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# Scaling-Up fire

José L. Torero *

*BRE Centre for Fire Safety Engineering, The University of Edinburgh, United Kingdom*

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**Abstract**

The role of combustion research in fire safety is revisited through the process of *Scaling-Up* fire. *Scaling-Up* fire requires the adequate definition of all the building blocks and couplings associated with the construction of a fire model. The model then has to deliver predictions of the evolution of a fire and its environment with the precision, completeness and robustness relevant to fire safety. Areas of combustion research relevant to the development of fire models emerge from an assessment of methodology, complexity, incompatibility and uncertainty associated to the *Scaling-Up* process.


*Keywords:* Fire research; Fire modelling; Fire safety

## 1. Relevance

The evolution of a fire in any realistic context (building, vehicle, forest, underground, etc.) is an extremely complex process where it could be suggested that predictions of accuracy, completeness and robustness relevant to fire safety are impossible. Relevant accuracy, completeness and robustness is defined as the ability to quantitatively predict all the variables necessary for design or performance assessment to a level of precision and robustness that justifies using these predictions. The value associated to knowledge gain is established by how this gain can be linked to a quantifiable improvement in the accuracy, completeness or robustness of the prediction.

The gain associated with an enhancement in knowledge can be easily established when the full process is completely described and the areas where the sub-processes that are coarsely represented have been clearly identified. This procedure starts with the more fundamental processes, linking them to generate more complex systems that in turn are further linked until the full process is described and an output can be obtained [1]. Refinement can then be punctually applied and clearly linked to an improved output. This building strategy will be defined here as *Scaling-Up*.

In extremely complex problems, the link between the sub-processes and the output is not always clear. The sub-processes and couplings between sub-processes tend to be coarsely modelled making it difficult to identify the consequences of a change. In this case, deterministic *Scaling-Up* is very difficult but probabilistic assessment can be an effective way to achieve the same objective. In probabilistic assessment, a refinement is introduced and the outcome is then monitored. If this is repeated a sufficient number of times, and if there is a consistent outcome, then the refinement can be deemed to result in a quantifiable gain without necessarily understanding the path followed. This approach is mostly statistical and therefore requires large populations to gain

* Present address: Department of Civil Engineering, The University of Queensland, Brisbane, Australia.
*E-mail address:* j.torero@ed.ac.uk

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sufficient confidence. To obtain a large population, the process under study needs to remain stable until the link between a component and the outcome is established.

The most difficult category corresponds to complex systems where processes and their links are still coarsely described and where each system to be modelled has a very small population. These are systems that evolve fast or are unique therefore the population available for study at any specific moment is always small. A general overview of the issues associated to the statistical treatment of these complex systems is provided by Neyman [2].

It has been suggested that fire problems belong to the last category [3,4]. Our understanding of the processes involved in fire is very coarse, nevertheless, the outcome is extremely sensitive to multiple variables resulting in many cases in drastic bifurcations (ignition, extinction, flashover, backdraught, etc.) therefore most fundamental processes need to be refined and coupled in precise and complex manners. Unfortunately, many of the links and couplings between these processes are unknown, thus it is currently not possible to relate improvements in the understanding of the fundamental processes to benefits for the outcome. Thus, it can be claimed that deterministic *Scaling-Up* of fires is currently not possible.

When addressing the problem via probabilistic tools, the evolution of our habitat (e.g. novel construction materials such as phase change insulation, discontinuation of fire retardants, new construction systems such as curtain walls, etc.) is much faster than the evolution of the fundamental science associated to fire [5,6]. This is in contrast to other disciplines such as medical research where the evolution of the subject, the human, is in the order of thousands of years. Thus, the problem in question will drastically evolve before science has been able to mature. Within the evolving habitat there is an infinite variation of specific scenarios making each overall process to be modelled unique. So, from the perspective of predictive capabilities, it can be claimed that each fire scenario has a population of one and the conclusions of one event cannot be used for a general assessment of benefit. Thus, statistical analysis as a *Scaling-Up* method for fire predictions will inevitably result in a low confidence output.

It is therefore clear that the *relevance* of research leading to the refinement of a specific component is linked to our capability to *Scale-Up*. Nevertheless, *Scaling-Up* Fire appears as the insurmountable challenge of fire safety. Combustion is one of the fundamental processes within the description of a fire and a component that could be refined by means of research. But given the difficulties associated to *Scaling-Up Fire*, the relevance of combustion research for fire safety seems questionable. This paper will discuss the relevance of combustion research in fire safety through a better understanding of the process of *Scaling-Up Fire.*

## 2. *Scaling-Up* fire

Fire safety involves a broad range of disciplines tied by a combustion process, "the fire" [7–14]. The combustion reaction will result in species and energy being released in an uncontrolled manner. The release of energy and species will negatively affect structures, people and the environment but will also activate countermeasures and result in human response (evacuation, intervention) intended to minimize the negative impact of the combustion process. A feedback loop exists by which the structure, people and countermeasures will also impact the combustion process. Therefore, fire safety can only be quantitatively assessed if the combustion process can be modelled within the context of its environment. The modelling of the combustion process within the context of its environment will be referred to here as "fire modelling."

Currently we have many models that attempt the *Scaling-Up* of fire [12,15]. These models can be deterministic, probabilistic and in some cases system models [16]. These models provide outputs with a specific level of precision, completeness and robustness and in all cases they include a representation of the combustion processes involved.

The simplest form of fire models are prescriptive regulations. For certain environments that share common characteristics a specific design form has been studied and its performance established and deemed acceptable. Different tools are then used to establish to what extent the context can be changed without exceeding the acceptable outcomes. Among these tools many incorporate combustion principles (classification of flammable liquids in relationship to ignition, hazard classification in relation to fire spread, sprinkler classification in relation to burning rates and heat of combustion, etc.) Once the potential context variation is defined then a classification emerges that provides the context bounds to which the solution can be applied. Therefore, the core of prescriptive design is the classification. If a designer follows a set of prescriptive rules that create the context where a solution is known to yield and adequate outcome then, another set of rules that implements the predefined solution guarantees performance. *Scaling-Up* is simply the extrapolation process that enables the use of the same solution in a context that lies within the bounds of the classification.

Fire models can also be explicit representations of the event and their outputs can be physical parameters such as velocities, temperatures,