QUALITY OF EMERGENCY STAIR TRAVEL DEVICES

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Abstract

Emergency stair travel devices are designed to evacuate people from buildings and used during initial unguided spontaneous evacuations as well as by professional emergency services. The requirements for evacuation chairs are varied: they are determined by the technical conditions of the building, by the specific way of operation of non-professional and professional operators, and on the other hand, they must take into account the specificity of evacuated people. The problem is to indicate the quality parameters of the evacuation chairs so that these chairs can be adapted to the organization and equipment system. The article aims to indicate and justify such quality parameters. The starting point was a quantitative analysis of scientific documents. It was found that there are only 33 scientific documents directly related to research on the evacuation of people with physical disabilities. Based on the literature, the tested evacuated devices were classified into three main types: hand-carried, tracked, and sled. Three groups of potential users of emergency stair travel devices have been identified: 1) "non-professional rescuer", i.e., a person assisting in the first spontaneous phase of evacuation; (2) "professional rescuer", meaning a firefighter or other professional who is physically fit and well versed in the operation of equipment and evacuation procedures; this type of user usually appears in the second phase of the evacuation; (3) evacuee. Each of these groups has specific needs and evaluates the quality of the device in different ways. Based on the analysis of scientific literature, the following predictors of the quality of emergency stair travel devices have been identified: average evacuation time(s), evacuation speed (m/s), number of rescuers (pcs.), effort of rescuers (estimated oxygen consumption or pulse rate) and comfort of the person being rescued (estimated by pulse frequency or based on surveys). The expert analysis points out that essential requirements for evacuation devices vary for different people and do not overlap. For a person being evacuated, for example, the position of the body during evacuation is important, and from the point of view of rescuers, the ease of use, mobility and tolerance for errors in use are important in case of evacuation. Both groups of rescuers have similar requirements, but they have different priorities.

Keywords: stair travel device, stair descent device, evacuation chair, rescue chair, rescue devices, people with disabilities, people with special needs, disability; mobility, evacuation; evacuate, rescue operation, rescue action, fire drills, building design, fire safety

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1. Introduction

Assistive technology, the devices for counterbalancing a disability, can be divided into personal and universal devices. Personal devices are tailored to the type of disability of a particular person and are generally used only by that person. Universal devices, on the other hand, offer functionality to the largest possible group of people and are usually used from time to time, i.e. when necessary. Emergency stair travel devices are inclusive assistive technology products designed to facilitate the safe and efficient movement of individuals with temporary or permanent mobility disabilities during critical or life-threatening situations. These devices play a vital role in facilitating the safe transportation of individuals up the stairs in an emergency scenario specifically in tall buildings, which are more challenging in emergency evacuation as compared to low buildings (Dewan, 2022).

There are two strategies for proceeding in the building once a threat has occurred. One of them is to ensure that people in the building can survive until the danger has been eliminated or until professional rescue services rescue them. An alternative strategy is to evacuate to a safe place inside another building, or outside. Such evacuation can be spontaneous and unguided, using previously planned organisational and equipment solutions. Usually, however, after the arrival of emergency services with the appropriate skills and equipment, the evacuation process is ordered and managed (BS 5588-8:2004). Regardless of the course of the evacuation, it is always required to ensure the shortest possible evacuation time, evacuate all people, and carry out the evacuation in a safe way for the evacuees and people supporting the evacuation of other people, including professional rescuers.

There are two primary evacuation philosophies for buildings (Lay, 2007):

- Simultaneous evacuation: all occupants are evacuated at the same time, regardless of what threat they are exposed to;
- Phased evacuation: only occupants at elevated risk are evacuated initially; others remain in place for later egress.

To ensure effective evacuations in any situation, the inclusion of emergency stair travel devices is paramount. Architects responsible for designing new multi-storey buildings and administrators overseeing such structures must diligently incorporate these devices into the evacuation system (PN-EN 17210:2021-06). They should be well adapted to local requirements to effectively support the evacuation process if necessary. This potential and practical effectiveness of emergency stair travel devices is their quality, because quality is defined as the degree to which a set of inherent characteristics fulfils a need or expectation that is stated, generally implied, or obligatory (EN ISO 9000:2000).

The article aims to indicate and justify the predictors for assessing the quality of emergency stair travel devices intended for people with disabilities. The undertaken topic justifies the formulation of the following research questions:

1. What is the scientific literature on emergency stair travel devices?
2. What are the types of emergency stair travel devices?
3. Who uses emergency stair travel devices, and what are their quality requirements?
4. How can the evacuation quality of people with mobility disabilities from buildings be measured with emergency stair travel devices?
5. What are emergency stair travel devices' quality practical components?

2. Methods

Problems related to the evacuation of people with special needs using emergency stairs travel devices are studied and described in the scientific literature. Three scientometric databases have been used to identify scientific documents: Scopus, Web of Science and Google Scholar. Queries were conducted based on keywords, and the results of the queries were subject to a four-stage evaluation (identification, screening, eligibility, included). This evaluation allowed gradual narrowing down of the number of literature sources only to studies on evacuating people with disabilities from buildings with the use of emergency stair travel devices. Keywords from the obtained list of publications were mapped using the Vos Viewer software (Centre for Science and Technology Studies, Leiden University, the Netherlands).

The qualitative parameters were identified using expert knowledge by a team of eight specialists from various fields, each with over 20 years of experience. The team consisted of:

- Scientist, a quality engineering professional who participates in R&D projects and deals with occupational safety and quality management.
- Scientist, a mechanical engineering and ergonomics professional who participates in R&D projects and deals with ergonomics of assistive technology devices used in daily living, e.g. wheelchairs (he uses a wheelchair daily, so the ergonomics issues are known to him not only from the theoretical but also from the practical side).
- A fire safety engineer, a professional firefighter who participates in rescue and firefighting operations, including evacuation of people during a fire or an accident using various techniques and methods.
- A fire safety engineer, a professional firefighter who works in the department dealing with verifying facilities and buildings in terms of compliance with the regulations and applicable standards before they are put into use.
- A paramedic who works in a medical rescue team.
- A designer of evacuation devices and equipment who designs and then executes evacuation chairs, mattresses, evacuation mats and auxiliary equipment designated for the evacuation of people with special needs.

- A product designer responsible for ergonomics and product design expression of evacuation devices and equipment.
- Coordinator for the production of evacuation devices and equipment with practical experience in the construction, testing and testing of this type of equipment.

3. Results

3.1. What is the scientific literature on emergency stair travel devices? State of art

Three scientometric databases (Scopus, Web of Science and Google Scholar) were used to identify scientific documents. Figure 1 shows the results of searching for scientific documents on emergency stair travel devices in these databases.

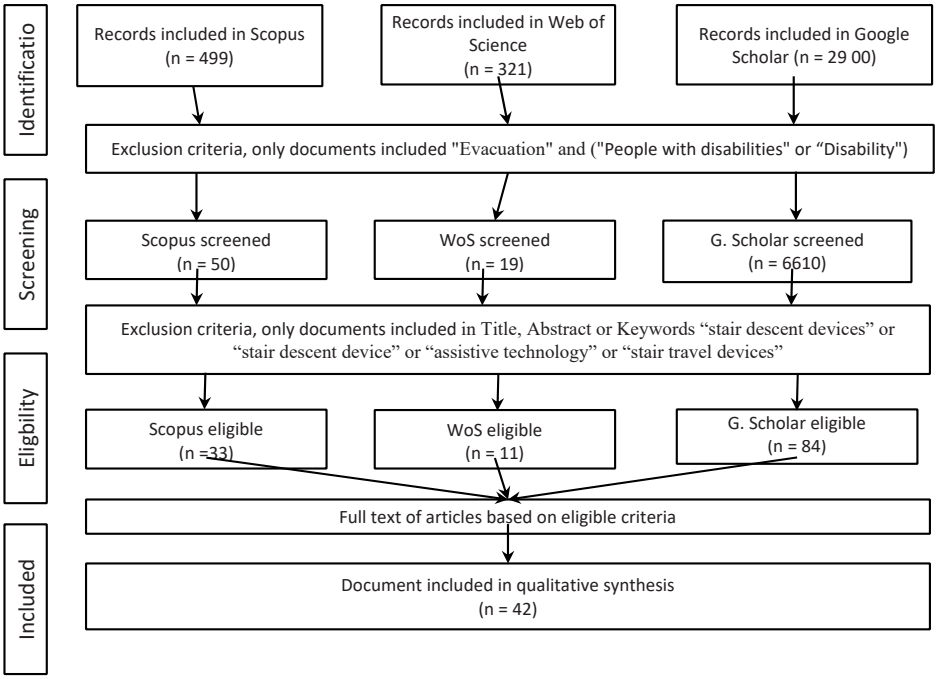

Figure 1. Flow chart of the literature analysis

As shown in Figure 1, a Scopus query based on the keywords "stair and evacuation" in the fields Title, abstract, and Keywords (TITLE-ABS-KEY) returns 499 publications. A similar query in the "Topic" field returns 321 results from the Web of Science Core Collection and ca. 29,000 records from Google Scholar. A keyword map from these publications is shown in Figure 2.

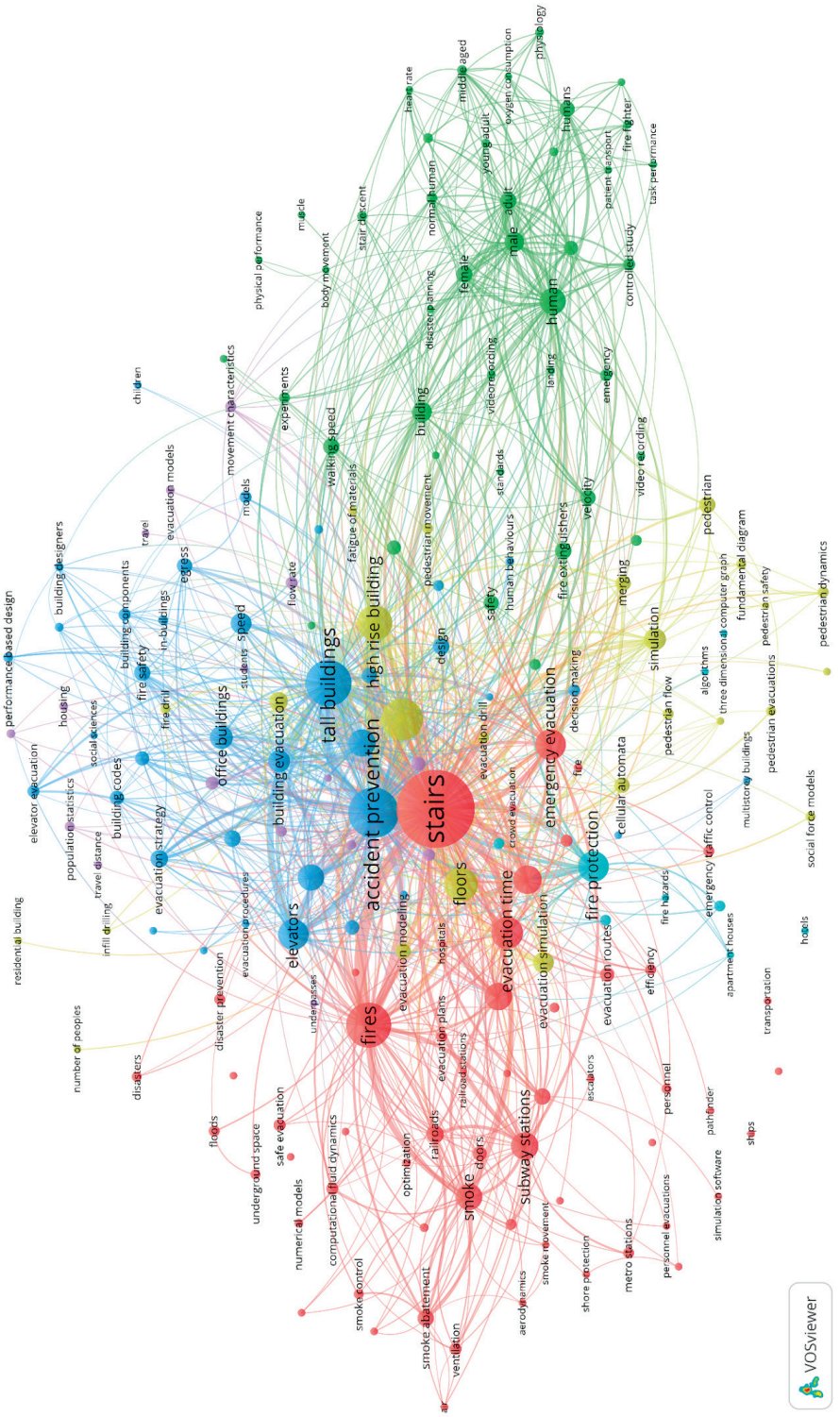

Figure 2. Entire problems of evacuation from buildings (keyword map based on 487 publications)

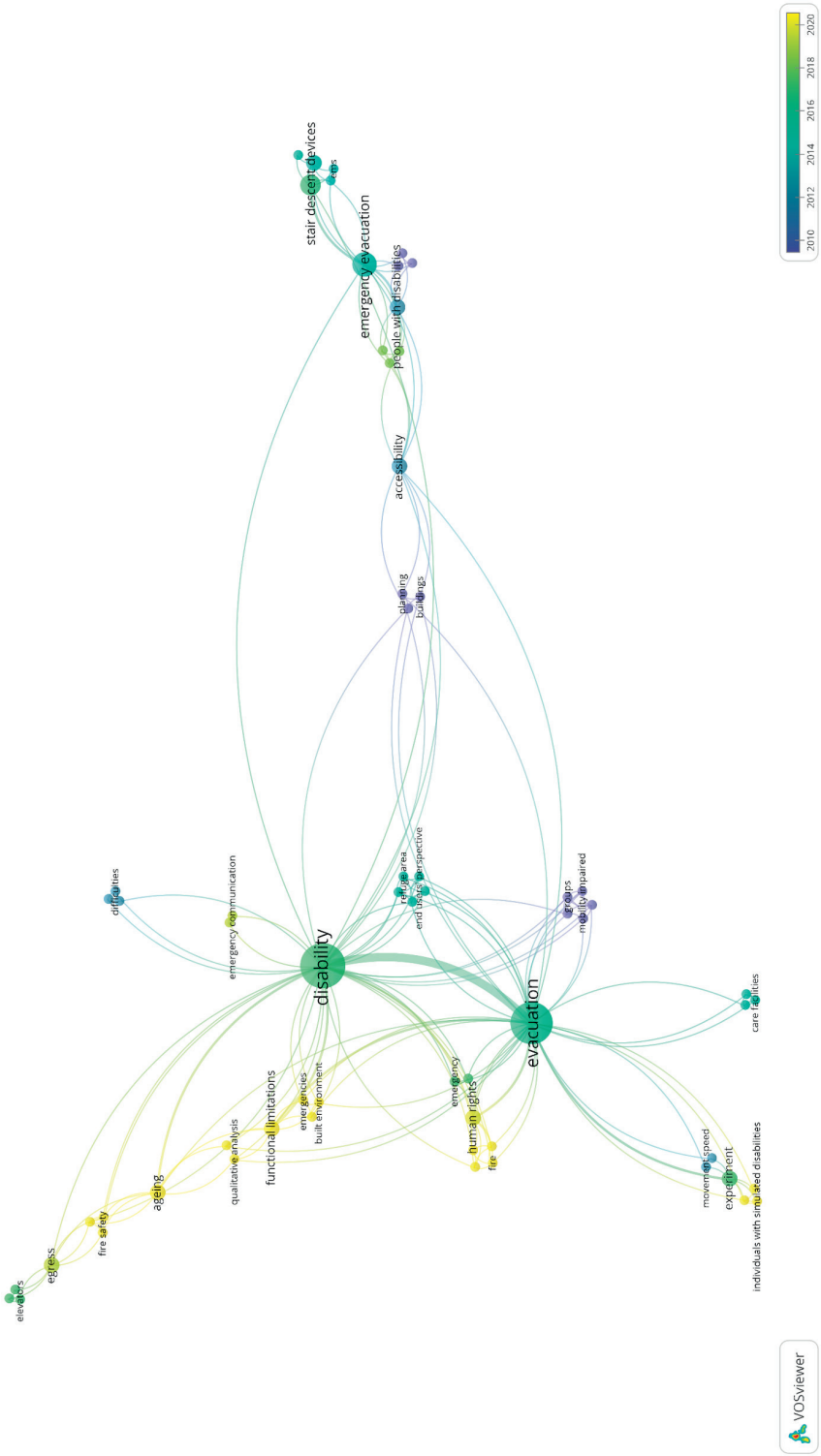

Figure 3. Narrowed down issues of evacuation concerning stair and evacuation and (disability or disabilities) (based on 33 publications)

The keyword map in Figure 2 shows the three main thematic areas of scientific publications on the evacuation of people from buildings, the red area covering the three main keywords "stairs", "fire" and "evacuation time" related to "functional" issues, including the issue of efficiency of evacuation at the moment of a fire hazard. The blue area, with the main keywords "accident preventing" and "tall buildings", concerns the issues of proper organisational arrangement of building interiors, so that evacuation from them can proceed as efficiently as possible; the third distinctive area of keywords concerns "human factor", characteristic for this area are keywords "human", "male" and "female".

After identifying literature sources on the evacuation of people from buildings, the analysis of documents was narrowed down to issues related to the evacuation of people with disabilities from buildings. The narrowing query was performed by adding a third variant keyword ("disabilit*"). The result comprised 50 scientific papers in Scopus. A review of these publications was made, obtaining a list of 33 publications that only concern the evacuation of people with disabilities from buildings. The keyword map of these 33 publications is shown in Figure 3.

Figure 3 shows that in these 33 publications, pairs of words evacuation and disability are most often combined. On the other hand, "stair descent devices" have the highest connectivity with "emergency evacuation" and "ems" (measurements of the electrical activity of firefighters' muscles). Colours indicate the relevance of keywords. An interesting new word is "human rights", which indicates linking the right to evacuate for all people with human rights.

After combining searches from the three analysed databases (Scopus, Web of Science and Google Scholar), eliminating duplicates and reviewing the publications' content, the list of publications on the evacuation of people with disabilities employing assistive technology comprised 42 articles. Keyword analysis of these publications allows us to conclude that devices for evacuating people with disabilities upstairs are sometimes called in scientific documents: stair descent device; stair descent devices; evacuation chairs; evacuation chairs; rescue chairs; rescue chairs; recovery devices; recovery devices; evacuate; rescue operations; rescue operation or emergency egress system.

3.2. Types of emergency stair travel devices

Devices for evacuating people with disabilities up the stairs originate from devices used by medical services to transport patients. Lavender et al. proposed a very well-justified functional classification of this type of device (Lavender et al., 2014), indicating three main types of stair evacuation devices: hand carried (Hedman et al., 2021), track (Mehta et al., 2015), sledge (Lavender et al., 2015). The evacuee hand-carried devices, shown in Figure 4, require at least two rescuers; typically, this number is from two to four. The high demand for rescuers is a disadvantage. They are designed in such a way that the evacuated person is carried on them. This requires adequate physical strength from the rescuers and at the same time limits

the weight of the evacuated person. The method of operation is also a potential threat to the evacuee (fall) and the rescuers (physical injury). The advantages of this type of device are high availability, simple design, ease of storage, ease of use and high efficiency, and the ability to move a person evacuated through various types of obstacles.

Figure 4. Hand-carried type of emergency stair travel devices (Emergency Medical, Fire & Mobility Supplies, 2023)

The second type is the track type, shown in Figure 5. Such devices require at least one rescuer, and usually, the recommended number of rescuers is two. Their design does not require lifting the evacuated person, which makes it easier for rescuers and simultaneously enables evacuation of people with greater weight, in practice up to about 240 kg. The disadvantage is the impossibility or difficulty in moving over obstacles, reducing the effective width of escape routes for other people. The significant advantages of this type of is the fact that they do not overburden the rescuers, have a low demand for rescuers and high efficiency of operation, including the ability to move the evacuated person over long distances on level ground — possibility of evacuating a person in a sitting position.

Figure 5. Track-type of emergency stair travel devices (EnSafe, 2023)

Devices designed to move evacuees in the supine position, shown in Figure 6, require at least two rescuers. Their design does not require lifting the evacuated person. Transport in the lying position may be a source of discomfort for the evacuee. However, a significant advantage of this type of device is the possibility of transporting an unconscious person.

Figure 6. Sled-type of emergency stair travel devices (EnSafe, 2023)

Table 1 summarizes the properties of the three groups of evacuation devices described.

Table 1. Predictors of the quality of devices for evacuating people with mobility impairments (source: own elaboration)

Feature	Carried	Track	Sledge
Rescuers required	Disadvantages (2-4 rescuers)	Advantages (1-2 rescuers)	Advantages (2 rescuers)
Capacity of transport over a terrain with obstacles	Yes	No	No
Ease of use	Yes	No	No
Ability to evacuate an unconscious, injured person	Yes	No	Yes
Ability to save a disabled person	Yes	Yes	Yes
Ability to save a bariatric person	No	Yes	Yes

Table 1 shows that there is no single ideal type of evacuation device. The quality, i.e., the effectiveness of various evacuation devices in supporting the evacuation, depends on three factors: who will be evacuated, who will be evacuating, and under what conditions the evacuation would be taking place.

3.3. Use of emergency stair travel devices and their quality requirements

In the context of this topic, quality is the degree to which evacuation equipment meets the current requirements of its user. The validity of the requirements depends on:

- Product life-cycle stage (these stages in the case of evacuation devices are: production and delivery, acquisition and assembly, waiting for use, servicing, training use, evacuation use and decommissioning),
- end-user specifics (certain and potential users of the product are: manufacturer/supplier, building administrator/investor, service technician/maintenance technician, building user, non-professional rescuer – random person, a person practising evacuation, professional rescuer – firefighter/medical rescuer, evacuated person).

Qualitative relations become transformed with the change in the life stage of the product and the type of user. Lines in Figure 7 indicate these relationships. The green lines indicate the qualitative relationships considered in this article.

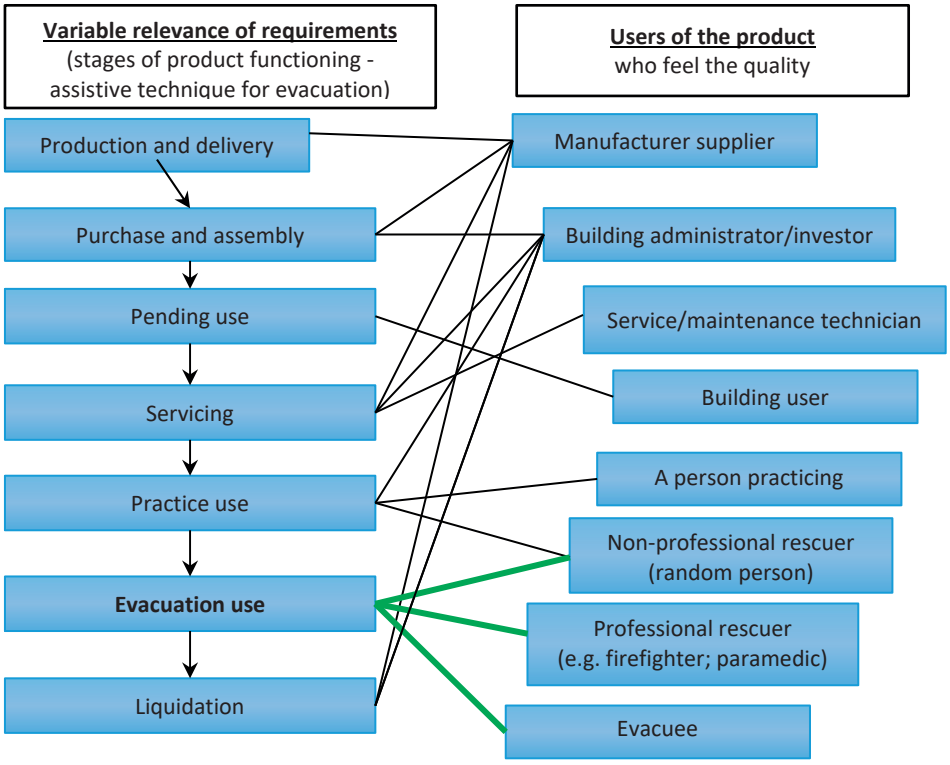

Figure 7. Qualitative links of various users with a specific (current) stage of product operation

Figure 7 shows that the way in which they can be used is of key importance from the point of view of the quality of evacuation using emergency stair travel devices. We can distinguish three types of people whose qualifications (non-professional rescuer, professional rescuer) or the place where they are (evacuated person) have an impact on the evacuation:

(1) "Non-professional rescuer", i.e. a random person providing help at the first spontaneous stage of evacuation; there is a diversity in limitations, such as age, height, physical strength, vision, hearing and technological skills.

(2) "Professional rescuer", such as a firefighter, paramedic or other professionals usually physically fit and well-versed in the operation of various evacuation devices and evacuation procedures; this kind of person usually appears in the second stage of the evacuation;

(3) Evacuees, similarly as the first group, are highly diverse in terms of needs [12], and these needs may change depending on the evacuation conditions [13, 14].

Each of these people evaluates the quality of the device differently.

3.4. How to measure the evacuation quality of people with mobility impairments from buildings using Emergency Stair Travel Devices?

An analysis of scientific literature provides essential information regarding objective evacuation parameters measured and scientifically analysed, which can determine the quality of different evacuation devices and allow comparison of evacuation devices or procedures. All the researchers aimed for these parameters to correspond to the primary function of the device, i.e. the ability to quickly and reliably evacuate the study group of people. The results of empirical research on evacuation devices are figures in various measured quantities presented in table 2.

Table 2. Scientifically tested product quality parameters during evacuation

Quality component	Unit	Who is affected by the quality component	Purpose of component changes	Reference
Average evacuation time	second	Rescuer, rescued person	Minimisation	(Adams and Galea, 2011; Lavender *et al.*, 2014; Mehta *et al.*, 2015)
Evacuation speed	m/s	Rescuer, rescued person	Maximisation	(Adams and Galea, 2011; Lavender *et al.*, 2014; Kuligowski *et al.*, 2013; Mehta *et al.*, 2015; Lavender *et al.*, 2015; Kuligowski *et al.*, 2015; Szulc, Cisek and Król, 2022)
Number of rescuers	pcs.	Rescuer	Minimisation	(Hedman *et al.*, 2021)

table 2 cont.

Quality component	Unit	Who is affected by the quality component	Purpose of component changes	Reference
Effort of rescuers	Pulse frequency	Rescuer	Minimisation	(Fredericks *et al.*, 2006; Lavender *et al.*, 2014, 2015; Hedman *et al.*, 2021)
Convenience of the rescued person	–	Rescued person	Maximisation	(Lavender *et al.*, 2012, 2013)

Table 2 can be treated as a scientific decomposition of the quality of evacuation devices.

In addition to the values specified in it, other objective or objectified parameters can be indicated. They have been collected in table 3.

Table 3. Product quality parameters during evacuation not scientifically tested

Quality component	Unit	Who is affected by the quality component	Purpose of component changes	Reference
Weight of the device ready for use	kg	Rescuer	Minimisation	–
Reliability	the probability of no failure in time	Rescuer, the rescued person	Maximisation	–
Ease of use	–	Rescuer	Maximisation	–
Universal application of the device	–	Rescuer, the rescued person	Maximisation	–

Objective parameters include the weight of ready for use device, which can be measured and compared. The weight should be as small as possible. Other indirect methods can measure the Reliability, Ease of Use, or Versatility of a device. All these quantities should be maximised.

3.5. Practical quality components for emergency stair travel devices?

Qualitative parameters were identified using qualitative expert knowledge taking into account the various described qualitative aspects, i.e., depending on who the evacuated person is and who is the person carrying out the evacuation. The analyses were made considering the use of evacuation devices for egress.

It is worth noting that the few available technical standards do not indicate a systematic list of quality features of emergency stair travel devices. For the needs of their research work, the authors of the article made such a division based on their design and research knowledge, as well as many years of practice related to this type of equipment. Figure 8 shows the results of the work of the expert team.

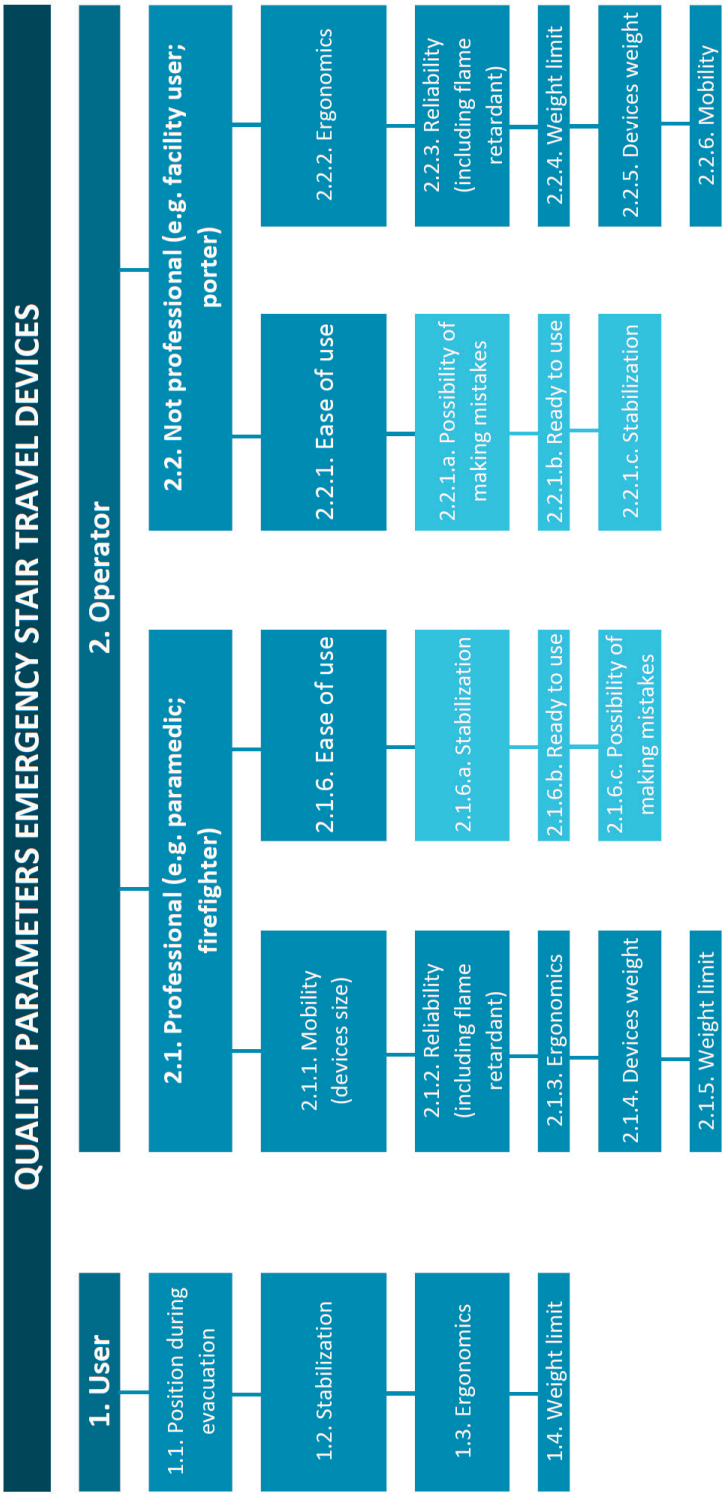

Figure 8. Identification of quality parameters of emergency stair travel devices

It summarises the quality features of evacuation equipment from three points of view: the evacuee and two types of device operators (rescuers).

The main division was about for whom this is an important quality parameter, i.e., for the evacuated person (evacuee) or the person who will carry out the evacuation (rescuer). For each of the people identified, the characteristics important when using evacuation equipment are different and do not overlap. Quality parameters relevant from the user's point of view are marked as 1.1, 1.2, 1.3, and 1.4.

Quality parameter 1.1 is "body position during evacuation". An evacuation chair is recommended for people who can maintain a stable sitting position during evacuation and cooperate with the chair operator (do not try to disturb him during the evacuation – people with mental disorders or in shock). An evacuation chair is not recommended for people with severe bends of the limbs or spinal injury. In the case of a four-wheel fixed evacuation chair (EnSafe.One Falcon type; Fig. 9) the body position during horizontal evacuation is similar to the body position in a standard chair.

Figure 9. Evacuation chair with fixed four wheels (tilted backward) (EnSafe, 2023)

The four-wheel fixed evacuation chair ensures easy transfer "to" and "from" the evacuation chair, e.g. into a wheelchair. When using this type of evacuation chair, there is no panic effect in the evacuee during preparation for evacuation downwards because this type of evacuation chair is tilted backward before traveling downstairs (Fig. 10).

Evacuation chairs with folding rear wheels (e.g., EnSafe.One Robin type; Fig. 13) offer a "sling" position during horizontal evacuation. In this type of chair, a transfer "to" and "from" the evacuation chair to the wheelchair is more complex as compared to the evacuation chair with fixed four wheels; additionally, when preparing the evacuation chair to travel downstairs, the evacuated person may experience discomfort, fear or even panic – especially when this activity is performed at the edge of the stairs (Fig. 11).

Figure 10. Method of tilting an evacuation chair with fixed four wheels (EnSafe, 2023)

Figure 11. Evacuation chair with foldable rear wheels (EnSafe, 2023)

An evacuation mattress (e.g. EnSafe.One PRIME; Fig. 12) requires a lying position of the evacuee during evacuation. This device enables the evacuation of a person with injuries (in the case of using a spinal board and performing initial stabilisation, the person responsible for evacuation or the Head of Rescue Action decides about the evacuation) and people who do not fully cooperate with the operator. Disabled people in wheelchairs have a difficult task if they want to make a self-transfer to an evacuation mattress because they have to lie down on a mattress spread on the floor (mattress thickness 6-10 cm). The mattress is ca. 60 cm wide and ensures safe, comfortable evacuation down the stairs.

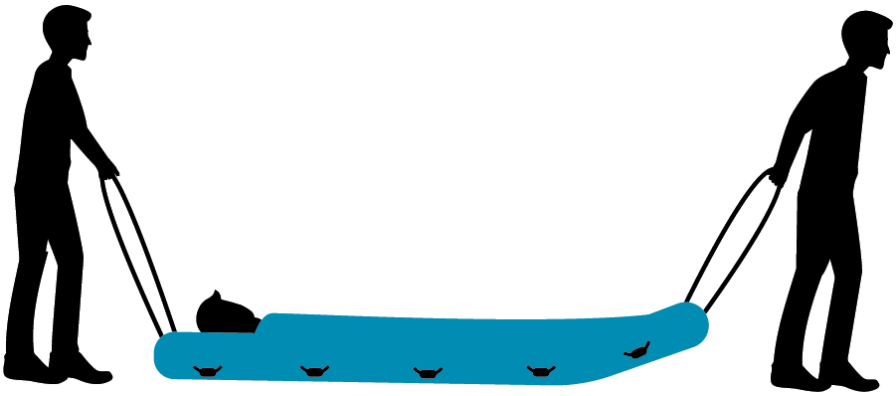

Figure 12. Evacuation mattress (EnSafe, 2023)

An evacuation mat (e.g. EnSafe.One Mat) enables evacuation in a lying position. It can be a psychological discomfort because some people are afraid that they would be dropped by rescuers, operators of the mat. In addition, because the mats are made of thin material, they are not as comfortable as evacuation mattresses and provide less protection to the evacuee.

Evacuation chairs and seats make it possible to evacuate persons by carrying them in a sitting position. As with mats, this can cause psychological discomfort – some people are afraid that rescuers, chair and seat operators, would drop them. In addition, the evacuated person is in very close direct contact with the rescuers, chair and seat operators, which may give the impression that the comfort zone has been violated.

Quality parameter 1.2 is "Stabilization" – the tighter the person evacuated on the chair or the evacuation mattress will be, the more securely provided, then their sense of psychological comfort during the evacuation is likely to be better; moreover, it will ensure a higher level of safety and protect against falling out, slipping out of the chair, mattress or mat.

Paradoxically the ergonomics for the evacuee (quality parameter 1.3) is not the most important one. Evacuation devices are not used for everyday transport, but merely for emergency evacuation, so it is assumed that the time spent in such a device by the evacuee would be relatively short (usually from several to several dozen minutes) and ergonomics understood as comfort for the evacuee is not a priority if we increase the usability of the given equipment and achieve its better degree of use, universality; based on own experience and the experience of people participating in the research indicated in the bibliography, it may be stated that people feel comfortable when they are not afraid that the structural elements of the building or stairs would cause pain or injury when in contact with them – this is particularly important when using mattresses and evacuation mats (the mattress protects the evacuee against the impact of the stairs thanks to the foam used; the mat does not provide such comfort and is not preferred by the user, i.e. the person

being evacuated); nevertheless, when designing this type of equipment or selecting one available on the market, attention should be paid to such aspects as:

- Evacuation chair – height adjustment of the headrest has been provided; structural elements in direct contact with the body of the evacuated person (back and leg rests, especially in the thigh space) have been appropriately profiled or covered with soft material;
- Evacuation mattress – ensured an appropriate foam thickness and soft head stabilizers ensuring comfort when dragging the mattress across the floor or going down the stairs; use of material covering the entire body of the evacuee up to the sternum area; limiter in the leg area protecting the person being carried from slipping out when going down the stairs;
- Evacuation mat – ensuring an appropriate number of carrying handles (recommended eight, i.e., two for each operator) and at least three safety straps protecting against falling out; limiter in the leg area to prevent the person being carried from slipping out during carrying.

Quality parameter 1.4, a weight limit is the maximum user weight allowed by the device. Only one of the standards (RESNA/ANSI regarding the requirements of stair travel devices for evacuation) indicates what should be the minimum load capacity and strength of this type of equipment and is 350 lbs (approx. 159 kg) (RESNA ED-1:2019). Evacuation equipment is used during situations that may cause direct threats to human life and health. Considering all of the above, the durability of this equipment should be maintained; therefore, the standard mentioned above indicates that a safety factor of 1.5 should be preserved during tests and studies. During testing, the evacuation chair must have a strength of 525 lbs (approx. 238 kg). This solution assures protection to the person being evacuated and the operator from potential damage to the evacuation chair when it is operated with a maximum load of 350 lbs (approx. 159 kg).

Quality parameters relevant from the point of view of the operator are divided into two main subgroups; the subgroup marked as 2.1 covers parameters related to professional rescuers. The subgroup marked as 2.2 include the point of view of non-professional rescuers (who usually initiate a rescue operation and lead it until the arrival of professional rescuers or join them spontaneously in case of mass threats). Quality parameter (2.1) can be decomposed into six elements from 2.1.1 to 2.1.6. The 2.1.1 parameter, the "mobility of the device" (related to its size) is an essential quality parameter because there is always "not enough" space for devices in ambulances or fire trucks; therefore, the size of the equipment often determines its usefulness; moreover, the equipment must be easy to carry by one rescuer; therefore as an effect its physical dimensions, such as height, width, and depth, are the primary selection criteria. The "reliability" (parameter 2.1.2) is crucial because the equipment used to save human life and health (class I medical device following the Regulation of the European Parliament and of the Council on medical devices (*Regulation (EU) 2017/745 of the European Parliament and of the Council of 5 April 2017 on medical devices, amending Directive 2001/83/EC, Regulation (EC)*

No 178/2002 and Regulation (EC) No 1223/2009 and repealing Council Directives 90/385/EEC and 93/42/EEC (Text with EEA relevance), 2017) it must be made of high-quality components ensuring it would not fail during operations; it must not be damaged or prevent evacuation or transport or cause additional injury to the evacuated person (user); equipment used especially by firefighters may be exposed to elevated temperatures; therefore this means that it should be made of a material that is at least difficult to ignite (EN 13501-1+A1:2019); it is recommended that this type of equipment have a quality assessment issued by independent institutions such as Technischer Überwachungsverein (TÜV), British Standards Institution or similar.

Parameter 2.1.3, the ergonomics, is essential because professional operators use evacuation devices also for transport; taking into account that there may be a repeated need to use the equipment during rescue or firefighting operations, this equipment must not cause harm to the body of the rescuer; it is recommended that the equipment meets the following recommendations:

- Evacuation/rescue chairs – the length of the main handle should be adjustable, ensuring proper extension during downward evacuation so that the rescuer does not have to lean forward towards the chair naturally; if the chair is equipped with additional handles for carrying and upward evacuation, ensuring proper extension, which increases the comfort of carrying and enables carrying the victim up the stairs in a position close to upright;
- Evacuation mattress – the appropriate length of the dragging handles so that the rescuer can pull the mattress in horizontal evacuation using his torso, the strength of the whole body, and moving with the face in the direction of evacuation, equipping the mattress with additional handles that allow it to be manoeuvred in tight staircases or narrow spaces;
- Evacuation mat – carrying handles of appropriate width so that it can be carried in firefighter's gloves; handles made of a material that is not very slippery after contact with water, which could cause the evacuee to drop during the evacuation.

Quality parameter 2.1.4 (weight of device) influences evacuation efficiency. Evacuation devices must be as light as possible because the rescuer will have to transport it horizontally from the car to the building (carrying it) and then in high-rise buildings with a staircase to a specific floor (during a fire or other random event, for safety reasons, rescuers do not use lifts and rescue lifts are not always available); rescuers take with them as much equipment as possible to help those in need as quickly and effectively as possible, which is why in Poland the fire brigade implements the programme "free hands for the fire brigade" (explanation: the fire brigade consists of two rescuers – one rescuer, one for safety reasons, it never conducts activities; at least two rescuers must carry out each operation – the troop).

Given the weight of the equipment and mobility for rescuers, evacuation chairs with foldable rear wheels are recommended (Fig. 13), rescue mattresses with the possibility of attaching rescue boards that can be carried at the back (Fig. 14), and rescue mats as permanent equipment and having minimal dimensions, so they can be personal equipment and be always with the rescuer (Fig. 15).

Figure 13. EnSafe.One ROBIN an evacuation chair with folding rear (EnSafe, 2023)

Figure 14. Rescue mattress enabling quick attachment and detachment of the spine board EnSafe.One RESCUE (EnSafe, 2023)

Figure 15. Rescue mat constituting the personal equipment of a rescuer; EnSafe.One RESCUE MAT (EnSafe, 2023)

Quality parameter 2.1.5, Weight limit, determines usability. According to the RESNA/ANSI standard, evacuation chairs must have a strength of at least 350 lbs (approx. 159 kg) (RESNA ED-1:2019, 2019). According to the EN-1865-1 standard, cardiac stretchers, chairs and mats must offer a load capacity of at least 150 kg (EN 1865-1+A1, 2015). Functional requirements indicated in the RESNA standard and the EN standards are similar. In most cases, they are sufficient; therefore, this parameter is less critical for the rescuer.

Parameter 2.1.6, ease of use, has three aspects, stabilisation, readiness to use and fault tolerance:

- (2.1.6.a) Stabilisation – when the person is more securely stabilised in the rescue device, the easier and faster would be evacuation because the rescuer will be sure that it is unlikely that the person could be threatened by falling out; it is recommended that the chair should have at least a stabilising upper body, one strap to stabilise the legs and a strap to stabilise the head; if an evacuation mattress is used, the more it stiffens and restricts the freedom of movement of the evacuee, the better for the rescuers because there would be less risk of the evacuee falling out of the mattress. As regards injured persons (spinal injury, back injury, fractures), evacuation on an evacuation chair or a standard mat or evacuation mattress may not be possible because it would

cause additional secondary injuries for the evacuee, which may result in deterioration of their health or may even prove to be life-threatening; in such cases, it is recommended to use a unique evacuation mattress that allows attaching an orthopaedic board on which a pre-treated victim is placed (it is necessary to remember to use an evacuation/rescue mattress (Fig. 16) which can be easily "attached" and "unhooked" from the rescue board to keep the "one plank" principle, i.e. that the injured person is not moved from cover to cover during the entire evacuation process and transport to the hospital in order to limit secondary injuries);

Figure 16. Rescue mattress with the capability of quick attachment and detachment of the orthopaedic board; EnSafe.One RESCUE (EnSafe, 2023)

- (2.1.6.b) readiness to use – the faster the equipment can be deployed during rescue operations, the better; however, the equipment is not "ready for use" when there are not enough rescuers on-site to operate it; evacuation chairs can be used by one rescuer, which is their great advantage; two people are needed to operate the mattress, and as regards mats and rescue stretchers, at least two (when a person weighs up to approx. 70 kg) or four people; taking into account this parameter, evacuation chairs are recommended for people with no injuries, and evacuation mattresses with the possibility of attaching a spine board to a bigger extent for people with severe injuries; rescue/evacuation mats and stretchers due to the number of rescuers necessary to operate them (usually four rescuers) are currently not recommended;
- (2.1.6.c) fault tolerance – the possibility of making mistakes by rescuers with respect to the analysed evacuation equipment is the least important parameter; rescuers know the equipment they have at their disposal; they practice with it regularly, know how to use it and use it in their work,

therefore, regardless of what kind of evacuation equipment they use, they are able to use it correctly.

As mentioned, subgroup 2.2 includes the point of view of non-professional rescuers. The ease of use (parameter 2.2.1) can be divided into three elements:

- (2.2.1.a) Possibility of making mistakes – the most important parameter from the user's point of view; many people in a stressful situation may not act rationally and their behaviour and thinking is likely to be affected by stress; often people are not able to use a fire extinguisher, although it seems to be very simple, therefore the use of an evacuation chair or mattress may cause problems and this should be taken into account when selecting equipment to be used by people in a given building; chairs, evacuation mattresses should be designed in such a way as to limit or exclude the possibility of making a mistake or their misuse; for use by non-professional operators, evacuation chairs with fixed four wheels are recommended (Fig. 17) - there are chairs available on the market that may be made ready for use with only two movements and it is not necessary to fold the rear wheels as in the chair indicated in Fig. 13 (this operation it is not intuitive and easy to remember, which means that people who will use this equipment incidentally, e.g. during annual exercises or trainings, will have a problem with their use and eventually may refrain from using them); we also recommend the use of evacuation mattresses that have descriptions of the sequence of actions on each element (Fig. 18);

Figure 17. Evacuation chair with four fixed wheels EnSafe.One FALCON (EnSafe, 2023)

Figure 18. Rescue mattress with marked functional elements; EnSafe.One RESCUE (EnSafe, 2023)

(2.2.1.b) Ready to use – in order to be used, evacuation devices must be located in generally accessible places during evacuation (near the staircase) or places where a person with special needs may be present; quite frequently it is not known who the evacuated person will be; therefore it is recommended to equip evacuation chairs and mattresses with fasteners that are easy to adjust, i.e., velcro fasteners (Fig. 19), airplane seat belts (Fig. 20) so that, regardless of the dimensions of the evacuated person (height, weight), they can be immediately secured with adjustable fasteners, belts for the person to be evacuated as quickly as possible; research and tests carried out by the authors of the article have shown that the use of the above solutions can save from 1 to 2.5 minutes, which directly affects the readiness of the equipment for evacuation;

Figure 19. Velcro used in the evacuation mattress; EnSafe.One PRIME (EnSafe, 2023)

Figure 20. Airplane type seat belts used in an evacuation chair; EnSafe.One FALCON (EnSafe, 2023)

- (2.2.1.c) Stabilisation is an important parameter in the same sense described in point 2.1.6.

Quality parameter 2.2.2 is Ergonomics. It cannot be assumed that non-professional operators would be physically as fit as professionals (rescuers), therefore, the equipment they are to use must minimise a situation in which they could lose control during evacuation; such a risk exists when an evacuation chair with foldable rear wheels is used while approaching the edge of the stairs (passing the edge of the stairs before the rear wheels are folded), evacuation downwards when the direction of evacuation is changed on the stairs landing and completing the evacuation at a level where vertical evacuation is switched to horizontal evacuation (lifting the chair up too late and in the case of shorter people with low weight, there may be a lack of control over the chair and it may tend to tip over towards the operator); therefore, for evacuation by non-professional rescuers, the use is recommended of evacuation chairs on four fixed wheels (Fig. 21), additionally with a stair lock (Fig. 22) preventing accidental descent, and evacuation mattresses – this equipment significantly reduces the occurrence of critical situations.

Quality parameter 2.2.3 is device reliability. It is worth mentioning that in public buildings it is also possible to use electric evacuation chairs that allow one person to evacuate upwards and downwards without the necessity of using a lot of force (Fig. 23) – this is especially important in buildings when evacuation is to proceed up the stairs; the most unreliable element of such a solution is the battery that may not be charged or damaged or damage to the engine or to transmission; in this case, it is recommended that the chair be constantly connected to a charger (a suitable battery and charger with a backup function must be provided); it is advisable that this type of chair should be able to evacuate downwards without a working battery or in the event of a motor failure (the use of a clutch is required); each evacuation equipment (class I medical device) should be serviced and maintained once a year to ensure that it is fully functional and safe when it is

Figure 21. Evacuation chair with four fixed wheels; EnSafe.One FALCON (EnSafe, 2023)

Figure 22. Safety lock against accidental descent downstairs in the evacuation chair; EnSafe.One FALCON (source: *(EnSafe, 2023)*)

necessary to use it; evacuation equipment can be used during a fire in the facility and, moreover, it is often stored on the escape route, therefore it should be made of a flame-retardant material as per EN-13501-1 or equivalent properties); it is recommended that this type of equipment have a quality assessment issued by independent institutions such as TUV, BSI, or similar.

Parameter 2.2.4 is the Weight limit. As as is well-known, each device can be used within the technical parameters for which it was designed; the standard permissible load is defined in the description of quality parameters relevant to the user; if non-professional operators use the equipment, the appropriate type of equipment should be selected, e.g., with respect to what people can or are in the building including bariatric people; the permissible load is a parameter that has an indirect importance for the chair operator, but has a direct impact on him.

Figure 23. Evacuation chair with the electric drive; EnSafe.One EVEREST (EnSafe, 2023)

Parameter 2.2.5 is the weight of the device. For a non-professional rescuer, this is a parameter of lesser importance because, in most cases, the chair and the evacuation mattress will be used where it is located, and there will be no need to transport it or move it between floors; nevertheless, it is recommended that the weight of the evacuation chairs, in particular, should be as low as possible (EN 1865-1+A1, 2015).

Mobility (parameter 2.2.6) for a non-professional rescuer is another less critical parameter; evacuation equipment is located in the area where it will be used and where adequate space in the building has been provided for its storage and use; moreover, it is recommended in the case of evacuation chairs to be stored in an unfolded position (if possible); this solution makes the evacuation process easier and improves it considerably.

4. Conclusions

The study is aimed at identifying predictors of the quality of devices designated for evacuating people with special needs from buildings. It was assumed that this quality is specific to the device user and the stage of the device life cycle. Three types of users were considered: evacuated persons, non-professional rescuers and professional rescuers. It was assumed that the use of devices for the evacuation of people with special needs is necessary.

Quality predictors indicated by available scientific literature are parameterized and non-parameterized. The parameterized predictors measure numerical values, and are comparable between literature sources. These predictors include among others average evacuation time, speed, number of rescuers, rescuers' effort, weight

of the device and reliability. The other predictors are difficult or impossible to parameterize. Some predictors can be expressed as numerical values, such as the comfort of the rescued person or reliability. The others are entirely subjective (e.g., ease of use or universality of use). Some measurable quality parameters have not been scientifically tested: weight of the ready for use device, reliability, ease of use and universality.

The expert analysis suggests that the essential requirements for evacuation devices differ for different people and do not overlap. For example, for an evacuee, the body position during evacuation is essential, while from the point of view of evacuation equipment operators, ease of use, mobility, and tolerance for errors in use are vital. Both groups of operators have similar requirements, but they have different priorities.

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JAKOŚĆ URZĄDZEŃ PRZEZNACZONYCH DO EWAKUACJI PO SCHODACH

Abstrakt

Urządzenia przeznaczone do ewakuacji osób z budynków używane są podczas początkowej niekierowanej ewakuacji spontanicznej, jak również przez profesjonalne służby ratownicze. Wymagania wobec krzeseł ewakuacyjnych są zróżnicowane, z jednej strony są one determinowane przez uwarunkowania techniczne budynku, z drugiej przez specyficzny sposób działania osób je używających, operatorów nieprofesjonalnych i profesjonalnych, a z trzeciej strony muszą uwzględniać specyfikę osób ewakuowanych. Problemem jest wskazanie parametrów jakościowych krzeseł ewakuacyjnych, tak żeby można było je dopasować do wymagań organizacyjnych i technicznych. Celem artykułu jest wskazanie i uzasadnienie takich parametrów jakościowych urządzeń ewakuacyjnych. Punktem wyjścia jest ilościowa analiza dokumentów naukowych. Ustalono, że istnieją zaledwie 33 dokumenty naukowe odnoszące się bezpośrednio do badań na temat ewakuacji osób z niepełnosprawnościami ruchowymi po schodach. Na podstawie literatury dokonano klasyfikacji badanych urządzeń do ewakuacji na trzy główne typy: urządzenia do przenoszenia, urządzenia do przewożenia i urządzenia do przeciągania po klatce schodowej. Zidentyfikowano trzy grupy potencjalnych użytkowników urządzeń do ewakuacji osób po schodach: 1) „ratownik nieprofesjonalny", czyli osoba, udzielająca pomocy w pierwszej spontanicznej fazie ewakuacji; (2) „ratownik profesjonalny", czyli strażak lub inny profesjonalista, który jest sprawny fizycznie i dobrze obeznany z działaniem urządzeń oraz procedurami ewakuacji, tego rodzaju osoba pojawia się zwykle w drugiej fazie ewakuacji; (3) osoba ewakuowana. Każda z tych grup ma specyficzne potrzeby i inaczej ocenia jakość urządzenia. Na podstawie analizy literatury naukowej zidentyfikowano następujące predyktory jakości urządzeń do ewakuacji po schodach: Średni czas ewakuacji (s), Prędkość ewakuacji (m/s), Liczba ratowników (szt.), Wysiłek ratowników (estymowany zużyciem tlenu lub częstotliwością pulsu), Wygoda osoby ratowanej (estymowana częstotliwością pulsu lub na podstawie badań ankietowych). Na podstawie analizy eksperckiej ustalono, że istotne wymagania wobec urządzeń do ewakuacji są różne dla różnych osób i nie pokrywają się. Dla osoby ewakuowanej np. istotna jest pozycja ciała podczas ewakuacji, a z punktu widzenia ratowników do ewakuacji ważne są łatwość użycia, mobilność i tolerancja na błędy w użyciu. Obydwie grupy ratowników mają podobne wymagania, jednak mają one zróżnicowany priorytet.

Słowa kluczowe: urządzenia do zjazdu po schodach; krzesło ewakuacyjne; krzesło ratownicze; urządzenia ratownicze; osoby z niepełnosprawnościami; osoby ze szczególnymi potrzebami; inwalidztwo; mobilność; ewakuacja; działania ratownicze; akcja ratownicza; ćwiczenia przeciwpożarowe; projekt budowlany; bezpieczeństwo przeciwpożarowe