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Knowledge FOr Resilient soCiEty



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WP 2

COMPILATION OF A LIST OF RESEARCH PHD THEMES, ACCORDING TO DISASTER TRENDS IN THE WESTERN BALKANS

List of research PhD themes

Deliverable 2.5

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There are many different ways to develop theory addressing research problems on the global level. A list of research PhD themes is compiled according to disaster trends in Western Balkan. HEIs Partners made a theoretical base for a problem and the type of theory development methodology to utilize. A second element important to researchers, and particularly relevant for beginning researchers, is the concept of making a contribution to knowledge. HEIs Partners defined contribution that needs to be delivered through doctorates and gave several methods how original research contributions can be made.

PhD THEMES

PhD thesis title 1

RISK MITIGATION OF POST-EARTHQUAKE FIRE IN URBAN BUILDINGS

General description

Balkan is seismically active region and the earthquake, as destructive load on structures, is already involved in the design codes. Post-earthquake fire (PEF) is considered as one of the highest risks and complicated problems affecting buildings in urban areas and can cause even more damage than the earthquake itself. However, most standards and codes ignore the implications of PEF and so buildings are not normally designed with PEF in mind.

The effects of post-earthquake fire on partially damaged buildings located in seismic urban regions have to be investigated.

Objectives

- Collect data on earthquakes in WBC in the last century, provide data on earthquake and PEF effects on structures and the potential risks to urban structures.
- Define methods for mitigating the risk at both the macro scale and micro scale.
- Recognise and codify the PEF factors and give recommendations for improving the design codes from aspect of risk mitigation.

Key references

- Behrouz Behnam. (2016). Post-Earthquake Fire Analysis in Urban Structures: Risk Management Strategies, Taylor & Francis, ISBN 9781498743914
- T. Nishino, T. Tanaka, A. Hokugo An evaluation method for the urban postearthquake fire risk considering multiple scenarios of fire spread and evacuation, Fire Safety Journal, Volume 54, November 2012, Pages 167-180
- Earthquake and post-earthquake fire performance SFPE: https://www.sfpe.org/page/FPE_ET_Issue_82/Earthquake-and-Post-Earthquake-Fire-Performance.htm

PERFORMANCE OF REINFORCED CONCRETE STRUCTURES SUBJECTED TO POST EARTHQUAKE FIRE

General description

Post earthquake fire (PEF) is a serious threat to structures that are partially damaged in a prior earthquake potentially leading to a quick collapse of the structure. The majority of standards and codes for the design of structures against earthquake, however, ignore the possibility of PEF and thus buildings designed with those codes fail swiftly when exposed to fire after earthquake. Because of this fact, there is a need for the incorporation of PEF into the process of analysis and design and to provide some quantitative measures on the level of associated effects.

Objectives

- Adopt a software (based on FEM) that will be capable for conducting both analysis: push-over analysis for seismic action followed by thermal and stress-strain analysis for fire action
- Parametric analysis on different types structural elements and frame structures
- Analyse data, draw conclusions and give recommendations for improving the design codes

Key references

- B.Wu & D.Niu, Post-earthquake fire performance of reinforced concrete columns, Structure and Infrastructure Engineering, Maintenance, Management, Life-Cycle Design and Performance, Vol.12, 2016-Issue 9, pp. 1106-1126
- Mousavi, S, ; Bagchi, A; and Kodur V.K.R. (2008). Review of post-earthquake fire hazard to building structures. Canadian Journal of Civil Engineering, 35: 689-698.
- Lj.Lazarov, M. Cvetkovska, K. Todorov, "Fire resistance of RC Frame in case of post earthquake fire", Journal of structural fire engineering, Vol.4, No.2, 2013 pp.87-94

NEURAL NETWORK APPROACH FOR RISK ASSESSMENT IN CONSTRUCTION PROJECTS

General description

This PhD will make an attempt to model the variation between predicted and actual cost flow due to inherent risk in construction. A neural network approach will be used to develop a cost flow risk assessment model. The network will be trained and tested with data obtained from different private contractors and construction projects facing environmental risks. The goal is to build a model that can accurately predict the possible value of the total environmental risks.

Objectives

- Make an inventory of most common risks that can occur during construction projects life cycle
- Make a solid data base for environmental risks, cost and other important factors that have high influence on project cost
- Develop a neural-network model that can offer a significant advantage in predicting the possible risks in construction projects.

Key references

Waziri B. Sh., Bala K. & Bustam Sh. Ah. (2017). Artificial Neural Networks in Construction Engineering and Management. International Journal of Architecture, Engineering and Construction, Vol. 6, 50-60.

Lazarevska M., Knežević M., Cvetkovska M. & Trombeva Gavrilovska A. (2014). Application of artificial neural networks in civil engineering. Technical Gazette, Vol. 21/No. 6. ISSN 1330-3651.

Boussabaine A.H. & Elhag T. M. S. (1997). A neurofuzzy model for predicting cost and duration of construction projects. Royal Institution of Chartered Surveyors, pp.1-9. ISBN 0-85406-840-6.

DETERMINATION OF FIRE RESISTANCE OF CIVIL ENGINEERING STRUCTURES USING ARTIFICIAL NEURAL NETWORKS

General description

Numerical analysis will be carried out for the reinforced concrete structural elements exposed to standard fire ISO 834. Using the results obtained from the numerical analysis this PhD will develop a neural-network model the will be able to predict the time of fire resistance of civil engineering structures. The neural network model will be trained and tested with data obtained from numerical analysis for different constructions and structural elements.

Objectives

- Conduct a numerical analysis for different structural elements exposed to fire
- Assemble and process data, determine the input and output parameters, define the neural-network model, train and test the model prediction accuracy
- Develop a prognostic neural-network model that can offer a significant advantage in predicting the time of fire resistance of civil engineering structures

Key references

Lazarevska M., Knežević M., Cvetkovska M. & Trombeva Gavrilovska A. (2014). Application of artificial neural networks in civil engineering. Technical Gazette, Vol. 21/No. 6. ISSN 1330-3651.

Lazarevska M., Knezevic M., Cvetkovska M., Ivanisevic N., Samardzioska T. & Trombeva-Gavriloska A. (2012). Fire-resistance prognostic model for reinforced concrete columns. Građevinar 64, 7.

EN1994-1-2: Eurocodes 2 to 4 – Design of concrete, steel and composite steel and concrete structures, Part 1-2: General rules - Structural fire design. (2005).

EVACUATION STRATEGIES AND DESIGN FOR COMPLEX BUILDINGS IN WESTERN BALKAN COUNTRIES

General description

A review of the current regulatory framework in WBC is performed. Codes and guidelines might need to be improved and updated in light of recent building trends in WBC. This PhD will make an inventory of existing building types in WBC and assess their vulnerabilities from the evacuation perspective. A novel methodology for the development of evacuation strategies and design methods will be created.

Objectives

- Make an inventory of most common complex building types in WBC
- Review current evacuation strategies adopted in complex buildings in WBC
- Develop improvements to existing evacuation strategies and design methods in light of European and International strategies

Key references

International Code Council. (2018). International Code Council

National Fire Protection Association. (2018). NFPA 101, life safety code.

Ronchi, E., & Nilsson, D. (2013). Fire evacuation in high-rise buildings: a review of human behaviour and modelling research. Fire Science Reviews, 2(1), 7. https://doi.org/10.1186/2193-0414-2-7

ASSESSING THE SUITABILITY OF PERFORMANCE-BASED STRATEGIES IN UNDERGROUND INFRASTRUCTURES IN WESTERN BALKAN COUNTRIES

General description

WBC includes a raising number of underground infrastructures (for transportation and other purposes). Prescriptive codes are commonly employed in WBC. It is important to assess the current fire safety status of such infrastructures and identify the suitability of performance-based strategies (e.g. based on RSET/ASET models) for existing and future underground infrastructures. Such analysis should include financial and risk analysis aspects and they should consider the WBC context.

Objectives

- Make an inventory of underground infrastructures typologies (e.g. road and rail tunnels, mines, etc.) in WBC
- Identify fire safety and evacuation criticalities of WBC underground infrastructures
- Assess the suitability of performance-based design fire safety strategy for WBC underground infrastructures

Key references

Fridolf, K., Nilsson, D., & Frantzich, H. (2011). Fire Evacuation in Underground Transportation Systems: A Review of Accidents and Empirical Research. Fire Technology, 49(2), 451–475. https://doi.org/10.1007/s10694-011-0217-x

NFPA, National Fire Protection Association (2017). Standard for road, tunnels, bridges, and other limited access highways (NFPA 502).

Ronchi, E., Colonna, P., Capote, J., Alvear, D., Berloco, N., & Cuesta, A. (2012). The evaluation of different evacuation models for assessing road tunnel safety analysis. Tunnelling and Underground Space Technology, 30, 74–84. https://doi.org/10.1016/j.tust.2012.02.008

CROWD MANAGEMENT FOR HIGH DENSITY OUTDOOR EVENTS

General description

Several events (music festivals, religious events, etc.) take place outdoor, which gathers thousands of people in public spaces. The management of such crowds can be difficult to make in case of emergency scenarios linked to natural and man-made disasters. This PhD topic will focus on collecting data on real crowded events in WBC and develop novel crowd management strategies for WBC outdoor events. This may include the use or development of novel modelling tools for decision support in case of emergencies.

Objectives

- Collect data on crowd flow in WBC outdoor events
- Analyse data and derive relationships for people densities, flows and speeds
- Review existing crowd management strategies in light of existing regulations and guidelines in WBC
- Develop novel crowd management strategies for outdoor events in WBC

Key references

Fruin, J. J. (1993). The causes and prevention of crowd disasters. Presented at the First International Conference on Engineering for Crowd Safety, London, England.

Fruin, J. J. (1987). Pedestrian Planning and Design ((Revised Edition)). Elevator World, Inc, Mobile, AL.

Ronchi, E., Nieto Uriz, F., Criel, X., & Reilly, P. (2016). Modelling large-scale evacuation of music festivals. Case Studies in Fire Safety, 5, 11–19. https://doi.org/10.1016/j.csfs.2015.12.002

TRAFFIC MODELLING AS DECISION SUPPORT FOR LARGE-SCALE DISASTERS

General description

Natural (flood, fires, landslides, etc.) and man-made (gas dispersion, terrorist attacks, etc.) disasters can lead to large-scale evacuation of thousands of people. The displacement of such large masses put a great strain on the transportation infrastructure and road network. Traffic models can be used as a decision support tool for assessing the need for evacuation. This PhD topic will focus on developing traffic modelling tools for aiding decision support in case of large-scale disasters

Objectives

- Review existing traffic models for large-scale disasters
- Categorize mass evacuation in relation to type of threat, transportation infrastructures and number of people involved
- Develop a decision support tool based on traffic modelling methods

Key references

Barceló, J. (2010). Fundamentals of traffic simulation (Vol. 145). Springer.

Jones, S. L., Sullivan, A. J., Cheekoti, N., Anderson, M. D., & Malave, D. (2004). Traffic simulation software comparison study. *UTCA Report*, 2217.

Pel, A. J., Bliemer, M. C. J., & Hoogendoorn, S. P. (2012). A review on travel behaviour modelling in dynamic traffic simulation models for evacuations. *Transportation*, *39*(1), 97–123. <u>https://doi.org/10.1007/s11116-011-9320-6</u>

RISK-INFORMED APPROACH TO FIRE SAFETY DESIGN

General description

Risk is governing the level of fire protection requirements in building design. The majority of fire safety design frameworks treat risk only implicitly, i.e. "hidden" from the end-user. The current regulatory framework and fire safety design standards need to be investigated for the compatibility with risk-informed FSE approach. The main goal of the PhD. thesis is to formulate a set of recommendations with regard to future implementation of risk-informed, performance-based fires safety design in selected WBC.

Objectives

- Investigate potential of incorporating risk-informed fire safety engineering into building design in selected WBC
- Review national fire statistics database suitability and identify necessary improvements
- Develop a framework for incorporation of risk-informed acceptance criteria into national legislation

Key references

HURLEY, Morgan J., et. Al., 2016. SFPE Handbook of Fire Protection Engineering. 5th. New York, NY: Springer New York. ISBN 978-1-4939-2564-3.

ISO 16732 Fire risk assessment (Parts 1-3)

HASOFER, A. M, BECK, V. R and BENNETTS, I. D, 2007. Risk analysis in building fire safety engineering. London: Butterworth-Heinemann. ISBN 978-0-7506-8156-8.

ADVANCED COMPUTER FIRE MODELLING

General description

The use of computer fire modelling is on the rise, however, its application is not always appropriate or correct. This PhD thesis aims to evaluate a series of case studies on the application selected computer fire models and analyse the differences with the standard design practice. Finally a perspective for future use of advanced computer fire models in WBC is presented.

Objectives

- Summarise the current practise in computer fire modelling
- Identify potential for the use fire computer models of in selected WBC
- Develop a series of case studies for demonstration of selected aspects of fire safety design assisted by advanced computer fire models

Key references

HURLEY, Morgan J., et. Al., 2016. SFPE Handbook of Fire Protection Engineering. 5th. New York, NY: Springer New York. ISBN 978-1-4939-2564-3.

JANSSENS, Marc L., 2000. An introduction to mathematical fire modeling. 2nd ed. Lancaster, Pa: Technomic Pub. Co. ISBN 1-56676-920-5. 2000

YEOH, Guan Heng and YUEN, Kwok Kit (eds.), 2009. Computational fluid dynamics in fire engineering: theory, modelling and practice. Amsterdam ; Boston: Elsevier. ISBN 978-0-7506-8589-4. 2009

FIRE-SAFE BUILDING EXTERIOR CLADDING

General description

A significant number of fatal fires of building exterior cladding has become a serious issue over the last two decades. There is an evident need for a well justified and robust set of fire safety design requirements for building exterior cladding. The main outcome of the PhD thesis is to develop a set of scientifically-supported recommendations for fire-safe application of building exterior cladding taking into account the height, use and other attributes of buildings.

Objectives

- Review significant fires involving building exterior cladding
- Review national and international requirements for building exterior cladding and its fire testing
- Develop a set of scientifically-supported recommendations for fire-safe application of building exterior cladding

Key references

National fire regulations

International Code Council. (2018). International Code Council

WHITE, Nathan and DELICHATSIOS, Michael, 2015. Fire Hazards of Exterior Wall Assemblies Containing Combustible Components. New York, NY: Springer New York. SpringerBriefs in Fire. ISBN 978-1-4939-2897-2.

EARLY FIRE DETECTION AND ALARM: A PRE-REQUISITE FOR SAFE EVACUATION

General description

Many fires develop for significant periods of time before being discovered which may lead to threatening conditions and reduced available evacuation times. Automatic fire detection and alarm systems (AFD) are very efficient in addressing this issue, however are not used extensively in WBC. The main goal of this PhD thesis is to provide scientific and technical background for increased incorporation of AFD in prescriptive and FSE fire codes in WBC.

Objectives

- Review current state of AFD requirement in WBC
- Through application of FSE tools and series of tests demonstrate differences in detection speed and accuracy in situations with and without AFD
- Produce a set of recommendations for improvement of the current fire codes in WBC with regard to AFD

Key references

National fire regulations

HURLEY, Morgan J., et. Al., 2016. SFPE Handbook of Fire Protection Engineering. 5th. New York, NY: Springer New York. ISBN 978-1-4939-2564-3. ROUX, Richard J, et al., 2015.

National fire alarm and signaling code handbook. Quincy, MA: National Fire Protection Association. ISBN 978-1-4559-0936-0.

DYNAMIC RISK ASSESSMENT OF FIRE SCENARIOS IN COMPLEX INFRASTRUCTURES

General description

Risk assessment is traditionally done by analysing fire scenarios using non-time resolved methods as fault and event trees. Further, the event chains e.g. leading to detection and warning, development of fire and fire spread, structural fire resistance or evacuation are assessed separately and are not considering the dynamic mutual dependencies of these event chains. The main goal of the PhD thesis is to perform a Monte Carlo type dynamic fire risk assessment of a complex infrastructure based on a performance based fire codes and to compare such with common fire risk assessment methods.

Objectives

- Review static and dynamic probabilistic fire risk assessment methods and suggest improvements
- Develop a probabilistic model calculating the safety levels and worst case fire scenarios for a complex building
- Develop a framework for incorporation of dynamic fire risk assessment methods into the fire safety strategy reports

Key references

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- Markert, F., Kozine, I. and Duijm, J. N. (2016) 'Process Risk Assessment using Dynamic Simulation of Scenarios', Chemical Engineering Transactions, 48(2015), pp. 181–186. doi: 10.3303/CET1648031
- Frantzich, H. (1998) 'Risk analysis and fire safety engineering', Fire Safety Journal. Elsevier, 31(4), pp. 313–329. doi: 10.1016/S0379-7112(98)00021-6.
- Di Maio, F., Rai, A. and Zio, E. (2016) 'A dynamic probabilistic safety margin characterization approach in support of Integrated Deterministic and Probabilistic Safety Analysis', Reliability Engineering & System Safety, 145, pp. 9–18. doi: http://dx.doi.org.proxy.findit.dtu.dk/10.1016/j.ress.2015.08.016.

MODELLING FIRE RISKS OF MODERN CARS IN CAR PARKS

General description

Modern cars carry an increasingly larger fraction of combustible materials; contain various alternative fuels (solids in batteries, liquids as ethanol/gasoline mixtures, gases as LNG, LPG or hydrogen). The main goal of the PhD is to model different car fire scenarios as well as car park fire and toxic gas spread scenarios to analyse evacuation scenarios and structural response of the closed car parks.

Objectives

- Development of various car fire models using FDS
- Development of closed car park fire spread scenarios and modelling of selected scenarios
- Development of a set of recommendations to build car parks for common and future vehicles

Key references

- Weisenpacher, P., Glasa, J. and Halada, L. (2016) 'Automobile interior fire and its spread to an adjacent vehicle', Journal of Fire Sciences, 34(4), pp. 305–322. doi: 10.1177/0734904116647972.
- Okamoto, K., Otake, T., Miyamoto, H., Honma, M. and Watanabe, N. (2013) 'Burning behavior of minivan passenger cars', Fire Safety Journal. Elsevier, 62, pp. 272–280. doi: 10.1016/J.FIRESAF.2013.09.010.
- Zhao, B. and Kruppa, J. (2004) 'Structural behaviour of an open car park under real fire scenarios', Fire and Materials, 28(24), pp. 269–280. doi: 10.1002/fam.867.

VULNERABILITY OF REINFORCED CONCRETE BRIDGES TO TRUCK FIRES

General description

Fire hazard represents a dangerous threat for bridges that can lead to severe structural consequences and economic losses. Despite recent cases of major bridge damages induced by fire and an increasing attention of the engineering community to the problem, no structural fire safety provisions exist at present and no guidance is given on how to design bridges against fire.

The proposed project will investigate the response of bridges to fire with a focus on ordinary and precast reinforced concrete (R.C.) bridge structures exposed to truck fires, which represent the most critical scenario from the point of view of both the fire action and the structural behaviour.

Purpose of the study is the development of design methods and fire safety guidelines for assessing and mitigating the vulnerability of main concrete bridge typologies to fire. The guidelines are expected to serve as design basis for industry and practitioners and be used by regulators for a prompt integration of fire safety requirements in bridge codes.

Objectives

- Investigate the response to truck fires of the R.C. decks of different bridge typologies, selected among those commonly used for concrete overpasses, such as beam system bridges, cable-stayed bridges and arch bridges. The investigation will be carried out by means of simplified calculation methods, numerical analyses, as well as experimental tests on medium scale samples exposed to high temperatures.
- Develop numerical models, calibrated on the experimental results and literature data, capable of simulating the response of a R.C. bridge deck to fire. The numerical work will include the implementation of a computational fluid dynamic (CFD) model for the simulation of the fire development, as well as a finite element model (FEM) for the study of the temperature evolution in the structure (thermal model) and the mechanical response of the bridge deck (mechanical model).
- Development of design guidelines for industry and practitioners: the guidelines are also intended to serve as input for a prompt inclusion of fire safety requirements in bridge codes and building regulations. As such, they should not just delineate general design recommendation and good practices, but clearly specify how the bridge vulnerability to fire can be assessed and how critical design choices and practical and economical countermeasures can be identified

Key references

 Astaneh-Asl, C. Noble, J. Son, A. Wemhoff, M. Thomas and L. McMichael, "Fire Protection of Steel Bridges and the Case of the MacArthur Maze Fire Collapse," in Proc. of the 1009 ASCE Technical Council on Lifeline Earthqualke Engineering Conference (TCLEE09), Oakland, CA, USA, 2009.

- M. Garlock, I. Paya-Zaforteza, V. Kodur and L. Gu, "Fire hazard in bridges: Review, assessment and repair strategies," Engineering Structures, vol.35, p. pp. 89–98, 2012.
- L. Giuliani, C. Crosti and F. Gentili, "Vulnerability of bridges to fire," in Proc. of the 6th Int. Conf. on Bridge Maintenance, Safety and Management (IABMAS 2012), Stresa, Italy, 2012.

IDENTIFICATION OF EFFICIENT DISASTER MANAGEMENT STRATEGIES

General description

A disaster management requires preparedness for various scenarios and the allocation of resources to efficiently reduce consequences and to regain functionality of infrastructure systems. In this sense, the Bayesian pre-posterior decision analysis should be utilised to identify optimal, effective and cost-efficient strategies leading to reduced risk and a high resilience.

Objectives

- Development of decision scenarios, probabilistic performance and consequence models and an objective function describing the disaster management
- Bayesian pre-posterior decision analysis to quantify the total risks and expected costs for several disaster management strategies
- Identification of effective strategies for disaster management in terms of risk reduction, cost-efficiency and resilience

Key references

- Thöns, S. and M. Stewart (2018). Assessment of Terrorism Risk Mitigation Measures for Iconic Bridges. IABMAS 2018 - 9th International Conference on Bridge Maintenance, Safety and Management, Melbourne, Australia
- Faber, M. H., J. Qin, S. Miraglia and S. Thöns (2017). On the Probabilistic Characterization of Robustness and Resilience. Procedia Engineering 198(Supplement C): 1070-1083. DOI: https://doi.org/10.1016/j.proeng.2017.07.151.
- Thöns, S. (2018). On the Value of Monitoring Information for the Structural Integrity and Risk Management. Computer-Aided Civil and Infrastructure Engineering 33(1): 79-94. DOI: 10.1111/mice.12332.

HOUSEHOLD PREPAREDNESS FOR CRISES AND DISASTERS

General description

How households prepare to withstand and handle crises and disasters is crucial for what negative consequences arise in various events. Extensive preparedness would mean lesser need of assistance from first responders and authorities, whereas low preparedness would require public actors to be able to provide extensive assistance. This thesis concerns studying how households are prepared to withstand various crises and disasters. What capacities and resources can they use if a disaster strikes? What are the reasons for households preparing and not preparing for different potential crises?

Objectives

- To what extent and how are household prepared to withstand various types of crises and disasters?
- What expectancies do public officials have on households' preparedness?
- What expectancies do households have on the ability of public actors to provide assistance during crises?

ENHANCING THE TREATMENT OF CREEPING CRISES

General description

Most crisis events are sudden and acute which means that there is a clear shift from the pre-crisis to the post-crisis phase. However, for some events these processes are much slower meaning that there is no distinct transformation from the pre- to the post-crisis phase- these events can be called slowly evolving crises or creeping crises. This can make both the detection and the response to such events problematic and the tools and methods might not be adapted to handle them.

Objectives

- What characterise slowly evolving crises and what other type of demands can be out on the management of such events?
- How can the management of slowly evolving crises be improved?

MAPPING NETWORKS INVOLVED IN THE MANAGEMENT OF CRISES

General description

How the network of actors involved in the management of crises is structured will influence how well these events can be responded to. Tightly couple networks would probably mean increased potential for good coordination and similar positive outcomes. Comparing the networks as they were structured in the response phase with how the networks were structured in the preparedness phase might reveal

Objectives

- Map network of actors involved in the response to crises
- Map network of actors involved in the preparedness phase to crises
- Compare the two types of maps in order to find patterns, correlations and explanations in order to improve future crisis response.

INCLUSIVE EGRESSIBILITY IN DISASTERS

General description

To date, extensive research has been conducted in the field of accessibility for people with disabilities and with limited functional capabilities. Nevertheless, there is limited to no understanding on evacuation capabilities of such populations and those can be improved. This thesis aims at performing a classification of physical, cognitive and functional impairments affecting egress and investigate models and solutions to enhance inclusive egressibility

Objectives

- To classify impairments affecting egressibility
- To review current provisions for people with disabilities in Western Balkan Countries
- To develop new strategies and solutions to promote inclusive egressibility

Key references

Butler, Kathryn, et al. "Perspectives of occupants with mobility impairments on evacuation methods for use during fire emergencies." *Fire Safety Journal* 91 (2017): 955-963.

Hashemi, Mahdi, and Hassan A. Karimi. "Indoor spatial model and accessibility index for emergency evacuation of people with disabilities." *Journal of Computing in Civil Engineering* 30.4 (2015): 04015056.

Twigg, John, Maria Kett, and Emma Lovell. "Disability inclusion and disaster risk reduction." (2018).