TOWARDS AN INTEGRATED FRAMEWORK FOR BUILDING RESILIENCE USING FLOOD MEMORY IN BUILT ENVIRONMENT

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ABSTRACT. The complexity of repeated changes in natural environment and their impact on the dynamic urban built environment setting, whether it is the primary physical impact by means of ingress of water to normally dry areas or evacuation from the forces of high velocity flood water, are challenging. There is constant change in level of exposure and vulnerability of surrounding built environment as a result of the memory stored within the system partly due to repeated impacts of flood events. Enhancement of resilience within the built environment against such irregular changes demands consideration of the interactions and feedbacks within built environment on a scenario specific basis reflecting antecedent memory within the system. It however still remains a challenge to direct the attributes of physical memory within built environment and utilise it for maintaining functionality in the system through enhancing resilience. This research adopts a literature review approach to identify those interconnected links which feeds back into the system and propose a framework which will help in identifying the potential vulnerability of the system in developing resilience with special reference to flood induced physical memory.

Keywords: Built-environment, Vulnerability, Framework, Resilience, Repeat flooding

1. INTRODUCTION

With the growing scale of activities such as building new properties and increase in the asset value in the built environment within flood prone areas it becomes increasingly important to understand how the changing pattern of extreme weather events impacts on the enhancement of resilience. While disasters inevitably restrict the effective functioning of the built environment, there are also features of the built environment system that can interact with hazard characteristics to improve or worsen disaster outcomes. This is especially important in the context of flooding as diminishing space for water often reduces the hydrological systems ability to effectively store and release water resulting in more severe and frequent flooding [1]. Given the changing environmental conditions and in recognition that some areas will be subject to repeated flooding, organisations such as the Environment Agency, Institution of Civil Engineers and RIBA advocate the idea of 'living with water' as a key policy direction for flood risk management [2,3]. The policy reduces the emphasis on trying to control water through massive structural interventions and embracing a more dynamic relationship between natural and built environment.

Lindell [4] from a social and behavioural context discusses disaster effects (for a given hazard scale) as determined by three primary pre-disaster situations: exposure of system (built environment) to hazard, characteristics of physical vulnerability and social vulnerability. From the environmental and socio-economic context of flooding the same thought is iterated by the global environmental change school of thought that the vulnerability within the built environment can change because the changing frequency and nature of disaster can create transient and fixed memory within the dynamic system [5, 6]. Memory can exist in antecedent form within the natural system and affect attitude towards risk within the built environment in enhancing resilience. However, as Holling [7] indicated, understanding vulnerability in the context of memory can be very complex because the problem zones are not equally distributed within the built environment and vary significantly according to system’s resilience pattern.

The paper takes an approach of reviewing the extant body of literature and identifying exemplars that indicate changes in built environment resilience as a result of changing aspects of the system's physical memory. The key concepts of physical vulnerability of the built environment towards repeated flooding and its influence on resilience are focussed widely. Therefore the first step was to look into the works from various fields of physical vulnerability of properties followed by introduction to different criteria of physical memory affecting resilience within built environment system. Here the focus is on physical vulnerability and resilience of infrastructures within the built environment. A framework is designed, by collating insights from literature within the context of system memory in building resilience, to gain better understanding of the concepts and interactions between them.

2. BUILT ENVIRONMENT AND REPEATED FLOODING

2.1 Vulnerability of built environment

Vulnerability in physical terms in the built environment is assessed by action of damaging agent on physical environment [8]. Changes in physical vulnerability depend upon specific disaster scenario and the inherent capacity to adapt to that scenario. For instance, with increased frequency and magnitude of flooding and repeated impact on built environment a physical memory is created with reference to certain level of vulnerability. The term physical memory is seen in this context as differential level of physical vulnerability caused by the antecedent effect of the damage within the built environment as a result of flooding within the limited window of recovery time between events. These differences are based on the level of the systems' susceptibility, intensity of the event and time factor towards recovery. As de Vries [9] mentioned, the memory of past hazard events and the quality with which the stakeholders and managers dealt with the situation has a significant impact on the future system vulnerability. It is important to understand how the system (built environment) reacts to repeated impacts and generates physical memory and what reactions are effective in developing resilience for the future given the existence of embedded memory in the system.

Vulnerability assessment evaluates both the acting damage agent (flood) and the vulnerable element (built environment). Both Adger [10] and Cutter [11] in their classical studies of vulnerability indicate consistently the criteria of intensity and susceptibility through which vulnerability is parameterised. Furthermore, In understanding of total risk assessment, factors such as type and nature of hazard (existence of damage agent), exposure of the element at risk (magnitude, frequency, duration and extent of hazard), its inherent level of vulnerability (conditions that make elements at risk exposed to hazard) have been emphasised as effective interconnected indicators. Gissing [12] emphasized the understanding of these factors is essential for decision making and enhancing resilience in case events of similar nature occur in the future.

Knowledge of the risk before an event can play an important role in reducing vulnerability and enhancing resilience within the system if risk reduction and reinstatement strategies are implemented. Memory is significant when learning and decision making for future events are activated and calibrated by experiences and strategies taken to reduce risk in the past. Indicators for physical building vulnerability were summarised by a basic framework of disaster model by Lindell and Prater [13]. The model explained that the pre-impact conditions are affected by the level of preparedness especially for properties affected by repeated effects of flooding. Physical impacts can be reduced by hazard mitigation and other preparedness practices [4]. Although the Lindell model emphasises the social aspects, structural vulnerability is seen as a pre-requisite or starting point which propagates through other dimensions of vulnerability such as social factors [14]. Interventions are associated with mitigation and preparedness which in turn are often manifestations of flood memory of previous events.

Since the focus of this research is towards physical vulnerability of the built environment, physical damage to buildings and their contents as a result of their structural vulnerability, a general understanding of physical vulnerability is germane. Physical or structural vulnerability of buildings arises as a result of construction design and materials that cannot resist stresses from infiltration into occupied buildings [13]. Researchers from different experience in different natural and built environment indicate that the main exposed factors which can cause physical damage to a building for any kind of property are the type of construction material, structural condition of the building, maintenance of the building and the way the space is used within the built-up area [15-17].

Characteristics of events such as speed of onset, intensity, scope, duration of impact and probability of occurrence are important for understanding the level of exposure to hazard [16]. Such understanding also helps people in improvising informed decision making during the recovery stage. It is possible to understand the level of impact if knowledge about the built environment such as structure or building characteristics and the type of damage that can be caused by flooding can be anticipated. Flood water can enter buildings through masonry joints; brickwork; cracks and any flaws in the construction; door thresholds and other service inlets such as pipes and sanitary appliances. Construction Industry Research and Information Association CIRIA [26] indicated in their report that level of flood water depth and duration below or above the ground floor can damage sockets, carpets, fittings and possessions and greater penetration of water leading to saturated floors and walls. Similarly, it can affect services such as water tanks, ground electrical or gas services. Longer duration of flooding can make repair costlier. Furthermore, in a case study in Cockermouth, UK Joseph *et al* [18] observed water related contamination inside buildings, such as leaking of sewage, salt water, or mud and silt inside the building can effect on total damage cost unless there is property level flood protection measures installed.

Structural characteristics of building are also important. As seen in the case of assessment of physical vulnerability, the buildings constructed without consideration of potential flood damage are at higher risk of getting affected by water intrusion than reinforced and suitably reinstated structures [16]. Similarly, masonry and concrete are less likely to get affected than light weight and block or timber which tends to crack when drying. But concrete structures take longer to dry out and if there are repeated events happening close together then the chances are that they will cause much higher damage to buildings due to the existing memory of previous event within the system. Additionally, susceptibility of a structure also depends on the state of maintenance of building. Uzielli *et al* [8] emphasized the standard of maintenance of buildings that can affect the total damage potential of property in future. Therefore poorly reinstated building following one flood will be more vulnerable to future damage building up on its inherent memory. Standard of maintenance can also affect the cost of building repair and replacement value during the recovery phase. Historic factors such as knowledge of previous flood and the damage caused by the historical flood is one of the prime criteria that help in identifying likelihood of future risk of a property. Repeated impacts experienced in the past can therefore affect the structural integrity of the properties, building memory into the physical fabric of the built environment.

Based on the above discussion it can be highlighted that the memory within the system of physical built environment can be attributed to: impacts from flood events; learning from past events; and taking actions based on that learning. These actions are designed to reduce the impact of flooding by taking up preparedness and mitigation measures and that improve future resilience against potential damage and disruptions.

2.2 Effect of memory on preparedness and adaptation against floods

On the basis of the lessons learnt from the physical vulnerability of the built environment and the inherent memory within the system, it is evident that there is a direct interaction between vulnerability of the system and the level of resilience. It is however difficult to specify the exact relationship in single term [10, 19]. After the Hyogo declaration in 2005 the UNISDR adopted the concept of resilience to be one of the most important aspects of disaster management [20]. However to understand the concept and enhance resilience it is important to have initial understanding of the main aspects of its determinants, measurement and how adaptability can be improved and maintained at a certain level [21]. Human memory intervenes within the vulnerability of system of physical environment in the form of reinstatement and adoption of measures for enhancing resilience. Kreibich *et al* [22] indicated that precautionary measures have a potential to reduce flood damage of buildings and their contents. Memory within the system often determines the kind of precautionary measure adopted, time of realisation of adaptation of measures and awareness as a result of experience reflecting the concepts of improvised disaster response and recovery in reducing vulnerability.

2.2.1 Kind of measure: Resistance and resilient measures as memory

The pathway through which the flood water enters a property is often determined by the resistance offered by the building material and its design which further affects the decision for implementation of appropriate measures suitable for either preventing the water from entering the property or making it resilient [23]. A body of resilience literature suggests that when a property is vulnerable to direct effect of flood water, it is important to limit damage by limiting the ingress of water. However, if the expectation is for deep flooding, guidance suggests that no attempt should be made to keep the water out of the property as the water pressure might structurally damage the property [24, 25]. Suggestions were also made regarding effective drying and decontamination of properties especially for repeatedly flooded properties [26, 27] and taking precautions such as shielding with water barriers, waterproof sealing, fortification, flood adapted use and interior fittings, and elevating the fixtures and other valuables higher where flood water have never reached before from learning from the past [22, 28].

The knowledge of antecedent memory which comes from experience of previous floods is very useful for quick resilience reinstatement because of the small timeframe available between repeated events [29, 30]. This can lead to significant damage reduction, up to 53 per cent for buildings and contents as seen in case of 2002 flood in Germany and also encourage other property holders to take up precautionary measures which went up to 42 per cent in this case [22]. Similar evidence was found among business properties in Australia where planning and mitigation activities could have effectively reduced direct damage by 80 per cent [12]. It was evident that such motivation can be enhanced by financial incentives and more stimulated information and knowledge campaigns to effect resilience enhancing behaviour. However with time memory can fade away, therefore required maintenance for preparedness may not happen. Therewith, to maintain a certain level of preparedness, memory has to be kept alive by other means over time.

Arnell *et al* [31] emphasized the role of changing pattern of crisis and its effect on another useful aspect of memory: property and content insurance. Insurance can be an effective response to the financial impact of floods, spreading the cost across wide populations in space and time. In the context of UK, Lamond *et al* [24] evidenced how the changing insurance environment may lead to poor restoration, potential deterioration and lack of ability to sell and reducing value of properties in future. In this case institutional memory by insurers is demonstrated with companies showing some reluctance to insure repeatedly flooded properties, particularly those flooded recently, while not fully taking into account future risk where recent flooding has not occurred. Physical memory within the system is therefore also dependent upon risk perception and rational behaviour of flood plain population and other stakeholders. Attitudinal and institutional change can help in enhancement of resilience through proper guidance and training.

2.2.2 Experience, guidance, training and sharing as memory

Flood damage of properties presents a number of challenges related to restorations, insurance claims and reinstatement to return the property in its pre-incident condition [23]. Such conditions need experience and knowledge to handle the situation. Experience of past events and history of preparedness encourage affected population to be prepared and exercise resilient living. Such findings are consistent with experience from North Dakota where the residents and business holders suffered from serious flood experiences between 1993 and 2003 and it was observed that there was significant level of increase in resilient actions among homeowners and businesses both. Percentage change in recovery plan increased from approximately 4 percent to 11 per cent, flood insurance among businesses increased from about 3 per cent to 12 per cent and flood insurance among home owners increased from 13 per cent to 27 per cent [32]. This clearly indicates that recent flood events can help in understanding and active learning of the nature and characteristics of disaster and extend learning from experience in the form of adopting preparatory measures and enhancing resilience.

Resilient measures also seem promising in case of repeatedly flooded residential properties in Cocker mouth, UK where flooding have occurred in close intervals [18]. Sometimes presence of experience as memory within the system may not reflect on the preparedness and adaptation measures at the first time. Rose *et al* [33] reflected how it can take up to 'three times' for residential properties to realise the importance of adaptation measures. Rapid action after disaster is important for enhancing resilience and reducing distress for a longer period of time [34]. Active Learning Network for Accountability and Performance (ALNAP) in humanitarian action accounted that both risk reduction and recovery measures are more likely to be effective when coping capacities are included in design criteria [35].

Memory on its own can also assist in speedy recovery by encouraging good practices through learning and sharing from individual household to the entire community. This is the concept of removing physical memory from the built environment system by learning from it, that is when antecedent physical memory in the system is reduced by incorporating appropriate training, best practice guidance's, faster response, and propagating knowledge of existing risk. This capacity can be built by institutionalisation of memory, where people will know what to do in case of flooding. Practices such as 'sustainable memory' generation [36] provide a platform for increased understanding of local memories and enhance community's adaptive capacity and resilience. It is evident that the more experience a community has of flooding, the past knowledge helps them in tackling the issue in an efficient manner based on using community resources [39].However, sometimes if events are too far apart then the memory from experience can fade away and antecedent memory does not help in encouraging motivation towards resilience. Such was the case of August 2002 event in Germany where flood plain population experienced a flood event 39 years ago [28].

The Scottish experience shows that understanding and drawing lessons from past knowledge can help in managing conflicting perspectives and ensure trust between partners from individual to catchment level flood risk management plan to reduce vulnerability within the community [37]. Community preparedness and experience sharing is important for facing floods in both the short and long term to be more resilient especially in case of repeated shocks.

2.2.3 Time of realisation as memory

Another important effect of memory towards preparedness and adaptation measures is realisation time for taking up adaptation measures. The time when preparedness measures are undertaken may affect the final value of damage, disruption and system's capacity to recover. The preparedness scenarios can be divided into three options: where no action is taken or none intended; action taken before flood and actions taken after flood event has taken place. Actions taken before flood are often dominated by previous knowledge and awareness and attitude towards existing risk. The case of flood in Elbe research shows that due to the lack of knowledge of existing risk in the area very few people were prepared on time for the disaster causing much higher damage [28]. Those unprepared and who suffered the most had almost no or very little knowledge, some took advantage of neighbourhood networks and prepared before and during floods. However, there was no drastic change in the situation after floods and 34 per cent of flood affected people still did not consider to take up any precautionary measure for various behavioural and perception oriented reason, but those who were prepared before flood, mean damage ratio was reduced by 29 per cent which can go up to 60-80 per cent [22].

It is also relevant that for maximum gain and cost effectiveness flood resilient measures should be undertaken during normal course of renovation at the time of repairs immediately after floods [39]. Resilient measures can help in quick reoccupation of properties with minimum disruption and with experience and knowledge this can be performed faster [18, 40]. The general trend among both households and businesses is that preparedness activities increase after flood event [41]. The effectiveness of realisation time as memory within the system is important for reduction of future damage from floods.

3. ROLE OF ANTECEDENT MEMORY TOWARDS VULNERABILITY OF BUILT ENVIRONMENT

On the basis of the knowledge gained from various events of the past it can be now illustrated how preparedness and adaptation measures, experience and knowledge and time of realisation of adaptive measures integrate with system memory to build up resilience for the future. Antecedent vulnerability may be overestimated for some systems or underestimated for others due to ignoring or neglecting system memory. Physical memory can be represented in the length and sequence of flooding, catchment characteristics, amount and frequency of flooding and in the nature and characteristics of property, preparedness and resilience measures adopted, time of adaptation and range of experience and attitude towards risk among flood plain population. The external factors such as preparedness types, time of realisation and experience and knowledge acts as drivers in contributing towards resilience scale through the system of physical memory of the built environment. Figure 1 illustrates how these memory factors within the system affect system resilience both internally and externally.

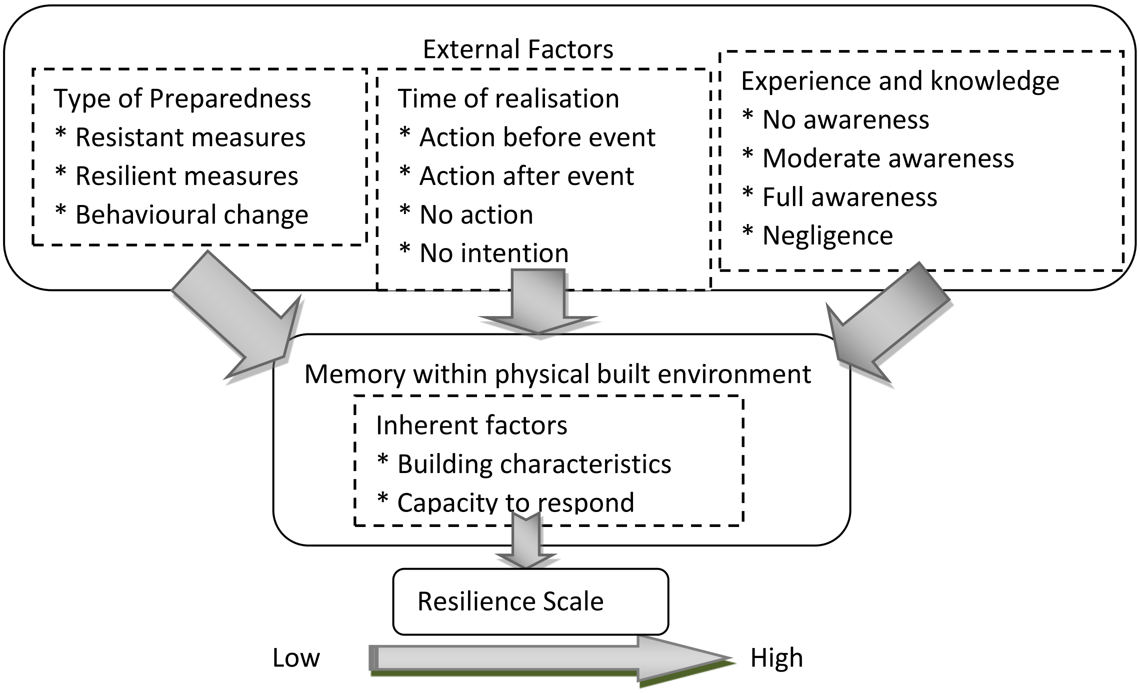

FIGURE 1: Conceptual model illustrating impact of memory on scale of resilience

The characteristics of building and capacity of response increases from within as the external forces acts on the system dynamics. Both internal and external aspects of memory need particular focussed attention to design values for resilient measures. Consideration of the existing memory on an area specific basis may be more effective in this case rather than one average solution for all types of properties in different locations. If the aim of flood management is to reduce total damage and disruption and enhance future resilience, the diagram shows that this can be best achieved when memory is integrated within system resilience throughout its different phases of development and maintenance.

4. CONCLUDING REMARKS

In the face of increased vulnerability, channelling of memory within the built environment system becomes an essential optimisation measure for flood adaptation and mitigation measures in enhancing resilience. Memory of physical damage in the system, and the corresponding preparedness measures, offers a collection of ideas focussed on system level properties associated with addressing design challenges in the built environment. It is evident that vulnerability changes with changing system memory through preparedness and adaptation measures and can be maintained by adequate training and knowledge of best practice guidance. However, there are several internal and external challenges associated with applying memory to the design of built environments due to its multiple facets. It is argued here that idea of system memory can augment the concept of resilience providing sufficiently rich examples to conform to the theoretical foundation for the concept. A possible avenue of application of the theory is discussed within the context of physical vulnerability with utilisation of embedded memory within the system of built environment. An explicit, framework for incorporating resilience and memory into the physical vulnerability of the built environment is presented. These ideas provide a theoretical lens to view the important problem of physical vulnerability and resilience within the built environment and the role of memory in terms of preparedness, timeliness and experience. Validation of such conceptual frameworks, will harness their capacity to represent the interconnections between different parts of the physical system and allow researchers and policymakers to analyse and explore feedbacks. Furthermore, these conceptualisation offer basis for multi-disciplinary discussions to develop possible pathways forward in resilience research and practice.

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