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Extending and validating a theoretical model to predict the effectiveness of building evacuations

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ABSTRACT

To predict the effectiveness of building evacuations is a very difficult task in the general case. In a previous work, the historical results of 47 evacuation drills in 15 different university buildings, both academic and residential, involving more than 19 000 persons, was analyzed, and a method based on dimensional analysis and statistical regression was proposed to give an estimation of the exit time in case of evacuation. Comparing this estimated exit time with the real values obtained in evacuation drills, more informed decisions on whether to invest in more training and/or preventive culture of the occupants or to invest in structural improvements of the buildings can be taken. In this work, we both propose a refinement of the method to calculate expected exit times, that leads to an even better adjustment between predictions and real-world results, and we use this refined model to predict the results of evacuations of a new building, whose use and characteristics are different from those previously studied, and whose data was provided by other authors in the bibliography. We show that there exists a correlation between the published results and the predictions generated by our model, both from a quantitative and qualitative point of view.

1. Introduction

It is very difficult to predict how well a particular building can be evacuated in the case of an emergency. Building evacuation depends on multiple factors and it is very hard to reach a holistic view of the problem. For this reason, as [1] pointed out, partial approaches are not rare in the literature. Many efforts in the study of evacuation drills are more focused on observing particular aspects that influence evacuations, such as the nature of pedestrian movement, evacuation decisions, route choice, or social influence, among other factors [2], than on collecting data from the entire building seen as a whole. As another example [3], studied fire drill evacuation data in eight office building occupancies, ranging from 6 to 62 storeys in height, but they focused on what happened in stairwells.

The rationale behind the use of partial, non-holistic approaches in the bibliography is that, in many cases, emergencies in buildings have been studied with the help of computational models, that only take into account certain aspects of the problem. There is a wide range of computational models available for this purpose [4]: said that there are more than 22 models that simulate the behavior of buildings with different variants (see also [5]). For example [6], used a computational model to generate the optimal door positions which minimize evacuation distance; while [7] developed a particular model to apply to shooter incidents. There are also proposals to use computational models in real time, such as [8,9]. Interestingly, other authors validate their model proposal with the help of virtual

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reality tools [10].

To predict the effectiveness of building evacuations from an holistic point of view [11], analyzes historical data of 47 evacuation drills in 15 different university buildings, both academic and residential, involving more than 19 000 persons, using a combination of dimensional analysis and statistical regression, in order to give a prediction of the ratio between the exit time and the number of people evacuated. Dimensional analysis [12,13] is a method for reducing complex physical problems to their simplest (most economical) forms prior to quantitative analysis or experimental investigation. It provides a method for calculating sets of dimensionless parameters from the given variables, even if the shape of the equation is still unknown and the choice of dimensionless parameters is not unique [14,15]. Dimensional analysis has been used in different science areas, from chemistry and mathematics to economics or techno-economics [16]. Besides this, the combination of dimensional analysis and statistical regression had already been used previously (see e.g. Ref. [17] or [18]). These techniques are particularly suited for the problem studied in Ref. [11], as that work aims to reduce a complex physical problem to a simpler form prior to investigation using statistical data.

In [11], the historical information collected by the University of Valladolid over the last decade regarding evacuation drills was analyzed. This information includes a total of 47 evacuation drills of 15 university buildings, both academic and residential, invoving 19 198 occupants and 688 external observers. With the help of the structural data of the evacuated buildings, a dimensioness parameter associated to each building, called Characterization of Building Evacuation (CBE) was calculated. Given the CBE for a particular building and the number of people occupying it, we were able to calculate an estimated exit time. The comparison of the estimated exit time for a given building with its measured exit times can be used to guide activities in order to improve the latter. For example, if the estimated time is shorter than the measured time, it would suggest that people behave worse than expected, and that it might be better to invest in improving people's behavior than investing in improving facilities to ease the evacuations. On the contrary, when the estimated time is longer than the measured time, it would suggest that it might be better to invest in the facilities to further ease the evacuation. By using this approach, more informed decisions on how to further improve exit times can be taken.

The proposal presented in Ref. [11] will be reviewed in detail in Sect. 3, as it is the basis for this new contribution. In this work, we extend that previous study, with the following new contributions:

- We have improved the calculation of the expected evacuation times, redefining the formula of that previous study from a statistical point of view. As a result, we have obtained a better adjustment of those predictions with respect to the data available.
- We have applied this new model to five evacuation drills carried out in a primary school in Spain [19]. We have augmented the input data with the building and drills information provided in that work. The results obtained show that the application of our model for that scenario is both consistent with the results obtained in that study from a quantitative point of view, and leads to interesting qualitative observations. This application of our model helps to validate the original proposal, also opening the door to further research.

This work shows that the approach followed by Ref. [11] makes it possible to simplify the study of the simulation results carried out by different authors in different circumstances, helping to find common points that facilitate comparisons. We are aware that it is still necessary to further strengthen the theoretical and empirical knowledge regarding such models, especially considering the enormous variety of conditions produced during an evacuation that depend on the different scenarios. To do so, more data regarding evacuation drills should be included by the research community in their published works. Having access to the data from the evacuation drills that many entities carry out regularly could be very useful for the advancement of investigations in this field. The more data made public in the bibliography, the better our model and other similar proposals will adjust to them.

This article is organized as follows: Section 2 describes some related work in this field. Section 3 summarizes our previous work, which is used as the baseline for this new contribution. Section 4 presents and discusses a model that improves the baseline model. In Sect. 5, we add data collected by other authors to the improved model proposed, applying the model and discussing some findings. Finally, Sect. 6 presents our conclusions.

2. Related work

Several authors have addressed the problem of taking into account all aspects of building evacuations simultaneously. The review of human behavior during building fire incidents by Ref. [20] demonstrated that it is essential to take a holistic approach in modeling building evacuation, incorporating different types of characteristics from different domains of knowledge. Ref. [21] gathered all the available data, studies and research at that moment in the field of human behavior during fires. Later [22], developed an extensive compilation of all empirical studies carried out to date, both with people and animals, concluding that there is a lack of unification to allow studies to be comparable and reproducible. More recently [23], analyzed 116 evacuation drill reports from Canada and realized that reports with more detailed data were needed for a better scientific and practical perspective, because the reports do not collect all the same types of data that would allow comparisons between different buildings and drills, or systematic studies of different aspects linked to the results of the drills.

In order to develop evacuation models, it is important that the real-world information gathered in different drills is made available to the community. Unfortunately, this is rarely the case. For example, even advocating the need of more data available for research, the data presented in Ref. [23] does not include the specific information related to each drill and building, thus preventing its use to feed other evacuation models. On the contrary [19], presented a dataset of five evacuation drills carried out in a primary school in Spain, with the aim that some subsets could be used for model configuration and validation. Later [24], used these data to feed a range of subsequent simulations, conducted by using four computer models and the Society of Fire Protection Engineering's hydraulic model, obtaining interesting conclusions. Although school buildings are not representative of all possible scenarios, it is useful to have this information to augment the available dataset and to assess the applicability of different theoretical models. There are other studies in elementary schools, but they do not study the behavior of people in various drills that completely evacuate the building, as in Ref. [19]. For example, there are works, such as [25,26], that studied particular aspects involved in evacuations in different real cases in primary schools, but without providing the data regarding the evacuation drills of the entire building.

In [11], we adhered to this view, gathering information from 47 evacuation drills in 15 different university buildings, while also proposing an analytical method to compare the evacuations of different buildings as a whole. As pointed out by Ref. [27], the more data there are from different evacuation drills from the same building, the less uncertainty there will be concerning human behavior and the more representative the results. To ensure the representativeness of the information feed to the model [11], recommends having data from two or more evacuation drills of the same building. As we stated in the work cited above, having data from more than one evacuation drill helped us to better isolate the particular results of a single drill with differences that can be explained in terms of the human behavior of the occupants of each building.

3. The baseline CBE model

[11] presented some experimental data regarding 47 evacuation drills in 15 different university buildings, and developed a theoretical model to give a prediction of the ratio between the exit time and the number of people evacuated. As long as this work proposes an improvement to that model, this section briefly summarizes that contribution, in order to put the new findings into

Table 1
Building parameters and drill information as presented in Ref. [11]. The right column (in grey) contains a new expression based on the data of each evacuation drill. The use of this expression is discussed in Sect. 4.

Building	Building characterization parameters					Values measured in each evacuation drill		New expression
Drill	Sf (m2)	F	St	E	Me (m)	Np	Te (min)	Te/Np*100
EII-SPC 2013-11	14 683	4	3	3	10	700	9	1.29
EII-SPC 2015-10	14 683	4	3	3	10	700	9	1.29
EII-SPC 2016-11	14 683	4	3	3	10	700	9	1.29
EII-SPC 2017-11	14 683	4	3	3	10	800	7	0.88
EII-SPC 2018-11	14 683	4	3	3	10	500	9	1.80
EII-SFM 2015-05	13 185	6	6	4	6.8	500	5	1.00
EII-SFM 2016-03	13 185	6	6	4	6.8	500	6	1.20
EII-SFM 2017-03	13 185	6	6	4	6.8	800	5	0.63
EII-SFM 2018-05	13 185	6	6	4	6.8	350	4	1.14
FC 2013-04	15 107	4	6	4	8.1	175	9	5.14
FC 2016-11	15 107	4	6	4	8.1	175	8	4.57
FC 2017-11	15 107	4	6	4	8.1	200	6	3.00
FC 2018-11	15 107	4	6	4	8.1	180	5	2.78
AFC 2013-04	11 166	4	7	7	11.23	225	8	3.56
AFC 2016-11	11 166	4	7	7	11.23	600	9	1.50
AFC 2017-11	11 166	4	7	7	11.23	900	5	0.56
AFC 2018-11	11 166	4	7	7	11.23	900	6	0.67
ETIC 2010-03	21 009	3	5	8	14.4	700	6	0.86
ETIC 2011-04	21 009	3	5	8	14.4	700	10	1.43
ETIC 2016-03	21 009	3	5	8	14.4	700	7	1.00
ETIC 2017-03	21 009	3	5	8	14.4	700	6	0.86
ETIC 2018-05	21 009	3	5	8	14.4	500	6	1.20
FFIA 2015-05	21 709	6	6	5	25	1 000	9	0.90
FFIA 2015-11	21 709	6	6	5	25	1 000	12	1.20
FFIA 2017-05	21 709	6	6	5	25	500	6	1.20
FFIA 2018-05	21 709	6	6	5	25	1 000	7	0.7
AVIII 2010	22 726	9	4	10	14	200	8	4.00
AVIII 2015-05	22 726	9	4	10	14	130	7	5.38
AVIII 2015-10	22 726	9	4	10	14	130	10	7.69
AVIII 2017-11	22 726	9	4	10	14	150	12	8.00
AVIII 2018-11	22 726	9	4	10	14	300	8	2.67
CMSCF 2016-05	6 514	8	3	4	3.4	15	8	53.33
CMSCF 2016-11	6 514	8	3	4	3.4	50	6	12.00
CMSCF 2017-11	6 514	8	3	4	3.4	55	4	7.27
CMSCF 2018-11	6 514	8	3	4	3.4	40	5	12.50
BRS 2013-04	2 155	2	1	2	2.01	80	4	5.00
BRS 2014	2 155	2	1	2	2.01	80	4	5.00
ETSA 2016-03	13 605	5	8	4	14.8	350	5	1.43
ETSA 2018-05	13 605	5	8	4	14.8	250	5	2.00
CMSCM 2017-05	4 057	5	2	3	4.1	50	6	12.00
CMSCM 2017-11	4 057	5	2	3	4.1	50	4	8.00
CMSCM 2018-11	4 057	5	2	3	4.1	31	3	9.68
LUCIA 2018-05	5 321	3	2	2	3.4	64	4	6.25
LUCIA 2018-11	5 321	3	2	2	3.4	43	3	6.98

perspective.

One of the advantages of the model is that it considers buildings as black boxes, abstracting away non-relevant characteristics. In that work, the data regarding the evacuation drills and the structural characteristics of the buildings being evacuated included the following information:

- The value of the following structural parameters for each building:
  - The total surface of the parts of the building usually occupied (Sf) (in m^2).
  - The number of floors that are usually occupied (F).
  - The number of different staircases that can be used as evacuation paths (St).
  - The number of exits from the building towards the outside (E).
  - The sum of the widths of the exits towards the outside of the building (Me) (in m).
- The elapsed times from when the evacuation alarm sounds until no more people leave the building (Te) for several evacuation drills conducted along the years (in min).
- The number of people leaving the building during that time interval (Np) in each drill.

Table 1 shows the data presented in Ref. [11], used to build that theoretical model. Most buildings are academic centers with classrooms or laboratories for students, offices, and other rooms. There are also student residences such as CMSCM, CMSCF and AVIII. AVIII also houses other activities that are governed by different managers. LUCIA is a building with laboratories, spaces and facilities dedicated to research. Their occupants are researchers with experience in evacuation drills. For the interested reader [11], includes additional information about the particular characteristics of each building and of their occupants.

In [11], a dimensionless number, called CBE (*Characterization of Building Evacuation*) was calculated using the structural data of the building. That dimensionless number characterizes the easiness of evacuation of the building. The CBE was defined as follows:

$$CBE = \frac{\sqrt{Sf}}{Me} * \frac{F}{Ea} \tag{1}$$

where *Ea* is the average number of exits per floor, including floor exits towards the staircases and floor exits towards the outside. *Ea* is obtained as follows:

$$Ea = \frac{St * (F - 1) + E}{F} \tag{2}$$

The left part of Table 2 (in white) shows a summarized version of the data collected in the evacuations drills, together with the CBE associated with each building, as presented in Ref. [11], where *ANp* is the average number of people evacuated for each building, and *ATe* is the average of the corresponding exit times. The fourth column presents the quotient of both values multiplied by 100, and the fifth column shows the CBE for each building. [11] used these values and statistical regression to obtain a polynomial formula, where *CBE* is the independent variable and *ATe/ANp**100 is the dependent variable. The obtained formula is the following:

$$f(x) = 0.001\,8x^2 + 0.121\,8x + 0.428\,9 \tag{3}$$

This formula presented a good adjustment to the data available, with $R^2 = 0.911$. This good adjustment suggested that the behavior pattern could be mathematically modeled by studying the simulations in this way.

We used this formula to get estimations of the exit time needed to evacuate each building, $\widehat{T}e$:

$$\widehat{T}e = \frac{Np * f(CBE)}{100} \tag{4}$$

We believe that $\widehat{T}e$ may be a useful indicator to predict the evacuation time of different buildings. [11] finished analyzing the coherence of the estimations returned by the model, with the average of the real values obtained during the drills, *ATe*. That analysis led to several interesting observations regarding the behavior of the occupants of each building, followed by a discussion on the applicability of the model to other buildings.

4. A new proposal for better evacuation time estimations

As intuition suggests, the value of *Te* is influenced by the total number of people that should leave the building. It can be expected that the higher the number of persons, *Np*, the longer it takes to evacuate the building [4]. This is because a higher *Np* means there is a higher possibility that some people will be late in leaving the building for various reasons, such as small incidents or problems in the evacuation, or simply reasons linked to the free will of human behavior.

Our initial study used the quotient of the averages of both values, that is, the ratio (*ATe/ANp*)*100. After that, we have found that results can still be improved if we take the former observation into account from the beginning. This led us to calculate (*Te/Np*)*100 and only later obtain their averages. Using the data presented in Table 1, the right column of that table (in grey) shows the values for the new expression, while the right part of Table 2 (in grey) shows the average values of (*Te/Np*)*100 for each evacuation drill of each building, together with their corresponding variances.

Fig. 1 shows the graphical representation of the CBE versus the new expression, *A*(*Te/Np**100). As in Ref. [11], we have used these values to obtain a polynomial formula for CBE with statistical regression. The obtained formula, also plotted in the figure, is the

Table 2
Intermediate values used to build our models. The left part (in white) includes the average number of people and exit times, the quotient of these averages, and the CBE for the considered buildings, as described in Ref. [11]. The right part (in grey) includes two new expressions: The average of the ratio *Te/Np**100 in each building, called *A*(*Te/Np**100), and the variance of this average, *Var*(*Te/Np**100). The rationale behind both values is described in Sect. 4.

Building	Avg. values from [11]				New proposal	
Drills	ANp	ATe	ATe/ANp*100	CBE	A(Te/Np*100)	Var(Te/Np*100)
EII-SPC	680.00	8.60	1.25	16.16	1.57	0.51
EII-SFM	537.50	5.00	0.93	17.88	0.99	0.07
FCMD	182.50	7.00	3.84	11.04	3.87	1.35
AFC	656.25	7.00	1.07	5.38	1.57	1.93
ETIC	660.00	7.00	1.06	5.03	1.06	0.05
FFia	875.00	8.50	0.97	6.06	0.87	0.13
AVIII	182.00	9.00	4.95	20.77	5.55	5.33
BRS	80.00	4.00	5.00	30.79	5.00	–
CMSCF	40.00	5.75	14.38	60.77	21.28	462.28
CMSCM	50.00	4.33	8.67	35.31	9.89	20.39
ETSA	300.00	5.00	1.67	5.47	1.71	0.16
LUCIA	53.50	3.50	6.54	32.18	6.61	0.26

following:

$$f(x) = 0.005\,4x^2 + 0.001\,2x + 1.251\,5 \tag{5}$$

This new formula presents a much better adjustment to the data, with $R^2 = 0.948$, that is, three points better than our previous proposal. All the qualitative discussion carried out in Ref. [11] regarding the behavior in the evacuation drills of each building with respect to the regression curve of the average behavior in drills is still valid.

Besides providing a better adjustment to the observed data, the new formulation also allows the variance of the ratio *Te/Np**100 to be examined, which can be seen as a qualitative vision of the different human behaviors in that building with respect to each drill. A bigger variance means a greater variability in the results obtained in different evacuation drills for the same building. In our case, looking at the data in Table 2, it can be seen that the three biggest values for the variance are those of the buildings that have residential activity, that is, buildings whose occupants and resident students responsible for evacuations may vary and, therefore, may not have accumulated experience from different, yearly evacuation drills.

5. Inclusion and comparison with data from other published research

As stated in Sect. 1 [19], presented data collection sets from five different evacuation drills carried out in a school in Spain. The authors expected that these data could be used for the configuration and validation of models. Later [24], used these data to feed a range of four computer-based simulations, conducted using four different evacuation models.

In this section, we use the data provided by Ref. [19] to augment the data presented in Ref. [11], obtaining a new adjustment formula and comparing its adjustment with the combined dataset. While the model presented in Ref. [11] is built using data that belongs exclusively to university buildings, the study presented in this section shows how data collected by different authors from drills conducted in both university and non-university buildings can be used together, thus extending the applicability of this proposal.

To do so, we first describe the characteristics of the Altamira building as presented in Ref. [19]. We then obtain the values for all the parameters needed by the CBE model, and we finally combine all the data in order to obtain a polynomial formula and discuss its accuracy and coherence with the observed results.

5.1. [19] buildings description

In [19], the authors presented the results of different evacuation drills in a school made up of two buildings, a main building and a smaller one. In this study, we incorporate the data from the main building to our model, which we call "AltamiraM". The building is

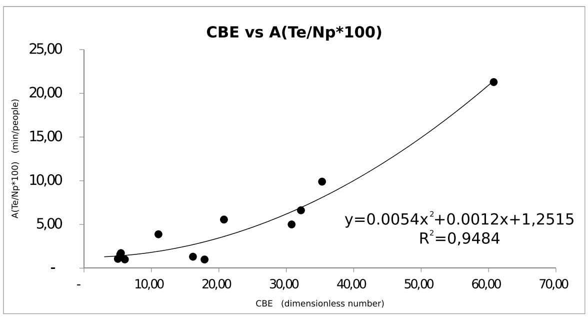

Fig. 1. New polynomial formula for the CBE, obtained by statistical regression of the available data, using *A*(*Te/Np**100).

composed of four storeys, P3 to P0. Fig. 2 shows the layout of the building. As can be seen in this figure, P1 has a grey area, corresponding to a classroom with a direct, independent exit door, and it does not share escape routes with the rest of the building, so it is not considered in this study. Regarding P0, it includes two closed, unused rooms that are also depicted in grey which are not considered either.

As can be seen in the floormap, several evacuation routes converge to the same exit points. This is not an uncommon situation in any building. The model handles this complexity by considering buildings as black boxes, and abstracting away the details of the particular layout of each floor. The addition of more data from different buildings and evacuation drills allows the researchers to further adjust it.

5.2. Obtaining building parameters

In order to incorporate this information to the model, we should first obtain the building characterization parameters. The first

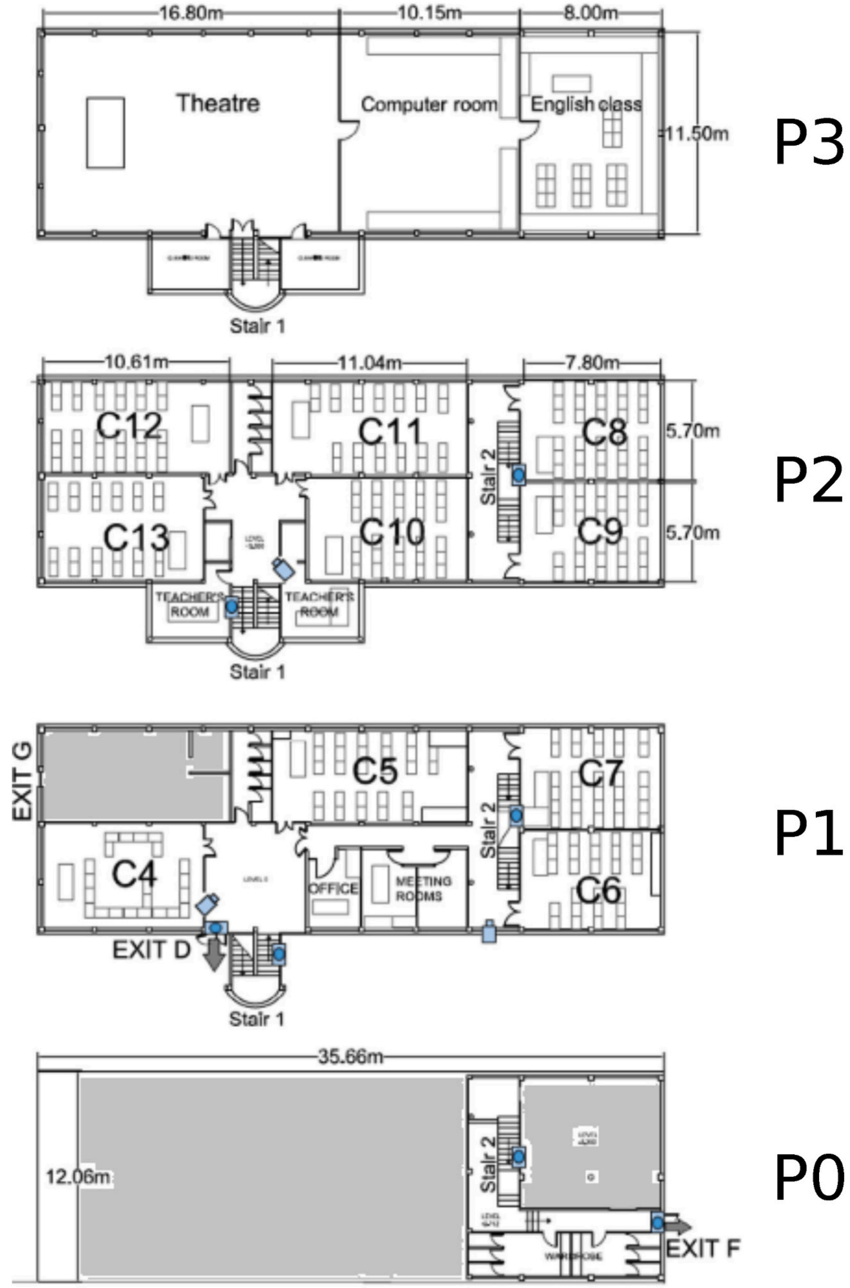

Fig. 2. Layout of the Main Building as presented by Ref. [19]. The shadowed areas represent rooms that will not be taken account in this study.

parameter that we calculate is *Sf*, that is, the total surface of the building, without the areas depicted in grey, for the reasons explained above.

From the dimensions indicated in the figure, the surfaces of each floor can be calculated as follows:

- P3 has $(16.8 + 10.15 + 8)m*11.5\ m + 33.20m^2 = 435.12m^2$.[1]
- P2 has $(16.8 + 10.15 + 8)m*(5.7 + 5.7)m + 33.20m^2 = 431.63\ \mathrm{m}^2$.
- P1 has $(16.8 + 10.15 + 8)m*(5.7 + 5.7)m - (10.61*5.7)m^2 = 337.95\ \mathrm{m}^2$.
- P0 has the stair 2: $(5.7 + 7.8)m*1.2\ m = 16.2\ \mathrm{m}^2$.

Using these values, Sf is equal to $435.12 + 431.63 + 337.95 + 16.2 = 1220.90m^2$.

We now establish the values for the rest of the parameters needed by the model.

- F is the number of floors with usual occupation. In this case, the lowest floor should not be counted since its function is only of transit, so F = 3.
- St is the number of staircases. In our case, St = 2.
- E is the number of exits. Exit G should not be counted because it is not communicated with any evacuation path of the building, so E = 2.
- Me is the sum of the widths of the exits towards the outside of the building. In our case, Me is the sum of Exit D (1.14 *m* wide) plus Exit F (0.8 *m* wide), that is, Me = 1.94.
- Regarding the evacuation times in minutes that are taken into consideration (Te), they are those corresponding to the time when all the evacuees left the Main Building, which is the one we study. The same occurs with the number of people evacuated (Np): We only take into consideration the people leaving the Main Building through exits D and F. Consequently, the data to be incorporated into this study are the data provided in Table 12 of [19]:
  - Drill E1: Evacuation time is 129s (that is, 2.15min) and Np = 263 people.
  - Drill E2: Evacuation time is 123s (that is, 2.05min) and Np = 225 people.
  - Drill E3: Evacuation time is 199s (that is, 3.32min) and Np = 247 people.
  - Drill E4: Evacuation time is 160s (that is, 2.67min) and Np = 244 people.
  - Drill E5: Evacuation time is 142s (that is, 2.37min) and Np = 264 people.

Table 3 summarizes the data that is incorporated into the model.

5.3. Data combination and results obtained

Using the building and drill parameters shown in Table 3, we can now augment Table 2 with an additional row (see Table 4).

It is interesting to see the low value of the variance for the Altamira school evacuation times. This means that it has a very stable behavior, not perceiving an evolution of learning in these drills, nor large incidents. The graphical representation of all these data can be made as shown in Fig. 3. Again, we used all these values and statistical regression to obtain a polynomial formula, where *CBE* is the independent variable and *ATe/ANp**100 is the dependent variable:

$$f(x) = 0.0065x^2 - 0.0704x + 1.6899 \quad (6)$$

The value of R^2, that represents how well this expression adjusts to the experimental data as depicted in Fig. 3, is equal to 0.9119. This value is slightly lower than in our previous formula, shown in Sect. 4, since this school does not behave in exactly the same way as the average of the university buildings studied. Nonetheless, the value obtained for R^2 is still good, confirming that this approach is robust enough to admit quantitative information from other buildings and evacuation drills. In addition, the analysis from a qualitative perspective is coherent, since in the graph we can see that the Altamira school point (*CBE* = 27.02; (*ATe/ANp*)*100 = 1.01) is below the curve. From a qualitative point of view, this means that, in this evacuation drill, the people of the Altamira school have left the building faster than the prediction returned by the model. As long as the model has been primarily fed with data belonging to evacuation drills of university buildings, our guess is that both the teachers' commitment to the safety and health of their underage students is higher than in a university environment, as well as the students' obedience to their teachers. In this sense, it is relevant to highlight that the evacuation times observed in Ref. [19] were higher in adolescents than in younger children, suggesting that the former are less likely to follow directions in an evacuation drill than the latter.

6. Conclusions and future work

In [11], a method based on dimensional analysis and statistical regression to predict the effectiveness of building evacuations was presented. This method is based on the use of a dimensionless parameter for each building called CBE (Characterization of Building Evacuations), that depends only on structural parameters of the building. The CBE allows to calculate an expected exit time for that building. By comparing this expected exit time with real exit times measured in evacuation drills, more informed decision can be taken in order to further improve the latter.

In this paper, the research described in Ref. [11] is extended in two ways. First, we show that, using the same input data presented

[1] The floorplan provided by Ref. [19] does not show the surface of the two rooms surrounding the stairs in P3 and P2. We have estimated their size with respect to the other elements of known sizes as $11.65\ m \times 2.85\ m = 33.20m^2$.

Table 3
Data of the Altamira Main building extracted from Ref. [19].

Building	Parameters inherent to the building					Values measured in the evacuation drill		
Drill	Sf (m2)	F	St	E	Me (m)	Np	Te (min)	Te/Np*100
AltamiraM Drill E1	1 220.90	3	2	2	1.94	263	2.15	0.82
AltamiraM Drill E2	1 220.90	3	2	2	1.94	225	2.05	0.91
AltamiraM Drill E3	1 220.90	3	2	2	1.94	247	3.32	1.34
AltamiraM Drill E4	1 220.90	3	2	2	1.94	244	2.67	1.09
AltamiraM Drill E5	1 220.90	3	2	2	1.94	264	2.37	0.90

Table 4
New row to be added to Table 2.

Building	Avg. values as in [11]				New proposal	
Drills	ANp	ATe	ATe/ANp*100	CBE	A(Te/Np*100)	Var(Te/Np*100)
AltamiraM	248.60	2.51	1.01	27.02	1.01	0.04

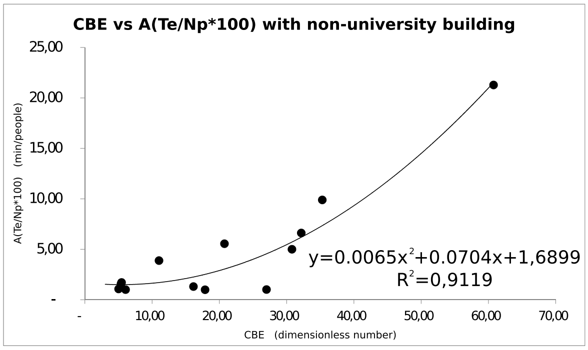

Fig. 3. Polynomial formula for the CBE obtained by the statistical regression of the available data, using the combined data from Tables 2 and 4

in that work, a better statistical adjustment can be obtained if we use the ratio $A(Te/Np*100)$ for each drill, instead of $(ATe/ANp*100)$. This change improves the R^2 value from 0.911 to 0.948. Second, we augmented the data used to feed the model with data published by other authors which represents an evacuation drill of a non-university building.

Our results show that the inclusion of this data in the model is consistent with the results obtained, both quantitatively and qualitatively. We consider this result promising, because it shows that it is possible to apply this theoretical model to study evacuation drills of buildings outside the university environment. Further research is needed to determine more precisely what kind of buildings can benefit from this approach. We believe that these results are promising and encourages research on this topic.

To further develop this theoretical evacuation model, more data is needed. We would like to encourage researchers in the field to publish data from evacuation drills, including a description of the evacuated buildings and their use. For example, in this paper, we have found that the evacuation drills added to the model were in fact faster than our predictions, probably because of the greater discipline associated with younger occupants. This is an example of an interesting issue related to human behavior that this model may help to analyze. It might be very instructive to have the possibility of comparing these results with other evacuation drills in the same or different contexts. This may lead to different interesting analyses, ranging from the influence of the structural building characteristics in the evacuation time, to the influence of cultural behavior with respect to the evacuation drills in different countries or population groups. We believe that this approach has a very direct, practical application, and we encourage professionals who organize evacuation drills to make public the data they obtain.

CrediT author statement

- **Maria D. Miñambres:** Conceptualization; Data curation; Formal analysis; Investigation; Visualization; Roles/Writing – original draft.
- **Diego R. Llanos:** Funding acquisition; Investigation; Metodology; Project administration; Resources; Supervision; Validation; Roles/Writing – Review & editing.
- **Angel M. Gento:** Investigation; Metodology; Supervision; Validation; Roles/Writing – Review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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