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Fire Resilient Cities: The Impact of Fire Regulations, Technological and Community Resilience

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***Abstract*—**Building resilience, sustainable buildings, urbanization, climate change, resilient cities, are just a few examples of where the focus of research has been in the last few years. It is obvious that there is a need to rethink how we are building our cities and how we are renovating our existing buildings. However, the question remaining is how can we assure that we are building sustainable yet resilient cities? There are many aspects one can touch upon when discussing resilience in cities, but after the event of Grenfell in June 2017, it has become clear that fire resilience must be a priority. We define resilience as a holistic approach including communities, society and systems, focusing not only on resisting the effects of a disaster, but also how it will cope and recover from it. Cities are an example of such a system, where components such as buildings have an important role to play. A building on fire will have an impact on the community, the economy, the environment, and so the entire system. Therefore, we believe that fire and resilience go hand in hand when we discuss building resilient cities. This article aims at discussing the current state of the concept of fire resilience and suggests actions to support the built of more fire resilient buildings. Using the case of Grenfell and the fire safety regulations in the UK, we will briefly compare the fire regulations in other European countries, more precisely France, Germany and Denmark, to underline the difference and make some suggestions to increase fire resilience via regulation. For this research, we will also include other types of resilience such as technological resilience, discussing the structure of buildings itself, as well as community resilience, considering the role of communities in building resilience. Our findings demonstrate that to increase fire resilience, amending existing regulations might be necessary, for example, how we performed reaction to fire tests and how we classify building products. However, as we are looking at national regulations, we are only able to make general suggestions for improvement. Another finding of this research is that the capacity of the community to recover and adapt after a fire is also an essential factor. Fundamentally, fire resilience, technological resilience and community resilience are closely connected. Building resilient cities is not only about sustainable buildings or energy efficiency; it is about assuring that all the aspects of resilience are included when building or renovating buildings. We must ask ourselves questions as: Who are the users of this building? Where is the building located? What are the components of the building, how was it designed and which construction products have been used? If we want to have resilient cities, we must answer these basic questions and assure that basic factors such as fire resilience are included in our assessment.

***Keywords*—**Buildings, cities, fire, resilience.

I. Introduction

FIRE has caused many damages throughout the years and is probably one of the oldest type of disaster known of mankind. The London fires in 1212 and 1666, the Chicago fire in 1871, Tokyo in 1923, Texas city in 1947 are just a few examples. Unfortunately, we have not yet managed to eradicate this type of disaster and we keep adding events to the list. One of the most recent tragic incidents in Europe happened at the Grenfell Tower in June 2017, where 72 people lost their lives [1]. After the incident, several questions were raised about the safety of the building and the materials used to refurbish it. As we are now approaching the "one year anniversary" of the disaster, some questions have been answered but little has been done to assure that such event would not happen again. The results of the preliminary enquiry have showed that the design of the building itself, with only one staircase as escape route and without the presence of sprinklers had an important impact. Another factor was the materials used for the refurbishment which was proven more combustible than the results of the fire resistance tests performed. As buildings are at the center of our cities, it is therefore of the outmost importance to assure that they are safe to be in. And there cannot be resilient cities without resilient buildings.

For this article, we will start by explaining the concepts of resilience and fire resilience. Using the case of the Grenfell Tower, we will study France, Germany and Denmark's national fire regulations for testing facades of high-rise buildings. We are focusing on high-rise buildings for this paper, first because it is not possible to review all fire regulations for all types of building in this article. It is also relevant to look at high-rise building since the increasing rate of urbanization is creating the need for more of this type of buildings in cities [2].

We will then discuss fire regulations and resilient cities, touching upon technological and community resilience. Finally, we will have a closer look at the link between fire resilience and resilient cities.

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II. The Concept of Resilience

The concept of resilience is now well known for those who are working within domains where the term is used. However, we find that even if the concept is often mentioned, few know how it can be defined. This can easily be explained by the fact that the term "resilience" has been used in different disciplines such as engineering, psychology and disaster risk management. Since the UN Hyogo Framework for Action adopted the term resilience in its aims within global disaster risk reduction in 2005 [3], the concept has gained momentum in many different areas and disciplines such as safety engineering, sociology, governance, emergency preparedness and urban development. We like to use the definition of the

UNISDR as it can be applied to all these disciplines: "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions" [4].

III. The Concept of Fire Resilience

Looking for a clear definition of fire resilience can become a lengthy process. We found that there is no clear definition of this concept. Instead we found several references to fire resistance, which is an engineering term defined as the ability to withstand the effect of a fire [5]. Referring to buildings, this definition of fire resistance is relevant; however, what is not included in this definition is how the fire in a building will affect the environment, the economy and the communities.

Fire resilience is also a terminology present in the environmental domain, as fires cause damages to the environment, for example through air pollution or forest fires. According to Holling, ecological resilience can be defined in two different ways. First, it can be defined by measuring resilience through the resistance to disturbance and how fast one can return to equilibrium, which is most often referred as engineering resilience. Second, by measuring resilience through the amount of disturbance a system can absorb before it changes its structure, which Holling refers to as ecological resilience [6].

The effects of fire can also be observed on the economy. A good example of such impact is the forest fires in California. Estimates for insured losses from wildfires in Northern California, owing to damages to business and residential properties and business disruption, were between \$8 billion and \$10.5 billion [7].

Finally, when a fire occurs, it will also have an impact on the communities. A fire destroying private houses, an apartment building, a school, a hospital, or a shopping center will affect people living and/or using the building. Children, residents or patients would have to be relocated, and there could be trauma related effects as well. Therefore, even without a clear definition of fire resilience, we can link the concept to existing resilience domains. Fire resilience is more than regulations or technological resilience. Fire has also an impact on the economy, the environment and communities. In the next section, we will shortly present three different fire regulations for façade of high-rise buildings to demonstrate how different the fire regulations are from one country to another.

IV. Fire Regulation for Facades in France

The main test for fire spread on facades in France is called LEPIR II. This test is made on a test rig build specifically for façade tests (see Fig. 1) [8]. This test is particular because it includes four openings, is clearly representing two stories of a building, and the rig is closed from all sides. This is a full-scale test and one of the "most complete of all current façade fire spread test methods" [9].

Fig. 1 LEPIR II test rig

The performance criteria are: non-propagation of the fire to the second level and no fire leap to the second level through the facade or the floor. For any integrated systems, there is also a temperature criterion which must not exceed 180 °C at the façade/floor junction, no rise in temperatures above 180 °C measured on the unexposed side of the floor at 50 mm away from the facade for the first 30 minutes of the test [10].

The length of the test varies depending on the type of system tested, but most current is 60 minutes, where the fire is extinguished after 30 minutes and the remaining time is used to observe that there will not be secondary inflammation of the test specimen [10].

This test is interesting to mention because even though it is considered as the most complete test, it is mainly used nationally and rarely used as a compared methodology, unlike the UK test method BS8414 or the German test DIN 4120-20. There are elements in this test that could give results which would be closer to how a façade system would behave under a fire. For example, the fact that there are several windows, or that the test rig represents clearly two stories of a building.

V. Fire Regulation for Facades in Germany

In Germany, the test that can be comparable to LEPIR II and SP105 can be found in DIN 4102-20. This test is a medium scale test, but there are of course other tests available such as the technical regulation A 2.2.1.5 which is a full-scale test for ETICS systems.

DIN 4102-20 has a test specimen that is L-shaped, at least 5,5 m high and can use either a burner or a crib for the fire load (see Fig. 2) [11].

Performance criteria are slightly different if the test is for combustible or non-combustible materials. If the test is for combustible materials, the burner would be turned off after 20 minutes, and for non-combustible materials, after 30 minutes. Then there will be some time allowed for observing the test specimen and assure that it will not keep burning or produce smoke for another 30 minutes.

The performance criteria include no burned damage on the test specimen 3,5 m or more above the fire chamber; the temperature under or over the surface of the insulation should not be over 500 °C at 3,5 m or more above the chamber and no continuous flaming for more than 30 seconds 3,5 m above the fire chamber. There is also no flaming allowed on the top of the specimen and no falling debris and droplets falling 90 seconds after the burners have been shut down [12].

Fig. 2 DIN 4120-20 test rig

This test is different from the French test as it does not include any openings other than for the crib or burner used. The French test also has a temperature criterion that is much lower than for the German test, which is also an interesting difference to mention. The temperature criterion is an important measurement. According to the National Fire Protection Association (NFPA), the upper limit of human temperature tenability is 212°F [13], which is equivalent of 100°C, so it gives us an idea of how extremely warm 500°C is. We will now study the test used in Denmark to add another test to compare.

VI. Fire Regulation for Facades in Denmark

In Denmark, the SP Fire 105 method is used. It evaluates a large-scale façade fire where the test object is 4 x 6 m (width x height) and resembles the real façade system as much as possible (see Fig. 3) [14]. The fire exposure lasts around 15-20 minutes. The fire source is 60 liters of heptane burning in trays with attached flame suppressors. "The performance criteria of the façade system are maximum temperatures of the combustion gases at the eave and maximum heat flux to the specimen in the middle of the first fictitious window. No flame-spread above the second floor is allowed" [15].

This test is again different from the two others, though includes openings, the temperature criteria are not well defined. The differences between the three tests are so fundamental that it becomes impossible to make a relevant comparison. Because fire safety regulations are of national competences, there has been little work on harmonizing the test system and so it has been difficult to assure cooperation between the countries on this topic. However, after Grenfell, the EU has reached out to member states and a consortium has been working on a possible harmonized system, which work is currently ongoing.

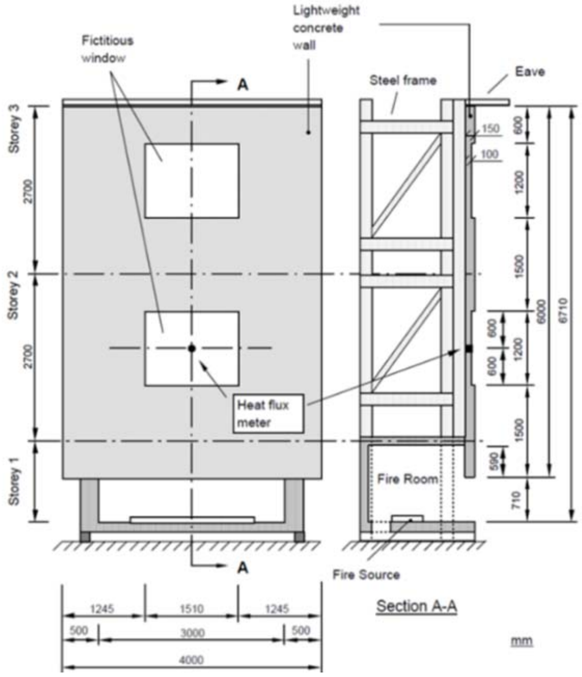

Fig. 3 SP Fire 105 test rig

One other important point from this section is that to get a robust test system, countries must not only base their system on their national disasters and experiences. Even though we hope to have learned a lot from the fire of the Grenfell Tower, we need to remember to have a holistic approach to fire resilience and consider all its dimensions. In the next section, we will demonstrate how fire resilience and technological resilience are linked.

VII. Technological Resilience

Fire safety regulations have an important role to increase fire resilience. However, it is not the only important factor. As we mentioned earlier, technological resilience is a factor. We have used Holling's definition of technological resilience earlier in this paper, where we explained that the "concept of resilience focuses on system's behaviour near a stable equilibrium and the rate at which a system returns to steady state following a disturbance" [16].

Other definitions of the concept can be found, such as Pimm's where one "measures how fast a variable that has been displaced from equilibrium returns to it" [17]; or Haimes defining resilience as "the ability of the system to withstand a major disruption within acceptable degradation parameters and to recover within an acceptable time and composite cost and risks" [18]. So, if we take the example of a building, for it to be technologically resilient would mean that it would not be affected by an unexpected event or would be able to quickly recover. Several solutions are available and so if brought together, they can make a difference on the level of resilience reached. For example, assure that there are sprinklers in the building so that small fires can be quickly extinguished, or have an alarm system that can alert first responders so they can rapidly respond. Another measure would be the use of non-combustible materials for high-rise and high-risk buildings. A combination of several of the mentioned solutions could increase buildings' fire resilience.

As mentioned earlier, solutions must contain elements from the different resilience dimensions to have an impact on the overall resilience of buildings and cities. We will now consider the role of the community in increasing resilience.

VIII. Community Resilience

Communities also have a role to play to strengthen fire resilience. Communities are composed of built, natural, social, and economic environments that influence one other in complex ways [19]. They absorb, adapt, or cope with unexpected events. Again, there are many definitions of community resilience; Magis defines community resilience as "the existence, development, and engagement of community resources by community members to thrive in an environment characterized by change, uncertainty, unpredictability, and surprise" [20]. Cutter et al. define community resilience as "the ability of social system to respond and recover from disasters and include those inherent conditions that allow the system to absorb impacts and cope with an event, as well as post-event, adaptive processes that facilitate the ability of the social system to re-organize, change and learn in response to threat" [21]. Aldrich and Meyer define community resilience as the "collective ability of neighbourhood or geographically defined area to deal with stressors and efficiently resume the rhythms of daily life through cooperation following shocks" [22]. We can easily link these definitions of community resilience to fire resilience. It is about involving communities in anticipating the disaster. Therefore, in order to have a community contributing to fire resilience, we need to involve the community into emergency planning activities, such as evacuation training, identification of key persons in case of an emergency, guidelines for social media use, tools for response, etc. The National Institute of Standards and Technology (NIST) has developed a Community resilience planning guide, using six steps to support more resilient cities (see Fig. 4) [23]. The NIST example demonstrates well the need for a strong community resilience for any disaster, fire included.

Regulations, technological and community resilience are three dimensions that can play a significant role in strengthening fire resilience. In the next section, we will look more precisely into the link between fire resilience and resilient cities.

IX. Fire Resilience and Resilient Cities

The short description of three fire regulations for façade testing was used to demonstrate how the systems can be different from a country to another. This is an important fact to understand as it demonstrates well that working towards more resilient cities is far from being a simple goal to achieve. Testing fire resilience on high-rise buildings is only one parameter part of a much bigger picture.

Fig. 4 NIST Community Resilience Planning Guide

We then looked at technological and community resilience, which are also important dimension of resilience that are playing an active role in increasing fire resilience. It is also important to define what resilient cities are and how fire resilience plays a role in this definition.

According to the organization "100 Resilient Cities", there are seven qualities a city must have to be resilient: reflective, resourceful, inclusive, integrated, robust, redundant and flexible [24]. Not all the seven qualities are relevant when considering fire resilience. We can look at the following qualities: reflective, inclusive, robust and flexible.

A reflective city comprises individuals and institutions that are learning from the past and will modify regulations and behaviors accordingly. If we then take the example of fire, we would assume that we have learned from the past mistakes and adjusted so that we would reduce the impact of fires. Yet, when we look closer to residential fires, we can observe that they are still present, and that their impact is much more serious than in the past. This can be explained by the fact that our houses are now containing all kinds of materials and notably plastic based items which are highly flammable and produce toxic smoke which has a negative impact on inhabitants and the environment [25].

An inclusive city can be defined by the processes of good governance and leadership to assure that the changes needed are addressed for everyone. A good example for this is obviously the UK who is now going into the revision of its fire safety regulation under the Approved Document B, as well as the Hackitt review which should be completed in May 2018 and the Grenfell Tower inquiry which is ongoing. Such processes are lengthy and will not always make conclusion that will satisfy all parties, but the system is in place and gives the opportunity for everyone to engage.

The definition of a robust city often includes assessing the infrastructures' ability to withstand the effect of a disaster. Again, when we link robustness to fire, it is to say that robust buildings are not expected to collapse rapidly because of a fire. It is also not expected that buildings will suddenly catch fire and burn down within a short time frame. However, several examples of this can be found just by doing a quick Google search: Sao Paulo in May 2018, Dubai in August 2017 and of course Grenfell in June 2017. This has happened in different places in the world, and for different reasons, but has been often observed that fire spread was caused by the building structure and/or construction materials.

Finally, a flexible city is a city that reflects the ability to adapt to changes and find alternatives solutions to the challenges brought by crises or new circumstances. To be flexible and fire resilient means that we need to keep doing research on materials to better understand their properties and use them in the best possible manner. For example, the use of non-combustible materials for facades of high-rise buildings is a good way to avoid unnecessary fire risks.

X. Findings

With this article, we have demonstrated the complexity of fire regulations and its effect on fire resilience. Changing fire safety regulations is difficult, as it is of national competences, but engaging the EU could provide solutions suitable for all member states. However, we need to be careful not to rest on existing systems, which have been mostly based on national disasters and experiences. We must develop a more scientific based approach, considering real scenario both representing the fire load and the building we are testing for. We have then studied technological resilience, for which we found that the choice of materials for buildings and the design of buildings itself can have a tremendous effect on their level of fire resilience. With community resilience, we have discussed the role of planning, preparation and training as important steps to increase community resilience and so fire resilience. Finally, we discussed the concept of resilient cities and how it can be linked to fire resilience. Through some of the resilient cities qualities that the "100 Resilient Cities" organization, pioneered by the Rockefeller Foundation, have cited, a city that is reflective, inclusive, robust and flexible is not only a resilient city but a fire resilient city.

XI. Conclusion

This article discussed the concept of fire resilience for which there is not much research to be found. Therefore, our suggestion would be to work further on the topic to understand better the effect of regulations, materials, design and communities in supporting fire resilience, as well as developing a common concept for fire resilience that can be used by all dimension of society.

References

[1] http://www.theweek.co.uk/grenfell-tower/92020/grenfell-tower-site-to-become-memorial-for-victims
[2] M. Ali and A. Aksamija, "Towards a better urban life: integration of cities and tall buildings", *4th Architectural Conference on High-rise buildings*, CTBUH research paper, 21p., 2008. http://global.ctbuh.org/resources/papers/download/303-toward-a-better-urban-life-integration-of-cities-and-tall-buildings.pdf
[3] United Nations "Hyogo framework for action 2005-2015: Building the Resilience of Nations and Communities to Disasters." *UNISDR*, 28p., 2005.
[4] https://www.unisdr.org/we/inform/terminology
[5] T. Gernay, S. Selamet, N. Todini, and N.E. Khorasani," Urban Infrastructure Resilience to Fire Disaster: An Overview", *Procedia engineering 161*, 1801-1805, 2016.
[6] C.S. Holling, "Engineering resilience versus ecological resilience." *In P. Schulze (eds.)*, Engineering Within Ecological Constraints. *National Academy Press,* Washington DC., p. 33, 1996.
[7] S. Stephenson," The Future Of Fire: Disaster Risks In Business Planning" https://www.forbes.com/sites/scottstephenson/2018/01/03/the-future-of-fire-disaster-risks-in-business-planning/#44031cef4d00
[8] Effectis, rapport d'essais n 14-x-210, Confidential.
[9] M. Smolka and all, "Semi-natural test methods to evaluate fire safety of wall claddings: Update", *MATEC Web of Conferences 46*, 01003 (2016).
[10] Direction générale de la sécurité civile et de la gestion des crises, «Protocole relatif à l'essai LEPIR II complémentaire à l'arrêté du 10 Septembre 1970 », *Ministère de l'Intérieur*, 9p, July 2014.
[11] Eurima, "A Comparison of BS8414 1 &2, draft DIN 4120-20, ISO 13785 1&2, EN 13823 and EN ISO 11925-2", *BRE Global*, report number CC 275194, issue 2, 20p., 28 June 2012.
[12] Draft final report: Development of a European approach to assess the fire performance of façades, November 10, 2017, Project: SI2.743702-30-CE-0830933/00-14.Unpublished.
[13] S. Marsar, "Survivability profiling: How long can victims survive in a fire?" *Fire engineering*, 2010. http://www.fireengineering.com/articles/2010/07/survivability-profiling-how-long-can-victims-survive-in-a-fire.html
[14] SP FIRE 105, - Method for fire testing of façade materials, Dnr 171-79-360 Department of Fire Technology, *Swedish National Testing and Research Institute*, issue number 5, Rev: 1994-09-09, 16p.
[15] J. Andersson and R. Jansson, "Façade fire tests – measurements and modelling", *MATEC Web of Conferences 9*, 02003, 2013.
[16] C.S. Holling," Engineering resilience versus ecological resilience." In P. Schulze (eds.). Engineering Within Ecological Constraints, *National Academy Press,* Washington DC, 1996.
[17] S.L. Pimm," The Balance of Nature?" Issues in the Species and Communities. *University of Chicago Press*, Chicago, 1991.
[18] Y.Y. Haimes, "On the definition of resilience in systems", *Risk Analysis*, 29(4), 498–501, 2009.
[19] F.H. Norris, S.P. Stevens, B. Pfefferbaum, K.F. Wyche, & R.L. Pfefferbaum, "Community resilience as a Metaphor, Theory, Set of Capacities, and Strategy for Disaster Readiness", *American Journal of Community Psychology*, 41(1-2), 2008.

[20] K. Magis, "Community Resilience: An Indicator of Social Sustainability," *Society & Natural Resources: An International Journal*, 23(5), 401–416, 2010.
[21] S.L. Cutter, L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate & J. Webb, "A place-based model for understanding community resilience to natural disasters" *Global Environmental Change*, 18(4), 598–606, 2008.
[22] P.D. Aldrich & A. Meyer, "Social Capital and Community Resilience", *American Behavioral Scientist*, 59(2),2015.
[23] NIST, "Toward a more resilient community: An Overview of the Community Resilience Planning Guide for Buildings and Infrastructure Systems", *US Department of Commerce*, 12p., October 2015.
[24] https://www.100resilientcities.org/resources/#section-4
[25] S. Kerber, "Analysis of Changing Residential Fire Dynamics and Its Implications on Firefighter Operational Timeframes", *UL*, 18p, 2014. https://newscience.ul.com/wp-content/uploads/2014/04/Analysis_of_Changing_Residential_Fire_Dynamics_and_Its_Implications_on_Firefighter_Operational_Timeframes.pdf