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BUILDING INFORMATION MODELING AS A TOOL FOR ENHANCING DISASTER RESILIENCE OF THE CONSTRUCTION INDUSTRY

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Research article

Abstract: As frequencies of the disasters are increasing, new technologies can be used to enhance disaster resilience performance of the construction industry. This paper investigates the usage of BIM (Building Information Modeling) in enhancing disaster resilience of the construction industry and in the establishment of the resilient built environment. In-depth literature review findings reveal BIM's contribution to the disaster resilience in the pre-disaster and post-disaster phases especially through influencing the performance of the supply chain, construction process, and rescue operations. This paper emphasises the need for BIM's integration to the education and training curriculums of the built environment professionals. Policy makers, construction professionals, professional bodies, academics can benefit from this research.

Keywords: Disaster resilient built environment, BIM, disaster resilient construction industry, disaster resilience, disaster resilient supply chain.

Introduction

The magnitudes and frequency of the natural hazards and man-made hazards are increasing due to different challenges including climate change, earthquake, under-development/poverty, pandemics (International Federation of Red Cross and Red Crescent Societies IFRC website). Disasters can endanger life, well-being, and environment (Gunes and Kovel, 2000; Dakhil and Alshawi, 2014) as they can have deathly consequences and as they can cause economic losses. Lill and Perera (2017) emphasized that between 2005-2015, disasters adversely affected approximately 1.5 billion people and caused approximately $1.3 trillion loss (The United Nations Office for Disaster Risk Reduction UNISDR, 2015). For example, as a result of the Sichuan earthquake in 2008, *"69,185 people died, 18,403 people went missing and a large number of houses were destroyed, and a large number of people were homeless unable to secure livelihoods"* (Lefei and Shuming, 2008; Jia and Zhu, 2012).

The resilience of the construction industry to disasters and to their consequences needs to be enhanced. 'Resilience' means the ways of improving societies' resistance and strength against disasters/hazards and reducing their adverse consequences as well as the probability of man-made hazards (Burnside and Carvalho, 2016; Haigh and Amaratunga, 2010). DFID (Department for International Development) (2011) defines disaster resilience as *'the ability of countries, communities and households to manage change, by maintaining or transforming living standards in the face of shocks or stresses … without compromising their long-term prospects'* (Governance and Social Development Research Centre GSDRC website). Disaster resilience depends on *'the degree to which the social system is capable of organising itself to increase its capacity for learning from past disasters for better future protection and to improve its risk reduction measures'* (UNISDR, 2005 as quoted from Lill and Perera, 2017). Inter-disciplinary solutions are required to cope with the challenges caused by the disasters (Haigh and Amaratunga, 2010). The resilience of the built environment can contribute to the mitigation of the economic consequences of disasters and to the recovery of the societies (Lill and Perera, 2017). For this reason, this paper aims to investigate the usage of BIM (Building Information Modeling) in enhancing disaster resilience of the construction industry and in establishment of the resilient built environment.

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Materials and methods

This paper aims to investigate the usage of BIM in enhancing disaster resilience of the construction industry and in establishment of the resilient built environment. With this aim, an in-depth literature review has been carried out on the following topics: need for disaster resilient construction industry, supply chain and resilient built environment; contribution of the construction industry to the disaster resilience; ways of enhancing resilience of the construction industry; BIM's contribution to the disaster resilience of the construction and supply chain both in the pre-disaster and post-disaster phases.

Results

The literature review findings have been summarized under the two subheadings, namely: contribution of the construction industry to the disaster resilience and enhancing resilience of the construction industry.

Contribution of the construction industry to the disaster resilience

The construction industry plays vital role in enhancing disaster resilience. Construction companies' resilience can influence resilience of the construction industry, relevant industries and of the communities (Haigh et al., 2006; Bosher, 2008; Haigh and Amaratunga, 2010; Wilkinson, et al., 2016). Speed of recovery in the post-disaster phase depends on the speed of the reconstruction of the built environment (Quarantelli, 2008; Wilkinson et al., 2016). Haigh and Amaratunga (2010) emphasized the built environment's importance in contributing to the communities' resilience stating that "*… when elements of it are damaged or destroyed, the ability of society to function - economically and socially - is severely disrupted…*" For this reason, actions taken for enhancing communities' resilience need to cover the ways of enhancing disaster resilience of the built environment and of the construction industry. Wilkinson et al. (2016) clarified this situation as follows:

"*Building the resilience of construction organisations is a key part of any overall resilience policy because of their role in restoration and reconstruction project delivery post-disaster… A resilient construction sector is responsive, adaptable and able to lead in a disaster... Loss of functionality of the construction sector leads to slow, uncoordinated recoveries.*" (Wilkinson, et al., 2016)

In the pre-disaster phase, construction companies need to enhance their resilience and invest in pre-disaster risk reduction at the company level as in the post-disaster phase, construction companies are expected to recover their own business' functionality, and to contribute to the post-disaster recovery and reconstruction (Wilkinson, et al., 2016). Both technical and organisational resiliences are important for improving overall resilience (Sapeciay et al., 2017).

In the pre-disaster phase, resilience of the construction industry can be enhanced through educating the construction professionals (Wilkinson, et al., 2016). Built environment professionals need to be equipped with the relevant skills and knowledge so that they can deal with the requirements of the pre- and post-disaster phases. Construction professionals can influence technical resilience of the constructions. Improved engineering for buildings and infrastructure can reduce the magnitude of the disasters' impact minimising their consequences (Mileti, 1999; Haigh and Amaratunga, 2010). Furthermore, construction professionals need to deal with challenges in the post-disaster phase enhancing the recovery process. Built environment professionals need to have strong leadership, ability to manage vulnerabilities and ability to adapt themselves to the changes (Wilkinson, et al., 2016). They need to be able to manage the boom-bust cycles as a result of disasters (Wilkinson, 2013; Wilkinson, et al., 2016) as construction industry needs to be able to adapt itself to changing and suddenly increasing workload in the post-disaster phase. Furthermore, built environment professionals need to be equipped with the skills and knowledge enabling them to have: project management and technical construction expertise (Haigh and Amaratunga, 2010); ability to work with BIM (Building Information Modelling) based construction (Haigh and Amaratunga, 2010); ability to achieve building damage assessment and safety evaluation (Wilkinson, et al., 2016). They need to be able to lead the restoration projects in the post-disaster phase (Baroudi and Rapp, 2016). Education for disaster restoration projects need to equip them with leadership traits via case studies, small group discussions, and role-playing (Baroudi and Rapp, 2016). Furthermore, they need to have ability to carry out waste management successfully and effectively (Karunasena and Amaratunga, 2016) especially in the post-disaster phase.

In the pre-disaster phase, resilience needs to be integrated to the codes, policies, culture and work practices. Building regulations and codes need to be prepared considering measures to control disaster waste generation as well as to support construction and demolition waste management (Karunasena and Amaratunga, 2016) as waste management is one of the main problems in the post-disaster phase. Furthermore, policies need to support movement towards resilient built environment. For this reason, policies need to encourage multidisciplinary, interinstitutional (e.g. professional bodies, construction companies, public entities, universities etc.), and international collaboration as well as relevant educations, trainings, researches, and establishment of codes, frameworks, and acts.

In the post-disaster phase, the construction industry needs to mobilize easily and quickly to carry out the damage assessment, removal and disposal of waste, repair and rehabilitation of infrastructure (Wilkinson, 2013; Wilkinson, et al., 2016), to provide emergency sheltering, temporary sheltering and temporary housing (Quarantelli, 1995; Haigh and Amaratunga, 2010) as well as to restore public services (Lizarralde and Boucher, 2004; Young, 2004; Jigyasu, 2002; Jigyasu, 2004; Haigh and Amaratunga, 2010) and to enable reconstruction (Sapeciay, et al., 2017). Disaster recovery requires disaster restoration and reconstruction of the built environment as appropriate (Baroudi and Rapp, 2016). As reconstruction is a dynamic process containing uncertainties (Wilkinson, et al., 2016), the construction industry professionals need to contribute to the solution of the potential conflicts which can emerge among the stakeholders in the reconstruction phase (Auf De Heide, 1989; Wilkinson, 2013; Wilkinson, et al., 2016). In the post disaster phase, waste generated in the post disaster phase endangers human health and can cause environmental degradation (Brown et al. 2011; EPA, 2008; FEMA, 2007; JEU, 2010; Kourmpanis et al. 2008; Karunasena and Amaratunga, 2016). For this reason, in the post-disaster phase, construction companies need to carry out efficient and effective construction and demolition waste management which requires waste generated due to disasters, demolitions and reconstruction to be collected, transported, processed and disposed (Karunasena et al., 2009; Karunasena, 2011; Karunasena and Amaratunga, 2016).

Both in the pre-disaster and post-disaster phases construction companies rely on the disaster resilience of their supply chains (SCs). As SC's resilience is important for the smooth flow of the works in the post-disaster phase, construction SC's resilience can enhance the resilience of the construction industry and the recovery period in the post-disaster phase. SC's resilience is related with the SC's capability in regaining its original configuration just after disasters with the help of collaboration among SC members (Boin et al., 2010; Sheffi and Rice, 2005; World Economic Forum, 2015; Ivanov et al., 2014; Papadopoulos, et al., 2017). SC's resilience is influenced by global competition and disasters. Upstream SC operations are influenced by *"the global price-based sourcing trends forcing organizations to purchase from cheaper but "less reliable" and "less sustainable" suppliers"* (Fahimnia and Jabbarzadeh, 2016). SCs can lose their resilience due to disruptions caused by disasters (Eskew, 2004; Tang, 2006; Chen, et al., 2015). Environmental risk can result in unavailability of suppliers in a region where disaster occurred. As suppliers are interdependent, a disruption in one supplier may disrupt other suppliers (Kamalahmadi and Parast, 2017). For this reason, as the risk of a company is not limited to its boundary anymore, the scope of risk management has been extended from the enterprise level to the SC level (Zeng and Yen, 2017). Chen et al. (2015) gave the 2011 flooding in Thailand, and eruption of an Icelandic volcano in 2010 as examples for SC disruptions and their adverse impacts in the post-disaster phase. In 2011 flooding in Thailand disrupted the computer manufacturers' SCs (BBC, 2011) whereas eruption of an Icelandic volcano in 2010 affected SCs dependent on air-freighted trade (Chen et al., 2015).

Enhancing resilience of the construction industry

New technologies can be used to enhance disaster resilience performance of the construction industry. BIM has started to be used to support construction project management. BIM became compulsory for applying to the tenders in various countries (e.g. UK). *"BIM refers to a combination or a set of technologies and organizational solutions that are expected to increase interorganizational and disciplinary collaboration in the construction industry and to improve the productivity and quality of the design, construction, and maintenance of buildings"* (Miettinen and Paavola, 2014). In other words, *"BIM is an ICT 'hub' to facilitate integration of information pertaining to a building throughout its lifecycle, in form of parametric nD data -whether geometrical or tabular, generated by an array of stakeholders into one centralised, real-time and interactive environment through collaborative working processes"* (Farr, et al., 2014). BIM can be beneficial in all project phases including refurbishment, facilities management, and demolition (Chong, et al., 2017: 4114; Liu, et al., 2015). BIM can support construction project management with respect to the various aspects including: cost planning and estimating (Yoon, et al., 2009); tracking and managing changes, and managing site logistics (Pooyan, et al., 2009; Chen and Luo, 2014); clash detection (Hardin, 2009), visualisation and simulation (Eastman et al., 2008), planning and maintaining building projects (Wang, et al., 2015). Furthermore, it can contribute to the analysis, coordination and communication for collaborative working, lifecycle information assessment and management, and sustainable design across project lifecycle stages (Liu, et al., 2015). BIM can contribute to the disaster resilience of the construction industry both in the pre- and post-disaster phases (Tab. 1).

In the pre-disaster phase, BIM can enhance the resilience of the constructions starting from the design phase. It can support resilience of the construction phase and of the SCs. In the design phase, BIM can enhance technical resilience of the constructions enabling simulations on their structural performance and resilience (Alirezaei, et al., 2016: 1058; Barazzetti et al., 2015). BIM can be used for estimation of damages to the building, assessment of the damage cost and environmental impacts of a damaged building due to earthquake (Alirezaei et al. 2016). Structural simulation of the historic buildings can be carried out via the two-step methodology (from Cloud to BIM from BIM to finite element model) developed by Barazzetti et al. (2015). In the design phase, BIM can support waste management in the post-disaster phase contributing to the recovery phase. BIM can support effective waste management with the help of deconstructability analysis (Akinade, et al., 2015) which can facilitate post-disaster waste management process. BIM based Deconstructability Assessment Score can be used for determining the extent to which a building could be deconstructed starting from the design stage (Akinade, et al., 2015). Furthermore, BIM can enable cost effective assessment of different design options to reduce construction waste (Lu et al., 2017; Liu et al., 2011; Liu, et al., 2015). Both in the design and construction phases, BIM can enhance the risk of accidents (man-made hazards). In the pre-disaster phase, BIM can contribute to the minimization of the occupational health and safety risks as well as to the improvement of the occupational health and safety performance (Zhang et al., 2015). For example, Zhang et al. (2015) invented an automated rule-checking framework that integrates safety into BIM enabling detection and prevention of fall-related hazards.

Tab. 1 BIM's role in the pre-disaster and post-disaster phases

Phases		
Pre-disaster phase		
	Design phase	Enabling of assessment of design options to reduce waste (Lu et al, 2017)
		Facilitating the design team's involvement far sooner in the process, and with more impact, thus designing out environmental inefficiencies (Alwan, et al., 2017)
		Minimising construction waste in their design projects (Liu et al., 2011; Liu, et al., 2015)
		Enabling deconstruct ability analysis (Akinade, et al., 2015)
		Enabling simulations on structural performance and resilience of the constructions (e.g. estimation of potential damages) (Alirezaei, et al., 2016; Barazzetti et al., 2015)
	Both design and construction phases	Enhancing occupational health and safety performance (Zhang et al., 2015)
	Construction phase	Improving the work-flow and enhancing the lean performance (Sacks et al., 2010)
		Enhancing SC's resilience
Post-disaster phase	Evacuation and rescue phase	Enabling rapid evacuation (Yenumula, et al., 2015; Tashakkori, et al., 2015)
		Assessing evacuees behaviour in the evacuation phase (Rüppel and Schatz, 2011)
		Controlling the evacuation regulation compliance of BIM data (Choi et al., 2014)
		Providing accurate information contributing to the building disaster management (Dakhil and Alshawi, 2014)
		Guiding the evacuees to the right and nearest exit (Yenumula, et al., 2015; Rüppel et al. 2010; Wang et al., 2015)
		Reducing indoor travel times in case of indoor disasters (Tashakkori, et al., 2015)
		Enhancing fire safety management (Wang et al., 2015)
	Recovery and reconstruction phases	Enhancing quality management and adaptation of the construction process to the change orders through 4D BIM (Chen and Luo, 2014)
		Enhancing SC's resilience

In the post-disaster phase, BIM can enhance the evacuation, recovery and reconstruction processes as well as SC's resilience enabling smooth and successful workflow. The built environment which has been built with BIM can enhance post-disaster phase and contribute to the recovery of the built environment and of the community (Haigh and Amaratunga, 2010).In the evacuation and rescue phases, BIM can enable rapid evacuation (Yenumula, et al., 2015; Tashakkori, et al., 2015) guiding the evacuees to the nearest exit (Yenumula, et al., 2015; Rüppel et al. 2010; Wang et al., 2015) and reducing indoor travel times (Tashakkori, et al., 2015). Yenumula, et al. (2015) developed a BIM-controlled signage system where the fire sensor detection module has been linked to a building's fire sensors to the BIM model so that occupants are lead to the exit and evacuated rapidly (Yenumula, et al., 2015). Similarly, Rüppel et al. (2010) designed a system integrated with BIM to help emergency rescuers find the shortest way to a location within a building (Wang, et al., 2015). Tashakkori, et al. (2015) developed an Indoor Emergency Spatial Model based on IFC to reduce indoor travel times in case of indoor disasters. Furthermore, BIM can contribute to the assessment of the evacuees' behaviour in the evacuation phase (Rüppel and Schatz, 2011). BIM can support control of the evacuation regulation compliance of BIM data (Choi et al., 2014). BIM can contribute to the fire safety management in the post-disaster phase. Wang, et al. (2015) designed a BIM-based model consisting of four modules (evacuation assessment, escape route planning, safety education, and equipment maintenance) to support fire safety management of buildings (Wang, et al., 2015). Li et al. (2014), on the other hand, introduced a BIM based algorithm to locate first rescuers and people to be evacuated in buildings in evacuation operations in case of fire disasters (Wang, et al., 2015). Furthermore, BIM can contribute to search and rescue efforts (Isikdag et al., 2008; Aziz et al., 2009).

BIM can support construction companies in dealing with the volatile and increased workload in the post-disaster phase. BIM can contribute to the construction process enhancing the quality and resilience of the construction. It can enhance quality management and adaptation of the construction process to the change orders through 4D BIM and presenting multi-dimensional data (e.g. design and time sequence data, etc.) (Chen and Luo, 2014). Furthermore, 'KanBIM', "a BIM-enabled pull flow construction management software system based on the Last Planner System™", can improve the work-flow and enhance the lean performance visualizing the product and work flow (Sacks et al., 2010). Similarly, construction process in the recovery phase can be enhanced by the "Construction site information model" (CoSIM) (Trani et al., 2015).

BIM can support resilience of the SC which is needed both in the pre-disaster and post-disaster phases. SC resilience is important for the effective emergency logistics so that the disaster affected areas receive relief services on time and as fast as possible in the post-disaster phase (Jia and Zhu, 2012). SC resilience can be enhanced through integrated logistics capabilities contributing to the unification and increased connectivity among the SC members, and inter-related SC capabilities (Jüttner and Maklan, 2011) including (Mandal, et al., 2016): the SC's visibility (the degree to which SC partners have access to both operational and managerial information related to the SC) (Barratt and Oke, 2007; Wei and Wang, 2010); SC flexibility (readiness of a SC with regard to alternate courses of actions through flexibility in resource planning); and SC velocity (speed to react to market changes) (Richey, 2009). Especially, SC flexibility and SC velocity are necessary for resilience (Mandal, et al., 2016). As SC partnerships can influence the integration of SC risk system, and the operations in SCs, the level of collaboration among SC partners contributes to the resilience of SCs (Zeng and Yen, 2017). Afshar and Haghani (2012) emphasised the importance of integrated logistics operations in response to natural disasters. As Lee (2004) highlights, a successful SC recovery strategy must comply with agility, adaptability, and alignment (Chen, et al., 2015). BIM can enable the SC to deal with the difficulties and challenges in the pre-disaster and post-disaster phases. BIM can support the resilience of the construction SC enabling real time information sharing throughout the construction SC (Shi, et al., 2016). BIM can enable tracking the SC status and delivery of materials through its integration with geographic information system (Irizarry, et al., 2013). Furthermore, BIM, supported by the augmented reality, can contribute to the real-time visualisation of the physical context of each construction activity and task (Wang, et al., 2013). BIM can enhance resilience of the SC contributing to the visibility, velocity, collaboration, and logistics of the SC.

Discussion

Frequencies and magnitudes of the natural disasters tend to increase especially due to the global warming. Natural disasters and man-made disasters (e.g. wars, accidents) endanger resilience and survival of the humanity. For this reason, taking effective precautions and actions to enhance resilience of the humanity to the disasters is important and requires international collaboration. As construction industry plays an important role in reducing adverse impacts of the disasters and in rapidly recovery in the post-disaster phase, enhancing resilience of the construction industry can contribute to the resilience of the humanity. Construction industry's resilience depends on various factors including the resilience of the built environment, construction project management, and of the SC.

New technologies such as BIM can be beneficial for the construction industry's resilience both in the pre-disaster and post-disaster phases. In the pre-disaster phase, BIM can enhance the resilience of the built environment, the design and construction phases as well as of the SCs (Tab. 1). BIM can support waste management enabling reduction in waste through deconstructability analysis (Akinade, et al., 2015), and cost effective assessment of different design options (Lu et al., 2017). Furthermore, BIM can support technical resilience of the constructions through structural simulations (Alirezaei, et al., 2016; Barazzetti et al., 2015). BIM can also contribute to the occupational health and safety performance (Zhang et al., 2015) reducing man-made hazards (e.g. accident). In the post-disaster phase, BIM can enhance evacuation and recovery processes including reconstruction as well as SC's resilience. BIM can enable rapid evacuation (Yenumula, et al., 2015; Tashakkori, et al., 2015) guiding the evacuees to the nearest exit (Yenumula, et al., 2015; Rüppel et al. 2010; Wang et al., 2015) and assessing evacuees' behaviour (Rüppel and Schatz, 2011). BIM can support the design team enabling them to control BIM data's compliance with the evacuation regulation (Choi et al., 2014). Furthermore, BIM can support construction companies to manage the increased workload due to the need for rapid reconstruction in the post-disaster phase. BIM can contribute to the quality management and change management (Chen and Luo, 2014) as well as to the lean performance of the construction process (Sacks et al., 2010). BIM can support the recovery and reconstruction phases enhancing SC's resilience as well as enabling fast recovery of the community and reconstruction of the built environment. For this reason, transformation of the construction project management process into a BIM based one and extending its scope to include facilities management are important for enhancing disaster resilience of the construction industry in the pre-disaster and post-disaster phases.

Even if BIM can enhance resilience of the construction industry, construction companies need to be aware of the fact that resilience needs to be integrated to the culture and work practices. Policies need to encourage multidisciplinary, interinstitutional (e.g. professional bodies, construction companies, public entities, universities etc.), and international collaboration as well as relevant educations, trainings, researches, and establishment of codes, frameworks, and acts. Built environment professionals need to be educated and trained so that they are equipped with all requirements of the disaster management. They need to be competent in BIM due to their role in establishment of the resilient built environment and community. Interdisciplinary and global collaboration in the field of education and research can support education and training on the disaster resilience. Disaster resilience concepts need to be integrated into the education of built environment professionals and stakeholders education (e.g. community; construction professionals; politicians, etc.). Requirements of the social, economic, political, managerial, legal, and technical aspects of the disaster resilience need to be integrated to the education and training of the built environment professionals. Resilient construction industry enhances resilience of the community. Establishment of the resilient built environment and communities is a multidisciplinary and multi stakeholder process which can be supported by interinstitutional and international collaboration. For this reason, governments, education, social and mass media as well as professional bodies need to contribute to the establishment of disaster resilient built environment and community in the pre- and post- disaster phases.

Conclusion

This paper investigated the usage of BIM in enhancing disaster resilience of the construction industry and in establishment of the resilient built environment. Need for disaster resilient built environment and community is increasing due to the increase in the frequency and magnitude of disasters. This paper emphasises that BIM can enhance resilience of the built environment, construction industry and of the SC in the pre-disaster phase (e.g. technical resilience) and post-disaster phase (e.g. evacuation, recovery and reconstruction process). It is important for the policy makers and stakeholders of the built environment to encourage BIM based construction for resilient built environment and construction industry. For this reason, BIM needs to be integrated to the education and training curriculums of built environment professionals so that the resilience of the construction industry can be enhanced. Built environment professionals play important roles with respect to the managerial, and technical aspects of the pre-disaster (e.g. establishing the resilient built environment) and post-disaster phases. Resilient construction industry, resilient built environment and community need to be considered together as they influence each other. Further research is recommended to be carried out on the ways for widespreading the usage of BIM for enhancing the disaster resilience as well as on the barriers against its usage as a tool for addressing many disaster resilience problems. Policy makers, construction professionals, professional bodies, and academics can get benefit from this research.

References

Afshar, A.; Haghani, A. 2012. Modeling integrated supply chain logistics in real-time large-scale disaster relief operations. *Socio-Economic Planning Sciences*, 46: 327-338.

Akinade, O.O., Oyedele, L.O., Bilal, M., Ajayi, S.O., Owolabi, H.A., Alaka, H.A., Bello, S.A. 2015. Waste minimisation through deconstruction: A BIM based Deconstructability Assessment Score (BIM-DAS). *Resources, Conservation and Recycling*, 105: 167-176.

Alirezaei, M., Noori, M., Tatari, O., Mackie, K.R., Elgamal, A. 2016. BIM-Based Damage Estimation of Buildings under Earthquake Loading Condition. International Conference on Sustainable Design, Engineering and Construction, *Procedia Engineering*, 145: 1051-1058.

Alwan, Z., Jones, P., Holgate, P. 2017. Strategic sustainable development in the UK construction industry, through the framework for strategic sustainable development, using Building Information Modelling. *Journal of Cleaner Production*, 140: 349-358.

Auf De Heide, E. 1989. Disaster Response: Principles and Preparation and Coordination, The Mosby Company, StLoius, MO.

Aziz, Z., Pena-Mora, F., Chen, A., Lantz, T. 2009. Supporting urban emergency response and recovery using RFID-based building assessment, *Disaster Prevention and Management*, 18(1): 35-48.

Barazzetti, L., Banfi, F., Brumana, R., Gusmeroli, G., Previtali, M., Schiantarelli, G. 2015. Cloud-to-BIM-to-FEM: Structural simulation with accurate historic BIM from laser scans. *Simulation Modelling Practice and Theory*, 57: 71-87.

Baroudi, B., Rapp, R. 2016. Disaster restoration project management: leadership education and methods. *International Journal of Disaster Resilience in the Built Environment*, 7(5): 434-443.

Barratt, M., Oke, A. 2007. Antecedents of supply chain visibility in retail supply chains: a resource-based theory perspective. *Journal of Operations Management*, 25(6): 1217-1233.

BBC, Oct 13, 2011. Thailand Floods Disrupt Production and Supply Chains. <http://www.bbc.co.uk/news/business-15285149> (20.10.14).

Boin, A., Kelle, P., Whybark, D.C. 2010. Resilient supply chains for extreme situations: outlining a new field of study. *International Journal of Production Economics*, 126(1): 1-6.

Bosher, L., Dainty, A., Carrillo, P., Glass, J., Price, A. 2008. Attaining improved resilience to floods: a proactive multi-stakeholder approach, *Disaster Prevention and Management*, 18(1): 9-22.

Brown, C., Mike, M., Seville, E. 2011. Disaster waste management: a review article, *Waste Management*, 31(1): 1085-1098.

Burnside, J., Carvalho, L.L. 2016. A stakeholder approach to building community resilience: awareness to implementation. *International Journal of Disaster Resilience in the Built Environment*, 7(1): 4-25.

Chen, L.M., Liu, Y.E., Yang, S.J.S. 2015. Robust supply chain strategies for recovering from unanticipated disasters. *Transportation Research Part E*, 77: 198-214.

Chen, L., Luo, H. 2014. A BIM-based construction quality management model and its applications. *Automation in Construction*, 46: 64-73.

Choi, J., Choi, J., Kim, I. 2014. Development of BIM-based evacuation regulation checking system for high-rise and complex buildings. *Automation in Construction*, 46: 38-49.

Chong, H.Y., Lee, C.Y., Wang, X. 2017. A mixed review of the adoption of Building Information Modelling (BIM) for sustainability. *Journal of Cleaner Production*, 142: 4114-4126.

Dakhil, A., Alshawi, M. 2014. Client's Role in Building Disaster Management through Building Information Modelling. 4th International Conference on Building Resilience, Building Resilience 2014, 8-10 September 2014, Salford Quays, United Kingdom. *Procedia Economics and Finance*, 18: 47-54.

DFID (2011). *Defining Disaster Resilience: A DFID Approach Paper*. DFID.

Eastman, C., Teicholz, P., Sacks, R., Liston, K. 2008. *BIM Handbook: A Guide to Building Information Modeling for Owners, managers, designers, engineers, and contractors*, John Wiley & Sons, Inc., Canada.

Eskew, M. 2004. Mitigating Supply Chain Risk. CEO, April 25-26.

Fahimnia, B., Jabbarzadeh, A. 2016. Marrying supply chain sustainability and resilience: A match made in heaven. *Transportation Research Part E*, 91: 306-324.

Farr, E.R.P., Piroozfar, P.A.E., Robinson, D. 2014. BIM as a generic configurator for facilitation of customisation in the AEC industry. *Automation in Construction*, 45: 119-125.

GSDRC website Disaster resilience http://www.gsdrc.org/topic-guides/disaster-resilience/concepts/what-is-disaster-resilience/.

Gunes, A. E., Kovel, J. P. 2000. Using GIS in emergency management operations. *Journal of Urban Planning and Development*, 126: 136-149.

Haigh, R., Amaratunga, D., Keraminiyage, K. 2006. An exploration of the construction industry's role in disaster preparedness, response and recovery, *Proceedings of the Annual International Research Conference of the Royal Institution of Chartered Surveyors (RICS COBRA 2006)*, The RICS and The Bartlett School, University College London, London.

Haigh, R., Amaratunga, D. 2010. An integrative review of the built environment discipline's role in the development of society's resilience to disasters. *International Journal of Disaster Resilience in the Built Environment*, 1(1): 11-24.

Hardin, B. 2009. *BIM and construction management: proven tools, methods, and workflows.* 1st edition Wiley Publish, Inc., Canada.

International Federation of Red Cross and Red Crescent Societies http://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/definition-of-hazard/.

Irizarry, J., P. Karan, E.P., Jalaei, F. 2013. Integrating BIM and GIS to improve the visual monitoring of construction supply chain management. *Automation in Construction*, 31: 241-254.

Isikdag, U., Underwood, J., Aouad, G. 2008. An investigation into the applicability of building information models in geospatial environment in support of site selection and fire response management processes, *Advanced Engineering Informatics*, 22(4): l504-l519.

Ivanov, D. Sokolov, B., Dolgui, A. 2014. The Ripple effect in supply chains: trade-off 'efficiency-flexibility-resilience' in disruption management. *International Journal of Production Research*, 52(7): 2154-2172.

Jia, G., Zhu, C. 2012. A Study on Emergency Supply Chain and Risk Based on Urgent Relief Service in Disasters. *Systems Engineering Procedia*, 5: 313-325.

Jigyasu, R. 2002. From Marathwada to Gujarat - emerging challenges in post-earthquake rehabilitation for sustainable eco-development in South Asia. *Proceedings of the First International Conference on Post-disaster Reconstruction: Improving Post-disaster Reconstruction in Developing Countries*, 23-25 May, Universite de Montreal, Montreal, Canada.

Jigyasu, R. 2004. Sustainable post-disaster reconstruction through integrated risk management. *Proceedings of the Second International Conference on Post-disaster Reconstruction*, Coventry University, Coventry, UK.

Joint UNEP/OCHA Environment Unit (JEU) 2010. Disaster Waste Management Guidelines, Joint UNEP/OCHA Environment Unit, Geneva.

Jüttner, U., Maklan, S. 2011. Supply chain resilience in the global financial crisis: an empirical study. *Supply Chain Management: An International Journal*, 16(4), 246-259.

Kamalahmadi, M., Parast, M.M. 2017. An assessment of supply chain disruption mitigation strategies. *International Journal of Production Economics*, 184: 210-230.

Karunasena, G. 2011. Chapter 14: sustainable post-disaster waste management: C&D waste. in Amaratunga, D. and Haigh, R. (Eds), *Post Disaster Reconstruction of the Built Environment: Rebuilding and Resilience*, Wiley-Blackwell, Oxford, 251-267.

Karunasena, G., Amaratunga, D., Haigh, R., Lill, I. (2009). Post disaster waste management strategies in developing countries: case of Sri Lanka. *International Journal of Strategic Property Management*, 13(2): 171-190.

Karunasena, G., Amaratunga, D. 2016. Capacity building for post disaster construction and demolition waste management A case of Sri Lanka. *Disaster Prevention and Management*, 25(2): 137-153.

Kourmpanis, B., Papadopoulos, A., Moustakas, K., Stylianou, M., Haralambous, K.J., Lolijodou, M. 2008. Preliminary study for the management of C&D waste. *Waste Management & Research*, 26(3): 267-275.

Lee, H. 2004. The triple-A supply chain. *Harvard Bus. Rev.*, 102-112 October.

Lefei L, Shuming T. 2008. An artificial emergency logistics planning system for severe disasters. *Intelligent Transportation Systems*, (7): 8689.

Li, N., Becerik-Gerber, B., Krishnamachari, B., Soibelman, L. 2014. A BIM centered indoor localization algorithm to support building fire emergency response operations. *Automation in Construction*, 42: 78-89.

Lill, I., Perera, P. 2017. Economic impact of disasters and the role of disaster resilience. *International Journal of Disaster Resilience in the Built Environment*, 8 (1).

Liu, Z., Osmani, M., Demian, P., Baldwin, A. 2015. A BIM-aided construction waste minimisation framework. *Automation in Construction*, 59: 1-23.

Liu, Z., Osmani, M., Demian, P., Baldwin, A. 2011. The potential usage of BIM to aid construction waste minimalisation. *Proceedings of the CIB W78-W102 2011: International Conference*, 26th-28th October 2011, Sophia Antipolis, France, paper 53.

Liu, Y., Yin, K., Chen, L., Wang, W., Liu, Y. 2016. A community-based disaster risk reduction system in Wanzhou, China. *International Journal of Disaster Risk Reduction*, 19: 379-389.

Lizarralde, G., Boucher, M. 2004. Learning from post-disaster reconstruction for pre-disaster planning. *Proceedings of the Second International Conference on Post-disaster Reconstruction: Planning for Reconstruction*, 22-23 April, Coventry University, Coventry, UK.

Lu, N., Thomas, K. 2010. Implementation of building information modeling (BIM) in modular construction: benefits and challenges, construction research congress 2010: innovation for reshaping construction practice, *Proceedings of the 2010 Construction Research Congress*, 1136-1145.

Lu, W., Webster, C., Chen, K., Zhang, X., Chen, X. 2017. Computational Building Information Modelling for construction waste management: Moving from rhetoric to reality. *Renewable and Sustainable Energy Reviews*, 68: 587-595.

Mandal, S., Sarathy, R., Korasiga, V.R., Bhattacharya, S., Dastidar, S.G. 2016. Achieving supply chain resilience The contribution of logistics and supply chain capabilities. *International Journal of Disaster Resilience in the Built Environment*, 7(5): 544 - 562.

Miettinen, R., Paavola, S. 2014. Beyond the BIM utopia: Approaches to the development and implementation of building information modeling. *Automation in Construction*, 43: 84-91.

Mileti, D. 1999. *Disasters by Design: A Reassessment of Natural Hazards in the United States*. Joseph Henry Press, Washington, DC.

Papadopoulos, T., Gunasekaran, A., Dubey, R, Altay, N., Childe, S.J., Fosso-Wamba, S. 2017. The role of Big Data in explaining disaster resilience in supply chains for sustainability. *Journal of Cleaner Production*, 142: 1108-1118.

Pooyan, A., Griffis, F.H., Lawrence, C. 2009. Building information model: the role and need of the constructors, Building a Sustainable Future. *Proceedings of the 2009 Construction Research Congress*, 467-476.

Quarantelli, E.L. 1995. What is a disaster? *International Journal of Mass Emergencies and Disasters*, 13(3): 221-9.

Quarantelli, D.R. 2008. *A brief note on disaster restoration. Reconstruction And Recovery: A Comparative Note Using Postearthquake Observations*, University of Delaware Disaster ResearchCenterPreliminaryPaper#359, Delwar.

Richey, R.G. 2009. The supply chain crisis and disaster pyramid. *International Journal of Physical Distribution and Logistics Management*, 39(7), 619-628.

Rüppel, U., Schatz, K. 2011. Designing a BIM-based serious game for fire safety evacuation simulations. *Advanced Engineering Informatics*, 25, 600-611.

Rüppel, U., Stube, K.M., Zwinger, U. 2010. Indoor navigation integration platform for firefighting purposes. *Proceedings of the 2010 International Conference on Indoor Positioning and Indoor Navigation (IPIN, 2010)*, 15-17 September, Zürich, Switzerland, 2010.

Sacks, R., Radosavljevic, M., Barak, R. 2010. Requirements for building information modeling based lean production management systems for construction. *Automation in Construction*, 19: 641-655.

Sapeciay, Z., Wilkinson, S., Costello, S.B. 2017. Building organisational resilience for the construction industry: New Zealand practitioners' perspective. *International Journal of Disaster Resilience in the Built Environment*, 8 (1).

Shadram, F., Johansson, T.D., Lu, W., Schade, J., Olofsson, T. 2016. An integrated BIM-based framework for minimizing embodied energy during building design. *Energy and Buildings*, 128: 592-604.

Sheffi, Y., Rice, Jr., J.B. 2005. A supply chain view of the resilient enterprise. *Sloan Management Review*, 47(1): 41-48.

Shi, Q, Ding, X., Zuo, J., Zillante, G. 2016. Mobile Internet based construction supply chain management: A critical review. *Automation in Construction*, 72: 143-154.

Tashakkori, H., Rajabifard, A., Kalantari, M. 2015. A new 3D indoor/outdoor spatial model for indoor emergency response facilitation. *Building and Environment*, 89: 170-182.

Tang, C.S. 2006. Robust strategies for mitigating supply chain disruptions. *International Journal of Logistics: Research and Applications*, 9 (1): 33-45.

Trani, M.L., Cassano, M., Todaro, D., Bossi, B. 2015. BIM level of detail for construction site design. Creative Construction Conference 2015 (CCC2015). *Procedia Engineering*, 123: 581-589.

UNISDR (2005b). *Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters*. World Conference on Disaster Reduction. 18-22 January 2005, Kobe, Hyogo, Japan. A/CONF.206/6. UNISDR.

UNISDR (2005). *Hyogo Framework for Action 2005-2015: Building the resilience of nations and communities to disasters*. United Nations Office for Disaster Risk Reduction (UNISDR).

UNISDR (2015). *Sendai Framework for Disaster Risk Reduction 2015-2030*. United Nations Office for Disaster Risk Reduction (UNISDR).

Wang, X., Love, P.E.D., Kim, M.J., Park, C., Sing, C.P., Hou, L. 2013. A conceptual framework for integrating building information modeling with augmented reality. *Automation in Construction*, 34: 37-44.

Wang, S.H., Wang, W.C., Wang, K.C., Shih, S.Y. 2015. Applying building information modeling to support fire safety management. *Automation in Construction*, 59: 158-167.

Wei, H.L., Wang, E.T. 2010. The strategic value of supply chain visibility: increasing the ability to reconfigure. *European Journal of Information Systems*, 19(2): 238-249.

Wilkinson, S. 2013. Reconstruction Stages, Build, November Issue, BRANZ.

Wilkinson, S., Chang-Richards, A.Y., Sapeciay, Z., Costello, S.B. 2016. Improving construction sector resilience. *International Journal of Disaster Resilience in the Built Environment*, 7 (2): 173-185.

World Economic Forum 2015. Building Resilience in Nepal through –report Public-private-partnerships. http://www3.weforum.org/docs/GAC15_Building_Resilience_in_Nepal_report_1510.pdf

Yenumula, K., Kolmer, C., Pan, J., Su X. 2015. BIM-Controlled Signage System for Building Evacuation. International Conference on Sustainable Design, Engineering and Construction. *Procedia Engineering*, 118: 284-289.

Yoon, S., Park, N., Choi, J. 2009. A BIM-based design method for energy-efficient building, *Proceedings of the 2009 Fifth International Joint Conference*, 376-381.

Young, I. 2004. Monserrat: post volcano reconstruction and rehabiliation - a case study. *Proceedings of the Second International Conference on Post-disaster Reconstruction: Planning for Reconstruction*, 22-23 April, Coventry University, Coventry, UK.

Zeng, B., Yen, B.C. 2017. Rethinking the role of partnerships in global supply chains: A risk-based perspective. *International Journal of Production Economics*, 185: 52-62.

Zhang, S., Sulankivi, K., Kiviniemi, M., Romo, I., Eastman, C.M., Teizer, J. 2015. BIM-based fall hazard identification and prevention in construction safety planning. *Safety Science*, 72: 31-45.