RECONCEPTUALISING HOSPITAL FACILITY RESILIENCE TO EXTREME WEATHER EVENTS USING A PANARCHY MODEL

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Hospitals represent critical social infrastructure assets that are essential for the effective functioning of any society and economy. The increasing incidence of climate-related extreme weather provides major challenges for hospitals and there is increasing evidence of hospital services being disrupted during such events. Given the vulnerability of hospitals to extreme weather and the significance of their service delivery to social and economic wellbeing, there is an urgent need for research into the factors that contribute towards hospital resilience in these situations. Using a panarchy model to integrate theories of ecological resilience, adaptation and learning, a new conceptual framework is presented to inform future research in this area and the way that hospital buildings are managed, used and adapted to make them more resilient to EWEs.

Keywords: hospital, panarchy, resilience, learning, adaptation

INTRODUCTION

It is essential to community health and wellbeing that hospitals are designed and constructed to remain operational both during and after extreme weather events (EWEs). EWEs are defined as "rare and severe occurrences of a climate variable above (or below) a threshold" [that is at] "either end of the continuum of the observed climate variable" (Field et al.,2012:7, Linnenluecke and Griffiths, 2010:2). EWEs include major flooding events, severe storms, prolonged heat waves, hurricanes and cyclones and the inability to prevent or predict such events creates a major challenge for many organisations (Chapman and Arbon 2008; Field et al 2012). In particular, in planning how to design and construct hospitals to enable users to respond to EWEs managers are faced with the dilemma of allocating limited resources to plan for future EWEs when they have no certainty of being directly affected by them (Winn et al. 2010). Given the low probability-high impact nature of EWEs, research indicates that the normal human response is to gamble on an event not happening and defer any response to the future, reacting to any event that may potentially occur rather than

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planning for it in advance (Taleb 2007). This is especially likely to happen in a resource-constrained environment like healthcare, despite the impact of EWEs on hospital infrastructure being potentially significant and widespread. These impacts range from direct damage to physical hospital infrastructure to changes in patient admissions which affects the way that hospital users interact with their built environment.

While research into the impact of EWEs on human health and hospital admissions is well advanced, research on built infrastructure impacts has just begun and there are no conceptual frameworks yet developed to guide it. However, we do know that in practice, hospital service delivery is increasingly being disrupted during such events (Loosemore et al 2010). Recent studies from a resilience perspective have focused on the physical capacity of a hospital to deal with disasters (Bruneau and Reinhorn 2007; Bosher 2008; Cimellaro et al. 2010). While valuable, when viewed from a socio-ecological perspective, there is a need for a wider focus on human capacity to adapt to improve the performance of the overall system. A better understanding of how people adapt to their hospital built environments during times of stress imposed by an EWE has important implications for the way that hospital buildings are designed, managed, used and adapted to make them more resilient. To address this need, the aim of this paper is to advance the theoretical notion of socio-ecological resilience as a new way to better conceptualise an understanding of hospital facility resilience to EWEs. Without a theory there is no basis for empirical research, so this paper presents an essential theoretical contribution to knowledge in this area rather than an empirical one.

RESILIENCE

In recent years, the terms ‘resilience’ and ‘adaptation’ have started to appear in the disaster management literature. Resilience literally means 'to bounce back' (Holling 1996) and has long been used to describe the elastic property of materials. This physical view has been applied as a metaphor to humans and communities. Despite widespread adoption of the term in the organisational literature, ‘resilience’ has different meanings to different people. So to clarify the perspective of this paper, in considering how hospitals respond to EWEs we are interested in resilience associated with the dynamic nature of systems, and their ability to react and to respond to shocks and keep delivering necessary healthcare services to the community (Holling 2001).

Importantly, in the field of ecology, a resilient ecosystem can ‘bounce back’ and maintain physical equilibrium in the face of a disturbance, or it can ‘step forward’ to a new state (Folke et al. 2004). The ecology literature differentiates between these two different types of resilience as: engineering and ecological resilience (Holling (1973, 1996). Holling (1973) defines engineering resilience as: the ability of a system to return to an equilibrium or steady-state after a disturbance [such as an EWE]. In contrast, ecological resilience is defined as the magnitude of disturbance that can be absorbed before the system changes its structure in order to remain within critical thresholds. Hence, engineering resilience differs from ecological resilience where the former relates to stability and the speed of return, the latter relates to flexibility and instability with a tendency to change into new states (McDaniel et al., 2008). Despite these differences which are rooted in different disciplinary traditions, what underpins both perspectives is the belief in the existence of equilibrium in systems, be it a pre-existing one to which a resilient system bounces back (engineering) or a new one to which it bounces forth (ecological). This common principle is now incorporated into contemporary definitions of resilience which see it as the potential of systems to change state or bounce back, and has been defined as "the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions" Hollnagel et al., 2011:xxxvi).

Research has shown that the resilience of physical and social systems is determined by four main properties: robustness, rapidity, resourcefulness and redundancy (Bruneau et al. 2003). Robustness is about the inherent strength or resistance in a system to withstand stress without losing its functionality. Rapidity refers to the speed at which disruptions can be overcome in a timely manner and avoid future loses. Resourcefulness indicates the diversity of options and redundancy reflects the ability to mobilise available resources efficiently. In a hospital context, resourcefulness can be described as the availability of back-up medical supplies as well as utilities services such as power generator, water supplier, and communication systems to maintain hospital service delivery during EWEs. Redundancy is the hospital system properties that allow for alternative options and choices to maintain their services such as using other health facilities (such as other community buildings and outpatient centres), back-up generators (to supply electricity), alternative travel routes (to get patients in and out) and alternative suppliers of drugs and equipment to deliver healthcare to the community. Robustness is provided by the physical strength of the building materials (strengthened shatter-proof glass, windows that are not blown-out by high winds, drains that prevent flooding to basements where services tend to be located, roofing materials that do not get torn off by winds etc.) Lastly, rapidity signifies the ability to re-build the hospital infrastructure and return quickly to 'normal' or 'new normal' (improved) system functions. From a built environment perspective this is provided by flexible designs and demountable or prefabricated materials that can be bolted back together after an EWE.

It is interesting, although not surprising, that research into infrastructure resilience adopts the engineering resilience perspective which focuses on the robustness of the built facility and the recovery time for the facility to return to normal service delivery (McDaniels et al., 2008). Hence, from an engineering perspective, Figure 1 presents a graphical illustration showing how infrastructure form and function can vary over time in the presence of an EWE. The graph illustrates the patterns of response in relation to EWEs and the slopes/scales may vary depending on the magnitude and duration of EWEs and the properties of the facility. The rate at which the infrastructure functions are lost indicates their susceptibility to EWEs as well as the magnitude of EWEs. As noted above, the extent of this loss depends on the robustness of the facility. Alternately, the rate at which the infrastructure recovers and returns to a 'business as usual' state indicates rapidity.

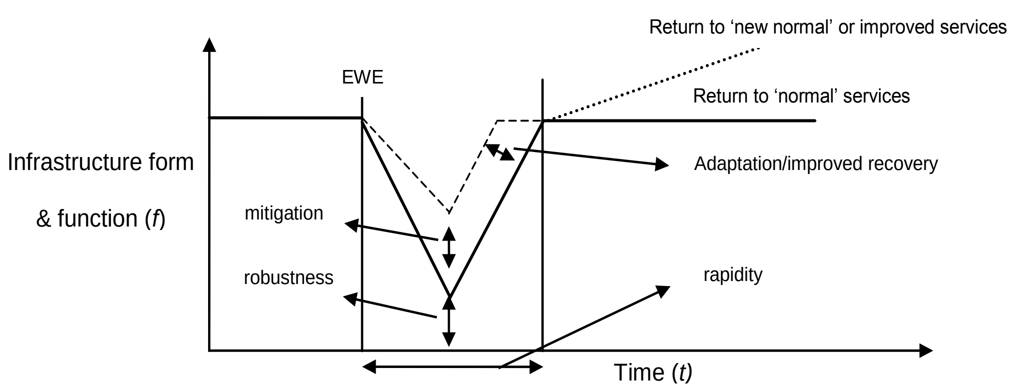

Figure 5: Quantitative measure of hospital facility resilience (source: McDaniels et al., (2008)

delivery. Hence, both perspectives of resilience highlight the significance of change in informing the performance of a system such as a hospital facility. Acknowledging change in improving resilience is demonstrated through a process called ‘panarchy’.

PANARCHY

The term ‘panarchy’ emerged from the field of ecological resilience to describe the process by which evolving hierarchical systems with multiple interrelated elements have to constantly interact with, and adapt to, their ever changing environments to remain stable (Gunderson and Holling 2002). Gunderson and Holling (2002) have developed the 'adaptive cycle' as a conceptual illustration of this process. The cycle is represented by four phases: exploitation/rapid growth, conservation, release, and reorganisation (Figure 2) (Gunderson and Holling 2002). Rapid growth (r) occurs during post-disturbance periods as a system’s environment stabilisers. As resources are built up, the system also enters into a mature and stable state (K). Stored resources are released when faced with a new disturbance (Ω) and the system begins to reorganise (α) as resources are made available, leading to a new period of stability and so-on. The adaptive cycle has been applied to many complex systems such as human and environment to assist in conceptualising and understanding resilience. However, its value has never been explored in the context of how hospitals (or indeed any other type of built infrastructure) can respondent effectively to threats such as EWEs.

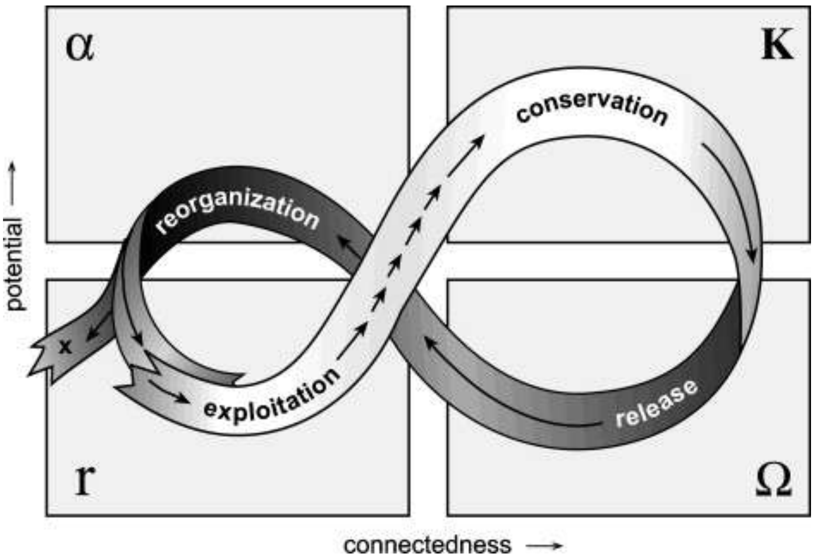

Figure 6: The panarchy adaptive cycle model (Source: Gunderson and Holling 2002)

Although a hospital facility is a complex multi-level system that is embedded within other complex multi-level systems (such as emergency services) in the community, we can demonstrate the value of the model by looking at the adaptive cycle at the level of the hospital as a single entity and in an idealised situation (Figure 3).

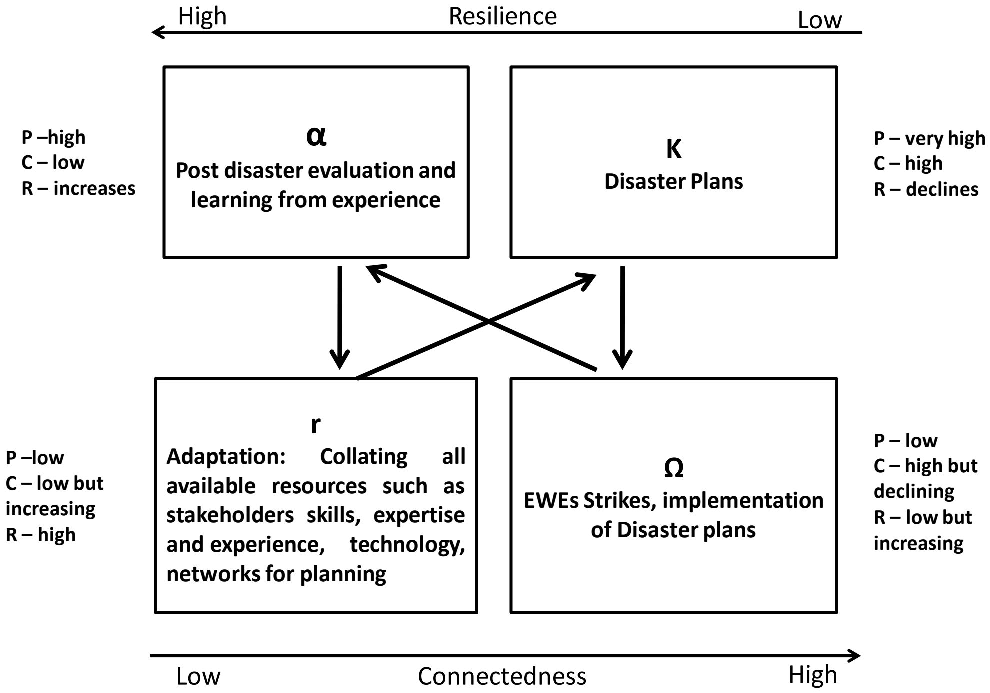

Figure 7: Hospital Facility Resilience Adaptive Cycle in normal scenario

In Figure 3, hospitals develop and store their disaster plans to deal with future disasters (K) which are then used to guide and coordinate actions when an EWE strikes (Ω). These disaster plans have many dimensions and including the way that the building is managed, used and adapted during an EWE to ensure that healthcare services can continue to be delivered to the community. In reality, no matter how thorough the planning, disaster plans are never perfect and in an ideal world hospital stakeholders learn from this experience and re-organise themselves to better cope with the on-going situation (α). While the connectedness is low, the potential to create new directions and pathways is high with individual learning thus increasing the resilience potential. The lessons learnt encourage the re-organisation of disaster planning structures and processes (including facilities management and building adaptation) enabling greater resilience to future EWEs (r). But as adaptation process draws closer to policy development, the connectedness between the hospital stakeholders on the structure increases, and pattern of disaster planning becomes increasingly rigid. Hence the hospital's resilience to EWE shock declines. The cycle continues as these new planning structures are stored as organisational knowledge and become imbedded once again leading to a new round of learning and adaptation. Recent research calls the type of resilience which is generated in this way (through learning from adverse events) 'evolutionary resilience' (Davoudi 2012).

It is also important to note that in Figure 3, each of the four phases are characterised by different levels of change in three dimensions: 1) the potential for accumulated resources available to the system which in context relates to appropriate policy plans (P); 2) the internal connectedness of the system components such as the hospital stakeholders dependence on the disaster planning structure and the pattern of developing the plans (C); 3) resilience, a measure of system's ability to deal with shocks which in this context related to collective learning and reasoning amongst hospital stakeholder during disaster planning that is associated with creativity and flexibility of disaster responses (R) (Gunderson and Holling 2002).

Another feature of the adaptive cycle is that the pathway between the four phases is not fixed but can vary subject to circumstances. For example, in Figure 4, after the disaster plans are prepared, the hospital carries out regular disaster drills and disaster education. In contrast to Figure 3, the cycle moves from ‘disaster plan’ (K) phase directly into ‘post disaster evaluation’ (α) phase, rather than waiting for an EWE to determine the way forward. Hence even in the absence of an EWE there is continuous learning and adaptation which prepares the hospital to deal with the challenges posed by EWEs more effectively and efficiently.

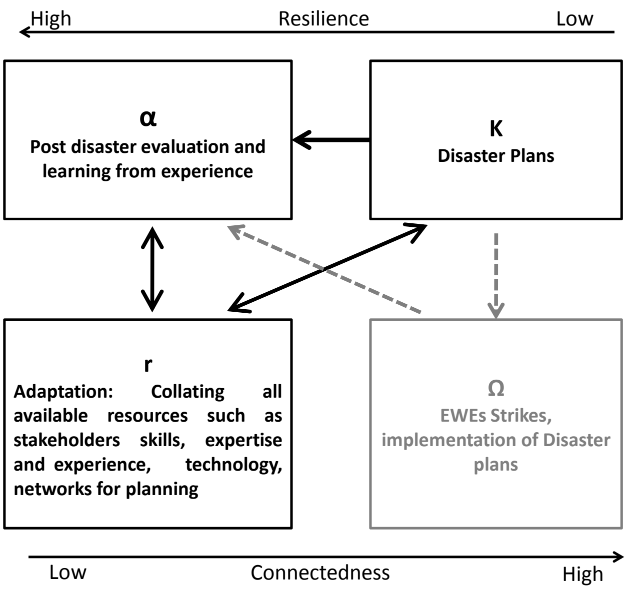

Figure 8: Hospital Facility Resilience Adaptive Cycle with continuous learning

The adaptive cycle also interacts across scales which indicate the interaction between various health sub systems at different levels. For example, Loosemore et al.'s (2012) analysis of hospital sub system interdependencies during an EWE using rich picture diagrams highlighted that the resilience of a single hospital system is also dependent on the resilience of other linked or interdependent systems in the wider community. For instance, cross scale interactions can occur with other healthcare infrastructure such as aged care facilities, or primary care (GP) centres. In other words, the resilience of hospital buildings cannot be treated in isolation but must be seen as part of a much bigger interdependent health infrastructure system. The necessity of engaging at multiple scales requires greater participation, open communication and networking, and these are critical in establishing trust and collective decision making amongst the hospital stakeholders who manage the resources for disaster response (Lebel et al. 2006). The key to the successful adaptation of an organisation to a changing environment is to recognise and leverage the various sub-systems associated with that organisation (Barabasi and Crandall 2003). The interconnectedness across scale and networks can encourage greater flexibility in planning and better coordinated response during disaster (Schein 1996). It also helps in identifying the gaps and redundancies in the wider community, such as facilities that can be utilized to continue hospital service delivery despite failure of the primary hospital building due to structural damages.

The above analysis illustrates that organisational learning amongst various hospital stakeholders is necessary for effective adaptation. As hospital stakeholders' knowledge, skills and understanding of EWE vulnerabilities increase, it facilitates interactions, collective reasoning and decision making for disaster response. As Field et al. (2012) point out, inter and intra organisational learning is central to adaptation and pivotal to improving organisational resilience to EWEs.

LEARNING

The Panarchy model is useful to understand how systems such as hospitals adapt and respond to EWEs. However, this model is limited in explaining the process of learning that facilitates adaptation. Hence, we draw from Nonaka and Takeuchi's knowledge creation SECI model (Figure 5) to help elaborate on this process.

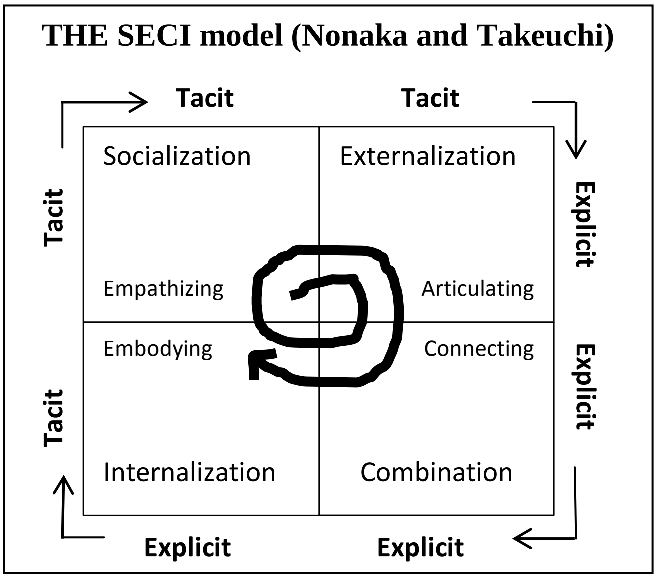

Figure 9: The SECI knowledge conversion model (Source: Nonaka and Takeuchi 1995)

Like the Adaptive Cycle, the SECI model consists of four phases that can help conceptualise the process of learning and knowledge transfer in hospitals during an EWE. In the SECI model, socialisation is the process of articulating tacit knowledge (lessons of past EWEs). Externalisation occurs when tacit knowledge is made explicit (people record the lessons in the form of disaster procedures). Combination is the process of connecting discrete elements of explicit knowledge into an explicit knowledge set that is more complex and systematic than any of its parts. In the context of responding to EWE's, this process involves the formulation of 'disaster management plans' which seek to bring disaster procedures together into a unified system of response. Finally, internalisation is the process of embodying this explicit knowledge as tacit knowledge to create a shared mental model between all stakeholders involved in responding to an EWE. When this embodied tacit knowledge is shared with other individuals it sets off a new spiral of knowledge creation through socialisation etc. In the context of responding to EWEs, this process may involve amendments to the disaster policy or procedure in responding to EWEs that is shared and accepted across the hospital.

RECONCEPTUALISING HOSPITAL FACILITY RESILIENCE

We can combine the resilience and learning theories discussed above to propose a new conceptual framework of hospital resilience which is focussed on the process of 'adaptive learning'. This new framework is called the Hospital Resilience Learning Cycle (HRLC) (Figure 6). The HRLC model is a dynamic model and illustrates that the process of learning and adaptation are inextricably linked in enhancing hospital facility resilience to EWEs. Since it combines both the adaptive cycle and SECI model it also has four phases: develop disaster plans, implement disaster plans, behavioural learning and social learning.

The HRLC model is a continuous cycle and in a practical sense it begins with phase one (develop disaster plan).

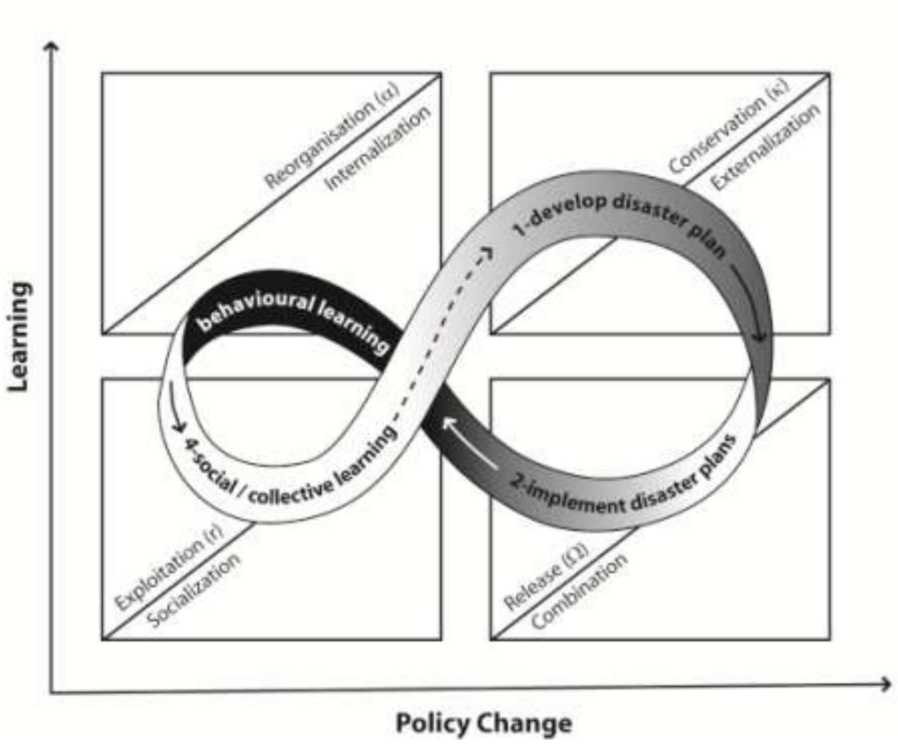

Figure 10: Hospital Resilience Learning Cycle

Phase 1 (Develop Disaster Plan) is the conservation phase of the adaptive cycle where the hospital develops an organisational memory in the form of disaster management plans. This phase relates to the externalisation phase of the SECI model where tacit knowledge from stakeholders' experience of EWEs is made explicit and recorded in the form of written procedures such as disaster plans. As pointed out above, this includes plans relating to how the building will be managed, used and adapted during an EWE.

Phase 2 (Implement Disaster Plan) relates to the release phase of the adaptive cycle and represents the deployment of resources through the implementation or activation of disaster plans developed in the conservation phase to deal with an EWE. It also relates to the combination phase of the SECI model since it involves integrating individual expertise from different parts of the organisation which are required to work together to manage, use or adapt the building to collectively deal with an EWE.

Phase 3 (Behavioural learning) is equivalent to the reorganisation phase in the adaptive cycle and the internalisation phase in the SECI model. It involves the restructuring of the organisation post disaster as the lessons learnt from the implementation phase are shared between the stakeholders (including those involved in managing, using and adapting the building) and absorbed to instinctively inform future responses.

Phase 4 (Social and collective learning) relates to the exploitation phase in the adaptive cycle and the socialisation phase in the SECI model. Here there is a rapid accumulation of new tacit knowledge as hospital stakeholders involved in a disaster response come together and share their experiences (including about how the building is managed, used and adapted). This accumulation of tacit knowledge is converted to explicit knowledge in the form of changes in the existing policy or development of new policies and plans in the first phase of the HRLC model (develop disaster plans) which continues the on-going adaptation over the life of a hospital to maintain its resilience.

CONCLUSIONS

The aim of this paper was to reconceptualise hospital facility resilience to EWEs using a Panarchy model which emerged out of ecological resilience theory. The HRLC model provides new behavioural insights into hospital resilience and has important implications for designing, facilities management and adapting hospitals to make them more resilient. It shows that EWEs provide an opportunity for learning amongst and between different hospital stakeholder groups and individuals, better preparing them to deal with disaster situations and informing future disaster planning. While pre-disaster knowledge is critical in initial disaster planning and design, post-disaster learning provides feedback on the effectiveness of the existing designs and facilities management enabling learning (about design performance and how people adapt to their built environment) which allows improvements to be made in the future. The implications for facilities managers and hospital designers is that they must be included in this learning process so that they can, like other hospital stakeholders, have the same opportunity to learn any lessons which may influence the way in which hospital buildings are managed, used and adapted to ensure that healthcare continues to be delivered to the community during an EWE. Given the traditional disempowerment and exclusion of health facilities managers from hospital planning and management processes, on-going research is exploring, not only the extent to which hospital building issues are incorporated into the initial disaster management plans in the conservation/externalisation stage of the HRLC model but to what extent facilities managers and designers are included in subsequent stages of the cycle to enable them to learn and adapt their facility to EWEs.

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