HERITAGE IMPLICATIONS IN EGRESS AND MODELLING

Georgette Harun, Luming Huang, Tim Young, and John Gales*

Fire and Civil Engineering, York University
11 Arboretum Ln
Toronto, Ontario, M3J 2S5, Canada
*e-mail: jgales@yorku.ca

ABSTRACT

Movement parameters which reflect diverse populations in egress such as those for cultural centers are in need. Furthermore, cultural centers which are often of heritage value see architectural changes through time which can complicate existing evacuation strategies. Herein we recorded and analyzed two real emergency evacuations of a heritage cultural center. Using recorded CCTV footage from these real events, we employ developed tracking software and post-processing algorithms to derive a novel movement profile for representing a diverse demographic expected within buildings similar to that considered herein. We then validated these movement parameters within two typical software against the actual egress observed in the two evacuations. By verifying modelling tools and validating input movement speeds for use in this infrastructure, our study then considers a range of actual and potential architectural changes a building may experience and the new architecture's implication on emergency evacuations. Practitioners may find the discussion herein useful towards planned or recently executed architectural changes in historic buildings such as cultural centers. The results lay the foundation for further work which will help enhance knowledge on decision making in evacuations.

INTRODUCTION AND BACKGROUND

Currently there exists a need to develop accurate movement speeds of diverse sets of infrastructures and buildings that can be utilized within evacuation modelling tools. This has been outlined through the SFPE research needs roadmap, and recently explored in the author's SFPE foundational report which considered a diverse range of structures (SFPE 2018) (Gales et al. 2020). Herein we describe the process of obtaining raw data which was later translated into movement speeds through the use of existing but modified open-access tracking software. We then utilize these movement speeds in existing software to validate the proposed movement speed profile, while also validating the use of these software tools for describing evacuation in complex cultural centers. The motivation of this current research project is to utilize evacuation modelling tools to understand the implications of architectural changes as are seen on heritage cultural centers.

The egress analysis of heritage buildings for new use is often performed by practitioners. Heritage buildings often present challenges with regards to emergency egress. New flow patterns, population density variations, changing and evolving demographics all reflect the challenges in egress design. These designs can affect the heritage value of these buildings and subsequently can conflict with conservation standards and guidelines. Herein we consider a 110 year old cultural center that has undergone several changes in use as well as structural and architectural modifications. It exemplifies the challenges in performing an egress analysis of a heritage building, which are discussed herein. The hundred-year-old cultural center serves the same purpose for which it was built, but it has not been exempted from the common changes of use that most heritage buildings experience. Most older buildings have changes in use and occupancy later in their lives to meet modern societal needs and changing industries (for example old industrial buildings becoming commercial offices). Even if the use has not changed, many interventions for structural stability are often required, changing the layout or certain building elements. When considering emergency egress in heritage buildings, there are often adjustments needed to the original egress routes to comply to modern building codes, while simultaneously respecting the heritage value of the structure and not changing those heritage defining elements. After many occupancy changes and hosting many different museums, extensive renovations altered the building's structure, organization, and egress routes to how they are today. These interventions have a variety of effects on the emergency egress, whether positive or negative, to be determined through modelling. The most significant addition to the building is the glass tower containing scissor stairs at the entrance to the building. These stairs provide additional connection between the second and fourth floors, where there was once supposed to be a separation between the public and private access to the building. The entire building is now open to the public, contrary to the original architect's intent, which causes unique egress challenges. In addition to the new staircase, six emergency exits were added to the various corners of the building, in an attempt to facilitate emergency egress. Another aspect of the renovations under consideration is the support columns for the new glass tower, which are placed very close to two of the three entrance doors. During regular ingress and egress the center door (not blocked by columns) is the only one utilized, but during emergency egress the two side doors are useful for evacuating the main entrance, where 70-90% of occupants exit according to the observed scenarios.

The museum study was conducted as a continuation of research program on a cultural center (Gales et al. 2020) (Champagne et al. 2019) (Mazur et al. 2019). Two scenarios are analyzed herein, originating from the CCTV records taken from real evacuations of this cultural center in 2016, on two separate occasions. From these recorded evacuations, the actual floor loadings and exit use rates were documented to create the two scenarios. A third scenario has not had its analysis completed, and therefore will only be included in future research. The following information was extracted and used for analysis: floor loading, exit use rates, and movement speeds organized by age demographic. A model of the building has been created and was utilized within different (though similar) movement based modelling software tools. The authors choose to consider two anon movement software technologies herein; Anon in the sense to not directly compare short comings, but to exemplify that the movement data inputs can be used with confidence (movement speeds unique to modified public heritage buildings). One of these softwares used a social forces based model where the other is based on the inverse steering movement model. The movement data was validated and the models verified to represent the real scenarios observed. An added point of interest with this particular case study was the heritage status of the building, and the major renovations and occupant changes throughout its year lifespan. The changes in use have an effect on the emergency egress, and many of the renovations had the purpose of improving the emergency egress of the building for the new occupancies. Therefore, in addition to the model validation, various simulations were run to be able to isolate the impact of specific elements of the renovation on the emergency egress of the building. The specific elements of interest were notably the columns in front of the entrance doors, the new tower stairs, and the new corner exits.

MOVEMENT PROFILE GENERATION

CCTV footage was analyzed to determine the time between the activation of the evacuation alarm and the movement of the occupants. This was applied as a pre-evacuation time in the models to best reflect the behaviours observed these are presented in Table 1. A custom movement profile for the museum occupants was derived from walking speeds observed during one of the real evacuations. The input movement speeds for the evacuation software used is intended to be taken from an uncongested environment. Through reviewing security camera footage, the atrium was selected as the people walking through this area met this criterion. Additional post-processing code was developed to be used in conjunction with Kinovea, freeware, open-source sports kinematics software. With this new post-processing code, it was possible to easily generate movement speeds from the CCTV footage provided by the cultural center. An example of Kinovea in use is shown below in Figure 1.

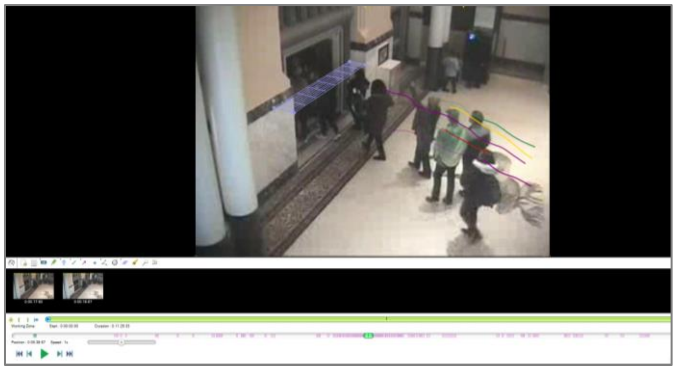

Figure 1: Example of Kinovea with tracking and perspective grid.

In regular use, Kinovea can track user-specified objects in video feeds, correcting for lens and angle distortion. However, Kinovea could not directly provide average speeds for an entire population, nor could it adapt to the occasional duplicate frames observed in low-framerate CCTV Video. Custom post-processing code was developed by the authors using excel VBA scripts to determine average speeds for entire populations over the course of tracking, while also detecting and accommodating frame duplicates from the camera footage. The developed script takes the coordinate data and times for each tracked object (i.e. person being tracked) and calculates the per-frame instantaneous speed. An overall average speed for each tracked object is generated based on the speeds observed over the object's entire track. Frame duplicates are detected when the change in coordinates between frames is zero. When this occurs, the duplicated frame's data is deleted, avoiding a velocity data point of 0 which would otherwise significantly impact average data. The developed script also sorts and categorizes the final average speeds based on the names manually given to the tracked objects within Kinovea. In this case, age demographics were tagged. 90 occupants passing through the atrium were analyzed. The population analyzed was composed of parents with children, adults, and youth. There were not enough seniors in the museum's footage to represent a statistically significant profile and this is in need for future use. The final profile is averaged and summarized in Table 2 below. The full profile broken between demographics was utilized in modelling efforts.

Table 1: Summarized pre-movement time.

Pre-Evacuation Time (Seconds)	**Percentage of Occupants (%)**
0-5	17
6 - 10	18
11 - 20	15
21 - 30	19
31 - 60	20
61 - 120	9
121 - 210	3

Table 2: Summarized movement profile (not separated by demographic).

New Profile	**Min Speed (m/s)**	**Max Speed**	**Mean**	**Std**
	0.58	1.98	1.15	0.28

MODELLING

In industry, Anon Software A and Anon Software B are both common pedestrian movement software used for evacuation analysis and prediction. They are both driven through similar movement frameworks, and were therefore chosen to analyze the cultural center crowd egress. The overarching goal of this paper is to validate movement profiles but not yet explore the software's decision making benefits or pitfalls. The names of the software used have not been included, as this is not a critique of any particular software. The intent is simply to show in both tools that the movement profile can represent the realistic speed of evacuation seen in reality. The authors restrain from making direct comparisons between the software's underlying mechanics as that is appropriate in future research – hence no imagery of the models are shown herein beyond the construction of the model space. In future research these implications may be beneficial to research.

Software A and Software B have similar construction and input procedures. For both, the model spaces were generated by using the cultural centre floor plans as supplied by the directors themselves and refined by the authors with surveying procedures in order to update certain aspects and incorporate blockages as would be present via exhibits. These floor plans were then transferred into a SketchUp file where elements were then defined in order to appropriately import into the software user space. The model space was then verified to ensure doorways, stairways, obstacles were assigned according to the floor plan to ensure the correct scale. Figure 2 shows the floor plan of the museum in SketchUp prior to import.

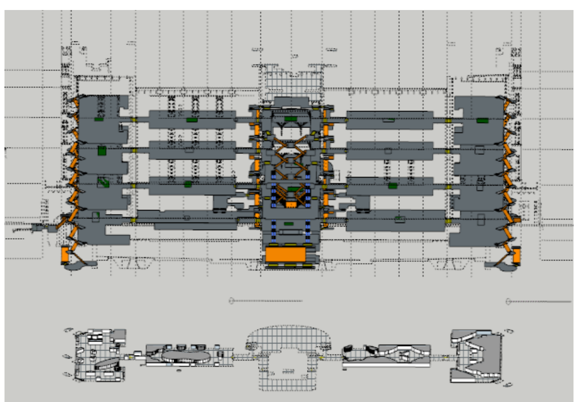

Figure 2: Cultural center museum floor plan rendered in SketchUp.

Modelling Validation of Movement Speeds

These models used the novel movement profile as defined in previous section by the authors. The validation of the profile was across two evacuation scenarios which reflect the first two evacuations. Note the profile was derived from data from Scenario 2 alone, but would be validated against Scenario 1 and 2. At the time of writing, the third scenario (the 2017 evacuation) has not been used for validation purposes as the footage is still being analyzed by the authors. The intent of these validation exercises is to verify the authors movement (pre and evacuation) profiles for use in a range of computational egress modelling tools. It is not to validate the decision making or underlying movement framework in the models.

Scenario 1 shows the modelling of a relatively large evacuation with a population of 1742 patrons that was rationally distributed in the museum. This represents a credible occupation on a given autumn day whereas the maximum allowed population of the building is 4000. In Scenario 1, all of the programmed agents were assigned the recorded pre-movement time developed by the authors and assigned tendency of choosing specific exits as were seen in the real evacuation. By assigning the exit use we do not attempt to interrogate modelling decision making on wayfinding. In Software B, the pre-evacuation time in the movement profile section was assigned to all of the agent population by giving a waiting task to all agents. The length of waiting time was assigned in percentage accordingly to Table 1. An exit seeking task was then assigned after agents finished their waiting tasks. The seeking task simulates the exit choosing tendencies of the reality, and the exit seeking task was assigned in percentage following the summarized exit usage rate according to the real events. The model of Scenario 1 in Software A is similarly constructed. Since Software A supports assigning a percentage pre-movement time directly in a table form, with the pre-movement time set up according to CCTV footage was analyzed to determine the time between the activation of the evacuation alarm and the movement of the occupants. This was applied as a pre-evacuation time in the models to best reflect the behaviours observed these are presented in Table 1. A custom movement profile for the museum occupants was derived from walking speeds observed during one of the real evacuations. The input movement speeds for the evacuation software used is intended to be taken from an uncongested environment. Through reviewing security camera footage, the atrium was selected as the people walking through this area met this criterion. Additional post-processing code was developed to be used in conjunction with Kinovea, freeware, open-source sports kinematics software. With this new post-processing code, it was possible to easily generate movement speeds from the CCTV footage provided by the cultural center. An example of Kinovea in use is shown below in Figure 1.

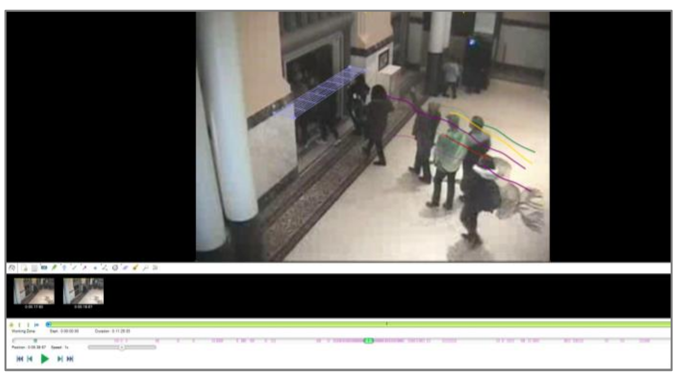

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Table , only one exit choosing task needed to be assigned to the agents to develop the scenario. The plot of the main entrance exit count comparison between two software was shown by Figure in comparison to the observed evacuation. The main entrance is shown as it represented a population of over 70% who exited in reality.

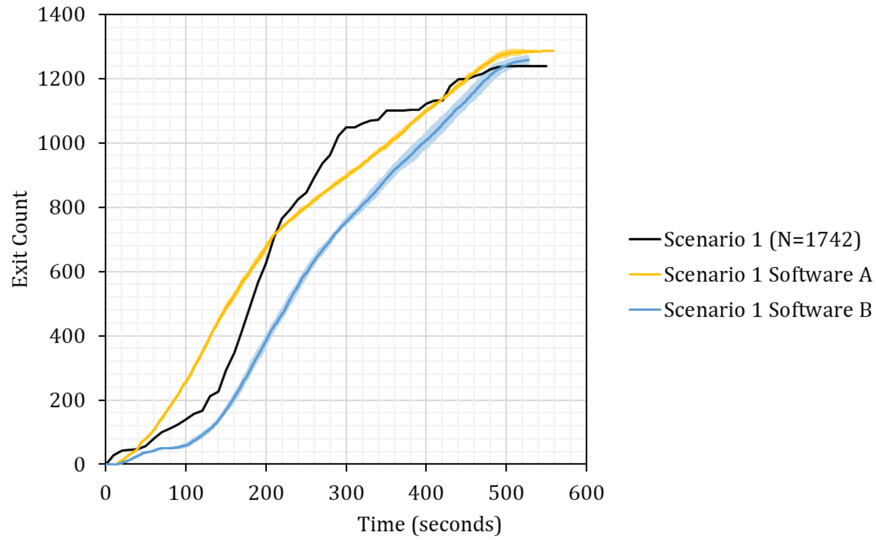

Figure 3: Comparison between the model results and real data for Scenario 1 (main entrance only).

Scenario 2 required additional consideration as in reality the majority of those leaving exited in the main entrance (>90%) and in addition the occupants were retrieving possessions such as coats during the evacuation (due to a snow storm). The population of the model is much lower with 459 agents. The authors analyzed footage of the event and concluded the process of coat retrieval was on average 60 seconds. In Software B, the agents were firstly assigned the waiting task same as Scenario 1 to simulate the pre-movement time reflective of their position in the cultural center. To simulate the exit choice the cost of route was manually set. The exit cost distribution was tuned close to the distribution recorded in the event. A waiting task initiator was also applied to the atrium floor so that once an agent enters the atrium, the agent will perform a 60 second wait time task to simulate the picking up coat process. After the waiting time, agents will continue their egress. In Software A, an alternative approach is applied. First, all agents had applied a general pre-evacuation time as before in Scenario 1. After the pre-evacuation time, approximately 92% of the population was assigned a task of picking up coat in the atrium. The 92% of population was assigned to seek for the atrium, waiting for 60 seconds in the atrium and extract from the main entrance. The other 10% of population will perform a normal evacuation that the agent will choose any exit with no restriction. The plot of the main entrance exit count comparison between two software is shown by Figure 4.

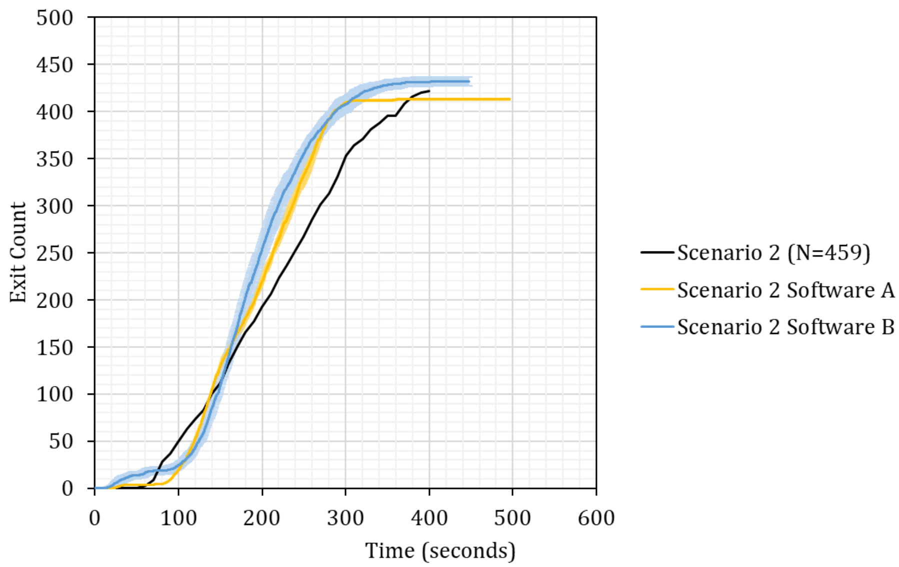

Figure 4: Comparison between the model results and real data for Scenario 2 main entrance usage.

In Scenario 1, both the simulation result curves have a trend that generally conforms to the real data curve. Before 100 seconds, Software B generates a mild increasing trend similar to the real situation, while the curve of Software A is steeper. At 200 seconds, Software A shows the same trend as the real situation that the exit count increasing rate is slightly decreased, while Software B simulates the decreasing trend after 250 seconds. Both software results in a similar total main entrance evacuation rate around 70%. The result generated from Software B is wider spread than Software A, illustrated by a wider shaded standard deviation area.

In Scenario 2, Both the software-generated result follows the trend of the real situation with a small difference between software. A notable difference between the simulated result and the real situation is the exit count increasing slope. It would relate to a small discrepancy between the ideal movement profile and real population movement speed. All modelled trends in Figure 4 suggest a plateau. This is actually not so as there are still a number of slow moving agents with large travel distances which result in these times appearing extended.

Heritage Considerations

A range of analyses of the original 1911 building configuration and the building as it is today after significant renovations were conducted. The purpose is to identify the effects of the renovations on the modern egress of the building and determine their efficacy. To isolate the effects of specific additions, (for example new emergency exits or stairwells,) simulations were run with all the additions as the building is now, with each addition tested individually to see their effect on the overall egress time. These models were built based on archival data about the museum, which are not entirely complete at this stage. More accurate models will be created as additional information is researched by the authors.

The elements that were analyzed specifically were new staircases added in the new tower, six new exits at the bottoms of existing staircases in the corners, and columns supporting the new towers located at the foyer (seen in Figure 5). As the first iteration of these analyses, it did not yet consider the behavioural aspects that were included in the validations. These aspects will be interesting to consider in future research, as the population will have significantly changed socially and demographically from the museums use 100 years ago till today.

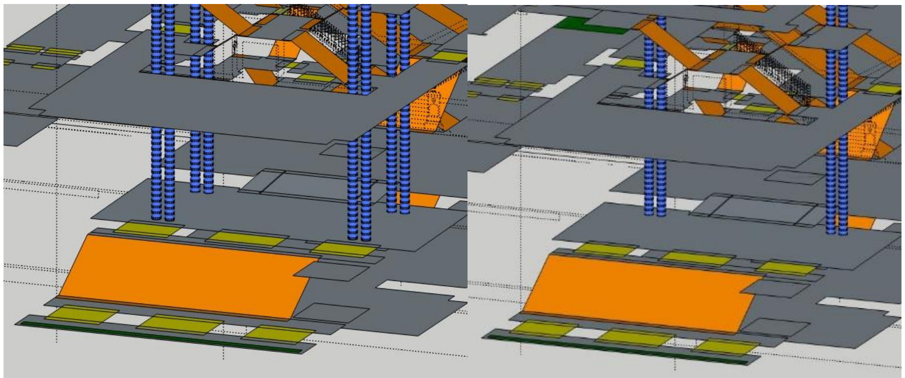

Figure 5: Model with and without the columns obstructing two of the three main entrance doors.

The occupant loading used was the maximum of 4000 for the museum to highlight the differences in egress times between the various scenarios in the worst situation, with or without certain additions. From the preliminary analyses, the new columns in the entrance, as well as the new staircase, had little effect on the egress time. The most significant additions in terms of egress were the six corner exits connecting directly to stairwells linking all four floors and the basement. The governing elements in the emergency egress of the building are still being explored, and the models will be further developed with some of the considerations discussed herein and more. These analyses are part of an important next step in this research, and give an idea of what interventions were effective in improving the egress of the structure and which weren't, which is valuable information when working with heritage buildings where minimizing interventions is recommended.

CONCLUSION

The comparison between Software A and Software B was completed with a model validation regarding movement speeds, as well as a preliminary analysis and heritage considerations. The model validation found similar results between the software when evaluating the main exit use, and only a slight difference of slope between the simulations and the real exit use data. That difference can be attributed to the idealization of the population's movement speeds. The preliminary parametric analysis using default parameters found minimal differences between total egress times with various populations. Overall, Software A and B were verified to produce similar analyses possibly influenced due to their similarity in movement algorithms. The comparison by parametric analysis will continue in future work. Future research will also expand upon the findings in this paper with the inclusion of the third recorded evacuation scenario for validation and more analysis on the renovation of the building and the heritage aspects that influenced the layout decisions.

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