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Development of a tool for assessing commercial building resilience

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Abstract

Built environment resilience is becoming a more established concept, although there are no schemes yet devised to comprehensively measure building resilience from the point of view of a commercial building owner. For a commercial building owner, 'building resilience' can be defined as the ability to protect, maintain, or restore the functionality of, value of, and income generated by a building after a damaging event or circumstance within a prescribed time frame. There is a need to measure the resilience of individual buildings to help owners make better decisions and protect their assets, to better assess the built environment resilience of larger geographic units such as communities and cities, and to complement existing assessments of building sustainability. Based on a conceptual examination of resilience measurement and a review of the literature and other resources, this study develops a new resilience assessment tool: the Australian Resilience Measurement Scheme for buildings (ARMS). The scheme adopts resilience as a holistic concept incorporating physical, infrastructural, environmental, economic–social, political–regulatory, and organisational resilience, and is rated according to dimensions, subdimensions, and items scored on a points system. The scheme will allow the aspects in which a building is performing well or poorly to be identified as well as give an overall resilience rating. This paper also examines the lessons to be learned from sustainability assessment tools for measuring and assessing resilience in terms of tool structure, the weightings of items and dimensions, item measurability, whether items are performance based or feature based, and benchmarking. The tool is its infancy, and work to further develop it is continuing. As has occurred with the assessment of building sustainability, the assessment of building resilience will increase in importance to stakeholders of the built environment.

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Keywords: Resilience of buildings; resilience assessment tool; metrics; Australia

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1. Introduction and background

1.1. Resilience and the need to measure it

The sustainability of the built environment and of individual buildings have long been a focus of research, including the development of systems for assessing/rating aspects of building sustainability such as energy efficiency, water use, and waste. Attention is now turning to built environment resilience. The US Department of Homeland Security Risk defines resilience as ‘the ability to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruption’. Bosher [1] defines a resilient built environment as one ‘designed, located, built, operated, and maintained in a way that maximises the ability of built assets, associated support systems (physical and institutional) and the people that reside or work within the built assets, to withstand, recover from, and mitigate the impacts of threats.’

Much more work has been directed towards examining resilience at the city and community scales [2] compared with the resilience of individual buildings. However, McAllister [3] has noted the lack of metrics available for measuring resilience and has called for such metrics to be established to assess built environment resilience at various scales from buildings to cities. Compared with the assessment of sustainability, for which many tools (e.g., BREEAM, LEED, GSAS, BEAMPlus) are available for rating the sustainability of individual buildings, tools for assessing resilience at the individual building level have only just started to be developed. For the case of an individual building, resilience could be defined as the ability to maintain or restore the functionality of a building after a damaging event/occurrence within a particular time frame.

Because the built environment continues to be vulnerable under certain circumstances and events [3], resilience needs to be measured so that weaknesses and gaps can be identified and improved, thereby better protecting the built environment, its functionality, and the connected economic and social domains. Furthermore, resilience needs to be improved so that built environment sustainability can be better protected. A building (or community) can be sustainable, but if it is not also resilient to disruption and disturbance, then sustainability is threatened, and the building (or community) is put at risk. Designing for resilience as well as sustainability is the approach needed for coping with uncertainty.

1.2. The assessment of resilience: conceptual considerations

Considerations in the assessment of resilience include the issues of ‘The resilience of what’? ‘For whom should it be measured’? ‘The resilience to what’? and ‘Why should it be measured’? Resilience in (and of) the built environment is viewed here as a holistic, multi-dimensional, multi-scale concept that cuts across the physical, infrastructural, environmental, economic–social, political–regulatory, and organisational domains. The scope of this paper is not to offer an approach for assessing the resilience of each of these domains, or of the built environment per se, but rather, with respect to the question of ‘the resilience of what’, the paper offers an approach to assessing the resilience of individual buildings in the context of these domains. That is, the system proposed is a building resilience rating tool, but one that considers a holistic range of resilience dimensions acting on a building to make the rating.

It is also essential to examine ‘resilience for whom’. This question refers to the various stakeholders, actors, and participants in the built environment—those responsible for its design, creation, operation, and maintenance. Such actors include: construction and property industry professionals such as material manufacturers, designers, engineers, architects, builders, and valuers; building owners; investors and financial institutions such as banks; regulators; occupants and users of buildings including tenants and workers; governments at the local, regional, and national levels; communities; and others including business and environmental groups. These various actors/stakeholders likely have differing conceptions of building resilience, of its importance, and of its assessment. This paper focuses on measuring building resilience from the perspective of building owners. Building owners have the greatest amount of investment in the functionality of the building, in the building as an asset, in the costs of constructing and/or maintaining it and operating it, and in the income obtained from its use (e.g., the owner using/occupying it or renting it to tenants). These facets are all of most concern to the building owner, to whom resilience, therefore, should be of vital importance.

The third aspect of resilience to consider is ‘resilience to what’? For the building owner, this is considered in terms of maintaining and protecting the functionality of the building, the asset value of the building, and the income derived from the building. Therefore, any threat to these aspects should be regarded as part of a conception of resilience, and thus the term covers the wide range of dimensions as identified above, including slow and fast environmental hazards, the physical design and condition of the building, surrounding infrastructure, and regulatory, economic, social, and organisational factors.

Fourth, as to 'why', there is a need to assess buildings for resilience for several reasons: (i) to identify and reduce vulnerabilities in building resilience; (ii) to assist building owners to plan for damaging events or circumstances; (iii) to help owners make informed decisions about their building(s) and better understand and protect their building(s) in terms of functionality, as an asset, and as a source of income; (iv) more widely, so that a more accurate and comprehensive picture can be attained of district, community, and city built environment resilience; and (v) to complement existing assessments of individual building sustainability.

Given the above, this paper presents an initial attempt at developing a resilience measurement tool from the perspective of the building owner, to be applied to individual buildings, with particular reference to commercial buildings in Australia. For the owner of a commercial building, 'building resilience' is here defined as the ability to protect, maintain, or restore the functionality of, value of, and income generated by a building either before a damaging event or circumstance, or after it within a prescribed time frame.

A very limited number of resilience assessment tools have recently started to be developed. One such tool is the Building Resilience Rating Tool (BRRT) developed by the Insurance Council of Australia (https://www.resilient.property). The BRRT is aimed at measuring and assessing the resilience of residential homes from the perspective of insurers. The tool uses hazard data about several hazards (including inundation, severe rain/hail, cyclone, bushfire, and earthquake) in a GIS database format. These data are overlain on data about building design and material characteristics that reflect resilience (in other words, the characteristics that will affect how the building may respond to natural hazards), and include such elements as floor height, roof cladding type, and the type and strength of external walls, windows, and external doors. The overlay of the two datasets produces an assessment of resilience for each house in the selected area with respect to each hazard on a 0 to 5 rating system for individual characteristics as well as an overall rating. The tool shows promise and is currently under development in a test phase. The resilience assessment tool presented in this paper differs from the BRRT in several respects, including: (i) The proposed tool measures the resilience of commercial buildings, whereas the BRRT measures residential housing resilience; (ii) The proposed tool measures building resilience from the point of view of a building owner, whereas the BRRT measures resilience for the purposes of insurers; (iii) in addition to the physical characteristics of the building and natural hazards, the proposed tool measures a much wider range of resilience dimensions, covering infrastructural, economic–social, political–regulatory, and organisational resilience; and (iv) the proposed tool measures a different array of subdimensions and items for physical building characteristics compared with the BRRT.

2. Development of the resilience assessment tool

The development of the presented tool is based on a review of more than 40 studies, including the academic literature and publications prepared by a diverse range of organisations. The studies were identified using keyword-based database searches relevant to the resilience of the built environment and of buildings. The selected studies were examined for conceptual content as well as aspects relevant to the measurement, assessment, or rating of building resilience. Dimensions, subdimensions, and items of resilience were developed by extracting concepts, ensuring that: (i) a rationale or evidential warrant was given for their importance; and (ii) they were relevant to the owner's interest in the building, i.e., affecting the resilience of a building in terms of its functionality, its value as an asset, and as an income generator. Concepts between studies were cross-checked, as were different terminologies for the same resilience aspect. A matrix was used to collate the different aspects, which were distilled into a set of dimensions and items capturing relevant aspects of building resilience.

Four information sources or literature streams were investigated to obtain conceptual and operational insights into developing a building resilience assessment system. These were: existing tools for the assessment of building sustainability; literature on community resilience/vulnerability; literature on the resilience and recovery of regions and cities with respect to environmental events/hazards and technological/human hazards; and approaches to and tools for measuring city/urban or infrastructural resilience. For the sake of brevity, only a small but representative sample of the selected source studies for developing items are cited here: Malalgoda et al. [2], McAllister [3], Valdes et al. [4], Bosher [5], Cutter et al. [6], Bahadur et al. [7], and Prieto [8].

The first iteration of the tool contains six resilience dimensions each containing several subdimensions. The subdimensions each contain items scored on a 5-point scale format, where 1 = 'very low / non-existent', 2 = 'low', 3 = 'moderate', 4 = 'high' and 5 = 'very high'. These points are summated to give subdimension scores, dimension scores, and an overall resilience score. The scheme allows the individual aspects in which a particular building is performing well/badly to be identified as well as providing an overall rating.

3. The resilience assessment tool

Table 1. Dimensions and subdimensions for measuring individual building resilience.

Dimension	Subdimension
Physical	Characteristics and quality of building information technology systems
	Quality of architectural design, construction, and materials
	Physical, mechanical, and electronic security
	History of building systems, including reported faults, maintenance, and upgrades
	Present condition of building structure and fabric
	Present condition of building mechanical, electrical, and plumbing systems
	Quality of warning and anti-damage systems such as fire alarms and sprinklers
Infrastructural	Characteristics and quality of the surrounding transportation system
	Characteristics and quality of the grid electricity system
	Characteristics and quality of the water supply system
	Characteristics and quality of drainage and wastewater and other infrastructure
	Characteristics and quality of communications infrastructure
	Presence and extent of self-sufficient building power and water supply
	Performance of utility companies for restoring services after a destructive event
Environmental	Availability and quality of environmental information, e.g., hazard maps, forecasts
	History of exposure to destructive events
	Hazard presented to the site/building by current or forecast of flooding
	Hazard presented to the site/building by forecast sea-level rise
	Hazard presented to the site/building by current or forecast level of bushfire
	Hazard presented to the site/building by current or forecast intensity of cyclone
	Hazard presented to the site/building by other natural events or conditions
	Proximity of site/building to emergency services
	Features of building incorporated specifically for resilience to hazards
	Site and positioning of building with respect to adjacent buildings and land uses
Economic–Social	Strength and resilience of local economy
	Strength and resilience of sectoral economy
	Social characteristics and social capital of the surrounding community
	Building use and occupancy
	Life safety and wellbeing of occupants/users
Political–Regulatory	Local government characteristics favouring built environment resilience
	Regional government characteristics favouring built environment resilience
	National government characteristics favouring built environment resilience
	Characteristics of building code and standards with respect to resilience
Organisational (building owner)	Existence and quality of business continuity plan
	Risk identification, analysis, assessment, and management
	Quality and reliability of decision-making processes
	Communication both internal and external to the organisation
	Awareness of and compliance with the political and regulatory landscape
	Economic aspects of organisational decisions regarding building asset

The tool includes six main dimensions of resilience: physical, infrastructural, environmental, economic–social, political, and organisational, as outlined briefly below. Because of space limitations, the full list of proposed dimensions and subdimensions is presented (Table 1) but only selected example subdimensions from the tool are shown fully itemised (Tables 2, 3 and 4).

3.1. Physical dimension

Physical resilience refers to the design, physical configuration, materials, and engineering aspects of a building. In this respect, a building's systems include architectural, structural, life safety, mechanical, electrical, plumbing, security, communication, and information technology systems, as well as the connections to external infrastructure and services. Ideally, these systems need to achieve a similar (and high) level of performance with respect to resilience. The condition of these systems and their history of faults/maintenance give a good measure of their resilience. Redundancy (the duplication of system components or functions to increase reliability) is an important aspect of building resilience. Physical resilience also includes accounting for the effects of repairs, material deterioration, and system degradation over time. Items for the 'History of building systems' subdimension are given in Table 2.

Table 2. Physical dimension: selected subdimension and items.

Subdimension	Item
History of building systems	Age of building and building standards/guideline/code applying when constructed
	History of faults and regularity/extent of maintenance of building fabric
	History of faults and regularity/extent of maintenance of building structure
	History of faults and regularity/extent of maintenance of building facade
	History of faults and regularity/extent of maintenance/upgrade of mechanical systems
	History of faults and regularity/extent of maintenance/upgrade of electrical systems
	History of faults and regularity/extent of maintenance/upgrade of plumbing systems

3.2. Infrastructural dimension

The infrastructural aspects of resilience relate to the connections to and the quality/reliability of local and regional infrastructural elements. These include systems for electrical power, water, electronic communications, transportation, sewerage, and waste/stormwater (e.g. [9]). All of these infrastructural systems are essential for the functionality of buildings. Resilience in these systems concerns their vulnerability to damage or failure, the impact of that damage or failure on the systems themselves, the flow-through impacts on the buildings connected to or reliant on such systems, and the speed and quality of system recovery from damage/failure. Failures of various magnitude and duration can affect any part of the infrastructural system. As an example, measurable aspects of electrical system infrastructural resilience with respect to a building could include utility companies' performance targets for and history of recovery and restoration of supply after a damaging event.

3.3. Environmental dimension

Environmental resilience is the resilience of a building to environmental phenomena. Developing environmental resilience capacity requires quantifying the environmental processes and disturbances that a particular building or site is likely to face, including the frequency and intensity of these events, and identifying how adaptive capacity can be built to cope with them. Such events or phenomena to be considered for many sites in Australia, based on historical data and well-constrained hazard risk information, include bush fires, riverine and marine flooding, cyclones, sea-level rise, and climate change. Climate change scenarios suggest altered frequencies and intensities of cyclones and increases in average and maximum temperatures. Climate change along with sea-level rise will alter the return periods of design environmental events and modify the risk profile of many built environment assets. Environmental resilience also includes site-scale aspects such as building adjacency issues.

3.4. Economic–Social dimension

An assessment of resilience also requires considering economic and social aspects. Economic aspects here refer to the wider economic environment as a context for the value and use of a building, including economic change and disturbance. From a building owner's point of view, factors such as the strength of and outlook for the sectoral economy within which the building use is placed, help indicate whether the building is economically resilient, as do building-specific indicators such as vacancy rates. Social resilience has two aspects. One is the characteristics of the community in which the building is located, including its social capital. The second aspect considers the building-specific measures of use and occupancy, as well as the life safety and well-being of occupants and users, which are human aspects of social resilience.

3.5. Political–Regulatory dimension

The political sphere includes the influence of legal frameworks, legislation, and policies applying to the design and operation and function of buildings, as well as those applying to the various activities of built environment stakeholders/actors. A key component is the building code and the standards and guidelines contained therein. The building regulation process inherently involves a trade-off between the rights of individuals to build in the manner that best suits them and the rights of society to have safe buildings in which to conduct commerce, work, and reside. Building codes represent a compromise between acceptable safety and reliability and economic practicality. This dimension also includes the capabilities and responsibilities of the various levels of government (local, regional, and national) with respect to formulating policies and actions that promote resilience, as well as the effectiveness of their planning and performance in dealing with events and emergencies, and the quality of their relationship with built environment stakeholders. Items for the 'Building code' subdimension are given in Table 3.

Table 3. Political–regulatory dimension: selected subdimension and items.

Subdimension	Item
Building code	Resilience characteristics are contained in building codes, standards, and guidelines
	Risk or reliability bases for hazards and built environment performance levels are consistent for different building elements
	Standards and guidelines in the building code are consistent with the latest environmental hazard/risk information
	Systems are in place to ensure that development in an area complies with building and planning regulations, including standards and codes
	Hazard/risk maps are integrated into the urban development plan and used as part of the planning permission process
	Extent to which existing buildings are required to meet current codes and standards
	Degree to which building standards and codes are changed over time to reflect available risk information and in response to events/disasters

3.6. Organisational dimension

Previously overlooked in this context, but nevertheless crucial to the resilience of buildings, are the characteristics of the organisations that control and make decisions about the building, namely, the building owners themselves (or their representatives). A more resilient organisation protects itself, its activities, and its interests by proactively anticipating change and disruption, and responding and adapting to externalities. Key aspects of organisational resilience are its ability to identify and manage risk and to develop high-quality decision-making processes. Risk, for an organisation, is the effect of uncertainty (stemming from both internal and external sources) on the achievement of its objectives. One way of modifying or managing risk is through insurance. Risk management describes how an organisation identifies, monitors, and treats risk (both threats and opportunities), and provides a reliable basis for decision-making and planning. Organisations should integrate processes for managing risk into all aspects of their activities (e.g., ISO31000), should ensure that risk–resilience analysis and management are used as the basis for developing and implementing decisions about buildings, and should have procedures in place for maintaining decision-making quality in dynamic conditions. Items for the ‘Risk identification and management’ and ‘Economic’ subdimensions are given in Table 4.

Table 4. Organisational (building owner) dimension: selected subdimensions and items.

Subdimension	Item
Risk identification and management	Quality and coverage of building asset insurance
	Quality and coverage of business interruption insurance
	Extent to which the organisation incorporates risk management guidelines as specified by standards such as ISO31000
	Ability to detect changes in resilience of building asset due to damage, repairs, maintenance, upgrades, and changes in functionality before and after hazard events
	Ability to analyze past hazards/events and impacts on building and plan accordingly
	Individuals or section(s) in the organisation that are responsible for aspects of risk management are clearly identified
Economic	Time and cost of recovery of partial and full functionality and occupancy of building after a destructive event in terms of usability and safety
	Economic and technical means available to reconstruct damaged buildings and restore functionality
	Use of economic tools/metrics to evaluate cost–benefit of potential improvements to building resilience and to compare mitigation and recovery options

4. Measuring and assessing resilience: lessons from sustainability tools

The measurement and assessment of building resilience are in their infancy. However, developing an approach for resilience measurement and assessment can be informed by sustainability rating tools. Sustainability rating tools are now well established, having gone through several phases of development and refinement over the last two decades. These tools cover a range of environmental aspects including energy efficiency, site characteristics, water use, waste, indoor environmental quality (IEQ), materials, building management, and ecology. Examples of such tools for rating the sustainability aspects of existing buildings (i.e., rating operational sustainability) include NABERS (Australia), BREEAM In-Use (various countries) LEED Operations & Maintenance (various countries), Green Mark for Existing Buildings (Singapore), and BEAM Plus for Existing Buildings (Hong Kong).

Based on an examination of documentation (guides, manuals, and technical briefs), Burroughs [10] made a comparative evaluation of 11 sustainability rating tools for building energy efficiency, and found that the tools vary with respect to the following aspects of energy measurement: (1) The weighting given to the energy-efficiency category relative to the overall rating and to other sustainability components/categories such as water, waste, and IEQ; (2) The use of feature-based energy items versus the use of performance-based energy assessment to assess energy efficiency, or a hybrid combining both; (3) The particular energy subcategories and items used and their weightings; (4) For the feature-based and hybrid approaches, the particular items and subcategories that are used to indicate energy efficiency; (5) For hybrid approaches, the weighting of performance-based assessment versus feature-based assessment in the energy-efficiency category; (6) The method used to assess energy performance (simulated or measured directly from data); and (7) The use and mode of energy-efficiency benchmarking.

These aspects of measuring energy efficiency are examined below in the context of measuring building resilience with regard to three topics: item and subcategory (subdimension) weightings, item measurability – performance based or feature based, and benchmarking.

4.1. Weightings of items, subcategories, and categories

It is not always clear from the documentation of sustainability tools as to the rationale for the various items, subcategories, and categories used to assess the overall sustainability of a building [11], nor for those used to assess energy efficiency within those same tools [10]. Although such tools are commonly described as ‘catering for the specific environmental, social, and economic aspects of the adopting country’, the justifications for aspects such as item/subcategory/category weightings and the particular features or items included to measure either overall sustainability or the energy efficiency/use category are commonly unclear or unavailable. For example, the energy use category is weighted at the following percentages of available credits/points in the following sustainability schemes for existing buildings: GSAS (Kuwait) 24%, Three-Star (China) 25%, GreenShip (Indonesia) 31%, BEAM Plus (Hong Kong) 33%, LOTUS (Vietnam) 33%, LEED O&M 34%, and Green Mark (Singapore) 49%.

The existing variation in the content and weightings of items and categories in sustainability assessment schemes points to the need for due consideration to be made on these aspects when designing a resilience assessment tool. The development of the GSAS sustainability tool is one of the clearer examples of how the rationale for the structure and content of a scheme was established. An Analytic Hierarchy Process (AHP) was used by GSAS developers to determine the relative importance or weights of the eight scheme categories, based on a survey of built environment stakeholders including industry and government representatives. An approach that seeks expert input along with AHP or a similar technique could also be used to establish item, subcategory, and category weightings for a resilience assessment tool.

4.2. Item measurability: performance-based or feature-based items

The approaches to energy performance assessment for the building sector can be classified into two major categories, namely performance-based and feature-based (or feature-specific) approaches [12]. Using the performance-based approach, assessment results are obtained by comparing the performance indicators (items) against established standards. Examples of performance-based items used to measure energy efficiency include CO_2 emissions and energy use intensity. For feature-based approaches, points are awarded when criteria relating to specified features are met. Feature-based items for energy efficiency in BEAM Plus for Existing Buildings (Hong Kong), for example, include specified criteria for the HVAC system used, renewable energy, lighting, appliances, and building energy management. For feature-based approaches, the overall rating is given by summing the points awarded across the feature-based items assessed and then across subcategories. Typically, feature-based items are used where performance-based items would be either impossible or unfeasible to measure.

Building rating systems may use the performance-based approach, or the feature-based approach, or a mixture of both (hybrid approach) [10]. For energy-efficiency assessment, although some schemes are entirely performance based (e.g., NABERS for Energy) and others are entirely feature based (e.g., Green Mark), the vast majority of schemes have taken a hybrid approach. The hybrid systems vary with regard to how much weighting within the energy category is given to energy performance measurement versus energy efficiency features. The points awarded have percentage weightings for energy performance versus features of 53% v. 47% in LEED O&M, 50% v. 50% in BEAM Plus, and GreenShip 67% v. 33%, for example.

The implications for measuring and assessing building resilience concern which items should be measured and whether they should/can be performance based or feature based or a mixture. An initial consideration of the resilience assessment tool being developed here suggests that items in the ‘History of building systems’ subdimension of the ‘Physical’ dimension of the proposed scheme (Table 2) could be quantified in terms of the number and severity of faults and regularity/extent of maintenance over a certain time frame, and thus these items are predisposed to being feature based. The items in the ‘Building code’ subdimension of the ‘Political–regulatory’ dimension (Table 3) also lend themselves to being feature based, assessed by presence/absence in some cases or by a sliding points scale in others. Items in the ‘Risk identification’ subdimension of the ‘Organisational’ dimension (Table 4) would appear to be best handled by feature-based measurement using a sliding scale of points. Most other subdimensions (Table 1) would likely be more amenable to being measured using feature-based rather than performance-based items, although work is continuing on this aspect of the resilience tool. Some subdimensions in the ‘Physical’ and ‘Infrastructural’ dimensions could conceivably be measured using performance-based items, and most subdimensions in the ‘Environmental’ dimensions should be suitable for performance-based measurement.

4.3. Benchmarking

The approaches to benchmarking for building sustainability can be broadly classified into (i) a comparison of assessment ratings with criterion values/standards based on statistics gained from reference sets of similar buildings (statistical benchmark or external reference), or (ii) modelled/simulated building behaviour and comparison with a hypothetical reference building (calculated benchmark or self-reference). The use of modelled building behaviour and comparison with hypothetical 'self-reference' buildings is common for comparing energy-efficiency ratings, but the tools/software and data for doing so are advanced and have been developed and refined over many years. In addition, the nature of the influences on building energy efficiency predispose themselves to be analyzed in such a way (including modelling material qualities, internal building configurations, heat transfer, occupancy profiles, and so on). The requirements for this type of self-reference benchmarking are unlikely to be achieved with respect to resilience given the content types of items that need to be measured for resilience. Therefore, the most promising pathway for benchmarking resilience assessments would appear to be through comparison with statistics gained from reference sets of buildings. A particular building would be rated for resilience by where it is positioned within the statistical distribution of the reference set, with certified rating levels (e.g., platinum, gold, silver, bronze) also being able to be identified.

5. Discussion: Major points and future tool development

This initial attempt at developing a building resilience assessment tool has confirmed, in the words of McAllister [3], that 'resilience is definitely not simple'. Some of the major points to emerge from the study are as follows. First, prior to developing metrics and tools for measuring and assessing resilience, conceptual issues such as what is resilience, the resilience of what, for whom, to what, and why, all need to be addressed. Without exploring and resolving such issues, and defining an overarching goal, an appropriate building resilience measurement tool is unlikely to be constructed, and the assessment of resilience will be misdirected and may not measure what is intended/desired to be measured.

Second, a building owner clearly has varying control over the different dimensions of resilience, which has implications for how organisations manage building resilience. The physical aspects of the building are under the owner's control, but infrastructure systems are to a large extent outside influence, although some control can be gained by self-sufficiency approaches. Environmental aspects are mainly outside control, but the owner can control risk in various ways to prepare for or mitigate hazards. Broader economic factors are essentially uncontrollable and instead require response and planning by the owner, but social/human factors such as the safety and wellbeing of building occupants are under the owner's influence. Much of the political–regulatory domain is not accessible. The organisational aspects of resilience are entirely under the building owner's control, with the key components with respect to the building being risk management and decision-making, highlighting the importance of organisational quality in the context of building resilience.

Third, as identified by McAllister [3], a plan for developing resilience in the built environment should ideally be based on performance goals for risk categorization, building/system functionality, and building/system recovery after a damaging event. This would include identifying systems by resilience performance category (e.g., critical v. non-critical), identifying specified recovery times for buildings, building systems, and infrastructure systems, and defining levels of building and infrastructural functionality. Resilience levels (e.g., routine, expected, and extreme) need to be defined with respect to associated risk-based performance goals and reliability-based hazard and failure criteria for different types of hazard. A resilient built environment considers the desired levels of functionality before, during, and after disruptive hazard events, as well as the steps needed to achieve such performance. If resilience performance goals are to be used, then corresponding metrics need to be devised to measure whether such goals are being achieved.

Fourth, the resilience of buildings depends in large part on the building codes and standards used at the time of construction. Therefore, the building code is vital, and as part of the development of resilience assessment there is a need to identify criteria for hazards and performance goals in codes and standards, as well as potential gaps such as differing risk or reliability bases for hazards and performance levels for different building types or components, or deficient risk profiling for the hazards of greatest threat across geographic areas. Ideally, resilience standards and performance criteria should be present in codes for all hazards and construction types/systems.

Fifth, lessons can be gained from the assessment of sustainability. Building sustainability rating systems such as BREEAM and LEED have evolved over time to include different components, different category compositions, and different weightings. It is likely that resilience rating tools will also evolve as information, understandings, and priorities change. Further, sustainability tools for existing buildings are of three types: performance based (measured), feature based, or a hybrid of the two. Using the first approach, assessment results are obtained by comparing performance against established standards, and for the second, points are awarded according to specified features attained across different items and categories and totalled according to point distribution. Resilience rating schemes could similarly be based on performance-based items, feature-based items, or a hybrid mixture of the two.

The development of the proposed resilience tool (ARMS) is in its infancy, and the next steps are as follows. First, the full array of items will be checked for completeness, relevance, and measurability (performance- and feature-based) by experts and built environment stakeholders (e.g., building owners). A check of the relevant Australian codes and standards for resilience standards and criteria will be made. Also, the points scoring scale will be reassessed/verified. Second, resilience dimensions, subdimensions, and items in the scheme will be weighted by importance. This will be achieved through conducting a survey of experts and building owners. The weightings will reflect the particular state of built environment knowledge, building stock characteristics, environmental conditions, and economic, social, and political–regulatory systems in Australia. Third, the scheme will be tested on a number of commercial buildings with different characteristics, in different locations, and subject to different conditions. The scheme will be calibrated and benchmarks set most likely through defining reference sets of buildings.

References

[1] L. Bosher, Introduction: the need for built-in resilience, in: L. Bosher (Ed.), Hazards and the built environment: attaining built-in resilience, Routledge, London, 2008, pp. 3–19.
[2] C. Malalgoda, D. Amaratunga, R. Haigh, Challenges in creating a disaster-resilient built environment, Procedia Economics and Finance 18 (2014) 736–744.
[3] T. McAllister, Developing guidelines and standards for disaster resilience of the built environment: a research needs assessment, US Department of Commerce, NIST, 2013.
[4] H. Valdes, A. Rego, J. Scott, J.V Aguayo, How to make cities more resilient: a handbook for local government leaders, United Nations UNISDR, Geneva, 2012.
[5] L. Bosher, Built-in resilience through disaster risk reduction: operational issues, Building Research Information 42(2) (2014) 240–254.
[6] S.L. Cutter, C.G. Burton, C.T. Emrich, Disaster resilience indicators for benchmarking baseline conditions, J. Homeland Security and Emergency Management, 7(1) (2010) 1–22.
[7] A.V. Bahadur, M. Ibrahim, T. Tanner, The resilience renaissance? Unpacking of resilience for tackling climate change and disasters, Discussion paper, UK Dept. Int. Devt, 2010.
[8] R. Preito, Challenges of dealing with uncertainty, PM World Journal IV(I) (2015) 1–22.
[9] S.E. Chang, T. McDaniels, J. Fox, R. Dhariwal, H. Longstaff, Toward disaster-resilient cities: characterizing resilience of infrastructure systems with expert judgments, Risk Analysis 34(3) (2014) 416–434.
[10] S. Burroughs, A comparison of energy-efficiency rating systems for existing buildings in Asia and the Middle East: implications for system adoption, in: Proceedings of the SEB16 Conference, Dubai, January 2016.
[11] U. Berardi, Sustainability assessment in the construction sector: rating systems and rated buildings, Sustainable Development 20(6) (2012) 411–424.
[12] S. Wang, C. Yan, F. Xiao, Quantitative energy performance assessment methods for existing buildings, Energy and Buildings 55 (2012) 873–888.