Assessment of Total Evacuation Systems for Tall Buildings: Literature Review

According to the definition of the National Fire Protection Association [NFPA, 2012], high-rise buildings are defined as "*buildings greater than 75 feet (approximately 23 m) in height where the building height is measured from the lowest level of fire department vehicle access to the floor of the highest occupiable story*".

According to Hall [2011], the main building uses that can be identified to categorise this type of buildings are office buildings, residential buildings (e.g., hotels, apartment buildings) and health care facilities. Each of these categorise present different characteristics from the point of view of both the infrastructure and the population. The analysis of the building use is therefore crucial to predict the possible behaviour of the occupants and provide an adequate fire safety design.

Although building codes establish the minimum requirements for the design of a high-rise building, additional life safety features are often necessary to mitigate the issues deriving from the complexity of this type of buildings and the additional difficulties in fire-fighting and rescue operations. The perspective of the technical International guidance, e.g., NFPA101 in the U.S. [NFPA, 2012], or the Approved Document B [The Building Regulation, 2006] in the UK, etc. is to provide information on the design of the egress components (e.g., geometric characteristics of the stairs) that can be applied for high-rise buildings. On the other hand, further information on the behavioural issues associated to the egress performance during high-rise building evacuations is still required. General concepts can be employed although additional specific recommendations are required given the particular features of this type of buildings. Dedicated recommendations have been provided by national and international committees, e.g. the GB50045-95, Code for Fire Protection Design of Tall Buildings in China [GB50045-95, 2005], the Fire Safety Requirements for super high-rise residential buildings in Singapore [Singapore Civil defence Force, 2006] or the chapter 7 of the Fire and Life Safety of National Building Code of India [Bureau of Indian Standards, 2005].

Recent US statistics [Hall, 2011] show that an average of 15,700 fires were reported in high-rise buildings per year in the USA, causing a total of 53 deaths, 546 injured, and $235 million in direct property damage per year. High-rise buildings present a lower number of fatalities than low-rise buildings of the same type. However, the attention on this type of buildings is raised by the fact that even a single high-rise building fire may cause a significant number of fatalities due to the possible high number of people involved. Researchers have performed in-depth analyses of particularly memorable incidents in order to study the high-rise fire problem. Examples are available in the literature, such as the MGM Grand Hotel Fire where the total number of fatalities was 85 [Best & Demers, 1982, Clark County Fire Department, 1981], the bombing of the Oklahoma Murray Federal Building resulting in 168 fatalities [Mallonee et al., 1996] or the

Chicago Cook County Administration Building Fire [Proulx & Reid, 2006] that resulted in 6 fatalities.

The Research on high-rise buildings became a growing concern to safety committees working on codes near the end of the 60ies [Galbreath, 1969, Melinek & Booth, 1975]. The design of exit stairs was the main issue analysed at the time, providing formulas of exit stair width and minimum total evacuation times. Significant work in this area was performed in the 70ies and 80ies [Pauls, 1978, Pauls, 1988]. The focus of these studies was the application of the hydraulic movement models taking into consideration the behavioural factors. This permitted to include the pre-evacuation activities of the occupants in the analysis of the actual evacuation times of tall buildings.

More recently, a great sense of awareness on this topic was raised by the World Trade Centre terrorist attack of 9/11 [Averill et al., 2005]. The event results in a paradigm shift to the assessment of high-rise buildings safety. It showed the importance of providing robust means of egress and the need for further investigating the interactions between the infrastructure, the procedures and the behaviour of the occupants [Galea et al., 2008a, Galea et al., 2008b]. Several questions have been prompted about the adequacy of our current safety regulations and emergency procedures for high-rise buildings. For what type of evacuation scenarios should we design high-rise building? What egress components are recommended to evacuate a high-rise building? Are elevators suitable for evacuation purposes? What design measures or procedures should be employed to improve egress efficiency? These questions do not have a simple answer and the specifics of each building need to be taken into account. In addition, the lack of knowledge in terms of the behavioural aspects taking place during a high-rise building evacuation is still evident [Kuligowski, 2011]. Specific recommendations on single aspects of the evacuation process rely therefore on a previous analysis of the single variables to be investigated. For this reason, there is a need to perform a review of the literature available on the main variables affecting high-rise evacuations, such as the egress components employed (i.e., stairs, elevators, etc.) and the strategies in use (phased evacuation, total evacuation, defend-in-place, etc.). In particular, there is a need for an analysis of the studies concerning the evacuation through vertical transport and methods to encourage the use of elevators for evacuation. There is also the need to investigate if the use of different components has been studied individually or if there are attempts to investigate the combinations of different egress strategies.

Evacuation models are often used in the safety design process in the context of the performancebased design approach. They may be employed both to compare different safety designs as well as define the adequate egress strategies of a building. There is a subsequent need to review the state-of-the-art of the different tools available and their applicability for the specific case of highrise buildings. Are they suitable to provide qualitative and quantitative information on the impact of the use of different egress components? Are they adequate to compare different design solutions and relocation strategies? These are some of the questions that need to be studied further to achieve a better understanding on the capabilities of egress models for simulating highrisebuilding evacuation scenarios. This analysis is a fundamental step to evaluate the strengths and weaknesses of the current egress models and consequently identify the aspects that need further research studies.