Anthropomorphic Data and Movement Speeds

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Forward:

This project presents a compilation of contemporary, project specific, movement speeds from existing published and unpublished data sets from industry and academic partners globally, with special considerations for accessibility, upwards/downwards movement, etc.).

The project also studied the underlying fundamental individual characteristics of movement and presents this information to set the stage for future improvements in data collection.

In addition to this report, the project output includes an online portal and connected living database, currently under development.

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John Gales, Julia Ferri, Georgette Harun, Chloe Jeanneret, Timothy Young, York University, Canada
Michael Kinsey, Will Wong, Jared Stock, Lingyi Chen, Arup
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About the SFPE Foundation:

The Society of Fire Protection Engineers (SFPE) established its Educational and Scientific Foundation in 1979. The Foundation is a charitable 501(c)(3) organization incorporated in the United States of America and supports a variety of research and education programs to foster its mission to is to enhance the scientific understanding of fire and its interaction with the natural and built environment.

Keywords: evacuation, pedestrian movement, crowd movement, pedestrian modeling, anthropometric data sets, movement speeds

Anthropometric Data and Movement Speeds

Final Report

May 6th , 2020

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Executive Summary

This final report has been created regarding the SFPE-York project on Anthropometric Data and Movement Speeds, in collaboration with the Arup Human Behaviour and Evacuation Skills team.

The goal of this project is to modernize movement and anthropometric datasets for practitioner usage.

This research project primarily focuses on the compilation of existing movement data (both published and soon to be published), and the acceleration of recent and soon-to-be-published movement data that fit within these themes. Herein, the anthropometric and movement data from our own research has been tabulated and included in the report. This can broadly include pedestrian behaviour in emergency and non-emergency circulation studies in stadiums, cultural centres, and train stations, with special considerations for accessibility, upwards/downwards movement, etc. The York movement profiles are tabulated within this document and where applicable legacy data is tabulated for comparison. They illustrate that project specific movement parameters are needed, and general parameters may not always align with contemporary movement.

The data provided herein and the data collected from community partners will be accessible by SFPE members and the general public through the online portal, developed by York-Arup research team, and stored in a connected database to the SFPE website.

An outlook on the future of evacuation modelling is included in the report's conclusions.

York University and Lund University have collaborated on an additional project that was supported using funding from this project which focuses on anthropometry. While this project can stand on its own, it is included as an Appendix A and referred to where relevant in the main report.

Acknowledgements for Main Body Text

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Data and Database Disclaimer

Table of Contents

1. Introduction 1
1.1 Final Report Summary 3
2. York - Arup Movement Speed Profiles 3
2.1 Automated Tracking Technology Methodologies 4
2.2 York University Stadium Profiles 5
2.3 Inter City Railway Station Profiles 11
2.4 Museum Profiles 13
2.5 Care and Retirement Home Profile 14
3. Lund University Movement Speeds and Anthropometric Data 15
4. SFPE Database Generation 16
5. Project Impact and Benefits to SFPE 20
6. Remaining Tasks and Future Work 22
7. Forecasting the Future of Evacuation Modelling 22
8. Selected References 24
Appendix A. 25

1. Introduction

Representing the movement of people properly has critical importance for the design of buildings and infrastructure – particularly in the case of emergency or evacuations with urgency, but also, for normal day-to-day circulation. These designs and analyses of movement in buildings and infrastructure can be considered some of the most performed design and analysis techniques a fire protection engineer may perform on a day to day working basis. Currently, pedestrian models are configured using speed and anthropometric input data. When engineers build and/or configure their pedestrian movement models, applicable and defensible data sets are required. Reducing the level of uncertainty is the objective as the existing data may not entirely be applicable to the designer's scenario or even be available.

Our field is often challenged, particularly today, by aging and more complicated vulnerable populations that occupy our spaces. Representing these individuals, in existing and new pedestrian movement models, is difficult because the movement data is rare[1] but critical to support the configuration and construction of movement models. By examining the existing research, many gaps are evident. For example, existing movement data sets are often presented as independent to the demographics for which they were derived from, as shown in Fruin commuter movement profiles. For the data sets where demographics are apparent, careful examination reveals that the movement profiles are just approximations at times, and not exactly based on observed and collected behavioural data. The commonly cited Ando profiles of movement are an example of this, which is revealed when this highly cited paper is obtained and translated. The recent SFPE handbook (2015) has tabulated a vast collection of project specific data sets tailored to various building types. This contribution representing a tremendous effort by its authors to collect data is a foundational resource to the practice. The handbook's speed of use would be enhanced in a database tool form, so as to quickly decipher which data set can apply for the practitioner's particular building type.

As part of a collaborative multi-institutional [2] and consultancy effort, York University (Canada) and ARUP have led an SFPE foundational study with Lund University aiming to compile and organize contemporary project specific movement and anthropometrical data sets as well as providing outlooks on future data collection and movement models that focus on Anthropometry. This collaboration has resulted in a living database being presented and hosted by SFPE online as well as new movement insights discussed in Appendix A. The intention of the database is to be easily updated and supported on the SFPE web infrastructure. This database will be described herein.

Since 2015, York University has been collecting movement data largely to inform consultancy projects for their industry and community partners. Most of which have not been published to date but are in final stages. Table 1 illustrates contemporary movement data sets collected by York University researchers in their own studies over these last three years used for this report. Datasets presented and used are only those in the final stages of preparation for journal and peer review submission and should be treated with caution in use (ie. we have not included them in the database at the time of writing). We are currently studying LRT and Airport movement profiles, but these will not be available in this report and are intended for future research.

[1] For example, consider aging populations within a long-term care home. Even holding an evacuation drill presents difficulties as, from an ethical consideration, one most have informed consent. Those with dementia or related impairments cannot give this consent to participate.

[2] This project is also collaborating with Lund University and their associates, and the SFPE Conseil St-Laurent, Québec (Appendix of this final report describes contributions and detailing of Lund's work directly).

It is intended that the datasets present in Table 1 will be incorporated within the living database for SFPE once they clear peer review and therefore we present them in informative form for the reader only they should be used with caution. In addition to these, a call for data from various academic and industrial partners was also made to populate the database with new data sets which will remain an ongoing process after the database is officially launched online. The database currently includes movement data from the 2015 handbook. The database will be complimentary to the next SFPE handbook (6th edition). The 6th edition tables are not formalized yet. However, at the time of writing it is indicated that these will be of similar form to the 5th edition but non-searchable as a database [3]. This final report was prepared for the SFPE foundation by these authors and their collaborators for the fire engineering community. This report concludes with a brief statement towards the authors' vision of the next advancements this field may experience. Specifically, the statements highlight how these data sets are to be utilized in existing and future models as well as current gaps in the field.

Table 1. York University Movement and Anthropometric Profile SFPE Datasets [4]

Building Type	Event Type	Average Number of People for Event	Event Frequency	Study Considerations that Align with Proposal Objectives
Train Station	Circulation Study	200	8 arrival/departures	Escalator use, pavilion baggage, diverse population, group behavior, bottlenecks, modern considerations (cell phones)
Toronto Stadium	Circulation Study	18,000	3 days of footage, multiple games per day	Accessibility focus, handbags and bags, age and mobility limitations, upwards/downwards movement
	Evacuation (Rain Event)	2,000	1 evacuation	Modern considerations (cellphones), effects of emergency, accessibility focus
Cultural Centre	Evacuation (Drill)	500 - 1700	3 evacuations	Cultural background, mobility limitations, group behavior, heritage building considerations, age limitations, linguistic evacuation cues
Old Age Home	Evacuation (Drill)	3- 25	9 evacuations	Age and mobility limitations, dependent behavior, public education on fire risk

[3] At the time of preparation of this report the 6th edition chapter that will include datasets has not yet been prepared. The PI met with Ruggiero Lovreglio Feb 25th 2020 to discuss the formatting and content for which the chapter would be prepared under. It was indicated a similar format would be used and movement data post 2015 would be included. It is the reports' authors recommendation, that once the 6th edition is formally created that its contents can then be included within the database.

[4] The researchers only include movement datasets in this report that are peer reviewed or will be submitted for peer review consideration in the 2020-21 fiscal year. Our Airport and LRT study are not included as they are in progress and too preliminary. These will be developed in future research.

1.1 Final Report Summary

This final report discusses the overall progress that occurred for the duration of the project (August 2019 to February 2020) on Anthropometric Data and Movement speeds. During that time, the researchers have been tabulating the movement speed data which has been recorded over the past several years by York and Arup researchers (since 2015). The parameters tabulated are the mean, median, standard deviation, maximum and minimum speeds for a variety of building configurations and types. These can be found within Section 2 (we do not separate as appendices seen in the interim report to SFPE).

One submitted journal paper and two conference papers (SFPE) by the researchers have illustrated impact (with many under preparation). These papers are listed in Section 5 and detail the methodologies used to extract this movement speed data, as well as contextually discuss the differences between general circulation and emergency egress movement profiles. Two abstracts have also been submitted for the SFPE conference in Auckland, NZ and Atlanta, USA that detail future considerations for movement behaviour, particularly in understanding emergency and non-emergency egress.

The report herein also includes Lund University's contribution, as an Appendix, to extract anthropometric data from existing and new movement sets. A continuing collaboration between York and Lund is underway in order to record tailored footage to complement their endeavours. The new movement footage would be complimentary to utilising the existing laboratory studies by Lund University researchers discussed herein. Further details of Lund University initiatives are described in the Appendix.

2. York - Arup Movement Speed Profiles

The data collected by York University and Arup presented herein all comes from field studies of real infrastructure using security, applied cameras and/or hand records. The data is not from laboratory studies though these have significant value as will be illustrated in the Appendix A. Rather, the data is focused on unimpeded movement sets. The authors intended to study group movement in greater detail in future research.

Section 2 briefly summarizes the movement speed data sets tabulated by the York University and Arup research teams. Each data set, in some form, is linked to a periodical (see references) that is in preparation or has been recently submitted and is under peer review. These data sets are presented in full where relevant in the text. The methodology utilised in most cases to extract each profile primarily considers recorded high-resolution films that were taken from carefully selected vantage points in the buildings and infrastructures using a series of Canon Mark III 5D cameras and GoPro 7s[5] with subsequent field survey to identify distances in the video frames for calibration. York University is a recipient of Canadian Foundation of Innovation funding which has expanded its capacity for movement filming considerations in this and future data collection exercises.[6]

Approximately eight students were required to participate in most data collection exercises. As technology is limited for extracting movement profiles from video, datasets were traditionally manually produced from videos (observing tracked and measured path, and time it took to transverse said path) until later stages of this research programme where automated tracking began to be developed and used. Each

[5] The datasets from old age homes were done through hand record keeping due to ethical considerations which restricted the use of cameras.

[6] CFI funding as contributed by the Canadian government has provided YorkU fire lab funding for camera equipment to be utilized in these and future data collection exercises.

individual profile's journey through a building or infrastructure was recorded for both travel distance and travel time. This was then used to generate an overall speed for each individual. After some experimental experience, the researchers noticed that 85 seconds were required to analyze and generate a profile for one person (through time acceleration of the footage). The development of automated scripts that could speed up this process, depending on the quality and angle taken of the film, were developed and utilised by the researchers as part of this project's later stages. These scripts were then used to increase the speed of extraction of other user data, taking approximately 10 seconds on average to generate individual agent profiles. In all cases, the demographic identification is subjective[7] to the user of the tools so, for consistency, 2+ students typically performed all analyses of each infrastructure type. The methodology of filming and movement speed data extraction is further discussed in the attached submitted papers. For now, only observational commentary is provided based on the profiles provided. We describe the process of automated tracking collection below for others to consider in their own procedures. As our methods still require additional validation, we have not provided these scripts.

While most provided data sets feature non-emergency scenarios, the researchers have produced as part of this submission a submitted journal article that considers the differences in urgency effect. That paper discusses the implications of emergency, non-emergency, and movement profiles with various external urgencies (fire, rain, etc). This was concurrently submitted with this report for SFPE technical committee to review.

The authorship of this report assumes no liability for the use of the movement profiles provided. These profiles still need to clear peer-review in future journal papers under preparation. They should be treated by the reader and practitioner with caution. In some cases, it was not possible to generate profiles with suitable numbers to guarantee statistical significance.

2.1 Automated Tracking Technology Methodologies

As technology is limited in extracting movement profiles from video, it is the team's experience that 85 seconds are required to analyze and generate a profile for one person. Automated scripts can speed up processes depending on the quality and angle taken of the film. An example is a software called, Kinovea, which is an open-source video analyzer which includes an object tracking function and can be further refined through MATLAB/Excel functions. The software was originally designed for measuring movements of sports activities. Surveyed measurements can be taken from the structure and used to create a perspective grid. This allows the footage to be calibrated, properly outputting the coordinates of people's heads as they walked through two markers. Herein we utilized both procedures. See Figure 1 for an example.

[7] We define subjective as quantifying who is elderly, and who is a young adult. We generalize children identified by their height, clothing, and were often accompanied by an adult guardian. Youth were identified by their clothing and accessories, a backpack for example. Adults were the default demographic and, as seen in the tables below, represented most of the population. Elderly were identified by physical appearance. Where possible these identifications were supplemented with survey taking which included demographic counts that matched proportions of those as identified.

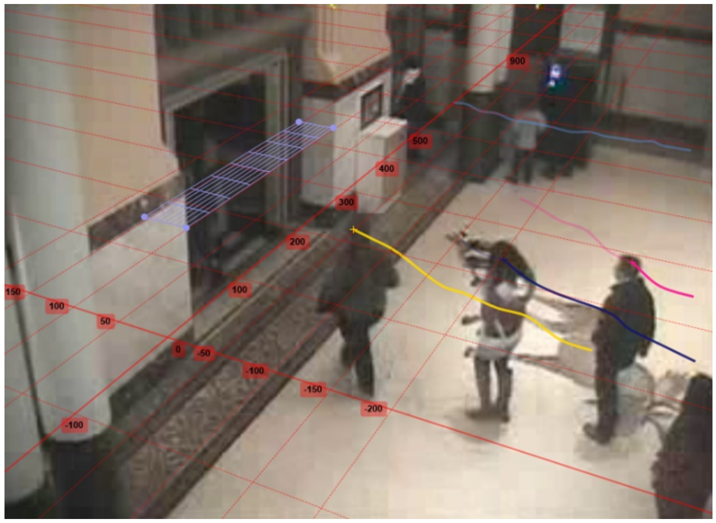

Figure 1. Movement Data Extraction Example using Automated Software

In our study, we extended this tool to be used to track pedestrian movement (it is originally developed for other purposes). The open source aspect of the code allowed the script to be changed, and the algorithms it is using to be adapted to other tracking software. In our case, we developed a procedure to assign demographic tags, and an extraction tool that would read the software's outputs and interpret them as a movement vector. The software did require good video footage, captured by the user using securely mounted video cameras or sourced from security cameras or other footage sources. Lens distortion needed to be removed to ensure accurate tracking. Lens distortion, in our case, is removed using a software called Shot-cut, which is also open-source. Newer Go Pros also inherently correct lens distortion if it is set to do so. The code for this script is still in development and is subject to improvements and change (see Section 5). In our use we verified the software's accuracy comparing automatically generated movement speeds to manually tracked movement speeds. Further validation should be peer reviewed in publication.

In the old age home, it must be recognized that ethical clearances restricted the video recording of elderly patients. As these individuals suffered from dementia, they were not in a suitable position to give informed consent. This resulted in the loss of significant quantitative and qualitative data in the analysis. A full journal paper describes that test series (see Section 5).

2.2 York University Stadium Profiles

York University is unique in that it has a professional sporting level stadium meant for professional Tennis tournaments that occur on an annual basis in August. The authors' have been granted exclusive access to this stadium for research purposes since 2018 for filming and interviewing attendees but are not allowed by the university ethics to manipulate ground conditions or invoke emergency conditions of egress.

The building's site also contains a pedestrian village with various restaurants, shops, and isolated events. This is a unique opportunity for the study of contemporary movement data sets of accessibility issues (visibly obese, intoxication, disabilities, etc). This is the fourth stadium York University researchers have studied, and the previous three studies (2016-2017) influenced the methodology of data collection efforts used for this stadium. These methods were documented by the authorship team in a FEMTC article in 2018 (see references). The current focus on data collection is to characterize accessibility considerations while preserving ethical considerations for filming. Each patron ticket explains that filming is taking place, disclosing this to attendees. Hence, the images of attendees can be utilized for publication and research purpose as they are informed. However, this is not a universal rule for all countries and jurisdictions. Since the data collection is considered low risk, this allows the authors to consider vulnerable populations. Over the course of the last two years, these data sets collected represent over 1.7 TB of 1080p resolution video and imagery. These films were taken from carefully selected vantage points in the stadium and grounds using a series of Canon Mark III 5D cameras and GoPro 7s. Approximately eight students were required to participate in data collection. These recorded videos are still being studied by York University researchers for movement speeds and behavioral cues for model verification and validation.

It is beyond the scope of this report to discuss the modelling endeavors underway regarding this stadium; however, it is within the scope to discuss the quality and interpretation of this collected data as it fits within the SFPE's foundation study. This will be discussed, as well as a discussion of the type of data needed for today and tomorrow's pedestrian movement models. Figure 2 details the considered stadium with the associated pedestrian village. Figure 3 details specific camera angles which were collected in addition to those shown in Figure 2.

The researchers are in final preparation of a two-part paper that illustrates the data provided (see Section 5).

Figure 2. York University Tennis Stadium and Pedestrian Village Filming

Figure 3. York University Tennis Stadium Selected Filming Angles

General Circulation

A sample size of at least 50 was utilised in four categories to assess unimpeded movement on level ground with profiles derived from the cemented pedestrian walkway at no grade (See Table 2 below). In general, these speeds were in excess of the general Fruin profile (provided as reference). This data however indicated slower speeds for elderly by as much as 19% and children by as much as 11% relative to the averaged young adult and adult.

Table 2. Able-Bodied Profiles for Unimpeded Movement on Level Ground

Agent Profile	Sample Size	Speed (m/s)				
		Min	Max	Mean	Median	SD
Child	52	0.34	5.04	**1.45**	1.30	0.75
Young Adult	50	0.71	3.92	**1.61**	1.52	0.58
Adult	51	0.67	3.53	**1.64**	1.65	0.59
Elderly	50	0.40	2.52	**1.32**	1.23	0.48
Fruin	-	0.65	2.05	**1.35**	-	0.25

Movement on Stairs

To derive movement speeds, nearly 300 pedestrians in the pedestrian village were analyzed. This was obtained from one day of footage. Each demographic (child, young adult, adult, elderly with further sub differentiation of 'able-bodied' and 'visibly' obese adults and elderly) was characterized at random with at least 50 profiles each. Time to travel a horizontal distance of over 20 m (as was measured in the field surveys of the stadium) was utilized to derive speed. Stairs were also considered in a parallel and similar analysis. In these cases, the stair dimensions abide by the local building code and were at a slope of 19.7 degrees grade. Both 'up' and 'down' stair movements were considered for each demographic profile, with both values collected separately for each profile (they were identified as marginally different). We report horizontal speeds as these are used in most pedestrian movement software. All of these profiles were chosen for pedestrians without obstructions of other groups nearby (unimpeded and independent of density). These are presented in Table 3 and 4 with variation (max/min) shown.

The stadium data does show distinct variation between each demographic (see below table). The SFPE handbook (2015) currently provides Stadium stair horizontal movement guidance. A study conducted at a German tennis tournament by Kretz et. Al. reported speeds with a mean of 0.71 m/s, and a range from 0.13 to 1.86 m/s across 91 people. However, this data was for a mixed range of ages and thus does not account for any effects of age demographics on movement speeds. The reported speed of 0.71 m/s is comparable to the adult movement speed of 0.73 m/s recorded in this study. However, elderly movement speeds were slower averaging 0.52 m/s. This is approximately a 30% speed reduction in elderly movement relative to adults. When compared to visibly obese people, elderly speeds dropped 20% and adults dropped 24% in speed.

For the stair movement analyses, profiles such as children, are subjective as more often than not they are guided by an older person, and would be influenced by this walking speed. Simply, their walking speeds were rarely direct routes because they would stop and wander or be controlled by their guardian. We do not tabulate these data points in this table.

It is hypothesized by the authors that the type of sporting event may have an impact on these speeds. Tennis has strict policies that those in attendance be within the stairwell prior to seating and prior to a match – hence they may be more motivated to enter the stadium, and once past the gate, slow on the stairs for seating. This gives credence that movement parameters may also be event specific and not just building specific.

Table 3. Able-Bodied Profiles for Unimpeded Stair Movement (Gradient = 17.9°)

Agent Profile	Sample Size	Horizontal Speed (m/s)					Direction
		Min	Max	Mean	Median	SD	
Adult	53	0.36	1.26	**0.71**	0.70	0.18	**Descent**
	54	0.42	1.40	**0.77**	0.72	0.20	**Ascent**
Elderly	50	0.16	0.96	**0.50**	0.52	0.18	**Descent**
	51	0.16	1.14	**0.55**	0.55	0.15	**Ascent**

Table 4. Obese Profiles for Unimpeded Stair Movement (Gradient = 17.9°)

Agent Profile	Sample Size	Horizontal Speed (m/s)					Direction
		Min	Max	Mean	Median	SD	
Adult	54	0.13	0.94	**0.50**	0.51	0.18	**Descent**
	54	0.17	1.57	**0.62**	0.58	0.23	**Ascent**
Elderly	54	0.14	0.78	**0.40**	0.39	0.14	**Descent**
	54	0.06	0.88	**0.42**	0.46	0.18	**Ascent**

Accessibility

Movement profiles were generated focusing on mobility patterns of persons with specific accessibility requirements (canes, crutches, electric wheel chair, family with young children, manual wheelchair, mobility scooter, oversized luggage, persons requiring assistance, rollator, roller suitcase, walking stick, etc.), as well as their movement speeds. A total of 2430 movement profiles were generated based on collected data from 2018. A similar criterion was utilized for adapting speed generation as above, by utilizing a specific distance and time. These profiles are illustrated within Table 5 and 6. It is important to recognize that the proportion of pedestrians with accessibility needs relative to the whole population within the stadium is low. Subsequently, the authors' characterized a total of only 3.7% of the overall attendance presented a type of mobility impairment. We then compared this low accessibility at the Toronto stadium to other stadiums we considered in past studies, and these stadiums measured below 5% in every case (these studies involved ticket pricing from 5$ to as much as 60$, suggesting that economics were not the factor in the low percentage).

To follow the low percentage observed in 2018, the authors also conducted a survey exercise in 2019 of over 60 people in attendance with accessibility needs during the middle of the tournament where accessibility-focused questions were discussed. While this is beyond the scope of this particular report to present the numeric of that survey's results, it was revealed that the stadium accessibility features were a driving factor in hampering those with needs in attending (see Figure 4).

Figure 4. Architectural factors that impacted accessibility movement were not considered

Difficulties with poorly maintained ramps, finding elevators, and inefficient washroom placement were the highest scoring reasons of concern for interviewed patrons.

Overall, the mean walking speed of those with visible accessibility needs were 33% less than those without (1.05 m/s versus 1.6 m/s for adults and young adults).

Table 5. Mobility-Limiting Impairment Profiles for Unimpeded Movement on Level Ground

		Speed (m/s)				
Agent Profile	**Sample Size**	**Min**	**Max**	**Mean**	**Median**	**SD**
Cane	62	0.21	1.68	**0.91**	0.88	0.28
Crutches	5	0.35	1.22	**0.68**	0.66	0.34
Mobility Scooter	23	0.57	2.71	**1.39**	1.47	0.45
Person Req. Assist	61	0.16	2.02	**0.98**	0.95	0.41
Walker (Rollator)	15	0.21	2.02	**1.07**	0.98	0.59
Walking Stick	23	0.14	1.68	**1.01**	1.04	0.41
Wheelchair (Electric)	17	0.06	1.76	**1.08**	1.01	0.46
Wheelchair (Manual)	54	0.06	3.54	**1.17**	1.10	0.50
Total	260	0.06	3.54	**1.05**	1.02	0.44

Table 6. Other Mobility Limiting Profiles for Unimpeded Movement on Level Ground

		Speed (m/s)				
Agent Profile	**Sample Size**	**Min**	**Max**	**Mean**	**Median**	**SD**
Family Group	1170	0.06	5.04	**1.11**	1.24	0.54
Oversize Luggage	849	0.08	4.72	**1.50**	1.45	0.55
Roller Suitcase	26	0.40	2.71	**1.64**	1.67	0.55
Other [8]	139	0.19	7.08	**1.82**	1.55	1.06
Total	2184	0.06	7.08	**1.39**	1.36	0.61

[8] The term "Other" includes any person that appeared to have a mobility impairment that is not included within the other categories. For this particular case study, this agent profile mostly consists of mascots and persons operating motorized vehicles (shuttles).

Accessibility (visibly obese)

While the implications of visibly obese individuals were discussed earlier, we noticed that, during unimpeded zero grade movement, a reduction of 21% was recorded in speed for adults, and 9% for visibly elderly.

Table 7. Overweight and Visibly Obese Profiles for Unimpeded Movement on Level Ground

Agent Profile	Sample Size	Speed (m/s) Min	Max	Mean	Median	SD
Adult	47	0.60	3.85	**1.30**	1.14	0.54
Elderly	31	0.46	3.37	**1.21**	1.04	0.63
Adult (Non Obese)	51	0.67	3.53	**1.64**	1.65	0.59
Elderly (Non Obese)	50	0.40	2.52	**1.31**	1.23	0.48
Total (Visibly Obese)	78	0.46	3.85	**1.27**	1.13	0.58

Intoxication / Inebriation

The filming vantage presented an opportunity to measure the speed upon which people exited a restaurant (The restaurant serves only alcohol. Food and non-acholic beverages are served next to the restaurant), and how long they stayed in the restaurant. It was not possible to measure the amount of alcohol or what alcohol was consumed, but it was possible to measure the time within the restaurant. Statistically, the researchers found no obvious trend between the time spent in the tent and changes (reductions) in movement speed. 50 agent profiles exiting were produced. The authors selectively measured the speed at which they entered the tent (similar to general circulation speed) noting a difference to their exit speed. Stair use was not monitored but should be considered in future studies. Results illustrated 37% decrease in speed in adults and elderly when you consider the general circulation speed. It was not possible to generalize for elderly population as our numeration was only five pedestrians so no statistically significant dataset can be formed. It should also be considered that there is no monitoring regarding the general circulation profile if these individuals did not consume alcohol. Additional research should be performed to more closely interrogate this type of movement profile.

Table 8. Unimpeded Movement before and after Alcohol Consumption on Level Ground

Agent Profile	Sample Size	Speed (m/s) Min	Max	Mean	Median	SD
Adult & Seniors	50	0.34	1.88	**1.02**	1.02	0.39
Adult (general circulation)	51	0.67	3.53	**1.64**	1.65	0.59

Egress with urgency

Performing an emergency egress (a fire scenario for example) was considered prohibited from an ethical standpoint by the university. Based on the authors' previous study where an emergency evacuation did occur (Ottawa Stadium) in 2018, the authors aimed to collect movement data for situations that may be considered high urgency, where particular key emergency behavioral cues may also be revealed. The authors' conducted a rare data collection exercise by timing a filming event with a torrential downpour of rain. It was critical that rain occurred suddenly, as the match would then be suspended, and a full evacuation of the stands would then take part. The authors were fortunate to record such an event and observed an egress of nearly 2000 people in the stadium.

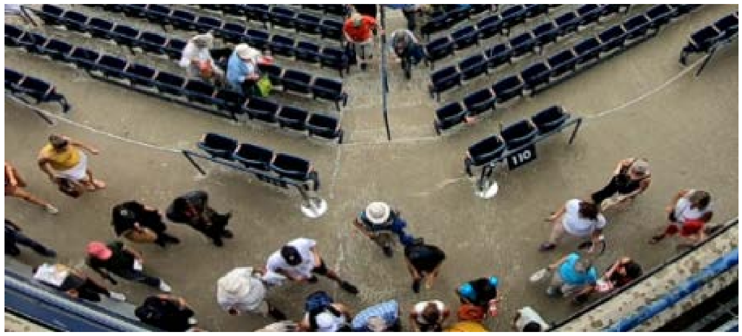

Figure 5. Toronto Stadium Bowl Egress (Egress with Urgency from Rain Event)

The entire stadium was recorded. Two gates were filmed at high resolution (one with security present and one without security present). It was not considered a large crowd capacity, but footage was obtained which made it possible to see crowd congestions at high resolutions as well as protective decision-making, albeit for a considered low-hazard movement scenario. Figure 5 illustrates an overhead film shot of this event at a gate. Complete egress occurred in less than 2.5 minutes with maximum travel distances of 43 m. The authors' publication (see Section 5), in preparation, details the movement behaviour in conditions considered to with urgency with a complicated nature where behavioural theories are at play in terms of protective action decision making and possibly an assortment of cognitive biases and other behavioural trends.

2.3 Inter City Railway Station Profiles

An inter-city railway station was also considered where group movement and luggage aspects were examined for 264 persons. Most, if not all, people in this study were carrying some degree of luggage. Speeds compared to the Fruin commuter were slower by approximately 30%. Groups traveling together were only observed in 24% of the total population considered. A demographic study was not performed on this data set. Data indicates lower group movement speeds the larger the group is, which would be expected. Researchers do not disclose the property being filmed as imagery was not permitted at this stage for publication in this report.

It should be noted that filming in these public spaces has considerable considerations that have to be made. The researchers explored the use of thermal cameras to obscure people's faces, however for group behaviour it was not possible to discretize the movement profiles of unimpeded flow. We did not use that technology, using instead a series of stationary Go Pros staged throughout the inter-city station concourse. We are currently summarizing these datasets for publication within a conference / journal paper. This has not been finalized at the time of this report's generation.

Figure 6. Thermal Camera options for inter-city rail

Table 9. Luggage Profiles for Unimpeded Movement on Level Ground

Agent Profile	Sample Size	Speed (m/s) Min	Max	Mean	Median	SD
No Bag	8	0.50	1.33	**0.88**	0.86	0.29
Backpack	49	0.31	1.36	**0.90**	1.00	0.28
Handheld Bag	55	0.36	1.46	**0.85**	0.83	0.27
Roller Suitcase	37	0.48	1.67	**0.94**	0.88	0.25
Backpack & Handheld Bag	22	0.44	1.08	**0.80**	0.83	0.18
Handheld Bag & Roller Suitcase	50	0.44	1.50	**0.94**	0.95	0.27
Roller Suitcase & Backpack	33	0.54	1.38	**0.91**	0.86	0.22
Backpack, Handheld Bag & Roller Suitcase	10	0.48	1.07	**0.82**	0.88	0.21
Fruin Commuter	-	0.65	2.05	**1.35**	-	0.25
Total	264	0.36	1.67	**0.89**	0.88	0.25

Table 10. Group Profiles for Unimpeded Movement on Level Ground

Profile Group Size	Sample Size		Speed (m/s)					% Population
	Groups	Individuals	Min	Max	Mean	Median	SD	
1	192	192	0.31	1.67	**0.93**	0.98	0.26	73%
2	24	43	0.44	1.33	**0.81**	0.80	0.20	16%
3	6	16	0.36	0.95	**0.77**	0.83	0.20	6%
4	2	8	0.71	0.91	**0.80**	0.78	0.10	3%
5	0	0	-	-	**-**	-	-	0%
6	1	5	0.48	0.58	**0.53**	0.54	0.03	2%
Total	225	264	-	-	**-**	-	-	100%

2.4 Museum Profiles

The following are the obtained agent profiles that represent the York University data collection focusing on travel speeds for the museum fire drill evacuation. It should be regarded that the data supplied has cultural implications, as are described in the papers developed as part of this program.

Manual Tracking

A museum fire drill evacuation was recorded in 2016. This study has been recently released from an NDA (see Champagne et al, 2019). Of these data sets recorded, it was possible to extract 174 movement profiles subdivided by demographics that differentiate between infants and children (other profiles are generic to children only). Though some demographics are of low number to ensure statistical relevancy.

The travel distances for each individual, on average, used to generate the movement profiles was 77 m. Movement speeds were heavily dominated by decision and way finding activities. These resulted in mean movement speeds ranging from 0.39 to 0.51 m/s, which is far below the default movement speeds in most evacuation modelling software. One potential explanation for this slow movement is that most attendees were in groups and moving at the slowest speed of the group. Another explanation is that the movement speeds presented above were generated using the average speed of the occupant's entire evacuation, and thus are affected by observed factors and actions which may reduce speed. These factors may include the traversal of stairs, congestion at doorways and bottlenecks, detours, waiting for group members, and/or pausing to put on coats or jackets.

Alternately, some movement speeds (labelled *Computer-Vision-Tracked*) presented below were calculated using a novel video analyzer as described in the next section.

Computer Vision Tracking

As technology is limited in extracting movement profiles from video, it is the team's experience that 85 seconds are required to analyze and generate a profile for one person. Automated scripts and software can speed up processes depending on the quality and angle taken of the film. An example is a software called Kinovea, which is an open-source video analyzer including an object tracking function (described above). This software's functions can be further refined through MATLAB/Excel functions and Hotkey scripts. Measurements can be taken from the structure and used to create a perspective grid. This allows the footage to be calibrated to account for the angle of the camera, properly outputting the coordinates of people's heads as they walked through the captured environment. Herein we utilized both procedures. See Figure 1 for an example.

Museum Movement Profiles

The agent profiles were generated by visual inspection and categorization into five groups: infant, child, youth, adult, and elderly. For the computer-generated walking speeds, an additional group called "parent & child" was created for children walking with their parents, as they would match their speed to walk together and influence each other's walking speed. The agent profiles were determined by a number of factors including height, clothing, accessories, and companions. For example, children were identified by their height, clothing, and were often accompanied by an adult guardian. Youth were identified by their clothing and accessories, a backpack for example. Adults were the default demographic and, as seen in the tables below, represented most of the population. Elderly were identified by their clothing and hair colour. The tables below present the walking speeds from both procedures. The computer-generated agent profiles were primarily taken in medium congestion to free-flow conditions, and a minimum of 30 agents tracked was decided upon to ensure a large sample size. To meet this condition, older children walking alone were combined with the Youth profile, and younger children walking with a parent were designated as Parent and Child. There were too few data points for elders and thus the profile was discarded. Future work across multiple evacuations may allow for a sufficient sample size.

Table 11. Able-Bodied Profiles for Fire Drill Movement throughout Entire Building

		Speed (m/s)				
Agent Profile	**Sample Size**	**Min**	**Max**	**Mean**	**Median**	**SD**
Infants with Adults	9	0.13	0.66	**0.32**	0.26	0.18
Child	26	0.12	1.03	**0.49**	0.45	0.26
Youth	11	0.21	0.61	**0.52**	0.58	0.14
Adult	117	0.1	2.38	**0.52**	0.51	0.26
Elderly	11	0.31	0.61	**0.5**	0.49	0.1
Total	174	0.1	2.38	**0.51**	0.51	0.25

Table 12. Able-Bodied Profiles for Fire Drill Movement throughout Atrium (Computer-Vision-Tracked)

		Speed (m/s)				
Agent Profile	**Sample Size**	**Min**	**Max**	**Mean**	**Median**	**SD**
Youth	30	0.6	1.98	**1.19**	1.15	0.25
Adult	30	0.79	1.74	**1.21**	1.21	0.25
Parent & Child	30	0.58	1.69	**1.06**	0.99	0.32
Total	90	0.58	1.98	**1.15**	1.15	0.28

2.5 Care and Retirement Home Profile

A profile for the movement of elderly population in fire drills was extracted from an accepted paper to the Fire and Materials Journal, as prepared by York University and Arup researchers [9]. This study involved manual collection of movement speed data of nine fire drills by hand. Cameras were not used to track individual movements. Ethical considerations for vulnerable populations restricted the use of cameras. It was deemed by our ethics boards that individuals in these residences could not give informed consent to be allowed to be filmed. This is because of the nature of dementia and related illnesses.

The measured average speeds (only for residents or residents being assisted) recorded in the drills (which reflect changes in speeds due to acceleration/deceleration based on measured linear distance from the floor plans and time door to door as taken at the drills) were derived as follows based 56 data sets of resident and assisted resident distance and time data: average 0.33 m/s, minimum 0.02 m/s, maximum 1.81 m/s, mean 0.3 m/s. This movement profile is subjected to limitations and these are described at length in the published journal paper. These data sets do not include anthropometric aspects of movements which should also be studied in a more holistic data collection and modelling study, but these

[9] Folk, L., Gonzales, K., Gales, J., Kinsey, M, and Carratin, E. (2020) Emergency Egress for the Elderly in Care Home Fire Situations. Fire and Materials (John Wiley). (Accepted).

current values do provide practitioners a valuable data set that can be utilised in conjunction with preliminary modelling of care and retirement homes. Subsequently, we have limited the scope of this profile generation as it requires additional building particularly as it implicitly includes the assistance and non-assisted residents in its calculation. This data sets compare to the nearly 1.32 m/s observed in elderly populations seen in the stadium study, and 1.07 for those with walkers (rollators).

The data was more in line with the work of Boyce (0.57 m/s), while the Museum aforementioned (0.5 m/s) was more conservative. This is largely due to the autonomy of those that would attend the sporting event compared to those requiring constant care afforded in the facilities. The values here provide important justification to associating project specific movement profiles.

Table 13. Unimpeded Movement for seniors and walkers

Agent Profile	Sample Size	Speed (m/s)				
		Min	Max	Mean	Median	SD
Elderly	56	0.02	1.81	**0.33**	0.3	0.29
Elderly (Stadium combined)	50	0.40	2.52	**1.32**	1.23	0.48
Walker (stadium)	13	0.21	2.02	**1.08**	0.82	0.64
Elderly (Museum)	11	0.31	0.61	**0.5**	0.49	0.1
Elderly (Boyce)[10]	118	0.1	1.02	**0.57**	-	-

3. Lund University Movement Speeds and Anthropometric Data

As part of the foundational project, York University has sub-contracted Lund University to explore Anthropometric data sets which can be considered upon for future data collection and modelling development. This report is included as an Appendix to this report as it represents one of the foundational studies sub projects and is referred to upon herein. This detailed appendix on activities being conducted by Lund University is provided at the conclusion of this main body text report.

Digital meetings occurred between York and Lund University (Håkan Frantzich, Pete Thompson, and Silvia Arias) at the end of each month for the duration of the project.

Lund University researchers currently have laboratory scale movement studies which they were planning to utilise to make anthropometric data sets. Their approach assumed a biomechanical model linked to the individual and his or her conditions and the influence of the environment. The model developed by Thompson et al. (2015) was adjusted with a new set of data on single-file pedestrian movement at different densities. The resulting model was expressed in forms of three equations that relate inter-person distance to biomechanical data such as height, foot length, and step length. Appendix A (included) details these efforts.

[10] Data from; K. Boyce, T. Shields, and G. Silcock, “Toward the characterization of building occupancies for fire safety engineering: capability of disabled people to Negotiate Doors,” in *Fire Technology*, Springer, 1999, 35 (1) pp. 68–78.

Digital meetings initially investigated whether the existing films obtained by York University for anthropometric study could be utilised for their purpose as a field validation, or if additional film recorded at another event may be planned and be more relevant for them to validate their findings.

A field study was planned between institutions to focus on exact quantification of the film, however ethical clearance was not obtained during the research project to allow recording at this time. This collaboration would need to continue beyond the course of this foundational study.

The resulting collaboration influenced required fields that would be present in the Database as described in Section 4.

4. SFPE Database Generation

Since the inception of the project, the York and Arup teams have liaised with SFPE's digital service team and confirmed the architecture of SFPE's website, database and hosting services to guide our database development and how to deliver a proficient solution.

The system design of the database was based on a review of SFPE's digital team to ensure its compatibility with SFPE's existing systems and to maximize ease of deployment and maintenance. Currently, the database is in the handover phase described below. This includes the final language of the legal aspects of utilising data within the database by researchers.

4.1 Database Contents (SFPE handbook 5th and 6th Editions) and Current Legality

The tables of human behavior data from Chapter 64 of the SFPE handbook (5th edition) were transcribed in digital xlsx format and included within the database. This chapter was originally prepared by Steven Gwynne and Karen Boyce.

This represents most data sets that were transcribed before 2015. Discussions with SFPE authors of the 6th edition were held by York Researchers. It was determined that the 6th edition would follow the same format (similar at least) as the 5th edition (see Footnote 3). Therefore, the database architecture was considered appropriate. Figure 7 details the final formulation. Grey text boxes represent the categories of datasets, where the green boxes represent the searchable parameters of each field.

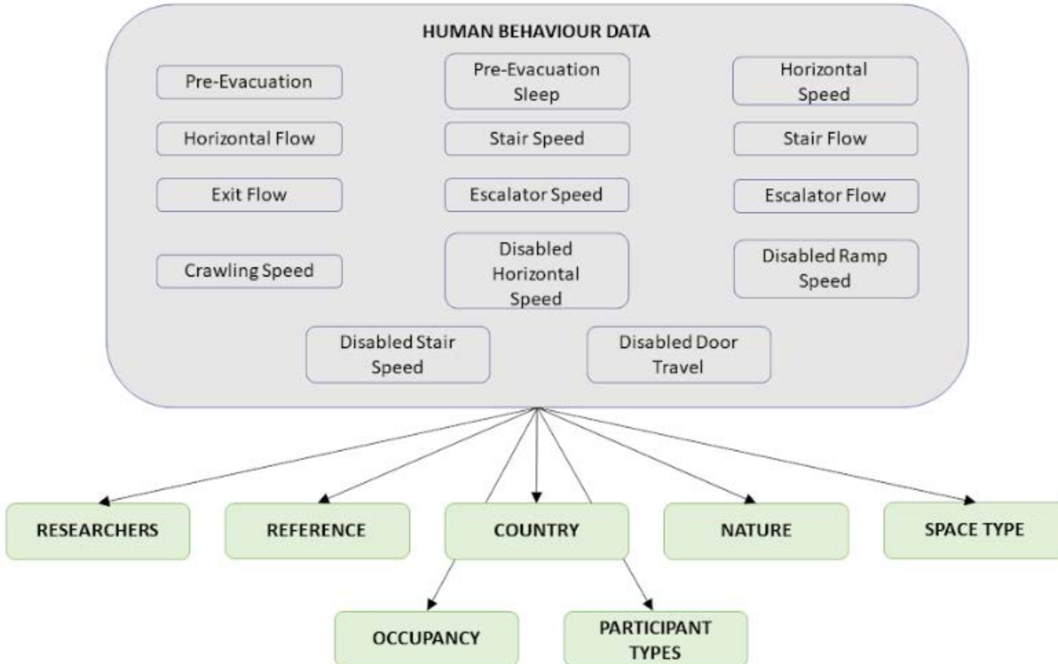

Figure 7. Schematic representation of SFPE digital database

The researchers made efforts to contact various researchers in the HBIF field. In most cases, research by others was underway. Most research focused on data collection methods utilising virtual reality for the interested reader. It was decided by the authors for now that the online database use the existing data-sets found in the 5th edition.

It is recognized that to maintain the database, a strict protocol needs to be followed for inputting new movement profiles into the database as this will be SFPE responsibility. In consensus with SFPE, we have decided not to allow direct user inputs into the database to prevent issues where poor-quality sets are updated or to be used and that data entry would primarily be SFPE's responsibility with some guidance. Based on initial concerns, Table 14 represents the pre-approved sources where datasets may be sourced and inputted into the database through contacting the society. These are based upon the criterion found in Chapter 64 of the 5th edition of the SFPE Handbook. In our table, red colour denotes that an expert in HBIF be consulted if that periodical's data is uploaded in the database (conferences and reports where peer review may not be complete). Blue assumes the periodical is peer reviewed and can be uploaded generally into the database. The researchers recommend that a person be considered to upload additional studies that appear in the 6th edition when it is ready for publication.

Table 14. Approved Sources that data set may be used (blue- approved; red- expert opinion)

Journals	Conferences	Technical Reports
• Journal of Fire Protection Engineering	• International Association for Fire Safety Science Symposium (IAFSS)	• National Institute of Standards and Technology (NIST)
• Fire Safety Journal	• Interflam	• National Fire Protection Association (NFPA)
		• National Research Council of Canada (NRCC)
		• Society of Fire Protection Engineers (SFPE)
• Fire Technology	• Conference on Pedestrian and Evacuation Dynamics PED	
• Fire and Materials	• Human Behaviour in Fire Symposium (HBIF)	• British Standard Institute (BSI)
• Safety Science	• Asia-Oceania Association for Fire and Technology	• Fire Protection Research Foundation
• International Journal of Performance- Based Fire Codes	• Mobility and Transport for Elderly and Disabled People	• Lund Department of Fire Safety Engineering
• Journal of Fire Sciences	• International Symposium on Tunnel Safety and Security	• VTT Technical Research Centre
• Building and Environment		
• Journal of Transportation Engineering		
• Transportation Research Record		
• Parallel Processing and Applied Mathematics		
• Traffic and Granular Flow		
• Procedia - Social and Behavioral Sciences		
• Physica A		
• Journal of Human Movement Science		

In collaboration with the SFPE Conseil St-Laurent, Québec the foundational project will continue over the course of 2021 to address missing movement profiles from the airport and railway station. Should the 6th edition take shape, we will subsequently upload these profiles as part of that research project.

A legality disclaimer will appear when the database is first used, as it will have to be acknowledged by the user that the database may contain errors and that it is the responsibility of the user to read the publication that the associated data comes from in order to determine whether it is relevant to their project. This is in addition to the database's functionality. This needs to be included so as to absolve SFPE and the researchers herein of the actions of users. This legal text will be formulated and finalized in the project hand off.

4.2 Online Database Features and Usage

The below figures represent screen shots of the database' infrastructure and used to demonstrate the functionality of the database. Associated user videos are recommended to be constructed once the database has been handed over and uploaded. York will plan to provide these videos.

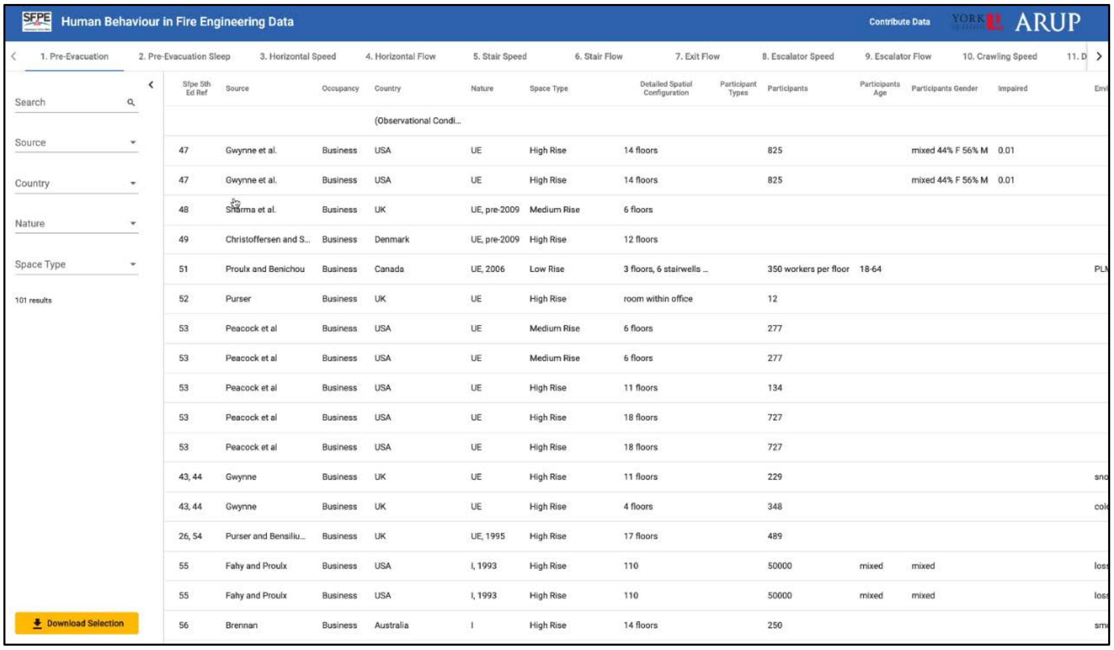

Figure 8. Visual representation of SFPE digital database upon accepting legal disclaimer

The database interface is simplified. The numerical categories sort the data into specific types of speed parameters. The second stage categories are the searchable parameters (Figure 9), though the left-hand screen illustrates the manual searches that are possible (illustrated in Figure 10). Once the user has sorted the datasets relevant to them, they may proceed to download using the bottom most yellow trigger.

Figure 9. Illustration of Searching Data by Occupancy

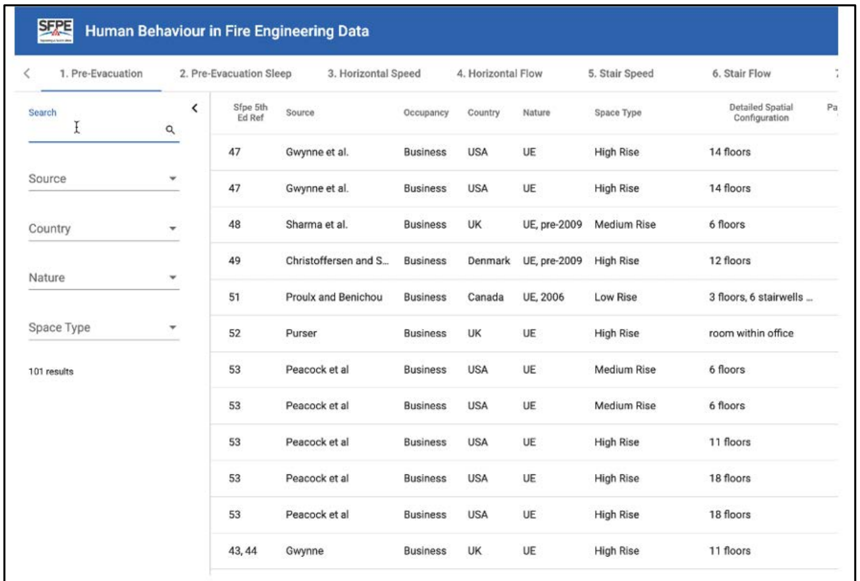

Figure 10. Illustration of Searching Data by search parameter (entering Gwynne is shown with result)

5. Project Impact and Benefits to SFPE

The authors have collected a significant amount of movement data (with and without emergency conditions) representing a view to modernizing the available data to support egress analysis. It is recognized that the global populations are increasing and buildings are becoming more complex. When an evacuation is needed egress systems must be designed to efficiently allow people to move from their initial position to a location of safety. The data commonly used to predict movement speeds are based on older data, often advocated not to be used by those who originally formulated them. With regards to buildings with large occupancies this data is not widely available and this project has introduced the collection of this data the authors have analyzed. While these datasets are certainly provisional, the report provides significant commentary to how these modern sets begin to differentiate from older data sets. Each set will require additional comparison to full literary sources, and this will occur as the datasets are distributed to the peer review cycle. For that reason, it is pre-mature to include them within the database, though significant to highlight to the educational and practitioner disciplines that these profiles are underway. During this review, data sets will be expanded upon where possible.

Four highly qualified undergraduate and graduate students have been trained in this research programme directly. These include Julia Ferri, Georgette Harun, Chloe Jeanneret and Timothy Young. The students have been able to interact directly with Arup Boston in their research by their professional engineers.

The contribution of the online database will allow researchers a faster way to access information regarding movement profiles that are relevant to their project.

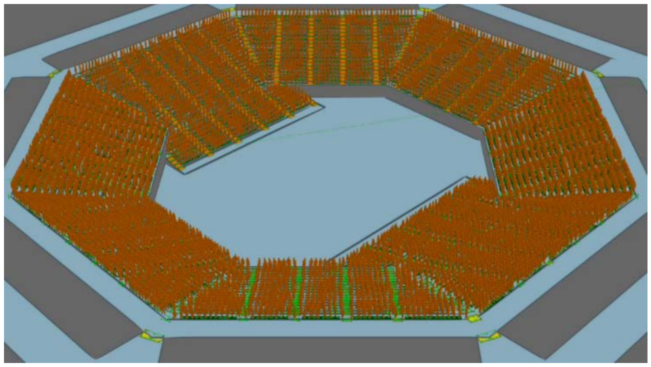

Figure 11. York University Stadium Digital Model in PED Software

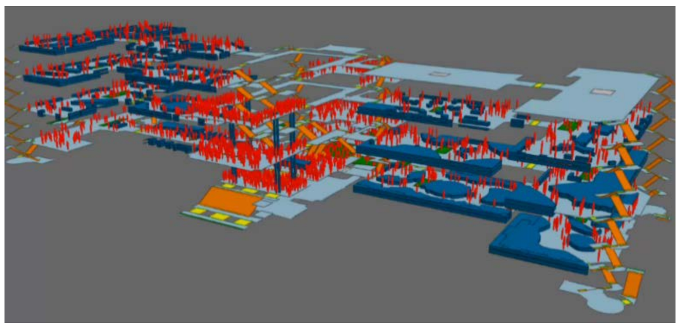

Figure 12. Museum Digital Model in PED Software

Of the research presented within Sections 2 and 4 of this report, there are two articles that have been submitted for publication, and four articles in the process of being submitted (within the next two to three months). These articles will acknowledge foundational support. Papers in progress deal with data shown for the stadium and museum projects. One article deals with considerations of using movement data from non-emergency to emergency situations. The latter paper deals with future implications to how data should be utilised and how frameworks such as PADM and Cognitive Bias are important in implementation of modelling tools. These are in draft form.

The SFPE conference paper deals explicitly with the generation of movement profiles, many of which are shown herein. The Fire and Materials article illustrates the published elderly agent profiles.

Accepted publications

- Folk, L., Gonzales, K., Gales, J., Kinsey, M, and Carratin, E. (2020) Emergency Egress for the Elderly in Care Home Fire Situations. Fire and Materials. (Accepted).
- Gales., J., Ferri, J., Harun, G., Young, T., Jeanneret C., Kinsey, M., Wong, W. (March 2020) Contemporary Anthropometric Data and Movement Speeds: Forecasting the Next Ten Years of Evacuation Modelling, SFPE Performance Based Design Conference. 7 pp. (Accepted).

Articles in final preparation

- Ferri, J., Gales, J., ManOram, M., Carattin, E. (2020) "Variability of Movement Abilities in Stadia – Part 1 – Current Crowd Demographics and Influences on Participation". (under review of industry partner for finalization)
- Ferri, J., Gales, J., ManOram, M., Carattin, E. (2020) "Variability of Movement Abilities in Stadia – Part 2 – Walking Speeds for Modelling Pedestrian Flow on Flat Ground and Stairs". (under review of industry partner for finalization)
- Harun, G., Young, T., Champagne, R., Gales, J., and Kinsey, M. (2020). "Emergency Evacuation and Exit Design Strategies for Cultural Centres in Heritage Structures". (under review of industry partner for finalization)
- Young, T., Ferri J., Gales, J., Kinsey M., Wong, W. (2020) "Variability of Behaviour in Stadia under various urgency levels". (under review of industry partner for finalization)

We note that many of the data sets presented are in developmental stages and still require peer review where more comprehensive literary analysis will be used to highlight this is noted. It was not the purpose to include comprehensive literary review in this report to keep the study on a high level and to be accessible.

6. Remaining Tasks and Future Work

The database transition and legal framework will require time to finalize. It is expected that the maintenances of uploading and hosting the database will fall on SFPE. It is expected that a low number of papers will be needed to be uploaded to the database as it is populated. However, from reaching out to community members, it appears these sets are in low number so should be easily facilitated for upload.

The datasets provided herein need to go through appropriate peer review before they can populate the database. This is in progress. Supplementary use in models should also be sought as this will be conducted as part of the SFPE funding leveraging with the St. Laurent local chapter and with Arup and their partners.

York university researchers initiated a call of interest among local SFPE chapters in Canada to continue this research programme herein into 2021. It was identified that the SFPE Conseil St-Laurent, Québec was in best position to help create a sustainable collaboration in Canada regarding academia and the local society. The funding for this project will be generated from an Mitacs Accelerate research program which will provide the research students a direct involvement with the society itself in Canada (approximately 1 dollar contributed to 1 dollar of applied funding). The leveraged funding will provide the students with scholarship stipends. We expect this to establish a continuing student chapter in parallel. The continuing research will aim to address the missing airport and railway datasets, and expand upon the datasets herein in number, and the tracking software is introduced but it is also noted that this is still being developed, and that a comprehensive validation exercise needs to be undertaken (We expect this to be shown with our airport and museum studies as those predominately use the software). This will be to support the creation of modelling tools that incorporate the data contained herein (Figures 11 and 12).

7. Forecasting the Future of Evacuation Modelling

The challenges in collecting data and analyzing it are expressed at length in this final SFPE foundation report. The authors' data sets were generated over years of study as early as 2015 and are still being finalized for peer review.

Behavioral data sets are slow to collect and produce, particularly due to the often-requested confidentiality of the parties involved and the ethical considerations of collecting the data in the first place. Various practitioners performing pedestrian movement studies collect data for a multitude of projects annually. That data is not easy to release due to confidentiality reasons. The York stadium project provides very specific data and is certainly not applicable to all types of stadiums (or even cultures), but it does provide very useful contemporary movement sets and behavioral trends with potential for anthropometric study differing substantially in values reported than those seen in Fruin studies. These sets align nicely for inclusion in new tabulations as planned by SFPE and in the database once they pass peer review. As this data collection for all buildings may be slow, it is paramount that presented data reflect current contemporary demographics and behaviors. In the absence of such, much policy is still being driven, particularly for stadiums, by movement rules of thumb conducted in the 1970 data collection studies that in some form is still in existence.

The existing trend to capture data, consisting of movement speeds and basic anthropometric data, fits within the existing movement frameworks and the current modelling tools which exist; however, it tends to negate the complicated decision-making behavior itself, which can have impact on certain assumptions made and should also be analyzed in the recorded videos. While these current movement models may be of commercial or research value, they ultimately are based on very simplified movement algorithm rules and limited data sets for validation. A number of these were developed in the 1980s-1990s when ASET / RSET was popularized and when computers were limited in processing power and unable to represent complicated movement behavior. The creation of revised movement AI and rule-based probabilistic behavior algorithms will have value in advancing modelling with the ability to lower uncertainty and develop robust behavioral frameworks for circulation and evacuation. In these cases, speed parameters may not be as critical, but rather the actual decision-making process being the most critical. Today, there are more modern advancements and critical thinking to how individuals interact with one another based on more complicated behavioral and decision-making theories, particularly as the field becomes very multi-disciplinary (bringing together psychologists, sociologists, engineers etc). There is difficulty in forecasting when these new models will appear that offer new ways to describe evacuation and circulation, however, we do know they will still require both emergency and non-emergency datasets to verify and validate. A living database and video analysis tools allow researchers and fire protection engineers to create and share their analyzed datasets in a standardized format, keeping the data used to populate future evacuation models easily accessible and up to date.

Lastly, the preservation of the raw data which was utilized to initially make data sets needs consideration. Many assumptions on the data found in the SFPE tabulations are based on quick glance, but to truly understand if it is applicable to the practitioners' project, there is use in the practitioners having the raw video feeds to decipher the quality of the data and to interrogate how calculations on movement were made. For example, there exists little video footage from the 1970 and 1980 movement studies that define the basic movement profiles used in our existing models by default. As we move towards digital living documents, it is the authors' opinion that data sets (video) also be considered for preservation. Too often when considering data sets from the past for which practitioners wish to analyze in greater detail, it comes to be acknowledged that the film was lost with time or never preserved. Although some videos may not be as useful to modern frameworks, future ones may see additional benefit to re-analyze in different contexts, particularly as behavioral data and decision-making frameworks are emerging and being developed in recent years.

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Appendix A.

Determining Evacuation Capability with Biomechanical Data

Peter Thompson, Håkan Frantzich, Silvia Arias & Jesper Friholm

Division of Fire Safety Engineering

LUND UNIVERSITY