horizontal breadth across the shoulders, measured to the protrusions of the deltoid muscles;
- shoulder breadth (biacromial) – horizontal distance across the shoulders measured between the acromia (bony points).

An analysis of the data provided by Still (2000, p. 34) and Pheasant (2003, p. 45) shows that the maximum values (95th percentile) adopted are those for the parameter of “shoulder breadth (bideltoid)”. In Polish anthropometric atlases, this corresponds to the following terms:

- shoulder breadth maximum (Nowak, 2000);
- elbow-to-elbow breadth (although defined differently (Table 1)) (Gedliczka, 2001).

According to the former PN-N-08012 standard, shoulder breadth is the maximum horizontal distance between the tops of the acromia of the right and left shoulder blade (PN-N-08012 – extended version of ISO 7250 – Basic list of anthropometric measurements). In the “Atlas” by Gedliczka (2001, Table 2), shoulder breadth is defined as the distance between points on the lateral surface of arms at the level of the shoulder joint axis.

Such a diversity of dimensions and terminologies calls for an analysis accounting for the time at which the respective data were collected. A steady rise in parameter values can be observed (Table 1) due, among others, to changes in lifestyle and nutritional intake. In addition, the “Atlas” by Nowak (2000) offers projections for the year 2010.



**Fig. 1.** Presentation of human model in evacuation models: a) FDS+Evac (Korhonen et al., 2010; Zhang, Zhu, Qiu, and Wang, 2019); b) SIMULEX (Thompson and Marchant, 1995a); c) Pathfinder (Pathfinder User Manual, 2020) d) Crowd Motion (Venel, 2010); e) (Zou et al., 2010).

Source:

**Table 1.** Comparison of anthropometric dimensions from selected anthropometric atlases

No.	Feature	5 <sup>th</sup> percentile value for women [cm]	95 <sup>th</sup> percentile value for men [cm]
1	Shoulder breadth (Gedliczka, 2001)*	35.8	48.7
2	Shoulder breadth (biacromial) (or Acromion breadth) (Nowak, 2000)	28.3	40.5
3	Shoulder breadth (biacromial) (Batogowska and Słowikowski, 1994)	27.1	41.9
4	Shoulder breadth maximum (Nowak, 2000)	39.5	58.8
5	Shoulder breadth maximum (Batogowska and Słowikowski, 1994)	36.2	50.5
6	Elbow-to-elbow breadth (Gedliczka, 2001)**	40.9	56.0

Key: \* Defined as distance between points on the lateral surface of arms at the level of shoulder joint axis. \*\* Defined as maximum body width with upper limbs dropped loosely.

Source: own work based on (Batogowska and Słowikowski, 1994; Gedliczka, 2001).

An analysis of data from Table 1 may suggest that the maximum values to be adopted for evacuation models made for calculation purposes are those provided in rows 4 and 6 of the table. Therefore, it is essential to update the values to reflect the latest data. To that end, research was undertaken presenting the impact of anthropometric parameter trends on the results of simulations of evacuation conditions.

## 2. Research methodology

The main aim of the study is to determine the impact of variations in anthropometric parameters on evacuation times and evacuee flow through emergency exit doors, by simulating evacuation conditions with the use of software (Pathfinder). The study focuses on a building with a fixed number of occupants (the maximum table seating capacity of 900) (Figure 2). The detailed assumptions regarding the research sample are as follows:

- ten evacuation scenarios with different anthropometric dimensions were selected and entered in the application software (Table 2); The variable was shoulder breadth maximum (cubitale laterale) (elbow-to-elbow breadth<sup>1</sup>), body height and chest depth (as a parameter to which elbow breadth can be reduced at high crowd density);
- the anthropometric dimension data were taken from the Polish anthropometric atlases: “Atlas miar człowieka” (Gedliczka, 2001) and “Atlas antropometryczny populacji polskiej” (Nowak, 2000) (the data in the latter atlas included a dimension projection for 2010, based on variability observations made before the year of publication) (Table 3);
- the relative proportions of sample sizes for groups with different dimensions was selected for Scenarios 4, 4a, 5, 5a;



**Fig. 2.** Sample view of the evacuation simulation according to the selected scenario in the sample building, generated in the Pathfinder software

Source: own work with the use of the Pathfinder software.

<sup>1</sup> As per “Atlas miar człowieka” (Gedliczka, 2001).

- the building came equipped with three emergency exits (doors) having the following widths: Door 02 (as per Pathfinder list): 120 cm, door 20: 150 cm, door 83: 170 cm;
- five simulations per scenario were conducted to reflect the variability of evacuee behaviour in the simulation model (the total number of simulations was 50);
- no population group restrictions were imposed on the choice of doors and stairwells (all building occupants were defined as exhibiting the same behaviour of heading for the emergency exit).

**Table 2.** List of research scenarios

Scenario number	Anthropometric features of evacuees in evacuation scenario
1	2
1	The distribution of shoulder breadths in the population mapped in the software application corresponded to the maximum shoulder breadths in the female and male populations (ranging from the 5th percentile female to the 95th percentile male) as per “Atlas miar człowieka” (Gedliczka, 2001); body height corresponded to border body heights in the female and male populations (ranging from the 5th percentile female to the 95th percentile male) as per “Atlas miar człowieka” (Gedliczka, 2001); a reduction in the maximum shoulder breadth to the upper border in the scenario was adopted (i.e. for men falling into the 95th percentile male, as per “Atlas miar człowieka” (Gedliczka, 2001)).
1a	Parameters similar to those in Scenario 1, although the data were drawn from “Atlas antropometryczny populacji polskiej” (Nowak, 2000).
2	The distribution of shoulder breadths in the population mapped in the software application corresponded to maximum shoulder breadths in the female population (ranging from the 5th percentile female to the 95th percentile female), as per “Atlas miar człowieka” (Gedliczka, 2001); body height corresponded to border body heights in the female population (from the 5th percentile female to the 95th percentile female) as per “Atlas miar człowieka” (Gedliczka, 2001); a reduction of maximum shoulder breadth to the upper border in the scenario was adopted (i.e. for a woman falling into the 95th percentile female, as per “Atlas miar człowieka” (Gedliczka, 2001)).
2a	Parameters similar to Scenario 2, although the data were drawn from “Atlas antropometryczny populacji polskiej” (Nowak, 2000).
3	The distribution of shoulder breadths in the population mapped in the software application corresponded to the maximum shoulder breadths in the male population (ranging from the 5th percentile male to the 95th percentile male) as per “Atlas miar człowieka” (Gedliczka, 2001); body height corresponded to border body heights in the male population (ranging from the 5th percentile male to the 95th percentile male) as per “Atlas miar człowieka” (Gedliczka, 2001); a reduction of the maximum shoulder breadth to the upper border in the scenario was adopted (i.e. for a man falling into the 95th percentile, as per “Atlas miar człowieka” (Gedliczka, 2001)).
3a	Parameters similar to Scenario 3, although the data were drawn from “Atlas antropometryczny populacji polskiej” (Nowak, 2000).

1	2
4	The distribution of shoulder breadths in the population mapped in the software application corresponded to maximum shoulder breadths in the adult female and male populations (ranging from the 5th percentile male to the 95th percentile male) as per “Atlas miar człowieka” (Gedliczka, 2001) and in children (boys and girls) aged 6 to 13 (ranging from the 5th percentile female to the 95th percentile male), as per “Atlas antropometryczny populacji polskiej” (Nowak, 2000)) in the following proportions: adults: 10%; children: 90% (distributed evenly by age groups). A similar population distribution was adopted for body height; a reduction of the maximum shoulder breadth to the upper borders in each age group (i.e. for men and boys falling into the 95th percentile) was adopted.
4a	Parameters similar to Scenario 4, although the data for adults were drawn from “Atlas antropometryczny populacji polskiej” (Nowak, 2000).
5	The distribution of shoulder breadths in the population mapped in the software application corresponded to the upper breadth borders in the population of adult men and women (ranging from C5K to C95M) as per “Atlas miar człowieka” (Gedliczka, 2001) and children (boys and girls) aged 14 to 18 (ranging from C5K to C95M, as per “Atlas antropometryczny populacji polskiej” (Nowak, 2000)) in the following proportions: adults: 10%; children: 90% (distributed evenly by age groups). A similar population distribution was adopted for body height; a reduction of the maximum shoulder breadth to the upper border in each age group (i.e. for C95M-sized men and boys) was adopted.
5a	Parameters similar to Scenario 5, although the data for adults were drawn from “Atlas antropometryczny populacji polskiej” (Nowak, 2000).

Source: own work.

**Table 3.** Anthropometric features by simulation scenario

Scenario no.	Age group	Population percentage	Name of anthropometric feature	5 <sup>th</sup> percentile female [cm]	50 <sup>th</sup> percentile female [cm]	95 <sup>th</sup> percentile female [cm]	5 <sup>th</sup> percentile male [cm]	50 <sup>th</sup> percentile male [cm]	95 <sup>th</sup> percentile male [cm]
1	2	3	4	5	6	7	8	9	10
1	♂: 20-65 ♀: 20-60	100	<ul style="list-style-type: none"> <li>elbow to elbow breadth:</li> <li>chest depth:</li> <li>stature:</li> </ul>	40.9	45.5	49.3	44.5	49.9	56.0
1a	♂: 19-65 ♀: 19-60	100	<ul style="list-style-type: none"> <li>shoulder breadth maximum:</li> <li>chest depth:</li> <li>stature:</li> </ul>	39.5	45.3	52.5	45.6	51.8	58.8
2	♀: 20-60	100	<ul style="list-style-type: none"> <li>elbow to elbow breadth:</li> <li>chest depth:</li> <li>stature:</li> </ul>	40.9	45.5	49.3	–	–	–

Table 3, cont.

1	2	3	4	5	6	7	8	9	10
2a	♀: 19-60	100	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	39.5 20.8 153.6	45.3 25.6 163.4	52.5 31.1 174.0	– – –	– – –	– – –
3	♂: 20-65	100	<ul style="list-style-type: none"> <li>• elbow to elbow breadth:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	– – –	– – –	– – –	44.5 21.4 164.3	49.9 24.2 174.8	56.0 28.0 185.4
3a	♂: 19-65	100	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	– – –	– – –	– – –	45.6 21.7 166.0	51.8 26.0 177.8	58.8 30.4 189.0
4/4a	♂: 20-65 ♀: 20-60	10	<ul style="list-style-type: none"> <li>• elbow to elbow breadth:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	40.9 22.8 152.4	45.5 26.3 161.1	49.3 32.1 170.7	44.5 21.4 164.3	49.9 24.2 174.8	56.0 28.0 185.4
	♂: 19-65 ♀: 19-60	10	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	39.5 20.8 153.6	45.3 25.6 163.4	52.5 31.1 174.0	45.6 21.7 166.0	51.8 26.0 177.8	58.8 30.4 189.0
	♂: 6 ♀: 6	11.25	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	25.1 12.0 113.2	29.3 13.3 120.8	34.1 14.6 128.5	26.1 12.4 113.9	30.2 13.8 121.1	33.9 15.2 128.5
	♂: 7 ♀: 7	11.25	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	25.8 12.3 117.5	30.8 13.7 124.9	35.1 15.1 132.6	26.5 12.9 117.8	30.7 14.4 125.1	34.5 15.9 134.4
	♂: 8 ♀: 8	11.25	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	26.1 12.5 120.6	30.9 14.1 130.9	35.6 15.7 141.3	26.8 13.0 122.6	31.5 14.7 132.3	36.8 16.4 141.8
	♂: 9 ♀: 9	11.25	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	26.4 12.7 125.9	31.2 14.6 136.6	35.8 16.5 147.5	26.9 13.6 127.7	32.0 15.3 136.9	37.0 17.0 145.6
	♂: 10 ♀: 10	11.25	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	28.4 12.7 132.4	34.7 14.9 141.5	40.8 17.1 150.9	28.5 13.7 131.8	34.7 15.4 141.5	40.1 17.1 150.0
	♂: 11 ♀: 11	11.25	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	30.0 13.1 137.2	35.9 15.1 149.1	41.6 17.6 161.0	30.6 13.7 135.3	35.4 15.7 146.3	40.9 17.7 156.0



1	2	3	4	5	6	7	8	9	10
4/4a	♂: 12 ♀: 12	11.25	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	31.9 13.7 144.4	37.3 15.8 155.5	42.4 17.9 166.4	32.3 14.3 143.9	37.5 16.5 155.2	42.7 18.7 166.7
	♂: 13 ♀: 13	11.25	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	32.8 13.9 149.5	38.0 16.3 160.0	42.9 18.7 170.3	33.1 14.7 147.7	38.8 17.3 160.9	44.5 19.9 173.8
5/5a	♂: 20-65 ♀: 20-60	10	<ul style="list-style-type: none"> <li>• elbow to elbow breadth:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	40.9 22.8 152.4	45.5 26.3 161.1	49.3 32.1 170.7	44.5 21.4 164.3	49.9 24.2 174.8	56.0 28.0 185.4
	♂: 19-65 ♀: 19-60	10	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	39.5 20.8 153.6	45.3 25.6 163.4	52.5 31.1 174.0	45.6 21.7 166.0	51.8 26.0 177.8	58.8 30.4 189.0
	♂: 14 ♀: 14	18	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	34.9 14.2 154.9	39.7 16.6 164.5	44.1 18.9 174.4	33.8 15.5 152.8	41.0 18.0 167.3	48.2 20.5 181.0
	♂: 15 ♀: 15	18	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	35.1 14.5 155.9	40.3 16.8 166.4	45.2 19.1 177.2	35.6 15.9 161.0	42.4 18.7 174.1	49.2 21.5 187.5
	♂: 16 ♀: 16	18	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	35.2 14.7 156.7	40.7 17.2 167.6	45.4 19.7 179.7	38.3 16.5 165.5	44.2 19.4 178.3	50.1 22.3 188.5
	♂: 17 ♀: 17	18	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	35.9 14.9 158.0	40.8 17.3 168.1	45.4 19.9 180.4	38.5 16.7 167.7	44.9 19.6 179.9	50.8 22.3 191.7
	♂: 18 ♀: 18	18	<ul style="list-style-type: none"> <li>• shoulder breadth maximum:</li> <li>• chest depth:</li> <li>• stature:</li> </ul>	36.9 15.4 159.2	41.2 17.4 168.6	46.2 19.9 181.1	40.8 16.9 170.8	45.8 19.6 181.2	51.5 22.5 192.1

Source: own work based on (Gedliczka, 2001; Nowak, 2000).

The following data were drawn from Table 3 to populate occupant profiles in Pathfinder:

- normal distribution of cylinder diameters based on maximum shoulder breadth as per “Atlas” (Nowak, 2000) (according to “Atlas” (Gedliczka, 2001) the breadth is measured elbow to elbow<sup>2</sup>);

<sup>2</sup> Defined as maximum body breadth with upper limbs hanging loosely.

- normal distribution of cylinder heights;
- diameter reduced to maximum chest depth.

The author chose not to adjust the speed of human movement in order to only assess anthropometric relationships (although body dimensions do affect stride length and speed of movement). The adopted default value for such speed was 1.19 m/s.

### 3. Results

The key measure in the simulations is evacuation time. Table 4 summarizes the results of simulation analyses for individual scenarios. The total evacuation time varies from test to test. The shortest evacuation time was obtained for Scenarios 4 and 4a, where the dimensions adopted are those corresponding to the populations of adults as well as children aged 6 to 13 years.

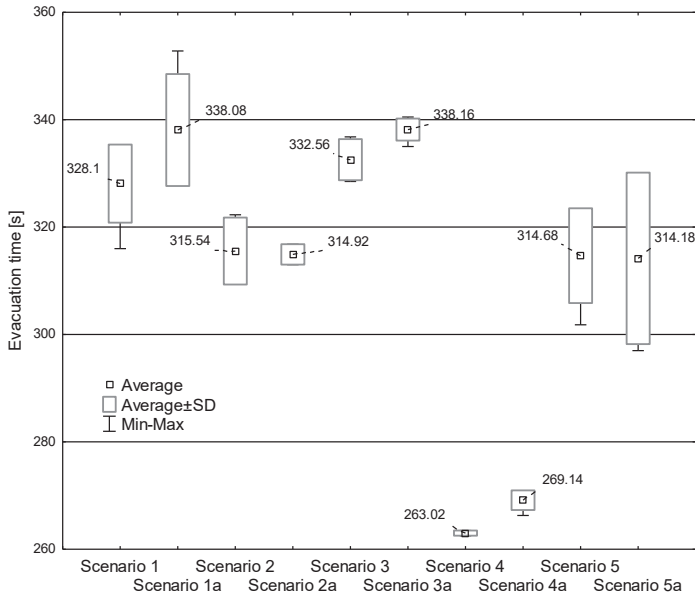
A significant increase in evacuation times is observed for Scenarios 5 and 5a, where the data concerns adults as well as adolescents aged 14 to 18 years. Another characteristic of this scenario is the significant gap between the results (Figure 3). The longest evacuation times are obtained for a mixed population of adults and for men. These groups are characterized by the largest border dimensions of the body.

**Table 4.** Evacuation times for individual scenarios and study tests

Scenario no.	Number of simulation tests	Evacuation time [s]						
		Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5	$\bar{x}$	SD
1	5	316.0	331.5	331.5	327.0	334.5	328.1	7.27
1a	5	352.8	340.8	340.8	328	328	338.08	10.42
2	5	312.5	310.3	310.3	322.3	322.3	315.54	6.24
2a	5	315.0	316.8	316.8	313.0	313.0	314.92	1.9
3	5	336.8	328.5	328.5	334.5	334.5	332.56	3.82
3a	5	340.5	338.0	338.0	335.0	339.3	338.16	2.05
4	5	263.5	263.3	263.3	262.5	262.5	263.02	0.48
4a	5	270.5	268.3	270.3	270.3	266.3	269.14	1.82
5	5	301.8	323.0	323.0	312.8	312.8	314.68	8.82
5a	5	328.8	297.0	297.0	327.3	320.8	314.18	15.97

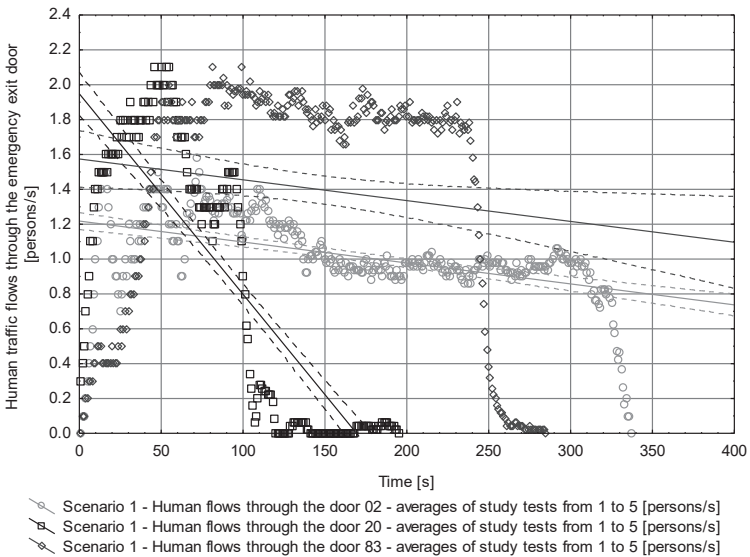
Source: own work.

Due to the layout of the rooms in the building (Figure 2), differences in the number of people exiting through each door were observed. During the tests, evacuation efficiency was not increased by allocating people to individual emergency exits.



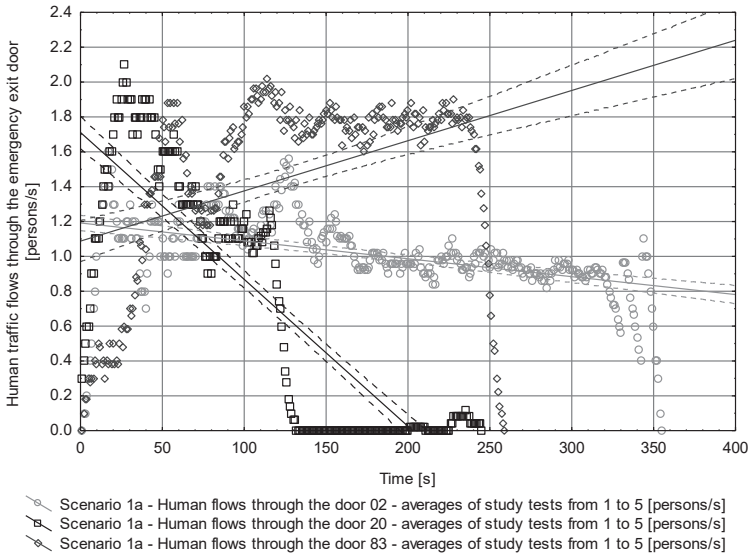
**Fig. 3.** Distribution of total evacuation times in individual simulation tests in the Pathfinder software

Source: own work with the use of the Statistica software.



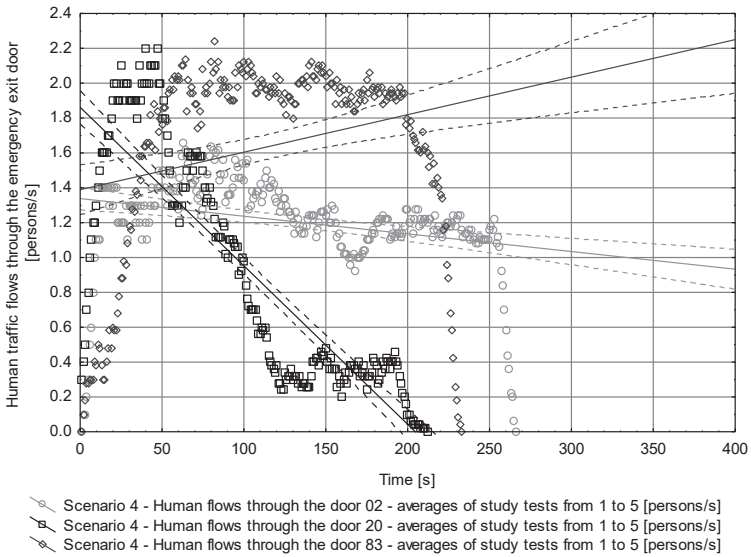
**Fig. 4.** Human traffic flows through emergency exit doors during evacuation in the tested building – Scenario 1

Source: own work with the use of the Statistica software.



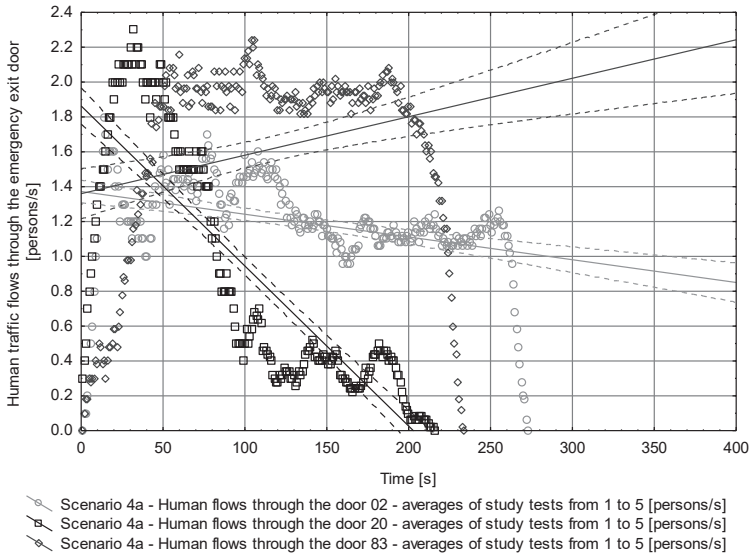
**Fig. 5.** Human traffic flows through emergency exit doors during evacuation in the tested building – Scenario 1a

Source: own work with the use of the Statistica software.



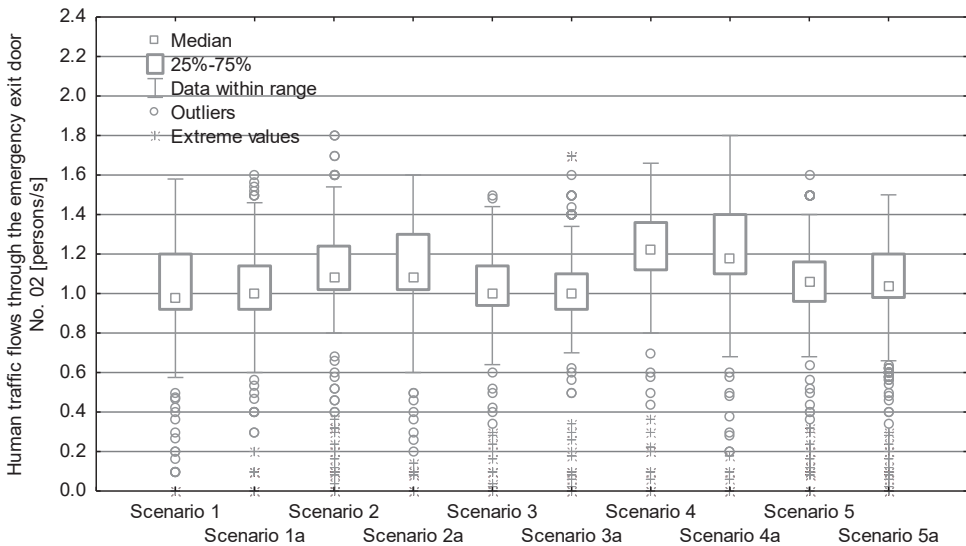
**Fig. 6.** Human traffic flows through emergency exit doors during evacuation in the tested building – Scenario 4

Source: own work with the use of the Statistica software.



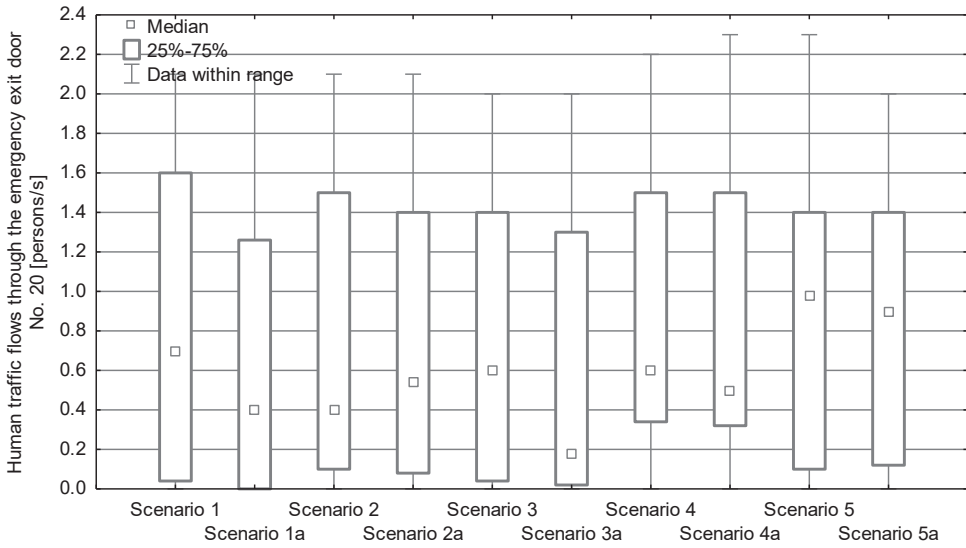
**Fig. 7.** Human traffic flows through emergency exit doors during evacuation in the tested building – Scenario 4a

Source: own work with the use of the Statistica software.



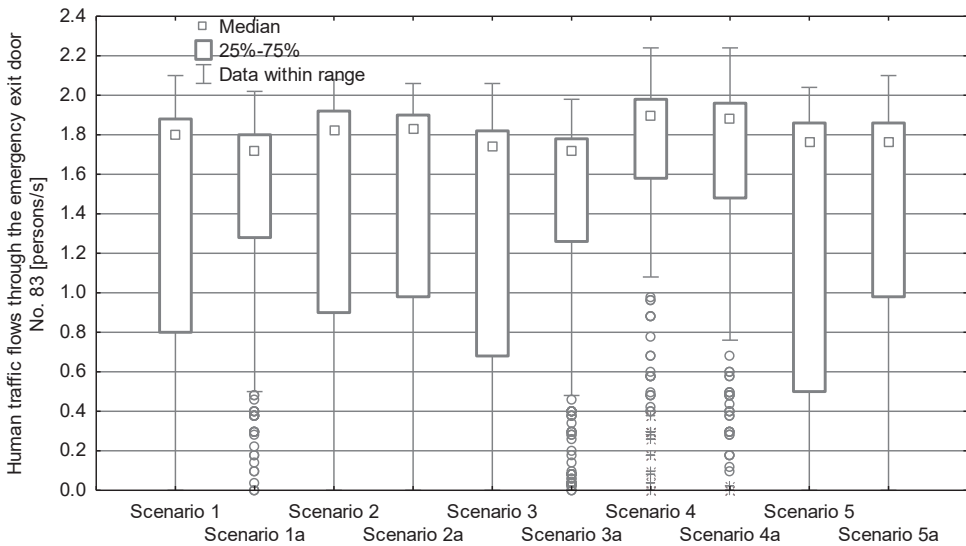
**Fig. 8.** Distributions of the times of human flows through emergency exit Door 02 for individual scenarios

Source: own work with the use of the Statistica application.



**Fig. 9.** Distributions of the times of human flows through emergency exit Door 20 for individual scenarios

Source: own work with the use of the Statistica application.



**Fig. 10.** Distributions of the times of human flows through emergency exit Door 83 for individual scenarios

Source: own work with the use of the Statistica application.

Figures 4, 5, 6 and 7 show examples of average distributions of human flows through emergency exit doors. The longest-lasting evacuation took place through Door 02 (about 340 people), while the quickest one was through Door 20 (about 160 people). The largest number of people (about 400) exited through Door 83. The evacuation trends are presented by means of regression curves.

The distributions of the times of human flows through individual emergency exit doors for each scenario are shown in the graphs (Figures 8, 9 and 10).

Since the longest-lasting evacuation took place through Door 02, the graph (Figure 8) shows constant flows. The highest values were obtained in Scenarios 4 and 4a. The lower quartiles and median distributions shown in Figure 9, which are close to zero, indicate a small number of people using Door 20. The discrepancy between the quartiles illustrates large flow fluctuations. This also applies to Door 83 (Figure 10), although the flow rates through that door are the highest.

The study results made it possible to draw the following applicable conclusions.

## 4. Conclusion

As presented in the individual sections of this paper, the study supports the conclusions regarding the importance of updating anthropometric dimensions in modelling evacuation conditions. The author observed that:

- increased discrepancies between anthropometric dimensions correlate with greater fluctuations in evacuation times during successive simulation tests;
- increased shoulder breadth correlates with longer evacuation times;
- reductions in shoulder breadths lead to accelerated traffic flow through doors.

In addition to anthropometric dimensions, simulation models consider many additional parameters designed to bring the findings closer to actual conditions. Therefore when measuring human flows, a comfort distance between individual people is assumed (Pathfinder User Manual, 2020; Zou, Xu, Gao, 2010). This rule is suspended for congestion, which reduces distances between people.

Gender dimorphism and people's age in a population should also be accounted for in modelling and planning safe evacuation solutions for buildings expected to see greater age diversities among their occupants (as well as occasionally for mass events). This is necessary in modelling solutions with a high level of ergonomic conformity (Dahlke, 2014). While the study highlights the complexity of the modelling process and the challenges faced in it, it also suggests the causes of the discrepancies between the models and the actual circumstances.

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