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Editorial

Special Issue on New Challenges in the Civil Structures for Fire Responses

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1. Introduction

Civil structures may be subjected to serious hazards during their lifespans, including natural hazards (i.e., earthquake, hurricanes, and tsunamis) and man-made hazards (i.e., fires and explosions). Fire is one of the most dangerous events, which can lead to environmental pollution, socioeconomic impacts, property losses, and even fatalities in the worst-case scenarios. Furthermore, sustainability and energy efficiency, which are main priorities in today's world, could highly increase the severity of fires in buildings, pushing the fields of fire protection and the innovation of structural materials to new frontiers and thus bringing new challenges with respect to the civil structures for fire responses. This topic is vital for guaranteeing adequate evacuation times and minimum safety conditions for firefighters, as well as minimizing the construction material resources used, economic costs, the loss of lives.

Therefore, this Special Issue aims to address the new challenges in the fire safety procedures of buildings, especially in terms of the fire dynamics and fire responses of different construction materials (nanomaterials, geopolymers, mortars, concretes, and steels) and structural elements (anchors, panels, and slabs), based on experimental tests, numerical simulations, and/or analytical models.

The editors thank all authors for their valuable contributions to the success of this Special Issue. Sixteen high-quality papers (including fifteen research papers and one review paper) were published based on research by more than fifty-five authors from across the world (including Europe, Asia, and Australia), representing fourteen different countries.

2. Innovations

This Special Issue provides scientific knowledge, guidelines, and insights on the main challenges in the field of fire safety engineering, mostly concerning the fire actions and the fire responses of materials and structural members. This section briefly presents the scientific innovations published in this Special Issue.

Agustini et al. [1] evaluated the impact of polypropylene fibres on the thermal conductivity of fly ash-based geopolymer foams at elevated temperatures. The authors assessed the thermal properties of the materials at ambient temperatures. It was observed that adding polypropylene fibres to the geopolymer matrix increased their tensile strength, while the an optimum number of fibres required to obtain the best thermal performance, which was similar to concrete [1], was identified.

Al-Mansouri et al. [2] extended the application range of Pinoteau's resistance integration method to the design of bonded anchors under fire conditions. European design standards provide limited guidance on the methods for cast-in-place or mechanical anchors and none for post-installed adhesive anchors. Therefore, the authors present and discuss adequate design methodologies for assessing such anchors in fire situations [2].

Brzezińska and Bryant [3] present a risk index method for a more holistic approach to support decision making in fire safety strategies for buildings, especially industrial buildings. This method enables the identification of the impacts of different fire protection methods on the fire safety level of a building [3].

Caetano et al. [4] conducted experimental tests on protected steel columns with thermally enhanced fire protection mortars. The authors focused on the development of fire protection mortars and on the influence of their composition, aggregate size, and the addition of silica micro- and nanoparticles on their thermal performance. It was concluded that the gypsum-based mortars exhibited a great thermal response, with perlite playing an important role in the mitigation of the thermal cracking effect. Additionally, the addition of silica micro- and nanoparticles could still strongly improve their thermal insulation, but their dosages should be limited [4].

Charlier et al. [5] proposed an analytical model for estimating the effects of incident heat fluxes on structural elements due to travelling fire scenarios. The authors presented the assumptions and limitations of the developed model. The results obtained using the model were also discussed. This model is a remarkable tool, which can support designers in tackling structural fire engineering problems involving travelling fires [5].

Darkhanbat et al. [6] proposed an egress model using a database and an artificial neural network model. Evacuation is a crucial safety measure that should always be well designed and planned, especially in high-occupancy buildings. The number of casualties in fire scenarios is strongly dependent on the evacuation planning. Correlations between the fire temperature and visibility, as well as toxic gas concentrations, were presented by the authors [6].

Duma et al. [7] extended the scope of the application of the existing simplified method for determining the bending resistance of slim floor beams (SFB) under elevated temperatures to other steel section configurations, including the asymmetric double-T steel cross-sections, since the Eurocodes do not yet allow for the assessment of their fire resistance. The authors identified a wide range of steel cross-section configurations in which this method can be useful [7].

Gamba and Franssen [8] presented a numerical model of a travelling fire (GoZone), combining the concept of a zone model with that of cellular automata, since it has been observed that the gas temperature distribution is not uniform in compartments with large floor areas. The authors found out that the GoZone software may be a useful tool for representing fires in large compartments in both air- and fuel-controlled fire conditions. The automatic transmission of the thermal results from this software to a thermo-mechanical software (SAFIR®) is the next ambition of the authors [8].

Haffke et al. [9] evaluated the energy-efficient pre-cast concrete sandwich panels under fire conditions and their impacts based on experimental tests. The authors identified the degree to which such panels can be fire-protective and the benefits of using glass fibre-reinforced polymeric bar connectors as a shear connection between two concrete wythes [9].

Heo et al. [10] investigated the structural fire performances of hollow-core slabs (manufactured using the extrusion method), based on experimental and numerical results. Precast concrete manufacturing under controlled environments provides superior quality of the structural materials, minimizes the self-weight of the members, and reduces the construction times and costs. The influences of different parameters on their fire responses were evaluated, including the slab depth, span, hollow ratio, concrete cover, and the load ratio. The authors observed the occurrence of some spalling, but its effects were neglected. The load ratio played a key role in the fire performance of these slabs. Nonetheless, a high fire resistance (2 h) could be achieved certain some parameters were properly designed [10].

Kannangara et al. [11] investigated the fire residual strength of a reactive powder geopolymer concrete (RPGC) for the first time. This material resulted from the combination of a geopolymer paste (using sodium-based alkaline solutions) and a reactive powder concrete, RPC (using fly ash). While the compressive strength of the RPGC was lower than the RPC at ambient temperatures (from 140 to 76 MPa), the latter exhibited poor behaviour at high temperatures, suffering from explosive spalling, in contrast with the former, in which low cracking levels were observed. Reductions of only about 33% were observed in the residual strength of the RPGC after exposure to 800 °C [11].

Kannangara et al. [12] still studied the influence of the initial evaporation on the residual performances of different fly ash-based geopolymer pastes after exposure to elevated temperatures. The authors observed that the initial strength (at 24 h) of the sealed specimens were up to 25% higher than that of the unsealed specimens at an ambient temperature, with the gladstone fly ash-based geopolymer specimens showing the highest strength. Nevertheless, gladstone/callide fly ash-based geopolymer specimens had the best residual strength at high temperatures (compared to ambient temperatures), exhibiting even higher strength after exposure 400 °C than in ambient conditions [12].

Lee and Choi [13] studied the mechanical properties of mild- and high-strength steels at elevated temperatures under steady-state conditions. Steel members are very prone to high temperatures when no fire protection is used due to the high thermal conductivity of steel, the high section factor of the common steel structural members (thin wall thickness), and the significant reduction of their mechanical properties with increasing temperatures (above 400 °C). The authors compared their results with other research works available in the literature and international standards and proposed equations for the reduction factors of the elastic modulus, yield strength, and tensile strength. It was suggested that the reduction factors for the yield strength of steels (especially of high-strength steels) in certain current design standards should be modified in order to ensure a safe design [13].

Lu et al. [14] investigated the impacts of both the compression level and temperature on the chloride ion permeability of basalt fibre-reinforced concrete (BFRC). Just as the residual strength of concrete should be evaluated after a fire scenario, the residual chloride ion penetration resistance should be also examined to verify the concrete durability requirements after such a disaster. The chloride ion permeability was assessed after exposing the specimens to different temperatures, including 200 °C, 400 °C, and 600 °C. Based on their results, the authors proposed a simple model for estimating the chloride ion diffusion coefficient of BFRC under such conditions [14].

Robson et al. [15] provided the first experimental analysis of the concrete cone failure of bonded anchors under tension and at high temperatures. Different heating rates were used. The results showed that the anchors' capacity was dependent on the embedment depth, heating scenario, and failure mode. The authors suggested the development of an alternative prediction method, differing from the existing one in EN 1992-4 Annex D, to enable more accurate predictions to be achieved and different heating scenarios to be examined [15].

Finally, Silva et al. [16] studied the thermo-mechanical behaviour of protected slim floor beams with intumescent coating materials in fire situations. The authors also presented the benefits and limitations associated with 2D and 3D FEM approaches. The fire resistance levels of different solutions of the slim floor beams were discussed, as well as the thickness of the intumescent coating, depending on the safety performance level. The results from this research may contribute towards the development of simple fire design methods for such beams in the Eurocodes [16].

3. Conclusions

It is the hope of the editors that this Special Issue will contribute towards new educational and technical materials, building regulations, and structural standardisations relative to the fire design, as well as the use of some innovative materials. The Special Issue hereby disseminates new knowledge within the field of fire safety engineering of buildings, based on scientific and practical research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Agustini, N.K.A.; Triwiyono, A.; Sulistyo, D.; Suyitno, S. Mechanical Properties and Thermal Conductivity of Fly Ash-Based Geopolymer Foams with Polypropylene Fibers. *Appl. Sci.* **2021**, *11*, 4886. [CrossRef]
2. Al-Mansouri, O.; Mège, R.; Pinoteau, N.; Guillet, T.; Piccinin, R.; McBride, K.; Abate, M.; Rémond, S. Design Recommendations for Bonded Anchors under Fire Conditions Using the Resistance Integration Method. *Appl. Sci.* **2021**, *11*, 7810. [CrossRef]
3. Brzezińska, D.; Bryant, P. Risk Index Method—A Tool for Building Fire Safety Assessments. *Appl. Sci.* **2021**, *11*, 3566. [CrossRef]
4. Caetano, H.; Laím, L.; Santiago, A.; Durães, L.; Shahbazian, A. Development of Passive Fire Protection Mortars. *Appl. Sci.* **2022**, *12*, 2093. [CrossRef]
5. Charlier, M.; Franssen, J.-M.; Dumont, F.; Nadjai, A.; Vassart, O. Development of an Analytical Model to Determine the Heat Fluxes to a Structural Element Due to a Travelling Fire. *Appl. Sci.* **2021**, *11*, 9263. [CrossRef]
6. Darkhanbat, K.; Heo, I.; Han, S.-J.; Cho, H.-C.; Kim, K.S. Real-Time Egress Model for Multiplex Buildings under Fire Based on Artificial Neural Network. *Appl. Sci.* **2021**, *11*, 6337. [CrossRef]
7. Duma, D.; Zaharia, R.; Pintea, D.; Both, I.; Hanus, F. Analytical Method for the Bending Resistance of Slim Floor Beams with Asymmetric Double-T Steel Section under ISO Fire. *Appl. Sci.* **2022**, *12*, 574. [CrossRef]
8. Gamba, A.; Franssen, J.-M. GoZone: A Numerical Model for Travelling Fires Based on Cellular Automata Concept. *Appl. Sci.* **2021**, *11*, 10679. [CrossRef]
9. Haffke, M.; Pahn, M.; Thiele, C.; Grzesiak, S. Experimental Investigation of Concrete Sandwich Walls with Glass-Fiber-Composite Connectors Exposed to Fire and Mechanical Loading. *Appl. Sci.* **2022**, *12*, 3872. [CrossRef]
10. Heo, I.; Darkhanbat, K.; Han, S.-J.; Choi, S.-H.; Jeong, H.; Kim, K.S. Experimental and Numerical Investigations on Fire-Resistance Performance of Precast Concrete Hollow-Core Slabs. *Appl. Sci.* **2021**, *11*, 11500. [CrossRef]
11. Kannangara, T.; Guerrieri, M.; Fragomeni, S.; Joseph, P. A Study of the Residual Strength of Reactive Powder-Based Geopolymer Concrete under Elevated Temperatures. *Appl. Sci.* **2021**, *11*, 11834. [CrossRef]
12. Kannangara, T.; Guerrieri, M.; Fragomeni, S.; Joseph, P. Effects of Initial Surface Evaporation on the Performance of Fly Ash-Based Geopolymer Paste at Elevated Temperatures. *Appl. Sci.* **2022**, *12*, 364. [CrossRef]
13. Lee, S.-H.; Choi, B.-J. Mechanical Properties of ASTM A572 Grades 50 and 60 Steels at High Temperatures. *Appl. Sci.* **2021**, *11*, 11833. [CrossRef]
14. Lu, L.; Wu, S.; Qin, Y.; Yuan, G.; Zhao, Q.; Doh, J.-H. The Chloride Ion Penetration Mechanism in Basalt Fiber Reinforced Concrete under Compression after Elevated Temperatures. *Appl. Sci.* **2021**, *11*, 10137. [CrossRef]
15. Robson, M.N.; Al-Mansouri, O.; Pinoteau, N.; Abate, M.; McBride, K.; Piccinin, R.; Rémond, S.; Hoxha, D. Experimental Investigation of the Concrete Cone Failure of Bonded Anchors at Room and High Temperature. *Appl. Sci.* **2022**, *12*, 4760. [CrossRef]
16. de Silva, D.; Alam, N.; Nadjai, A.; Nigro, E.; Ali, F. Finite Element Modelling for Structural Performance of Slim Floors in Fire and Influence of Protection Materials. *Appl. Sci.* **2021**, *11*, 11291. [CrossRef]