An Online Survey of Pedestrian Evacuation Model Usage and Users

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Abstract. Pedestrian evacuation models are often used to assess life safety in the performance-based design process within fire safety engineering. Within this paper, a summary of data collected via an international online survey regarding the models and users' experiences and needs is presented. This survey consisted of 22 questions focusing on: the assessment of the pedestrian evacuation model user community; their stated importance of model features to select a model; usage/awareness of models; knowledge of model validation and verification; training; and usage of multiple models. As such, the survey allowed the collection of information useful for instructing future pedestrian evacuation model development. The survey represents an expanded version of a previous survey conducted by the authors in 2011. Results with the previous survey were compared to identify any changes in preference and usage by pedestrian evacuation model users. The survey was completed by 234 respondents from 41 countries. The respondents had a wide range of education and occupational backgrounds and use models for a variety of different purposes. The results identified a total of 72 pedestrian evacuation models currently in use and indicated the most known models. In addition, the most used models were identified, and the results highlighted that the three key factors used to select a pedestrian evacuation model are overall consistent with the results of the 2011 survey: verification and validation, documentation, and data output of the model.

Keywords: Evacuation models, Egress, Simulation, Online survey, Modelling

1. Introduction

Investigations on how people behave during fire emergencies have been carried out for over a century with some of the first investigations dating back to 1909 focusing on the study of movement speeds [1]. Such studies have been used as the basis for the development of several pedestrian evacuation models: computational models able to represent the movement and/or behaviour of people during an emergency evacuation scenario using either microscopic, macroscopic, or meso-

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scopic approaches [2]. Given this definition, pedestrian evacuation models refer here to any egress model, pedestrian model, or crowd model that can be used to represent emergency evacuation scenarios. Today such tools are widely adopted in the building design process where performance-based design is applied [3].

One of the first attempts to develop a computer pedestrian evacuation models was done in the 1970s by Bazjanac [4] to investigate elevator performance in high-rise buildings in emergency scenarios. Since this study, several other computer pedestrian evacuation models have been developed using different approaches to simulate evacuee behaviours. Gwynne et al. [5] and Kuligowski et al. [3, 6] have provided a review of 22 and 26 pedestrian evacuation models respectively by categorizing them depending on their features such as modelling method, validation, refinement of population, structure, and simulated behaviour. Another review was carried out in 2013 by Duives et al. [7], in which 27 crowd simulation models suitable for evacuation purposes were compared.

To date, the number of computer pedestrian evacuation models for fire safety engineering applications and their complexity is continuously increasing. As such, it is of key importance to better understand current users' experiences and their needs for next generations of computer pedestrian evacuation models. Initial attempts to address this issue were in studies carried out by Ronchi and Kinsey [8] and Lovreglio et al. [9]. The former study presents the results of an international online survey carried out in 2011 aimed at investigating the main factors affecting the selection and use of computer pedestrian evacuation models, as well as identification of the most used and popular models. The latter study presents the results of a similar online survey, but with a regional focus, i.e., respondents were all from New Zealand.

This paper represents an attempt to investigate the global *status quo* of pedestrian evacuation modelling. To achieve this, an international online survey has been carried out in 2018. The goals of the study are to assess (1) the current field of applications of pedestrian evacuation models and how often they are used; (2) the level of expertise of the pedestrian evacuation model community, training attained as well as years of experience in the field; (3) if/why respondents have changed from one pedestrian evacuation model to another and (4) the assessment of new features needed in pedestrian evacuation models (e.g., Building Information Modelling support, etc.). The survey was developed by adopting an expanded version of the survey conducted by Ronchi and Kinsey [8]. The motivation to conduct the survey was linked to the fact that a number of models and their characteristics have since been enhanced/developed in addition to significant proliferation in teaching the use of pedestrian evacuation modelling within high education and adoption within industry. The target audience for the survey included several groups such as students, fire safety engineers, software engineers, behavioural scientists, and researchers involved in pedestrian evacuation modelling. A comparison with the early study from 2011 [8] was performed to identify the changes which occurred in the pedestrian evacuation modelling community and models since then.

2. Methods

An online survey was developed which included a set of closed-ended questions which provided a number of methodological benefits for collecting data. Using an online survey is an optimal approach to reach a large international audience. Moreover, previous studies have shown that the use of online surveys can increase the chances of increased sample size [8, 10, 11]. However, the use of online surveys introduces some limitations regarding assessing the response rate: advertising the survey on social media and forums does not allow researchers to estimate how many people read the advertisement and thus the percentage of people deciding to take part in the survey. This may be associated with a response bias linked to the fact that people interested in the survey topic might be more willing to respond to it. Another limitation is the inability to ensure consistency with the environment in which the respondents completed the survey which may influence the answers given. It should also be noted that the survey was disseminated in English language, thus restricting the group of respondents to English-speaking people. The survey was developed using a survey tool developed and hosted by Google. As such, the survey was only accessible to respondents and global regions where Google services are accessible (which has changed since the original survey when Google was more widely available in different countries).

The survey questions were phrased in order to be simple to understand, reduce any ambiguity, and thus make them easy and quick to answer. In doing so the expectation was to obtain a higher sample size and reduce the number of incomplete responses. Moreover, such a technique simplifies the data analysis as there is no need to apply coding protocols (which may also be associated with several issues, e.g. inconsistencies in coding performed by different researchers), which are instead necessary for open-ended questionnaires and interviews [12, 13]. However, the limitations regarding the methodological choice of closed-ended questions relate to limiting/affecting the variety of responses and viewpoints [14]. To address this issue, respondents were permitted to provide customised responses (e.g. “other”) which were not included in the available options in addition to being able to write an open-ended comment at the end of the survey to allow the respondents to add other information regarding the survey topic.

3. Survey

The online survey consisted of 22 questions divided into two sections. Most of the selected questions are based on the early study from 2011 [8] to allow comparisons between the new and existing results. A number of new questions referring to Building Information Modelling (BIM) were added considering its increasing prominence in the building design process and specifically within the fire safety engineering domain [15, 16]. This is exemplified by a number of pedestrian evacuation models allowing BIM formats (e.g., such as Industry Foundation Classes (IFC) formats) to import building geometries into a model. In addition, BIM tools such as Autodesk Revit and Vectorworks are developing capabilities to integrate pedestrian evacuation models within the core design software. Additional

Figure 1. Demographics and background of the respondents. Note: the sum of the percentages of (b), (c), (d) is higher than 100% as the respondents had the chance to choose multiple options.

questions were also added regarding practical factors that could affect the choice of a pedestrian evacuation model and if/why respondents changed to using an alternate pedestrian evacuation model.

The first part of the survey requested respondents to provide information regarding demographics, educational, and work background. The second part of the survey refers to asking respondents about the following:

- (a) Model awareness and selection: which pedestrian evacuation models respondents are familiar with and mainly use.
- (b) General and practical factors affecting the model selection.
- (c) Model use: which pedestrian evacuation models respondents and in which contexts/buildings and how often respondents used these models.
- (d) Training: how respondents learnt the use of computer pedestrian evacuation models.
- (e) Model change: if/why respondents have changed computer pedestrian evacuation models.
- (f) The need for BIM support.

The survey was made available online and disseminated through social networks (e.g. LinkedIn and Twitter) and email lists for a period of 5 months (Jan 2018–May 2018). The goal was to achieve a relevant number of respondents belonging to different areas of expertise that use different models. Given the fact that the main network of the authors is primarily in the fire safety engineering domain, the majority of the people reached out by the survey were indeed belonging to that community. The aim was to collect data from a comparable sample size to the 2011 survey by Ronchi and Kinsey [8] (i.e. 198 respondents). The dissemination method was similar to the one performed in 2011, thus it is likely that some of the respondents who responded to the survey in 2011 replied also to the current survey. However, it is not possible to identify these respondents as they were not asked if they had completed the previous survey.

4. Respondents' Characteristics

The survey was filled out by 234 respondents from all around the world. The respondents came from a variety of countries (see Fig. 1a), educational and work backgrounds (Fig. 1b–d), and experiences with different pedestrian evacuation models (Fig. 1e).

Within the 2011 survey by Ronchi and Kinsey [8], the country of residence with highest percentage of response were the United Kingdom (16%), Germany (15%), and the US (10%). By comparison, in the current study the country of residence with the highest percentage of respondents were United Kingdom (9%),

(a)

(b)

(c)

(d)

(e)

Australia (7%), New Zealand (6%), Sweden (6%), and Italy (6%) (see Fig. 1a). This can be due to the new authors' affiliation, their countries of origin and their current network. It should be noted that one of the authors is based in Oceania, thus explaining why the number of respondents in this region is higher than in the survey conducted in 2011. It should also be noted that survey platform was hosted by Google which was available in China in the 2011 survey, however, has since been blocked which would have inhibited/restricted participation from China. In addition, the previous survey was made available in different languages including English, German, Chinese, and Italian which would have also influenced regional responses.

Figure 1b and c indicates that most of the sample is made of respondents from engineering and fire engineering backgrounds and that a quarter of the sample works in academia while the remainder works in industry or other fire safety-related areas. These results are comparable to those observed in the 2011 survey by Ronchi and Kinsey [8].

Finally, Fig. 1e indicates that almost 60% of the sample has between zero to five years of experience with pedestrian evacuation models. This level experience is consistent with that observed in the 2011 survey [8]. In the 2011 survey, there were 61% of respondents that had more than 5 years' experience with pedestrian evacuation models. The current sample includes 41% of respondents having more than 5 years' experience. Respondents of the current survey were not asked if they participated in the 2011 survey so it is unclear if previous participation influenced the results.

5. Results

The main results of the survey are presented below and relate to (1) model awareness, (2) model selection, (3) model usage, (4) Training, change of model used, and BIM integration.

5.1. Model Awareness

The results indicate that the total number of computer pedestrian evacuation models the respondents are aware of is equal to 72. This data was collected by allowing users to tick boxes from a list provided in the survey. This list was taken from the original survey and expanded including new models. However, the respondents had the chance to add the name of further models if these were not included in the provided list.

The models which are known by at least 10% of the sample are listed in Fig. 2. The three pedestrian evacuation models which respondents were most aware of were: Pathfinder [17], FDS+Evac [18], and STEPS [19]. The remaining pedestrian evacuation models which users were most aware of were Exodus [20], Simulex [21], MassMotion [22], Legion [23], VISSIM/Viswalk [24], EVACNET [25], EGRESS [26], Pedestrian Dynamics [27], SimWalk [28], FPETool [29], Evacuatz [30], EVACSIM [31].

Figure 2. Computer pedestrian evacuation models known by the sample. Note: the sum of the percentages is higher than 100% as the respondents had the chance to choose multiple options.

5.2. Model Selection

The respondents as a whole identified a set of 32 pedestrian evacuation models which they mainly used. The models used by at least 1% of the sample are listed in Fig. 3. All of these models are from the list of the most known computer pedestrian evacuation models presented in Sect. 5.1 with the exception of crowd:it [32]. It is worth highlighting that 6% of the sample stated they did not to use any pedestrian evacuation model (i.e. they may only use hand calculations, e.g., [33, 34]).

The respondents were presented with a list of general factors affecting their selection of pedestrian evacuation models. They were asked to state how important they thought each factor was when selecting a model based on a 5-point Likert scale (5 = very important and 1 = not important). For conducting analysis of all results, all scores were averaged for each factor and then placed in order in accordance with their ranking (the higher the value the more important the factor). A Wilcoxon Signed-Rank tests was used here to determine if any statistically significant difference existed between factors so that each factor could be given an ordinal value of importance (see black box ordinal values in Fig. 4) relative to the other factors. The analysis indicates that all the factors can be divided into six ordinal classes of relative importance. Factors belonging to the same class have a score that is not statistically different assuming a level of significance of 0.05 according to the Wilcoxon Signed-Rank test. It should be noted that the factor ‘Visual realism of graphics’ represents how visually realistic the computer graphics of the simulated environment are whereas the factor ‘Visual realism of behaviour’

Figure 3. Computer pedestrian evacuation model mainly used by the sample. Respondents could select only one model when replying to this question.

refers to how realistic people movement, decision making, and actions are within the simulate environment.

Finally, the respondents were asked to select among a list of practical factors affecting the selection of pedestrian evacuation models. The ordered list of these factors is illustrated in Fig. 5, showing that the level of trust in the research/development done with the model was on ranked of greatest importance when choosing a pedestrian evacuation model (44%).

5.3. Model Usage

The scenarios and circumstances in which models are used are reported in Fig. 6a, b respectively. Results show that the type of infrastructure in which pedestrian evacuation models are used the most by the survey respondents, i.e., at least 40% of respondents use them in this context, are: train/metro stations (49%), shopping malls (49%), arenas/stadia (48%), high-rise buildings (48%), residential/office buildings (43%), and theatres (40%). The main context of usage were code/standard compliance (63%), aiding analysing design of new structures (60%), aiding/analysing design of existing structures (48%), research (25%), aiding/analysing procedural instructions (17%), and others (3%).

Respondents were also asked to state how often they use pedestrian evacuation models. The frequency results are shown in Fig. 7, showing that most people used them “at least once a month” (29%) followed by “at least once a year” (28%).

Finally, 44% of the sample reported that they use more than one pedestrian evacuation model. The reason stated are shown in Fig. 8 with the most common being “different projects need models with different features/capabilities” (59%) followed by “I use the pedestrian/evacuation model which I think is most suit-

Figure 4. General factors affecting model selection. The values on the right-end side of the figure indicate overall relative order of importance e.g. 1 = most important, 2 = second most important, etc.

able for each specific project” (57%) which highlights the nature of the project largely governs which pedestrian evacuation model is used.

5.4. Training, Change of Model in Use and Building Information Modelling

Results from the sample indicate that respondents used several approaches to learn how to use pedestrian evacuation models (see Fig. 9) with most (72%) teaching themselves and 36% having taken either a short course (< 10 training hours) or long course (> 10 training hours).

Amongst the survey respondents, 23% reported that they have changed pedestrian evacuation models during their experience. Around two-thirds of respondents stated they changed models due to either other reasons not stated, e.g., cost, lack of upgrades, likelihood to get a project approved (31%) or usability and management of the input/outputs of the model (31%). Just 20% of respondents stated they changed models due to a client, project and employer requirements.

Regarding the integration of pedestrian evacuation models in Building Information Modelling (BIM) tools (see Fig. 11), only 21% of respondents used BIM tools in the pedestrian evacuation modelling process. Moreover, the majority of respondents indicated that they would like to see further integration with BIM regarding automatic geometry building functionality to save model build times (55%), BIM software to include data regarding the type of people in a building to inform the pedestrian evacuation modelling process (33%), the wish to do pedestrian evacuation modelling directly within a BIM software (21%), ability to automatically do hand calculations within a BIM software (17%) and 5% gave other considerations. A total of 14% of the respondents think that BIM is not so rele-

Figure 5. Practical factors affecting model selection. Note: the sum of the percentages is higher than 100% as the respondents had the chance to choose multiple options.

vant to pedestrian evacuation modelling and 12% of respondents did not know what BIM is.

6. Data Comparison

Given the similarities between the questionnaire used in this study and the one adopted by Ronchi and Kinsey [8], it is possible to analyse if there were any changes in the results for the questions in common. These relate to awareness and usage of models as well as the general factors affecting pedestrian evacuation model selection.

Figure 12 illustrates the proportion of response awareness of the most popular pedestrian evacuation models in 2018 survey compared to the same models in the 2011 survey. A Chi square test was used to determine if the differences in results were statistically significant. The results indicate significantly more people were aware of the Pathfinder model now compared to 2011, however, there is no significant difference regarding differences in awareness for the STEPS and FDS + Evac models.

Table 1 compares the score order of the general factors affecting the selection of pedestrian evacuation models between each survey. The table illustrates that there is no difference for the first eight factors, i.e., the order is identical for both 2011 and 2018, indicating that factors affecting the choice of pedestrian evacuation models remained overall consistent. This supports the reproducibility of the results and provides confidence the ordinal list is unchanged over the period of time since the previous study.

Figure 6. (a) type of buildings and (b) context where computer pedestrian evacuation models are used. Note: the sum of the percentages is higher than 100% as the respondents had the chance to choose multiple options.

7. Discussion

The results of the online survey indicate that the sample, made of 234 respondents from 41 countries, is aware of a total of 72 computer pedestrian evacuation models. However, only 15 of these models are known by at least 10% of the sample: Pathfinder [17], FDS + Evac [18], STEPS [19], Exodus [20], Simulex [21], MassMotion [22], Legion [23], VISSIM/Viswalk [24], EVACNET [25], EGRESS [26], Pedestrian Dynamics [27], SimWalk [28], FPETool [29], EvacuonZ [30], EVAC-SIM [31] (Fig. 2). This highlights most people are not aware of all the available pedestrian evacuation models. From a model selection viewpoint, the results suggest that the 12 most commonly used pedestrian evacuation models are: Pathfinder [17], STEPS [19], MassMotion [22], VISSIM/Viswalk [24], Pedestrian Dynamics [27], Legion [23], FDS + Evac [18], crowd:it [32], Simulex [21], Exodus [20], EGRESS [26] and EvacuonZ [30] (Fig. 3). Furthermore, the data indicates that a significantly higher number of respondents use Pathfinder (35%) compared to any other pedestrian evacuation model. The data also suggests that despite the large number of models available (over 60 models), a limited number of models seem to be the most used.

Several potential factors may contribute to the increased awareness and usage of given pedestrian evacuation models. First, the age of the pedestrian evacuation models can affect the results as some are much older than others which could mean they have had longer to build a user base. The second factor is the regional use of models in relation to the sample of respondents and type of sample respondents (mostly in the fire safety engineering industry). Third, regional marketing/sales can impact pedestrian evacuation model awareness as generally the most

Figure 7. How often computer pedestrian evacuation models are used.

used models have agreements with resellers which can have varying scales of operation and impact in different regions. Fourth, the level of sophistication and continual development of the models can have an impact as the most used models may offer more features and may be more continuously updated compared to others. In addition, some of the models were developed for academic/research purposes and have limited marketing for wide spread adoption within the fire engineering industry. Another influencing factor relates to the free general academic/research use and subsequent wide spread tuition/adoption in fire engineering courses at universities which has grown significantly in recent times since the previous survey. Conversely some of the models are not freely available for general academic use or taught at universities which may influence awareness and usage. Pedestrian evacuation model developers whose models ranked low in the results may look to increase awareness/usage of their models through adopting/improving some of the items listed above.

General and practical factors affecting the selection of pedestrian evacuation models were investigated (see Figs. 4 and 5). Identical to the results of the 2011 survey, the data indicates that the most important general factor affecting the selection of a pedestrian evacuation model is the verification and validation: the level of reliability a model has to accurately represent reality is of key importance to users. It is evident a number of pedestrian evacuation model developers also agree with many of them producing dedicated validation and verification documentation or publishing papers presenting results of validation case studies, see for instance [35–39]. Furthermore, the development of international efforts to provide standard methods for conducting validation/verification of evacuations models [40–44] (including an ongoing effort performed within the Technical Committee 92 on Fire Safety of the International Standards Organization, ISO), will facilitate users being able to assess and compare more easily pedestrian evacua-

Figure 8. Reasons behind the use of multiple models. Note: the sum of the percentages is higher than 100% as the respondents had the chance to choose multiple options.

tion models. The data indicates that users ranked the second most important factors when selecting a pedestrian evacuation model were jointly Data Output, Documentation, and Continual Development of the model. This would appear to be closely aligned with validation/verification which requires data output, documentation, and continual development. In contrast, respondents stated the most popular practical factor when selecting a model is trust in the research done to develop the pedestrian evacuation model. This is closely connected with main factor for selecting a model being verification and validation. Indeed, the basis for verification and validation is research which provides data that models can be developed and compared with. This suggests it would be advantageous for pedestrian evacuation model developers to invest more resources in research and data collection which can be used for validation and continual model development in order to provide users with increased confidence for using their models. Finally, it should be noted that part of the sample might not have known the difference between “CAD files importing” and “Integration with Building Information Modelling (BIM)” considering that 12% of respondents said they did not know what BIM is.

Regarding the types of usage pedestrian evacuation models are used for, results indicate that more than 60% of the sample use pedestrian evacuation models to assess whether buildings are compliant with codes/standards and to aid in the design of new structures. Commonly pedestrian evacuation models are used where a building design cannot meet prescriptive fire requirements and so performance-based design is adopted in order to demonstrate people can evacuate before untenable conditions occur. Alternatively, pedestrian evacuation models may be used to compare evacuation results of a building design which is complaint with prescriptive fire requirements with the actual building design (which is not compliant with prescriptive fire requirements) to assess if there is any significant differ-

Figure 9. Type of training used by respondents to learn computer pedestrian evacuation models. Note: the sum of the percentages is higher than 100% as the respondents had the chance to choose multiple options.

ence in the results. Considering building design teams are developing ever more novel structures and pushing the technological boundaries of building design which may mean compliance with prescriptive fire requirements is challenging, it is unsurprising that the majority of pedestrian evacuation models are used for new buildings. What is perhaps surprising is that almost half of responses stated that pedestrian evacuation models were used for assessment of existing buildings. This may include where upgrade works or renovations/re-designs cause a non-compliance with prescriptive fire requirements. In both cases pedestrian evacuation models may initially be run and required to be re-run multiple times as the design changes. As such, the ease with which the pedestrian evacuation model allows users to make updates to a model is important to users which is supported by the data as the third most important factor when selecting to use a pedestrian evacuation model. This suggests pedestrian evacuation model developers should consider improving clarity with user interfaces and clear/simple work flows of how to change models (e.g. ideally with fewer clicks) in order to improve usability of the software.

The most common building types pedestrian evacuation models were adopted/used were train/metro stations, shopping malls, and arenas/stadia. This is unsurprising considering train/metro stations may be located deep underground and present a significant challenge for egress with large numbers of people being required to evacuate upwards (unlike most other types of buildings which downward evacuation is more common) [45]. Upgrade works to existing/older train/metro stations which potentially may not fully comply with the latest prescriptive fire requirements is also common, as such performance-based design may be adopted. Similarly, shopping malls and arenas/stadia typically contain large indoor enclosures where the potential for smoke spread during a fire is increased. Such

Figure 10. Reasons behind the need for the change of computer pedestrian evacuation models.

spaces commonly exceed maximum fire compartment sizes within prescriptive fire requirements, so performance-based design is also commonly adopted. Considering these results, it may be advantageous for pedestrian evacuation model developers to review the workflows of users developing models of such types of structures. This may facilitate identification of potential areas where new features could be developed, or workflows optimised to support model applications for these building types.

In terms of how often respondents use pedestrian evacuation models, there is a wide range of frequency with which different people use pedestrian evacuation models. Just over a third of respondents (37%) use models at least once a week which potentially reflects users' jobs as heavily focused on using pedestrian evacuation models. Finally, it was observed that more than 40% of the respondents had the need to use more than one pedestrian evacuation models as there are different needs for different projects and users select the model which is more suitable for the project goals (Fig. 8). This suggests it may be advantageous for pedestrian evacuation model developers to consider such users (who may not always need access to a given model) by offering temporary licensing options or 'pay per use' options for model usage in order to provide financial flexibility in their use. This could also increase breadth of adoption for such pedestrian evacuation models with it being more financially viable to use multiple models for a company (rather than being financially obligated/biased to use the model which a company currently pays a license for).

A novelty of this study is the investigation on how users got were trained in how to use models, the reason why they might stop using a model, and the use of BIM tools. The results indicate that the large majority of the sample were self-taught how to use pedestrian evacuation models using tutorials and documentation while only 20% and 16% of the sample stated that they attended short or long courses on this topic (Fig. 9). The data also highlights that costs, lack of

Figure 11. How respondents perceive BIM tools for pedestrian evacuation modelling. Note: the sum of the percentages is higher than 100% as the respondents had the chance to choose multiple options.

upgrades, likelihood to get a project approval, and usability represents the most common reasons motivating the change of pedestrian evacuation models (Fig. 10). Finally, the respondents indicate that they would like to have BIM tools to facilitate their analysis and save time (Fig. 11). As such, the expansion of the original survey provided new insights on the user needs. However, future versions of this survey need to investigate other questions concerning other features of pedestrian evacuation models, such as the interactions with fire models and transport models. In addition, future surveys may look to sample of other decision makers (i.e. senior company managers) rather than modellers as target groups in order to investigate their perspectives on modelling in light of their experience in the industry.

A comparison of the survey results was conducted with the previous survey results published in 2011 by Ronchi and Kinsey [8]. It is worth highlighting that the top three known pedestrian evacuation models in the current survey are among the most well-known models in 2011 [8]. Figure 12 illustrates how the percentage of users for STEPS and FDS + Evac are consistent while the awareness and usage of Pathfinder has significantly increased since the 2011 survey. The comparison regarding the general factors affecting model selection shows that the first eight factors have an identical order in both surveys. It is worth highlighting that the sample in 2018 is slightly different from the sample in 2011. The 2011 survey included slightly less response (198 compared to 234) coming from a slightly narrower range of countries (36 countries compared to 41). Furthermore, the current survey was only provided in English given the limited number of responses obtained in languages other than English in the 2011 survey. The results from the current study are largely consistent with the 2011 study which suggests the impact of any difference in survey dissemination/sampling between the surveys

Figure 12. Computer pedestrian evacuation models known by the sample in 2011 and 2018. (*) indicates a statistical change of percentage between 2011 and 2018.

Table 1
Orders of the general factors affecting computer pedestrian evacuation model selection in 2011 and 2018

General factors	Order	
	2011	2018
Validation/verification	1	1
Data output	2	2
Documentation (explaining how the model works)	3	3
Continual development of the model incorporating new features	4	4
Usability of the software (is it user friendly?)	5	5
Flexibility to control agents	6	6
Research into human behaviour done by the developer	7	7
CAD files importing	8	8
Emergent behaviour	10	9
Feedback/opinion about the model by other users	11	10
Inclusion of data specific to certain environments	13	11
Visual realism of behaviour	9	12
Fire/hazard data importing	14	13
Cost	12	14
Visual realism of graphics	13	15

is of negligible impact. It should be highlighted that the authors' affiliation being focused in the fire engineering field may have skewed the sampling to response from a fire engineering background. Indeed, the primary target respondents of the survey are those from a fire engineering background. However, it should be noted that respondents originated from a wide variety of countries (41 countries) and only a 62% of survey respondents stated they worked in the fire engineering

domain, thus findings should not be considered only being applicable to the fire engineering community. Further investigation is required to determine if and to what extent how a greater representation of non-fire engineer response would impact the results. Indeed whilst many of the pedestrian evacuation models listed in the survey are also used primarily for general pedestrian modelling, it is uncertain if the results from the survey are applicable to general pedestrian modelling outside of the fire engineering field (e.g., urban planning, comfort analyses and pedestrian flow optimizations in normal conditions). This is considered beyond the scope of the current study.

8. Conclusion

This study investigated pedestrian evacuation model awareness and usage via an online survey, based on an expanded version of the survey developed in 2011 by Ronchi and Kinsey [8]. The original survey was modified to investigate new trends and features within pedestrian evacuation modelling, such as the use of BIM, potential use of multiple pedestrian evacuation models, and training. The results indicate that despite the large number of models available (over 70 models) a limited number of models seems to be the most used as only 12 models were used by at least 1% of the sample. Results suggest that verification and validation is the most important factor affecting the selection of a pedestrian evacuation models which indicate the need for continuous investments in research and data collection which can be used for verification/validation and model development. The survey shows that the main use of pedestrian evacuation models relate to building compliance with codes/standards and aid in the design of new structures. The most common building types for utilising pedestrian evacuation models were identified as train/metro stations, shopping malls, and arenas/stadia. The data indicates that the majority of mode users are self-taught regarding how to use pedestrian evacuation models (via tutorials and documentation) and would prefer greater BIM integration to facilitate their analysis in addition to saving time. The comparison of the current study with the 2011 study by Ronchi and Kinsey [8] indicates that the three most known models remain the same and that general factors affecting model choice shows that the first eight factors have an identical order of importance in 2011 and in 2018.

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