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# Handbook of Cognitive and Autonomous Systems for Fire Resilient Infrastructures

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# Preface

We continue to view buildings as gravity-defying structures designed to withstand the adversity of humans, nature, and time. One of the most extreme events a structure might undergo is fire. Unlike other traditional load actions (i.e., wind, seismic events, etc., which are primarily bound to a seasonal or geographical location/region), fire, on the other hand, can virtually break out anywhere and anytime. While fire has been noted as a critical issue over the past few years, research on this area continues to favor dated experimental and numerical approaches. To further complicate this matter, the fire design of structures still heavily relies on prescriptive solutions with little room for innovation or flexibility.

Unfortunately, the past few years have witnessed a drastic surge in both frequency and intensity of fire incidents, both of which are transforming our history—and, more specifically, our fire engineering history. The aftermath of these incidents is a continuous reminder of the serious flaws in our virtually unchanged, decades-old construction philosophy. It is equally concerning and troubling that structural engineers seem to converge on the notion that it is quite impractical, and perhaps unfeasible, to "truly" design fire-resistant structures. This motivates adopting a new look into this challenge, perhaps one that draws inspiration from the advent rise of automation and robotics. This is the primary motivation behind this handbook.

Through this lens, buildings (or structures) are not to be thought of as a series of passive and rigid arrangements of load-bearing members; but rather, we must appreciate the philosophically striking similarities between such buildings and robots. For example, buildings and robots are often subjected to external and/or internal forces. As such, they are designed with embedded structural systems capable of handling such effects to maintain structural integrity. Furthermore, both buildings and robots frequently operate in extreme environmental conditions under a continually complex combination of temperature, pressure, and stress. Nowadays, buildings are commonly being supplemented with sensory instruments, primarily to monitor their "health" as to give insights into deteriorating processes (i.e., corrosion), energy consumption, or into occupants' preferences (e.g., thermal comfort, etc.). Similarly, robots are also embedded with sensors to enable self-diagnostic interaction with surrounding environments and to deliver valuable information to human operators. One can see that there is more to buildings and robots than meets the eye.

The above discussion promotes the following question, what if buildings are designed to incorporate robotic features? What if buildings have cognitive and autonomous abilities? How can we realize such abilities?

With the onset of the fourth industrial revolution, advances in artificial intelligence (AI), internet-of-things (IoT), and robotics are expected to be heavily integrated into the construction industry. Unlike other works, this handbook is not interested in adopting robots as construction workers, nor as 3D printers, but rather seeks to integrate signature features from robots into skyscrapers and infrastructure with especial attention to disaster-induced collapse mitigation.

From this book's perspective, future buildings can be thought of as giant shape-shifting robots with cognitive and autonomous capabilities. The cognitive capability refers to a building's intelligence to understand its surroundings and interact with its occupants. For instance, a cognitive skyscraper will be able to identify the breakout of a disaster (i.e., multistory fire) while at the same time analyzing cascading events in real time using state-of-the-art AI. Such a skyscraper will also be able to pinpoint vulnerable regions or load-bearing components and foresee how damages arising from an extreme event can lead to unwarranted failure/collapse. This is equivalent to a robot assessing its own condition in the event of a mechanical arm impairment or loss. In this scenario, the robot will seek to first understand the impact of such loss, and then it will attempt to devise plausible solutions to overcome such damage.

However, "*knowing without action is useless*." Preliminary efforts have shown how a cognitive building is not only able to convey its predictions to occupants and first responders to facilitate evacuation but also be able to physically turn this information into actions (Naser 2019, 2020). In order to build up the "action" component, future skyscrapers can be supplemented with tentacle-like, and self-deployable (TL-SD) robotic load-bearing structural components. Such components are to be designed independently of the main structural system and hence can be integrated into building façade or compartment boundaries (see Fig. 1). The deployment of a TL-SD structural component can be activated once the cognitive component of the building detects excessive deformations or instability. The deployment of such a tentacle starts by unfolding and inflating a TL-SD structural component into a relatively stiff configuration through pressurized dynamic sliding and shape-memory hinges etc.—similar to those often used in octopus-inspired robots.

Thus, a building equipped with TL-SD structural components will have the capability to autonomously reconfigure its internal structure to divert the adverse effects of extreme events away from its occupants, as well as critical load-bearing members, and possibly towards outside the building; thereby preventing significant damage and collapse. Such events can include extreme temperatures in excess of 800–1000 °C, significant seismic vibration, blast, or impact. As a result, a cognitive and autonomous shape-shifting skyscraper can achieve higher levels of structural resilience (survivability) under extreme environments. This improved performance mitigates failure (collapse), thus allowing first responders to tackle the adverse effects of disasters.

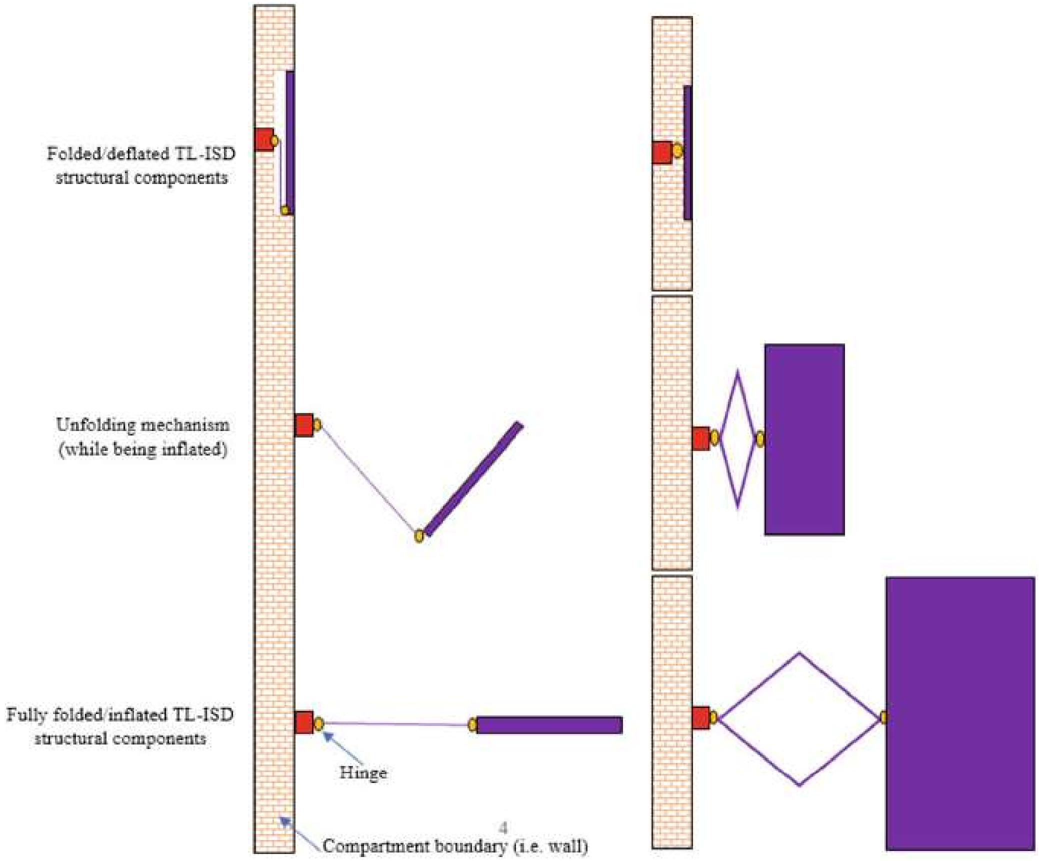

**Fig. 1** Details of a TL-SD structural component

Despite the above optimistic look, one should note that the construction industry is notorious for its inertia and slow adoption of new technologies. Open discussions and collaborations are needed to enable a smooth transition from theory to design to implementation.

Notably, this forward-looking handbook addresses the critical issue of bringing buildings and emergency responders together, a rather novel approach to fire safety even in the twenty-first century. Incredibly, most building designs today do not consider the interaction between firefighters and the buildings they operate in. This handbook literally fills in this gap by providing cutting-edge research, providing design professionals with an understanding of the needs of firefighters and how that impacts building design.

This handbook homes findings from 13 chapters from leading experts on fire safety, engineering, and firefighting from around the world. These experts share state-of-the-art information with regard to various aspects of modernizing the future of safety, engineering, and firefighting. This handbook starts with Chap. 1 where Brian Meacham presents a look into *Sociotechnical Systems Framing for Performance-Based Design for Fire Safety* to lay the foundation for transforming our ways of tackling fire hazards. Then, enters Chap. 2 by Vytenis Babrauskas, to draw a picture for *A Twenty-First Century Approach to Fire Resistance* that stretches our comfort zone into a new frontier. In Chap. 3, Casey Grant showcases a roadmap to *Integrating Modern Technologies to Realize Fire-Resistant Infrastructures*. It is in this chapter that we start to tie automation concepts often seen in parallel fields to our fire domain. In Chap. 4, *Intelligent Science Empowers Building Fire Protection Technology Development*, Feng Luo goes on to showcase how existing fire protection technologies can tremendously improve by borrowing the concepts of IoT and AI.

LaMalva and Medina present us with a look into how the integration of automation will reshape our building codes and standards in Chap. 5, *Building Codes and the Fire Regulatory Context of Smart and Autonomous Infrastructure*. Then, in Chap. 6, Xinyan Huang and colleagues deliver *Perspectives of Using Artificial Intelligence in Building Fire Safety*, thereby delving into the depth of AI and its role in improving building fire safety. Chapters 7 and 8 are written in collaboration between Brian Lattimer and Jonathan Hodges. These two chapters specialize in *Intelligent Firefighting* and *The Role of Artificial Intelligence in Firefighting*—a key resource for our first responders in the new era of cognitive and autonomous structures. Charles Jennings' Chap. 9, *Implementing AI to Assist Situation Awareness: Organizational and Policy Challenges,* focuses specifically on the use of artificial intelligence to provide real-time situational awareness on changing conditions for emergency responders.

The last four chapters capture intricate details with regard to burning questions we continue to face. For example, in Chap. 10, Wojciech Kowalski and colleagues chart a *probabilistic-based reliability approach to overcoming fire hazards in structures*. Chapter 11 is titled *Autonomous Sensor-Driven Pressurization Systems: Novel Solutions and Future Trends*, where Wojciech Węgrzyński and Piotr Antosiewicz focus on autonomous solutions for smoke control in buildings to maintain smoke-free evacuation routes under fires. Ana Sausa revisits the classical standard fire testing from a new perspective—one that incorporates *Hybrid Fire Testing* to enable us to move from component-level testing to system-level fire testing in Chap. 12. Finally, in Chap. 13, Liming Jiang and colleagues give an approach for *Realistic Fire Resistance Evaluation in the Context of Autonomous Infrastructure*.

This handbook started with an idea that we shared during 2018–2019. Initially, we were hoping to complete this handbook by 2020. Little did we know that a pandemic was on the horizon. While the pandemic challenged our initial deadline, we could not have delivered this handbook without the hard work of our contributors. Our hats go to them. Finally, we would like to thank Springer for lending our contributors and us this platform to showcase a glimpse of what the future holds for our domain. A special thanks go to Paul Drougas, Kritheka Elango and R.Savita for believing in the message of this handbook, continued support, and for taking the lead on editing and formatting this handbook.

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