Rethinking Off-Site Manufacturing for Disaster Resilience

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1. Introduction

The world today is continuing to witness many recurring natural hazard-induced disasters, the magnitude and impact of which have increased tremendously (Guha-Sapir *et al.*, 2013; Ferris *et al.*, 2013; Opdyke, 2018). In addition, increasing global temperature and rising sea level are continuing to cause unprecedented challenges for many countries. In this respect, the United Nations quotes that even if countries achieve their most ambitious climate promises, they will still not be able to reduce temperature rises. Given these challenges, this indicates the possibility of increased occurrences of tropical cyclones and heavy rainfall. Whilst these issues alone are palpable and significant, Bournay, (2007) acknowledged that population growth and infrastructure development contributed to increasing the world's exposure to these natural hazards. This increase in natural hazard-induced disaster occurrence has drawn the attention of policy makers, governments and many organisations to focus more on the enhancement of society's capacity to withstand disasters (Altay and Green, 2006).

Off-site manufacturing (OSM) is seen as part of a broader spectrum of innovative contemporary techniques that seeks performance improvement in the construction industry. Moreover, there is a growing trend in the adoption and uptake of OSM worldwide. Whilst there are several reasons for this, this chapter focuses exclusively on the challenges of disaster management in relation to offsite manufacturing practices. In this regard, OSM has the potential to enhance disaster management capabilities and reduce damage to both human and material resources. However, in order to operationalise this, there is an exigent need to re-evaluate current disaster management practices contextually, so that they align and support OSM practice. The reciprocal of this also applies.

This chapter contextually explores OSM principles with disaster management practice. In doing so, it aims to challenge current thinking (given the fragmented nature of disaster management *per se*), in order to encourage the uptake and adoption of blended OSM solutions. The rationale here is to showcase how these solutions can be developed, nurtured personalised to meet country-specific contexts (and concomitant challenges). This work forms part of a wider study in this area, to understand the fundamentals of disaster management and OSM. A conceptual framework is presented for discussion. This engages the doctrines of OSM and disaster management through three governing principles.

2. Off-Site Manufacturing

Off-site has been defined in many different ways. Ostensibly, it includes the manufacture and pre-assembly of components, elements or modules before installation into their final location. The process is often referred to using a plethora of terms, including: offsite production (OSP), off-site fabrication (OSF), off-site manufacturing (OSM), off-site construction (OSC), pre-assembly and prefabrication. Other authors have proffered further terms such as manufactured construction, Industrialised Building Systems (which encompass the concept of off-site), and ‘pre-fabricated construction’ (Taylor, 2010; Goulding *et al.*, 2015). From a United Kingdom (UK) perspective, the UK Parliament Select Committee defined off-site manufacturing as “bringing together a range of construction processes, components, elements or modules in a factory before installation into their final location” (Select Committee on Science and Technology, 2018). In essence, off-site construction seeks to make all or some of the construction works of a construction project a ‘manufacturing’ process, as opposed to the traditional way of building ‘in-situ’ on site. Notwithstanding these different definitions and terminologies, in order to avoid confusion, this chapter follows the definition of OSM, where this is used to denote a situation where the majority of a building is manufactured and pre-assembled elsewhere before being erected on site.

Whilst the use of OSM has increased over the years, it has fallen short of the levels expected, especially considering its broad benefits; and its promise of revolutionising the industry using ‘manufacturing principles’ to remove inefficient, wasteful and unproductive processes and deliver enhanced value. In this respect, part of the UK parliament’s Select Committee on Science and Technology in 2018 was to understand OSM uptake by considering the potential benefits for construction, including any drawbacks or obstacles to its wider use. Moreover, how government policy could encourage economically and environmentally sustainable practice in the construction industry (to facilitate OSM). The fundamental rationale behind the review was that OSM could be used to deliver construction productivity improvements; given that the industry has long been criticised for poor productivity (especially when benchmarked against other industry sectors). Similar reviews such as this have also been undertaken in various countries - from Malaysia, through to Japan, the United States (US) and Australia.

A typical exemplar of OSM benefits includes that proffered by Galante *et al.* (2017), where this work reviewed how OSM could enhance affordability of housing, including the potential benefits and challenges regarding its implementation. These discussions are summarised in the Table 1. However, it is important to also reflect on these issues cognisant of the impact of time, cost and quality. This is particularly important as this review highlighted further benefits such as reduced disruption to surrounding community/neighbours and increased accessibility to employment opportunities. Moreover, this review further highlights how OSM has struggled to take off within the predominant mainstream traditional construction environment, as manufacturers have either had to cease their operations or still struggle to maintain viability. This is not new. In fact, this (and several other issues) have been acknowledged in extant literature as being inhibitors to uptake (Goulding and Arif, 2013). Notwithstanding this, Galante *et al.* (2017) also highlighted technical challenges associated with OSM implementation, which included the wider remit associated with financing and business models. Given this, it seems that there is a real need to understand OSM business models in much more detail. This is important as viable business models (driven by steady flow of development projects and business output) are considered key requirements for OSM uptake in construction. Ostensibly, creating greater demand for OSM output is a necessity. This not only helps foster commitment, but by default, then provides evidential chains needed for investment and innovation – particularly by manufacturers. However, in a context where the cost of construction continues to rise, the affordability and availability of OSM presents significant advantages, but only if this is approached with strategic purpose.

Table 1: Benefits and Challenges of OSM in Construction (Adapted from Galante *et al.*, 2017)

<table>
<tr><th>Benefits of OSM in Construction</th><th>Implementation Challenges of OSM in Construction</th></tr>
<tr><td>Cost Savings
• Labour-related cost savings (due to production efficiencies, reduced reliance on outside weather, use of machinery and automation, reduced requirements of high-skilled labour etc.);
• Economies of scale (due to standardised processes, consistency and higher volumes);
• Procurement savings (ability to reduce / eliminate costs associated with sub-contractors).</td><td>Technical Challenges Relating to Material/Design
• Less flexibility in timing and possible alterations to unit deign;
• Requirement to include additional materials to protect modules in transit and on site;
• Lack of expertise in module installation;
• Weather damage due to lack of proper protection.</td></tr>
<tr><td>Time Savings
• Ability to undertake work simultaneously rather than sequentially – leading to 40%-50% time savings.</td><td>Technical Challenges due to Regulations
• Challenges in transportation, installation and inspection;
• Lack of regulation to ensure compliance at a logical point in the production process.</td></tr>
<tr><td>Further Cost Savings due to Time Savings
• Reduced time leading to further cost savings (due to reduced preliminaries);
• Reduced time leading to reduced financing costs (due to faster return for equity and reduced interest on construction loans).</td><td>Technical Challenges due to Construction Site Conditions
• Characteristics of sites that make installation of modules challenging.</td></tr>
<tr><td>Benefits due to Construction Method
• Environmental and quality improvements due to the ability to leverage advanced technologies;
• Greater precision and reduced waste;
• Fostering innovations in design.</td><td rowspan="3">Challenges of OSM Financing and Business Models
• Financing and capitalisation of projects:
○ Upfront capital requirements
• Development pipeline and capacity:
○ Vulnerability of manufacturing facilities to down cycles (reduced demand);
○ Challenges of maintaining workforce during periods of reduced demand;
○ Limited capital availability reducing the capacity to satisfy / generate new business.</td></tr>
<tr><td>Labour-Related Benefits
• Safer and healthier working environment;
• Reduced volatility of employment due to inclement weather;
• Routine and predictable work schedules;
• Accessible employment opportunities.</td></tr>
<tr><td>Other
• Ability to provide affordable housing options (reduced prices / rent);
• Ability to achieve projects previously thought economically impractical;
• Less disruption to surrounding community and neighbours.</td></tr>
</table>

The uptake and adoption of Building Information Modelling (BIM) was significantly enhanced following the UK government's mandate of 'persuading' stakeholders to use Level 2 BIM by 2016. This approach was considered radical but highly successful. Given this, perhaps an approach of this nature might also help increase in the use and uptake of OSM? Historically, government intervention normally acts as a promotional catalyst, especially if supported by mandatory regulations or policy change. A good example here is the US and Malaysia. There are also many other issues that need to be considered. For example, Arif *et al.* (2012) highlighted the need of research to identify the pervading issues that limited the uptake of offsite practices; the corollary here was that in doing so, these could be better understood so that OSM could be promoted in a more reasoned and defendable way. This included paying due consideration to the existing societal, cultural, and current business models associated with conventional thinking and practice.

Reflecting back on the issue of disaster management and OSM, it seems that there are some interesting parallels to unpick. On one hand, it could be argued that any such increase in the general uptake of OSM practices in construction would (more than likely) create a positive impact on its subsequent use in disaster management – including construction work related to disaster preparedness, response and recovery. However, on the other hand, the 'pull' factor needs to be carefully established in order to support this in relation to disaster management. This is the main treatise, as a strong driver for offsite manufacturing is one which clearly aligns to the needs of disaster management (preparedness, response and recovery). This is the core argument of this chapter – which will be elaborated later. So, it is important to start to appreciate the context of disaster management and its inherent characteristics, constraints, and pressures associated with the process. For instance, Wedawatta *et al.* (2012) discussed the uniquely challenging nature of post-flood reinstatement work with the current practices of construction professionals involved. On this theme, Thurairajah *et al.* (2010) [should this be Thurairajah and Baldry (2010)] highlighted the specific need to develop communities that can cope with these challenges (during post disaster situations), by considering their views in order to improve disaster resilience. However, disaster resilience is complex and multi-layered. Moreover, it can be more uniquely challenging when endeavouring to align disaster resilience to OSM. That being said, there are several benefits of doing this. Despite the significant depth and breadth of research on the two distinct domains of disaster resilience and OSM in construction, there are opportunities to explore – particularly the OSM evidential chain and its alignment to disaster resilience. This chapter presents this arrangement through a new structured approach, one which more meaningfully embeds the context of disaster resilience through three entwined concepts.

3. Disaster Management

3.1 Introduction

The United Nations (2016) describes a disaster as 'a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the followings: human, material, economic and environmental losses and impacts'. Extant literature also seems to resonate with this definition, where disasters are mostly viewed as being an event or as a consequence of hazard and vulnerability. However, in order to maintain the records of disasters that have occurred in the past, certain institutions such as the Centre for Research on the Epidemiology of Disasters, United Nations International Strategy for Disaster Reduction (UNISDR) use different criteria to define a disaster. Other definitions also exist. For example, the Sendai Framework for Disaster Risk Reduction 2015-2030 views disasters under different categories, based on: the scale of disasters (small and large), the frequency of occurrence (frequent and infrequent) and speed of emergence (slow on-set and sudden on-set). However, many earlier studies have tended to categorise disasters into natural, man-made or hybrid disasters (Shaluf *et al.*, 2007). Given this, it is important to acknowledge from the outset that changes in the way disasters are categorised within the disaster management literature can sometimes affect perception.

While highlighting the causes of disasters, Shaluf *et al.* (2007) explained the interaction between 'Human, Organisational, and Technological' (HOT) factors and 'Regulatory, Infrastructural and Preparedness' (RIP) factors. Where the HOT factors were: operator and managerial errors; purposive acts such as terrorist attacks or war; policy failures; inadequate resource allocations for safety; communication failures, misperceptions of the extent and nature of hazards; inadequate emergency plans; cost pressures which curtail safety; faulty design; defective equipment etc. (Shaluf et al, 2007). The RIP factors included: hazardous technologies entering communities; weak physical and social infrastructure that determine a community's capacity to prevent and cope; inadequate essential services such as water, electricity, transportation, communication, etc. that allow hazardous conditions to exist within communities; inadequate on- and off-site emergency plans; lack of emergency medical capacity; and ill-prepared civil defence authorities.

Thus, it is important to acknowledge at this juncture that many factors need to be considered to determine the level of risk when contemplating disasters. On this theme, according to Ariyabandu and Wickramasinghe (2003), the level of risk on disasters is determined by the type of hazard and the calculation of the level of vulnerability (which is determined by social, physical and attitudinal variables). The United Nations Office for Disaster Risk Reduction (UNISDR, 2016) defines 'Hazard' as 'A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation'. Hazards can also include latent conditions that may represent future threats. Similarly, 'Vulnerability' was defined as 'the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards (UNISDR, 2016). In this respect, the degree of vulnerability of the affected population can also be used to document the magnitude of a disaster (Ariyabandu and Wickramasinghe, 2003).

In summary, literature has highlighted that although many countries have focused on reactive strategies to address disasters, the increased frequency of disasters now calls for a more focussed approach, using proactive strategies to tackle these disasters (Ramanuja, 2015). Hence, the management of disasters has migrated from a focus on post-disaster efforts, to one which engages a more holistic approach (Chakrabarti, 2011). Thus, depending on the nature and scale of disasters (and the local capacity of being able to cope with these disasters), the extent of internal and external assistance will by default differ; and consequently, the nature and management of these activities will need to be varied.

3.2 Disaster Management: Core Challenges

Whilst it is beyond the scope of this chapter to disentangle some of the main theories and concepts originating from disaster management literature *per se*, it is important to make clear a couple of distinctions. For example, Ariyabandu and Wickramasinghe (2003) defined disaster management as a collective term which encompassed all aspects of planning for (and responding to) disasters, which includes both pre and post disaster activities. Disaster management literature also embraces the process of rebuilding affected areas. This is commonly termed the "disaster management cycle" – the cyclical process of which portrays different stages of interventions. The disaster management cycle is divided into Pre- disaster and Post-disaster stages, along with “Preparedness”, “Recovery” and “Response” phases (Figure 1).

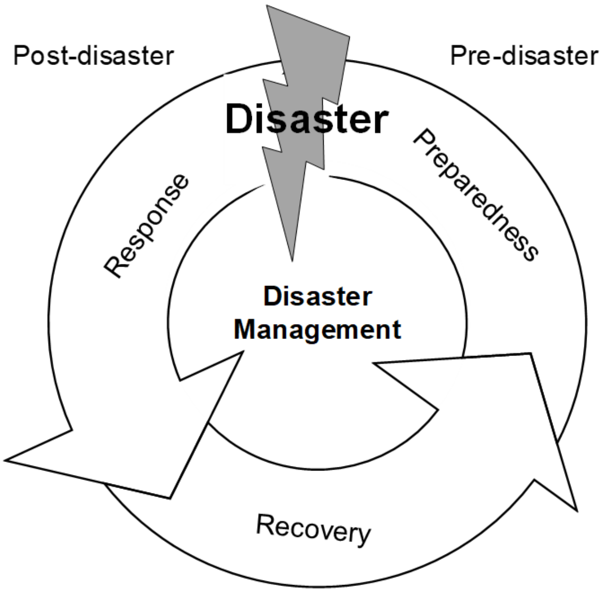

Figure 1: Disaster Management Cycle [attribution needed – is this UN (2008) or your own?]

Although some of the terminologies used in the disaster management cycle vary slightly in extant literature, López-Carres *et al.* (2014) attempted to understand the disaster management cycle through two phases: Prevention and disaster risk reduction, and Response and recovery. Similarly, Iqbal *et al.* (2018) demonstrated the disaster management cycle through pre-disaster and post-disaster phases. Other authors such as Delaney and Shrader (2000) identified that the disaster management cycle included: disaster mitigation and prevention, preparedness, emergency, rehabilitation and reconstruction. In addition, the Food and Agriculture Organisation of the United Nations (2008) presented the disaster management cycle through three distinct phases: Disaster Risk Reduction, Disaster Response and Disaster Recovery – presented in the form of a Disaster Risk Management Framework (DRMF). These collective views on the disaster management cycle highlight the magnitude and scope of this area, including the processes involved. This debate continues to unfold. However, the main thing to present at this juncture is that whilst literature presents different disaster management models (with varying degrees of complexity), the core message to impart here is need to consider the particular types of interventions needed; cognisant not only of OSM (within the context of this chapter), but the engagement mechanisms needed to shape public policies, including plans that either modify the causes of disasters or mitigate their effects on people, property and infrastructure.

In order to provide additional clarity and structure, this chapter follows the three phases presented in Figure 1. In doing so, it aims to present disaster management challenges in context,

especially considering the types of intervention efforts needed from built environment professionals.
These three phases are:

- **Preparedness** - seen as the knowledge and capacities developed by governments, professionals, response and recovery organisations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions (UNISDR, 2009);
- **Response** - the actions taken immediately after a disaster has occurred in order to: save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected;
- **Recovery** - 'restoring or improving of livelihoods and health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development and "build back better", to avoid or reduce future disaster risk'.

Previous disaster experiences have highlighted insufficient levels of preparedness and response in disaster-affected areas, including the impact of delays on the recovery process (Rus *et al.*, 2018). The above three phases are further expanded in order to provide additional insight into phase complexity, especially the need to create disaster resilience.

Preparedness Phase

In a disaster cycle, the pre-disaster stage aims to addresses disaster risk reduction by including mitigation and preparedness. Mitigation activities relate to eliminating or reducing the probability of occurrence or reduction of the effects from unavoidable disasters (Delaney and Shrader, 2000). The mitigation process also includes the development of: building/safety codes; zoning and land use management; preventive health care and public education; and other issues such as vulnerability analysis. The success of these mitigation measures depends to some extent on the integration of appropriate measures enshrined in national and regional development planning. Moreover, its effectiveness also depends on the availability of information on hazards, emergency risks and the counter measures that need to be taken. In this respect, Thurairajah *et al.* (2010) [should this be Thurairajah and Baldry (2010)] emphasised the need to address existing flaws in disaster management-related policies and frameworks at national/international levels in order to improve disaster risk reduction; additionally emphasising the importance of bottom up disaster risk reduction strategies to include the needs of vulnerable people.

Given the importance of the "Preparedness" phase, Haghebaert (2007) stated that top-down disaster risk reduction programmes often failed to address specific vulnerabilities, needs and demands of 'at-risk' communities; and that this process required direct consultation and dialogue with the respective communities concerned (as those communities understood local realities and contexts much better than 'outsiders'). Similarly on this theme, Aldunce and Leon (2007) highlighted that vulnerable communities often possessed skills, knowledge, resources and capacities which were also often overlooked/underutilised; and that in certain situations external actors could even underestimate the significance or potential consequences of these.

In this respect, vulnerabilities and ‘at-risk’ communities tend to include: elderly/infirm people, children, and people with disabilities/impairments.

During the disaster preparedness phase, measures are normally undertaken to control the impact of the event by ensuring a structured response is in place, including establishing mechanisms for responding quickly and effectively to disasters (International Labour Organisation, 2003). Whilst these do not aim to prevent the occurrence of a disaster *per se*, this stage includes the development of awareness. This awareness includes the general aspects of disasters, human behaviour, disaster signs, methods of successful evacuation, first-aid measures etc. This phase also contains the formation and training of local committees, including: the building of communication systems, meteorological observation systems, facilitation of basic utility systems (such as water supplies/sanitation etc.). However, in practice, there are many other challenges that need to be included in this phase, such as the socio-political context, communication streams, cultural dimensions, resource availability etc.

Response Phase

The post-disaster phase includes disaster response and recovery, as these components play a major role in rebuilding disaster affected communities. The disaster response phase aims to provide immediate assistance, specifically to maintain life, improve health and support the morale of the affected population. It also involves immediate critical interventions needed; these can last for days, weeks or months depending on the nature of the disaster and local conditions (Jones, 2006). The response phase often engages relief agencies or groups of people to focus exclusively on the prevention of additional loss of life, which includes such actions as search and rescue, provision of emergency food and water, temporary shelters, and temporary transport. In essence, this phase aims to meet the basic needs of people until more permanent and sustainable solutions can be provided. Humanitarian organisations are also often heavily present during this phase. There is no distinct point at which immediate relief changes into rehabilitation and then into long-term reconstruction development. However, the response phase tends to include medium-term interventions needed, such as the construction of transitional housing, provision of basic food to the affected population, provision of social services, road clearing, income generation, and water system rehabilitation (Delaney and Shrader, 2000).

In the event of large-scale disasters, temporary housing is often provided in order to improve welfare, comfort, protection, privacy and the transition to more favourable circumstances for those affected (Sinclair, 2003). Temporary housing is used to bridge the gap between the response phase and the recovery (long-term permanent reconstruction) phase. However, the primary purpose and provision of temporary housing can in some instances lead to further challenges - to both the disaster-affected communities and the organisations delivering this provision. For example, immediately after a significant disaster, people are typically offered emergency shelters. However, these only tend to last for a couple of months. Thereafter, people are then normally relocated to temporary shelters until permanent houses are rebuilt (nb. temporary shelters are also sometimes referred as transitional houses). In this respect, temporary housing can be defined as a physical structure where people reside and shelter after a disaster until they are resettled in a permanent place (Johnson, 2007). Unfortunately, this is where problems start to occur, as in many instances, communities end up using temporary shelters for much longer than anticipated due to the time taken for reconstruction - which also impacts on the lack of cultural consideration regarding the rebuilding process, infrastructure reconstruction and relocation areas (Johnson, 2007). This lack of consideration of needs and requirements is an important undertaking, as this can often lead to the implementation of insufficient solutions in terms of performance and meeting users' needs. Given this, a holistic approach is needed which considers both the transitional and permanent needs of the affected users and associated communities.

Recovery Phase

The disaster recovery phase provides windows of opportunity for physical, social, political and environmental development; not only to reconstruct the impacted areas, but also to improve the socio-economic and physical conditions of the impacted community (International Labour Organisation, 2003). The recovery phase therefore includes long-term activities, which continue until all systems return to normal or to an improved status. Acknowledging this, the recovery period often includes substantial investment in rebuilding the physical and social infrastructure of affected regions. In this respect, the construction industry tends to make a major contribution to this phase, which is also referred to as the post-disaster reconstruction phase. The phrase 'build back better' has been a mantra for shelter response since the Hyogo Framework for Action (UN, 2005). In pursuance of this, several studies have been conducted to explore the drivers needed to improve the quality of shelter and welfare of those affected by the disaster. This has resulted in refocused efforts towards improving building practices and addressing the underlying knowledge gaps among construction stakeholders (Opyke, 2018). For example, Thurairajah *et al.* (2010) [should this be Thurairajah and Baldry (2010)] highlighted the need to develop communities that can cope with the post-disaster challenges, including the need to improve disaster resilience by considering community views. Literature has also highlighted many instances where people affected by a disaster have been provided with housing which does not really suit their requirements (Johnson *et al.*, 2006). On this issue, there is a need to acknowledge that the provision of permanent housing should not prevent the future development of disaster-affected communities.

Two of the main challenges that are normally faced during the recovery phase is that of time and cost overruns in reconstruction (Rus *et al.*, 2018). This is particularly appreciable in developing countries, where houses are built on unsuitable areas such as wet-lands, flood plains, lower lands prone to flooding etc. Thus, restorative provision needs to consider the local lifestyle, culture, beliefs and the need to accommodate further development for future needs. This includes issues of layout and proximity between houses, social problems, lack of communication and coordination between different stakeholders etc., all of which have an impact on the recovery phase. A typical example of these challenges includes infrastructure provision such as road network, transport systems and sewerage systems. Where even the construction of toilets without proper investigation into local site conditions can create additional hygiene issues (Care, 2016). It is therefore important to envisage these problems beforehand.

There are several opportunities that can be exploited during the reconstruction phase. This includes the need increase preparedness in order to reduce vulnerability and increase stakeholder acceptance. Compared to other phases, the amount of actual work carried out during reconstruction is considerable. In fact, most of the actual construction is carried out during this phase (which include significant investment). It is therefore really important to plan for this in advance, as in some cases, the disaster recovery has not actually contributed to long-term development; but more as a destabiliser (Bradshaw, 2001; Anderson and Woodrow, 1998). The corollary of such actions can therefore result in prolonged reconstruction activities and wasted opportunities. This resonates with the findings by Jones, (2006), who observed that despite improvements in the emergency response process (to natural hazard induced disasters), permanent reconstruction is often inefficiently managed, uncoordinated and slow to get off the ground. It is therefore important to appreciate that the success of redeveloping communities depends on pre-planning. This requires conjoined thinking to leverage all vested parties (individuals, organisations, governments, international bodies etc.) to address post and pre-disaster situations.

3.3 Disaster Resilience

Originating within the body of literature on ecology, the term 'resilience' was initially attributed to ecological systems, their stability and behaviour (Holling, 1973; Adger, 2000; Gallopín, 2006). The term has subsequently been applied in a range of subject localities such as psychology, materials sciences, economics, environmental studies and social sciences (Adger, 2000; McDaniels *et al.*, 2008). This term is also widely used and applied within the context of geological/geophysical hazards such as earthquakes and landslides and hydrometeorological hazards such as cyclones and flooding (within the context of natural hazard related disasters). Even within this context, resilience has been defined in different ways by researchers – see (Manyena, 2006; Paton, 2007; Cutter *et al.*, 2008).

Following a review by an open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction, the term agreed for 'resilience' (from a disaster risk reduction point of view) was "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management" (United Nations, 2016). In essence, this definition is an incorporation of many of the key facets of resilience identified in extant literature, including the concepts of absorbing impacts and bouncing back for quick recovery. The definition considers resilience as a dynamic process and encompasses the views of: preparedness, response and recovery; all with a view to learn from and adapt to potential risks. Often, the aspects of preparedness, response and recovery are seen as distinct stages of the disaster risk reduction cycle. However, considering these as 'stages' seem to contribute to a more reactive approach to resilience as opposed to the 'proactive' approach intended and often advocated. As such, intertwined concepts that cut-across stages in the disaster risk reduction process are further articulated and developed in this chapter.

4. Research Methodology

4.1 Introduction

A desktop study was conducted to explore the fundamental principles of offsite manufacturing and disaster management. Through initial literature review (reported above), challenges in disaster management initiatives and potential opportunities from OSM were identified. This noted a paucity of work related to the use of OSM in disaster contexts. Housing was one of the areas where some research had been undertaken. Given this, housing (temporary and long term) was seen as a crucial step in disaster response and reconstruction. Following the initial reviews of OSM and challenges in disaster resilient construction, a further review was conducted to assess how OSM could contribute to a more proactive approach to disaster resilience – especially, to contribute towards the preparedness, response and recovery aspects of disaster risk reduction process. The following sections provide developmental narrative using two case studies to aid discussion. This draws attention of how OSM could be used to link these stages in order to create a holistic and cohesive disaster risk reduction process. These two cases were purposefully sampled to be distinct, so that they could be used to explore the above phenomenon. Case 1 was a housing initiative where offsite manufacturing had been used for disaster rehabilitation and recovery. Case 2 presents an initiative where OSM offered significant potential, yet was underutilised. These two cases are considered 'representative', given the nature of this work and the need to capture integrated OSM facilitation to address disaster resilient construction. These two cases are presented below.

4.2 Case 1: Half a House, Constitución, Chile (Greenspan, 2018)

In 2010, a devastating 8.8 magnitude earthquake in Chile affected many people in major cities such as Constitución [nb. do you mean Concepción as this is often mentioned as an affected city?], Arauco and Coronel. This left several thousand people, and hundreds of families homeless. As part of the relief effort, an architecture firm called Elemental was hired by the Chilean government to create a master plan for the city. This included new housing for people displaced by the disaster. They developed half of the houses based on modular construction in order to incorporate the idea of adaptability. In this respect, housing was conceived as an ongoing project wherein residents were considered co-creators. This was considered radical and controversial approach toward housing. However, in 2016, the firm's founder, Alejandro Aravena, was awarded the Pritzker Prize (one of the top prizes in the field) for the company's efforts in providing affordable homes.

The design was simple, two-story homes, each with a wall that ran down the middle, splitting the house in two. With amenity connections, one side of the house was ready to be moved into while the other side provided rooms to expand into as and when needed, in a manner that best fitted with individual circumstances, supported by classes and direction from Elemental staff (Greenspan, 2016). In this way, Elemental were able to rapidly respond to the situation and provide a form of temporary housing that could grow into a permanent residence for the people of Constitución. It developed a system that could be applied in many situations, including provision of shelter following a disaster as well as in areas of high population in need of affordable housing. This satisfied disaster relief and reconstruction as well as the necessities for a shelter to become a home.

4.3 Case 2: Resettlement programme in Kalutara, Galle, Ratnapura and Matara in Sri Lanka (NBRO, 2018)

In May 2017, the central and southern half of Sri Lanka was affected by severe landslides and floods which took many lives. Almost 500,000 people were affected by this incident. As a result, the Sri Lankan government proposed to resettle families living in hazard prone areas of Ratnapura, Kalutara, Galle and Matara districts. As part of this initiative, the National Building Research Organisation (NBRO) prepared resilient house plans which were considered adaptive to landslides and floods. In addition to these plans, the NBRO prepared a hazard resilient housing construction manual (NBRO, 2015) to promote the use of hazard resilient engineering design and construction practices for building houses in Sri Lanka.

The NBRO provided design and construction guidelines for each type of disaster in addition to technical guidance on land section, topography, consideration of vulnerabilities, reinforced concrete structures, including foundations, superstructure, openings and water bodies. These resilient aspects were created for each disaster profile based on past events and ongoing research. The principle followed in the resettlement programme was to provide disaster resilient basic 'core' housing units first, which could then be expanded and adapted by the occupants. In this respect, Case 2 is comparable to Case 1. The houses, however, are currently being built in-situ without the use of OSM practices. These adaptable, resilient building designs are a significant improvement in post-disaster housing construction in Sri Lanka, where previous housing projects have been associated with numerous drawbacks (Wedawatta *et al.*, 2018). However, some of the issues such as considerable delays in construction, low quality workmanship standards, and workers on the ground not adhering to technical specifications have been noted in recent post-disaster housing projects.

5. Key Findings: OSM Principles for Disaster Contexts

5.1 Introduction

Within the dynamic process of disaster resilience, the involvement of construction work is often required throughout. As noted in the UK's government's written evidence (Department for Business Energy and Industrial Strategy, 2018) submitted to the parliamentary inquiry, offsite construction techniques often require a fundamental change to the business model currently being used in the construction sector - from a service model to a manufacturing one; and that this would require significant capital investment. As such, firms are unlikely to make this investment and take on the commercial risks of adopting new business model unless there is a strong pipeline of future demand (Department for Business Energy and Industrial Strategy, 2018). Given the demand for construction works to meet the needs of preparedness, response and recovery in relation to disaster resilience, it is proffered that OSM is uniquely placed, and could therefore be considered a demand-driven pull factor for the use of offsite practices. In this respect, the actual process of "how" offsite manufacturing can facilitate disaster preparedness, response and recovery is visited in the next sections, supported by case studies and additional examples.

Figure 2 presents three distinct yet intertwined concepts (disaster proofing, emergency readiness and adaptability). These three concepts cut across disaster preparedness, response and recovery.

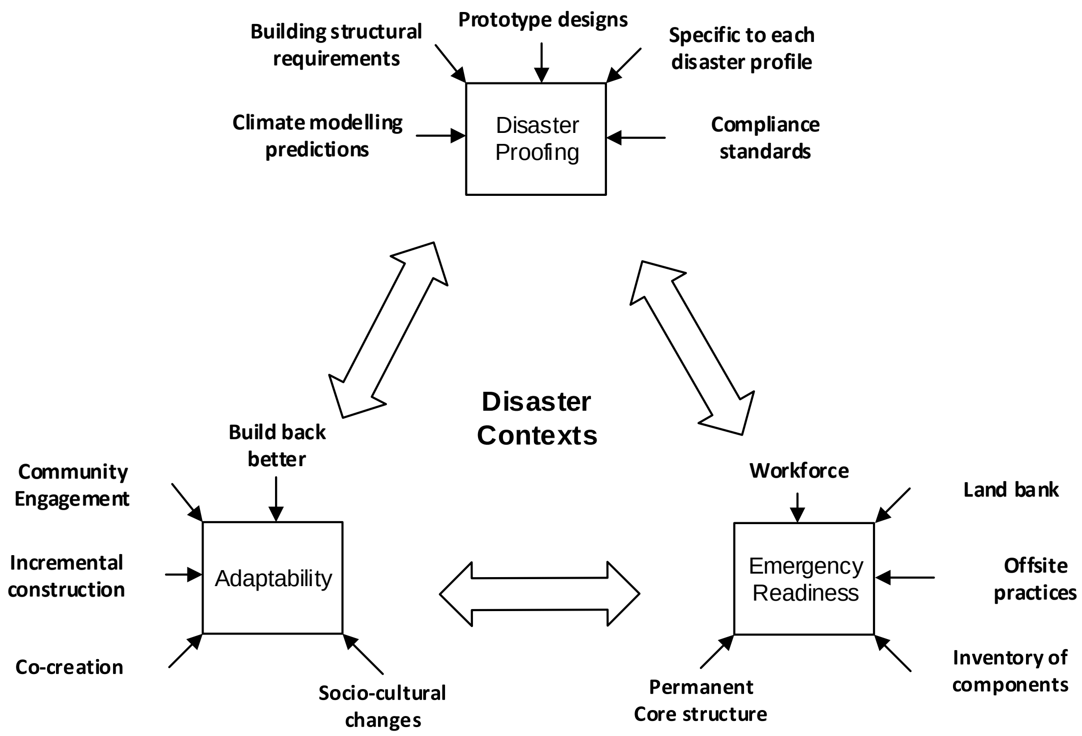

Figure 2: OSM principles for disaster contexts

5.2 Three Governing Principles

From literature, it can be seen that there is a specific need to build homes (post disaster) that consider both transitional and permanent needs of the affected communities. This is a significant undertaking. Several studies have identified that removing (or minimising) stakeholder engagement can often lead to a raft of challenges in transitional permanent housing, from 'acceptance' through to coordination and general communication between disparate parties and subsequent providers. This is often exacerbated where policies and information from the preparedness stage has not been properly transferred to the stakeholders involved in the other stages – including the affected communities. This fragmented approach to disaster resilience therefore needs to be addressed. As such, three governing principles for OSM in disaster contexts are presented in this chapter (Figure 2) in order to i) address some of the above concerns and ii) create a proactive and holistic disaster resilience solution. However, the scope of this discussion is limited specifically to housing, as housing remains the fundamental construction-related human requirement.

Principle 1: Disaster Proofing

The focus of disaster proofing relates specifically to incorporating resilience features into construction, for example, raised floor levels, flood resistant external doors etc. for flood protection (before such disasters occur). As such, this requires considerable forethought and planning, which is informed by a number of evidence-chains, not least on the potential risks, extent and severity, securing a detailed risk assessment (including climate modelling) etc. The advantage provided by offsite manufacturing here is its ability to develop potential housing designs to suit different risk profiles and exacting standards required. As discussed by Blismas *et al.* (2006), offsite manufacturing offers the ability to achieve higher quality standards in construction. Moreover, products can be tried and tested in the factory – the process of which offers greater consistency and quality control, allowing consistent standards to be achieved (Blismas *et al.*, 2006). This is just one issue. In many countries, mass housing is provided via pre-designed houses that occupiers can buy depending on their choices. Offsite manufacturing is ideal for such contexts. As discussed in Case 2, the National Building Research Organisation in Sri Lanka developed prototype designs for houses to suit different disaster risk profiles. The intention here was to design and produce components that incorporated resilience features. However, a key obstacle experienced was achieving the required standards due to a number of issues, not least, lack of technical knowledge among construction trades who build these houses at the local level (Wijegunarathna *et al.*, 2018). Therefore, the use of OSM would remove this obstacle as most of the manufacturing of components is typically built in a factory.

Given the exacting nature of disaster proofing, dissenters often present an argument that disaster proofing in the built environment often incurs significant additional costs. For example, evidence suggests that incorporating flood protection features within a building tends to cost extra (Wassell *et al.*, 2009; Joseph *et al.*, 2011). However, evidence also suggests that considerable cost savings on housing construction can be achieved using offsite manufacturing methods. There are several studies to reinforce this, including the findings of a case study by the UK government which estimated cost savings of 10-20% could be achieved by building homes using offsite technologies (Homes and Communities Agency, 2015). Similarly, Pan and Sidwell (2011) observed significant cost savings in using offsite manufacturing in the UK. The use of OSM enabled the use of cost engineering to achieve cost reductions and greater effectiveness; including: learning efficiencies, technological innovation, multinational partnering, engaging in-house build management etc. (Pan and Sidwell, 2011). This presents somewhat of a paradox regarding the extra costs and the potential cost savings available through OSM. It could (for example) be argued that the cost savings offered by OSM can be used to offset any extra costs associated with disaster proofing – or even achieve the required levels at a lower cost than using traditional in-situ construction methods.

One final point needs to be raised at this juncture is that of resilience. A key feature of the globally accepted definition of resilience is achieving resilience "in a timely and efficient manner". It could be argued that using offsite manufacturing methods is in line with this key objective, as this offers efficiencies in terms of cost, quality as well as time. Whilst it is accepted that further research is required to demonstrate clear cost comparisons between traditional housing and disaster-proofed housing using offsite methods, there are clear indications that serviceable solutions are available for uptake. However, as also discussed above, there needs to be a clear business case in place to justify the capital investment often needed for offsite manufacturing.

Principle 2: Emergency Readiness

Emergency readiness in this context refers to the ability to respond quickly to disaster situations in a planned manner. Studies have suggested that arranging planned actions in anticipation of a natural disaster can aid lessen the sense of urgency should a disaster arise. In the two case studies presented above, it was particularly notable how significant the local governments' role was in this process, particularly for pre-allocating land plots (land banks) for housing and the affected communities. For example, in case study 1, the Chilean government went a step further by creating a permanent core structure for temporary sheltering in these allocated land plots.

Here housing was conceived as an ongoing project, where the local community and residents come together in order to create socially acceptable dwellings. In this respect, Quarantelli (1995) suggested distinguishing between four somewhat different phenomena in relation to post-disaster sheltering and housing: emergency sheltering, temporary sheltering, temporary housing, and permanent housing. Whilst the boundaries between emergency and temporary sheltering are not distinct, the purpose of emergency sheltering is to provide short-term accommodation to disaster victims (typically hours or overnight), whereas, temporary sheltering often lasts for longer periods. As such, emergency sheltering therefore needs to be arranged within hours of a disaster occurring, with the provision of temporary sheltering often taking a couple of days to be arranged (Johnson *et al.*, 2006). The key requirement here is the speed of response required. Whilst, options such as hotels, tents, public buildings etc. are often used as emergency shelters, the provision of temporary sheltering tends to require more fit-for-purpose solutions in order to provide a decent living environment for those affected.

A relevant concept that is applicable here is that of 'flat pack homes', which are pre-fabricated and can simply be erected on site. 'Better Shelter' designed by the IKEA foundation in association with the United Nations Refugee Agency and deployed in many disaster situations worldwide is a great example of this (Better Shelter, 2015). Whilst this provision costs more than a tent, it offers many other advantages, including a safer, more dignified, longer lasting and cost-efficient solution than traditionally used tents. Others factors that need to be considered here are that of: ease of assembly, adaptability for different locations and uses, reusability and sustainability. This project is an example of how socio-cultural and socio-economic drivers and expectations can be addressed. Temporary accommodation solutions can also be used in different (non-disaster) contexts, including medium and long-term solutions made up of a kit of moveable and reusable parts and offsite techniques (Anon, 2017). The message here is that solutions are readily available; and that it can be argued that countries vulnerable to disasters could keep a stock of such temporary shelters, so that these can be quickly erected on site as an emergency readiness solution.

Principle 3: Adaptability

One of the concepts seldom discussed is the fact that the built environment created after reconstruction is more often than not significantly different to that before the event of the disaster. Given this, the affected communities often need time to adopt (and adapt) to the social and cultural changes presented in this new environment. This period of adjustment involves adaptability, where adaptability is referred to as the ability to improve and adjust buildings to suit the new environment. For example, as presented in case study 1, the Chilean government commissioned houses that would be able to evolve over time on an incremental basis. The underpinning rationale here was that sustainable success of this idea accepted that temporary dwellings can often form the core of a permanent structure. As initially, when people received their new house, this was typically unfinished with minimum facilities. However, the residents were able to define and design their own extension around the core structure of the house to build their own home. This allowed them to co-create their homes incorporating social preferences and cultural representations.

Following the adaptability theme, it is also important to acknowledge that community engagement can often help those affected to re-focus and re-group after a disaster event – thereby allowing social cohesion and development to occur. In this respect, Ophiyandri *et al.* (2010) found that a community-based approach was more successful in terms of construction quality, satisfaction and accountability. Given this, OSM provides an opportunity for this engagement, particularly in the early stages where synergies (between OSM and traditional approaches) can be maximised to deliver incremental improvement. In doing so, this in turn can help improve acceptance and delivery of appropriate designs in terms of cultural and local contexts. Coincidentally, a key priority agreed as part of the Sendai Framework for Disaster Risk Reduction 2015–2030 was to build back better in recovery, rehabilitation and reconstruction (UNISDR, 2015). However, the opportunity to build back better has only been acknowledged in limited instances (Wedawatta *et al.*, 2012). It is advocated that this needs to change, particularly to render adaptation and disaster proofing for future events. It is therefore proffered that offsite manufacturing could offer significant opportunities for incorporating disaster proofing in a systematic and managed way - thus facilitating the target of 'building back better'.

6. Conclusion

This chapter highlighted the need to reflect on disaster management. It emphasised that whilst several countries have focused on reactive-driven strategies in order to address disasters *per se*, there is now a need to deliver a more focussed approach using proactive strategies. In doing so, it proffered that the management of disasters also needs to engage a more holistic approach as the nature and management of activities need to be conjoined. The concept of OSM was introduced as a potential vehicle for delivering a new approach to disaster management – particularly through the three phases of 'Preparedness', 'Response' and 'Recovery'. The challenge posed here was that of developing resilience. Two case studies were critiqued as part of the narrative, which was followed by a discussion on the three governing principles which interlink "Adaptability", "Emergency Readiness" and "Disaster Proofing". This was presented in the form of an OSM principles for disaster contexts relationship model.

Key Learning Points

- ✪ Previous approaches to disaster management have highlighted the need for preparedness and response - including the impact of delays on the recovery process. However, it is also important to focus intervention efforts from built environment professionals on: 'Preparedness', 'Response' and 'Recovery';

- ✪ OSM offers significant potential of being able to deliver solutions to three governing principles within disaster contexts – these being: i) Adaptability ii) Emergency Readiness and iii) Disaster Proofing;

- ✪ Within the disaster management cycle, it is important to engage all stakeholders in the development of solution generation. Conjoined synergies can be used to leverage OSM principles within disaster contexts, but this will require strategic convergence. More importantly, it is also important not to lose sight of engaging end-user acceptance (in terms of design, delivery, and local/ cultural contexts) given the importance of 'building back better'.

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