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LOST IN ABSTRACTION: THE COMPLEXITY OF REAL ENVIRONMENTS VS THE ASSUMPTIONS OF MODELS

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ABSTRACT

Many if not most fire evacuation models are relatively insensitive to the complexity of human behavior in the built environment. The complexity of human behavior and the very long feedback loop on building disasters can lead to the approval of structures that have massive inherent vulnerabilities. Buildings last a very long time. How does the designer propose to validate the model for the lifetime of the building? What keeps the occupant characteristics within the range proposed by the engineer? What keeps the reactions of the occupants predictable in the future based on the reactions of people with the current characteristics? Fire evacuation models routinely include what is claimed to be "engineering judgment". But while engineering judgment is well designed to interpolate data between known data points in the presence of an adequate covering law, it cannot be extended to extrapolating from mere observational data in the absence of a suitable "*covering law*".

This is especially true with regards to complex structures, i.e. buildings that involve complex variables that lack supporting data or are difficult to predict. We need better tools to understand the link between people and the built environment. In the process of abstraction and simplification, significant details and complex variables tend to be lost leading the models to overoptimistic outputs.

Some modelers may think that the inputs to behavioral models represent *universal reality* and they do not take into account *Unknown Unknowns*, which include:

- Wayfinding in unconventional evacuation paths (old and new buildings)
- Unconventional walking surface (old buildings)
- Cultural confusion (old and new buildings, e.g. airports)
- Unpredictable human behaviors

This paper will illustrate a small portion of this core issue in the use of behavioral models. We examine the assumptions routinely used in such models when compared to the reality of complex structures.

INTRODUCTION

People die from fires, even in code compliant buildings. They often die because evacuation is too complex or too difficult or too dangerous. Emergency wayfinding design and management, evacuation modeling and fire safety regulation remain major topics for research.

- ***Designers*** often do not understand how to design for fire safety and why seemingly small details are critical. They routinely make assumptions based on conventional buildings, standard reactions and normal wayfinding aids. They often assume compliance with a code provides safety.
- ***Fire Codes*** normally do not differentiate between simple and complex structures. Code makers make the *heroic assumption* that complexity is not important. Heroic assumptions are also made that code compliance is routine (e.g.: is there a requirement that says that exit sign should be more prominent in complex structures? see Fig. 1).
- ***Evacuation models*** also make *heroic assumptions* about the predictability of human behavior, and its stability over the lifetime of the building, and contain *hidden implicit assumptions* about the evacuation environment in a *wide variety of fire settings*.

Many if not most fire models are relatively insensitive to the complexity of the built environment. Sophisticated mathematical models represent one of the hallmarks of so called "***performance based fire safety design***". But these models are overwhelmingly created and used by engineers with little background or training in the limits of predicting human behavior in complex environments. In addition, the target audience for these models is not behavioral scientists or the research community but instead they are directed towards regulators with even less understanding of human behavior or the limits of modeling. This can create a defective "feedback loop" in which regulators assume an expertise on the part of the engineers that they do not have.

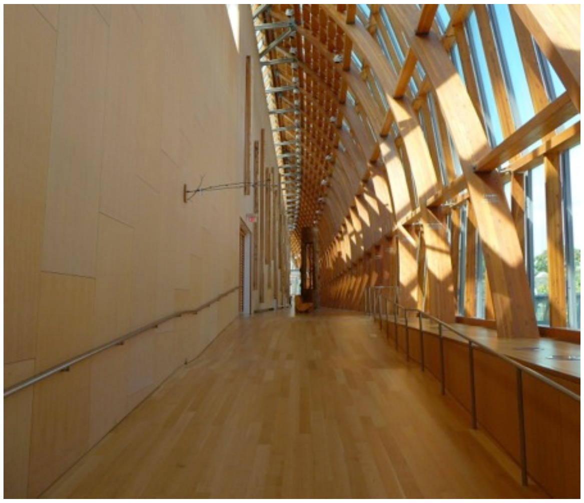

Figure 1. Galleria Italia, AGO, Toronto (2004). Complex museum with lots of visitors from all over the world. Very small exit sign on a long corridor.

The process of design and approval for the funnel staircase at the Comcast Center at the University of Maryland shows exactly this kind of defective feedback (Fig. 2).

Figure 2. Regulators approved this exit funnel based on a mathematical exit analysis that simply ignored the problem of crowd crush.

While some developers may understand the limitations of fire models, overwhelmingly the current role of such models is to get "a number" that can be used to satisfy the regulatory authorities who have to approve the building. This *forensic* approach to fire safety, combined with the complexity of behavioral science and the very long feedback loop on building disasters can lead to the approval of structures that have massive inherent vulnerabilities.

As just one example, since buildings last a very long time, a knowledgeable reviewer would ask the question "HOW does the designer propose to validate the data used in the model or the parameters of the model itself for the lifetime of the building?"

Human behaviors are not physical constants. What keeps the occupant characteristics within the range proposed by the engineer? What keeps the reactions of the occupants predictable in the future based on the reactions of people with the current characteristics? Fire evacuation models routinely include what can be charitably called "guesswork", often masquerading as unsupported "engineering judgment". But while engineering judgment is well designed to interpolate data between known data points in the presence of an adequate physical law, it cannot be extended to extrapolating from mere observational data in the absence of what the philosopher of science Hempel would call a "covering law" (Eidin, 2010).

While there is a massive and ongoing debate over the Hempel's concept of a "covering law" in a very simplified form it explains the existence of the so called Natural sciences. The key to a covering law is that it is a ***universal generalization of unrestricted scope.***

The *laws* of thermodynamics and gravity and chemical reactions are such *universal generalization of unrestricted scope.* Such laws can be used to take data and make *scientific predictions.*

But such laws are not common outside the physical sciences. As just one example, even with massive quantities of mathematically tractable data prediction of the stock market has proved to be essentially impossible.

Without an adequate covering law behavioral observations cannot automatically be used to make scientific predictions.

Scientific predictions require the existence of some underlying ***law*** that makes it possible to extrapolate observations. Engineers are brought up in the physical sciences in which such laws are routine so they can assume that in other areas they can simply assume the existence of a covering law.

The problem of prediction of human behavior is especially difficult when applied to complex structures i.e. buildings that involve complex variables that lack supporting data or are difficult to predict (like malls, historic buildings, airports etc…).

Complex structures demonstrate the frontiers of the use of models and clearly illustrate the need to carefully examine and distinguish between what we know and what we don't know (Fig. 3).

Fire protection engineering needs better tools to understand the link between people and the built environment. In the process of abstraction and simplification, significant details and complex variables tend to be lost leading the models to overoptimistic outputs.

Figure 3. Vatican Museum Hallway, Rome (1580). Historic buildings are iconic examples of complex structures. They host lots of untested variables: very long and unclear exit paths and lots of people with different backgrounds and abilites.

PERFORMANCE BASED DESIGN UNDER UNCERTAINTY

"Professional" judgement

The behavioral sciences have totally different intellectual structures from the physical sciences. Physical sciences are assumed to have "covering laws" which may be complex and difficult to discover and define but they are widely assumed to exist. Physics is the same everywhere. ***No such assumptions can be made for behavioral science***. Behavioral sciences are observational and correlational. Explanations are situation specific. More important, behavioral experiments may be ***explanatory*** but are rarely ***predictive.*** As noted above, vast effort has gone into predicting the stock market but, despite overwhelming and accurate data, such efforts end in complete failure. In addition ethical and practical limits on human experiments often make for very weak research conclusions. Behavioral uncertainties are extremely large and include types of uncertainties unknown to physical science models.

The claim that scientists can ever accurately predict human behavior based on past data is extremely controversial among social scientists c.f.. Mazlish (1998) *Uncertain Sciences*. Mathematician John Casti (1989) has also explored the problems of uncertainty in such models. The idea that behavioral science could lead to accurate predictions of human behavior is actually straight out of science fiction. *Psychohistory* was articulated by biochemist Isaac Azimov in his Foundation Trilogy. In the same vein Star Trek's Mr. Spock could come up with precise numerical solutions for predicting human behavior. But outside of science fiction it is unclear how to validate such behavioral predictions.

The bottom line is that even with masses of correct data, the absence of well defined covering laws makes future behavioral prediction highly unreliable. Consider the recent paper by Johnson, Johnson and Sutherland (2012) evaluating the "***stay or go***" reaction of Australians to wildfires. While it contains a substantial discussion of engineering analysis of data, it makes no suggestion that Fire Engineers possess special engineering judgment on wildfire evacuation separate from analysis of relevant data.

Even today, in the FSE community there is concern that what purports to be *professional judgment* or ***engineering judgment*** is poorly defined and difficult to quantify. As Woodrow et al. (2013) report: "Heuristic knowledge is essential for the top FSE designers and design firms when working outside the prescriptive codes. How this experimental knowledge should (or could) be developed within the limited timescale of University FSE programs or in the early stages of a fire safety's engineer's career, is a serious issue for both universities and for the FSE profession". But what is the basis for such judgments? Designers routinely assume conventional buildings, standard reactions and normal wayfinding aids.

On a recent paper Gwynne and Kuligowski (2012) also warn modelers from inexpert model misuse claiming that "results are produced through the use of inappropriate data and/or behavioural settings, which can lead to the generation of inappropriate or incredible results". In order to propose a means to combat accidental model misuse, the authors suggest to ***bound default settings*** for each of the core behavioral elements. In such a circumstance "if the model user wishes to decrease the conservative nature of a particular estimate or set of estimates, *which will almost certainly be the case*, he/she would then be required to explicitly ***justify*** the modification of the bounding default value. This approach then allows the immediate use of the model, but in effect forces the user to modify the settings in order to obtain a credible scenario for the purposes of design". But even if the paper proposes a method for avoiding out-of-the-box misuse of input data, it still does not state ***how*** and ***what kind*** of ***expert judgement*** is to be employed.

These case studies illustrates some of the problems with such assumptions. *Extrapolation* from data points, in the *absence of a covering law*, can easily lead to *errors*.

Fire scenarios

The problem of ***arbitrary data*** appears to be aggravated if the goal is confidential regulatory approval rather than published engineering analysis.
Dr. Hall of the NFPA sensibly cautions users of fire risk models.

If only a few scenarios are modeled explicitly then each one is implicitly required to be representative of a much larger and more varied collection of other scenarios. There may be no good evidence to support this.
A fire risk analysis without a long list of stated assumptions is bound to be a model with many hidden assumptions, which are almost certain to be less well founded, if examined than a list of "shaky" but explicit assumptions.

This caution has not prevented people from making detailed predictions of the fire risk of proposed buildings despite lack of detailed knowledge of the soft variables. But are these predictions the product of a "scientific" understanding of fire? Or are they simply more or less what Hall calls a series of guesses? More importantly how are the uncertainties in the process resolved? *Aleatory* uncertainty describes to the quality of data used in the process, which in the case of future fires may not be well documented at all. Aleatory issues such as the input fire, fire load or human behavior are often described with words like "assumptions" and "expert judgment". Dubious suggestions are even made e.g. "code compliance can be routinely assumed, "sprinkler systems are always functioning or that "fire alarms result in instant purposeful movement" (Brannigan, 1999).

Even today there is still a lot of concern on the problems related to the inability of professional judgment to develop credible fire scenarios. As Johnson et at. recently stated (2013) "In building code and regulatory terms there appears to be at last three different approaches to the development of fire scenarios. These range from essentially leaving the choice of scenarios to the fire safety engineers at one end to the tight prescription and specification of fire scenarios and inputs to fire engineering analysis by regulation at the other end of the spectrum".

Therefore it is paramount that the engineer has the capability of carefully discriminating input data before putting them in the model, in the event s/he is in charge of choosing fire scenarios.

Anyway, even if "fire scenarios and design fires are key inputs to any fire safety engineering analysis and testing of the suitability of a building design to meet the Performance Requirements set by building regulations, hazard analysis and fire scenario development have been identified as two areas of weakness in fire safety engineering practice. This is despite there being a number of well established guidance documents to assist fire safety engineers and approval officials" (Johnson et a., 2013).

Heuristics

No one knows if we can extrapolate from simple structures to complex structures. Today, data on human behavior in fire and fire disasters are scarce and scattered in many research reports around the world. In addition, evacuation drills and experiments have been undertaken primarily in very simple buildings with alert and trained people, i.e. offices.
When the ***complexity*** and ***context*** of a problem are not understood, many disasters could happen. As one example, the Kaprun disaster happened because of the transposition of technical solutions and regulation from one environment to one other (Meyer, 2003).

Another example has been given by Babrauskas: "a few years ago, Margaret Law wrote a very interesting paper where she castigated UK designers for mindlessly selecting a 5 MW design fire in inappropriate situations. It turns out that there has been one category of situations—sprinkler-protected shops opening onto an enclosed shopping mall—for which a 5 MW fire has been rationally determined to be a conservative value. But then numerous designers, adopting the principle that "In a storm, any port will do" proceeded to use this design fire for situations where no rationale whatsoever had been developed. If rational bases for a certain design philosophy are not available, it would only seem prudent to avoid using that type of design, in preference to committing design improprieties.

Law focused on a steady-state peak heat release rate (HRR) value, but the growth period is also of much concern in considering fires which may occur. Here, and equally troublesome situation exists. Typically, designers using FSE-based codes do not attempt to delineate an actual HRR curve. Instead, it has become a *heuristic* of the FPE profession that all real fires can be closely matched up to one of four idealized t^2 fires, termed 'slow,' 'medium,' 'fast,' and 'ultrafast.' This approach has now been used for so much engineering work that many practitioners feel that it is soundly based in fire physics—yet this is far from being true".

LOST IN ABSTRACTION

Models are simplifications of reality. In the process of abstraction many important details tend to be lost in favor of often unsupported ***claims*** of predictive power. Analyzing and properly choosing the data is paramount in every engineering project. Evacuation modeling should add quality to decision making, not simply lead to overoptimistic outputs. Here are some of the key features that tend to be lost in the process of abstraction, especially when dealing with buildings that step out of conventional design.

Reification

Evacuation modelers must always be careful with using *unproven* categories of variables (parameters). Just because a modeler can give something a name does not mean the underlying entity acutally exists.

Confusing the "name" of an abstraction with the "real object" is one of the fundamental errors in safety regulation. For example at the Mt. Blanc tunnel fire vegetable oil was allowed in the tunnel while kerosene was not even though both have almost the same heat of combustion. Regulators had described flammable liquids in terms of their "ease of ignition" and had ***reified*** that characteritic into an overall statement of hazard. But ease of ignition is only one characteritic of the overall fire hazard. For example fuel load can be described in ***MJ/m2*** but it is almost useless without analysis of the heat release rate.

Modelers must always be aware of when they are dealing with complex abstractions and when they are dealing with measurement of real "objects".

Walking speed can be used to illustrate the problem. *Walking speed*, is an abstraction, not a measurement of a defined constant. Engineers act as if *Walking speed* is a real thing which "exists" and all they have to do is go out and measure it. The problem is that without a covering law that tells how to project the observation, all the observer has is a single observation. That observation can be demonstrably inadequate. As one example, observing people walking on smooth unbroken level modern surfaces may tell us nothing about walking on ramps (Figure 4). The ramp in figure 4 is very unusual. This ramp is very long, it has a very unusual layout and it's not protected from fire or smoke. An evacuation modeler would probably consider only walking speed. But gradient is not the only issue on a ramp even in perfect non emergency conditions. In fact, gradient does not take into account human behaviors and factors.

Walking speed in the real world is certainly bounded by 0 on the one hand and some large number on the other but prediction of the specific walking speed of humans in any given environment is subject to vast uncertainty, an uncertianty which almost always should include ZERO.

Walking speed, as used in a model, is an abstraction not a statement of scientific measurement. Even if based on observations it is still not demonstrable as science.

Figure 4. Vatican Museum Stairway, Rome (1932). Unusually long, non protected double helical ramp. Gradient is not the only issue. Fatigue, smoke's toxicity, people's behavior may be additional elements that actually affect evacuation.

The use of Abstractions, that are named as if they are real, can easily lead to the problem of *reification*, which consists of treating the abstraction (***walking speed***) as if it were a "real" entity. Those familiar with plastics remember how "self extinguishing" was promoted based on the outcome of a meaninless test.

Similar "assessment" cannot necessarily be reliably used to make "estimates" of what will happen in an emergency. Human actions are not governed by immutable physical laws. They are subject to both internal controls and external environments.
These limitations have also been taken into account by Ronchi et al. (2013), in particular the authors state "the requirement to test unconventional stair designs can be added in order to extend the applicability of building evacuation models to those scenarios (e.g. spiral stairs, curved stairs, etc.). It should also be

noted that current models do not generally permit a direct representation of the impact of fatigue on walking speeds on stairs. Once this feature is implemented in the models, a corresponding verification test would need to be developed". While a useful thought, there is still a suggestion that testing such designs leads to data which is useable in a model. That is an unwarranted assumption. *The more unusual the conditions the greater the uncertainty in the prediction of human response to the circumstances.*

Of course evacuation behavior is not only a matter of physical attributes but also psychological features. How does the modeler treat confusion? As regards the example in Fig. 4 above this is a double helical ramp. Will people be able to figure out how to exit? What is the "walking speed" of people crossing each other up and down the ramp?

Buildings themselves are a good example of the problem of reification. Modelers may think that buildings do not change temporarily their occupancy type during their lifetime. However, as shown in figure 5, even shopping centers and malls may be used, by a lot of different people, for very different purposes.

Figure 5. Contemporary malls may be used for different purposes other than shopping. Do modelers consider crowds of teenagers attending pop concerts?

Unpredicted parameters and variables

The *values* of variables used in models may also change during the lifetime of a building. Do modelers take into account all the changes of the environment and of the occupants that could occur in the building as time goes by? Are they sure they can foresee them? (Fig. 6 and 7)

Unless there is an analytical/regulatory system designed to monitor, evaluate and regulate the characteristics of the building, all variables dealing with future fuel load, exit paths and occupant characteristics are simply guesswork.

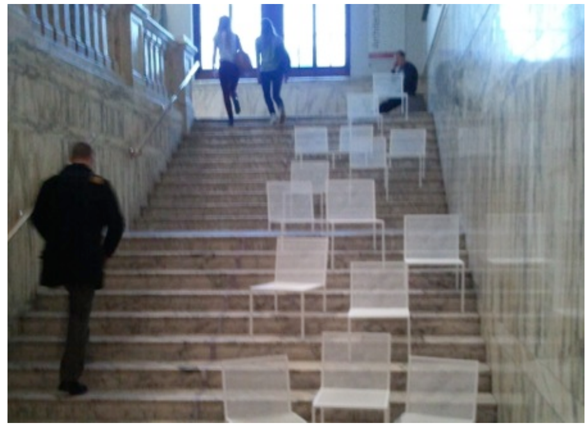

Figure 6. Victoria Alber Hall (1852). Temporary exhibition (2012) with fixed chairs on the stairway. Such a situation may change people's flow considerably. Are we sure the evacuation modeler will be able to predict such a circumstance?

This guesswork is amplified if the variables themselves are poorly stated. As an example the mass of fuel present in an area may be easily measured at any given time, even if its future presence can only be guessed (Fig. 7).

Figure 7. Palazzo della Ragione, Padua, (1218-1306). Changes during the lifetime of the building that affect behavior and situational awareness. This temporary exhibition (2011) represents a new fireload and layout.

However the ***fire load*** i.e. the fire which that ***fuel load*** will produce is not even easily "measured" from the simple calculation of mass. Imagine the difficulty enforcing of a performance based design manual that says:

The fire load that can be produced from the fuel load shall be limited to 15 megawatts and fire growth of the fuel load shall not exceed the specified t^2 fire.

How would a regulator even begin to analyze such a fuel load? Yet without such a control system the Performance based design is simply a wild guess.

Now add in the behavioral problem. The design manual or regulation would also have to say:

No groups shall be admitted whose collective behavioral characteristics vary from those in the performance based design.

Exit models must grapple with the problem of predicting human behavior far into the future with an almost total absence of covering laws.

<u>Behavioral uncertainty: unpredictable human behaviors</u>

Exit models are routinely claimed to ***<u>predict</u>*** the time to exit a building or other structure. Such exit models are largely ***forensic science***, used primarily to obtain regulatory approval. The basic belief in the exit models, as articulated above is that "initial conditions" and equations "determine" the outcome. Rarely are the uncertainty bands provided.

In contrast to the confidence of fire engineers, analysts of the stock market are routinely shown to be unable to predict much more limited human actions with much better data, even where fortunes could be made by accurate predictions.

Human factors represent qualitative aspects that are difficult to be predict and/or lack sufficient data and/or a covering law.

Given the uncertainty and the lack of data of human behavioral, psychological and physiological aspects how can the evacuation modeler extrapolate to make accurate predictions? What is "engineering judgment" when applied to human behavior in the absence of adequate theory and supporting data?

Consider this exit stairway in the Uffizi (Fig. 8). It is directly below the most valuable and visited paintings in the Uffizi. It shows the open door to the massive fuel load of the museum store. In a fire the guard is supposed to keep the store door closed and the exit door open. But the key safety question in a fire evacuation may be whether the guard at the bottom of the stair stays at the post and performs the functions properly, like the captain of the ***Titanic***, or runs for personal safety at the first sign of trouble like the captain of the ***Costa Concordia***. Exactly what engineering judgments would support either assumption? (Carattin, Brannigan, 2012)

Figure 8. Uffizi Gallery, Florence: if the bookstore is on fire this door is the only barrier to effluent spreading up the primary exit stair from the collections.

Consider again the report on V&V of evacuation models by Ronchi et al.; the authors state "In this context, the assessment of the variability of simulation results in relation to *behavioural uncertainty* is a key issue to be discussed. This is reflected in the estimation of the convergence of an individual evacuation simulation scenario towards an "average" predicted occupant evacuation time-curve. The assessment of evacuation model results may also include the analysis of the tails of the distribution rather than the analysis of the peaks (i.e. average values). Nevertheless, the authors argue that the study of the average model predictions together with the variability of results around the average is deemed to be a useful method to analyse *behavioural uncertainty"*.

When talking about behavioral uncertainty, the authors discuss about "**average**" human behavior predictions: but what about those behaviors that step out of ***average*** that cannot be predicted? How does the model deal with it?

<u>MODELS VS REALITY</u>

Many models are validated on few experimental data and on simple assumptions. How can the evacuation modeler extrapolate predictions in the absence of an adequate covering law? How does the evacuation modeler deal when facing with structures that go beyond conventional design?

Many modelers may think that all the inputs they put in models are universal and they do not take into account Unknown Unknowns. The quality of the theory and data are key issues.

Here are some examples of limiting problems to help modelers understand the limitations of evacuation models when dealing with the complexity of parameters and variables in the real world.

Pre-evacuation time

Data on pre-evacuation time is still scarce and relate primarily on experiments undertaken in simple structures (i.e. offices) with trained and alert participants, especially in English-speaking countries.

How about pre-evacaution time in more complex environments? No one knows if we can extrapolate from simple structures to complex structures. Complex structures host a lot of complex variables that lack supporting data to be predicted, especially as regards all those factors that may delay people's egress from buildings.

Wayfinding in unconventional evacuation paths

Many evacuation models assume standard and simple layouts (e.g.: rooms connected through corridors) but the majority of complex buildings host very different complex layouts. It is well established in the scientific literature that people tend to get lost (even in ordinary wayfinding in buildings that are designed with complex layouts (Carlsonet al., 2010). Complex structures usually host a lot of people in them. Evacuation problems in such buildings can be unusually severe. In case of an evacuation, large numbers of people have to egress quicky through unusual environments. As just one example, as regards historic structures, exit pathways are very different from modern buildings and may be not easily recognized. There are usually "room to room" exit paths, that are typical in historic buildings but rare in modern buildings (Fig. 9).

Figure 9. Kunstmuseum Basel (1661). Room to room layouts are unusual in modern buildings. People's wayfinding expectations, inside these buildings, could be easily disattended.

Room to room layouts can disattend people's cognitive expectations about how to wayfind inside the building: they can raise both the possibility of dead ends and wrong turns. Exit pathways are usually very long and there are usually a few exits, there is no obvious exit path and there is no virtually fire protection. Cognitive stress and toxity may affect people's behavior considerably before they finally reach the exit (Carattin, Brannigan, 2012). Exit pathways can be very complex and long even in contemporary buildings, as shown in the airport in Fig. 10.

Figuea 10. Phoenix International Airport. Like historic buildings, airports are usually made up of very complex layouts with long and unclear exit paths. This corridor is very long connects terminals with large open-spaces. Area of refuge at the end of corridor.

Visibility and comprehensibility of exit cues

A condition of a model may be that a value for a certain variable is known to an acceptable level of certainty.

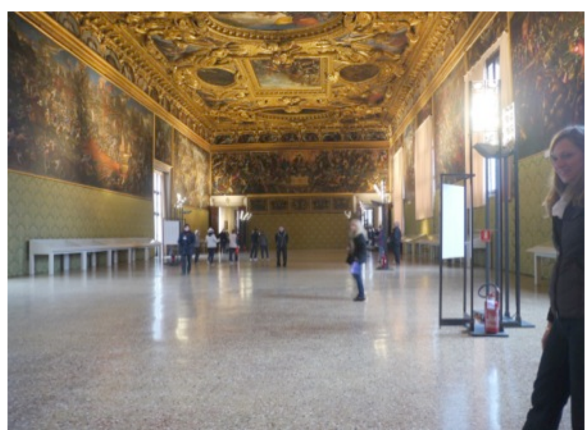

Figure 11. Ducal Palace, Venice (IX-XVII Century). Large open space, with numeours distractions and unclear exit paths. Only two exits, difficult to spot especially in the presence of big crowds of people.

For example, the comprehensibility and visibility of exit signs from all points of a large open space room might be a condition for the use of a model that depends on individuals finding the exit (Fig. 11, previous page, and 12).

Figure 12. Charlotte-Douglas Intl. Airport. Large open spaces with unclear exit paths. Ambiguous exit signage. It is not clear where the emergency exit is located and how long is the emergency exit path (e.g.: do the evacuee have to go though the terminal and the baggage claim to finally find the exit?).

If the condition is not met the model will not give valid answers. Setting appropriate conditions for the use of a model can answer the question of whether engineering judgment can be used to interpolate from known data.

<u>Travel speed aka Walking speed</u>

Travel speed (m/sec) is a parameter usually expressed as "the maximum uncongested walking speed at which individual evacuees move towards a place of safety".

The core problem with walking speed has been discussed above.

To state the definition shows the crux of the problem. While each individual has a potential walking speed, which will vary from zero to a maximum given the environment, the walking speed of a line or column is clearly affected by the slowest component. Any non zero claim of walking speed involves guesswork, which arguably increases as the purported speed gets larger.

Unconventional design

Modelers must always be aware of when they are dealing with abstractions and when they are dealing with measurement of real objects. *Walking speed,* for example, is an abstraction, not a measurement. Walking on smooth unbroken modern surfaces may tell us nothing about travel in an unsual ascending and slippery ramp (Figure 13) or unusual and very long ramps (Figure 14).

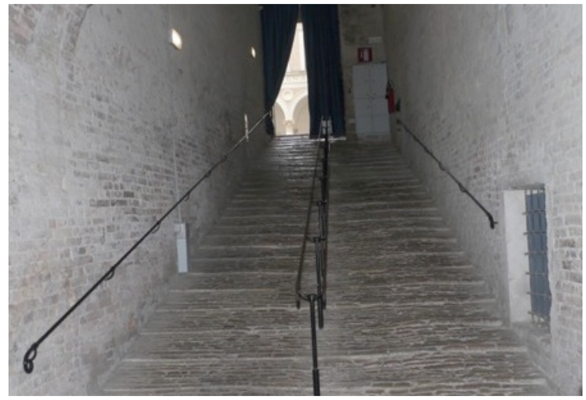

Figure 13. Ducal Palace, Urbino (XV Century). Unusual ascending stair exit, surfaces could easily be very slippery.

Figure 14. London City Hall (2012). Contemporary building with usual and very long ramp.

<u>Route availability and usage</u>

Blocking of exits

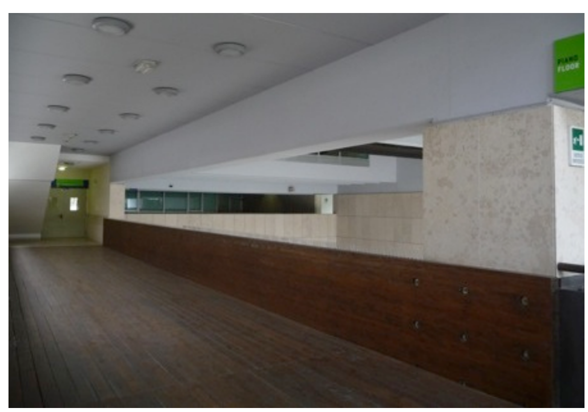

Figure 15. Centro Culturale Candiani, Mestre (recently completed). Very complex building with a cinema, showrooms and offices. External emergency exit walkway made entirely of wood instead.

How do evacuation models deal with the operational problem of exit blocking?

An assumption of a model might be that people move toward the closest exit (or the furthest one, if the modeler considers conservative default values). Anyway, if the closest exit is unavailable due to a fire (Fig. 15, previous page) or changes of the environment, the assumption might not be met and the model could give not valid results.

Flow conditions

People's density

Flow conditions (persons/sec) is defined as "the relationship between speed/flow, population density and population size" (Gwynne et al., 2012)

As can be seen from the example shown in Figures 16 and 17, flow conditions may depend on numerous *additional* variables, related to the occupants and the building itself.

The pictures show the Dinosaur Hall (a rectangular space with a ceiling about 7 meters high) at London Museum of Natural History. The Hall is visited by crowds of different people from all over the world. Visitors can admire dinosaurs through an elevated walkway about 10 feet of the floor that runs the full length of the room and then deposits them back under the museum's maze (Figure 16). The walkway is very crowded, it acts as both a viewing and a holding area for crowds waiting to see an animated Tyrannosaurus Rex (Figure 17).

The walkway is very crowded and full of children and pushchairs (Figure 17).

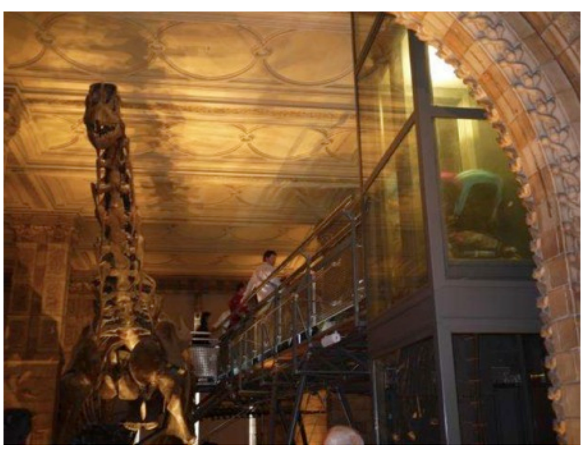

Figure 16. Elevated walkway inside the Dinosaur Hall at London Museum of Natural History. The walkway is very crowded and runs 7 meters high along the dinosaurs and then puts visitors back into the museum's maze.

Figure 17. Narrow elevated walkway very crowded with people from various contries and vith different degree of abilites. Numerous pushchairs that could impede rapid evacuation and create bottlenecks.

Who can guess exactly the number of people that can pass by a certain point over a period of time? What do we know about what will really happen in an emergency due to cultural confusion? Are we sure that *0.67 persons/s* (Gwynne 2012) is a value conservative enough for such circumstances?

DISCUSSION

Level of safety cannot be determined by engineers who do not anticipate the unique features and variables of buildings.

Human intentional decision making is a significant limitation of fire models. Many technical variables in fire models are actually the output of uncertain human decision. Human intentional uncertainty is not captured in traditional models of aleatory and epistemic uncertainty.

The product of human decision can be put into the model as estimations only if they are supported by adequate data and the model is valid over the full range of decisions. Otherwise, uncertainties have to be treated as conditions of the model. Violation of a condition invalidates the output of the model.

Many human decision which cannot be predicted might be controlled. With control strategies the values of the variables could kept within the range required by the model. Performance based regulation will require a regulatory system capable of keeping all variables required by the model within bounds of the model conditions.

Unless there is an analytical/regulatory system designed to continuously monitor evaluate and regulate the characteristics of the building, all variables dealing with fuel load, exit paths and occupant characteristics are simply guesswork. This guesswork is amplified if the variables themselves are poorly stated.

Many parameters and variables could certainly bounded by 0 and some large number but prediction of the parameter in any environment is subject to vast uncertainty.

Evacuation modeling should represent a tool for gaining insights on evacuation performance, not a means to get regulatory approval.

In case of too many uncertainties, designer should focus on redundancy instead of regulatory approval at all costs. We agree with Babrauskas (1999) that dealt with the "sufficiency" viewpoint of the FSE-based design schemes, it is all too easy to purportedly demonstrate that everything suffices, anyway "there have been very few major fire disasters which did not involve a series of failures. Under traditional fire protection philosophies, if any one safety system fails, normally what results is a nuisance fire, not a disaster. Catastrophes tend to take place only when a string of failures occur in a row".

CONCLUSION

- Engineers need to consult other professions on the difficulties and problems of predicting human behavior.
- Assumption that behavior is reliable and predictable cannot be made without a far stronger research base.
- Any model should state not only the data it uses, but the covering law that allows that data to be used for predictions.
- Assumptions used in models should be explicit to prevent misuse or mistakes.
- Behavior cannot always be predicted but it can be controlled
- Redundancy in design could be a solution to uncertainty

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CREDITS

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