Disaster resiliency measurement frameworks

State of the art

Leila Irajifar[1], Tooran Alizadeh[2], Neil Sipe[3]

Abstract

Since adoption of the Hyogo Framework for Action 2005-2015 “Building the resilience of nations and communities to disasters”, the concept of disaster resilience has gained a wider interest and has become more popular among academic researchers and practitioners. Although the literature on urban studies and also the practical planning documents recurrently refers to resilience concept as a managerial principle behind making resilient cities and regions, operationalizing this concept in urban and regional planning context raises critical challenges in terms of its determinants and assessment.

There exist a number of disaster resiliency frameworks and indicator sets in varying degrees of comprehensiveness, accuracy and validity which offer communities a set of indicators to measure and manage their resiliency in order to preserve their critical structures and functions in the face of disturbances and recover quickly to the desired pre-disaster conditions.

This paper presents a critical review of resiliency models in the international urban resilience literature. It starts by defining and individuating the resiliency concept from other similar related concepts in disaster literature. Then it defines a framework for evaluation of resiliency models for aligning it to urban studies discipline, using a number of criteria including comprehensiveness, structure of components and indicator building methods, scale and unit of analysis, dynamics, data requirements, validation and operationality, and actual and potential applications. The paper ends by speculating about the most promising opportunities to further improve the resiliency models in urban context by using a set of resilience attributes which already embedded in the discourse of urban theory to evaluate the resiliency of each city’s built environment and the way people have adapted to that built environment to recover following a disaster. The findings suggest that fostering these resilience attributes within different urban components, can potentially assist in the design and planning of resilient cities which have an enhanced capacity to absorb the shock and recover quickly.

[1] PhD candidate; School of Urban and Environmental Planning; Griffith University; 170 Kessels road, QLD, Australia ;leila.irajifar@griffithuni.edu.au
[2] Senior Lecturer; School of Urban and Environmental Planning; Griffith University; t.alizadeh@griffith.edu.au
[3] Associate Professor; School of Urban and Environmental Planning; Griffith University; n.sipe@griffith.edu.au

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Introduction

More than a decade after starting attempts for quantifying community resilience, endeavors are still ongoing to refine and develop more applicable resilience models (Gilbert, 2010). There exist a number of centers which are investigating urban resiliency in different scales, mostly based in the US. They have developed a few disaster resilience models of varying degrees of comprehensiveness and sophistication, some of which have been and are being applied to real-life communities and places for purposes of research and/or policy analysis and/or education (Manyena, 2006, Renschler et al., 2010b).

This paper offers an overview of current disaster resiliency models. It starts by examining the general definitional issues of the concept and then presents eight resiliency models which will be evaluated later by criteria such as comprehensiveness, models structure and components, methods, scale and unit of analysis, dynamics, data requirements, validation and operationality, and actual and potential applications. The paper shows that most of the existing frameworks have not been fully operationalized and validated with real data yet, and ends with speculating about the most capable avenues to further develop effective and implementable planning and design strategies for increasing the resilience of cities to the potential future shocks.

Disaster resilience

The concept of resilience originated in the field of ecology, but it has been used within a wide diversity of disciplines from psychology, geography, social science to engineering and systems science (Klein et al., 2003, Manyena, 2006, Norris, 2008). Following the work of Timmerman (1998), many definitions of the concept of disaster resilience appeared in the hazard and disaster field in the last three decades. They are all roughly comprised of two common features for disaster resiliency: 1) the ability to resist and absorb disturbances, 2) the ability to reorganize and recover reasonably quickly (retain the same basic structure and ways of functioning) (Mayunga, 2009). Long-lasting concerns from the research community focus on disagreements as to the definition of resilience, whether resilience is an outcome or a process, what type of resilience is being addressed (economic systems, infrastructure systems, ecological systems, or community systems), and which policy realm (counterterrorism; climate change; emergency management; long-term disaster recovery; environmental restoration) it should target (Cutter et al., 2010).

The wide use of resilience is the recognition of its value but that some applications have stretched the concept beyond its original meaning to the point that the concept itself runs the risk of becoming meaningless and a source of theoretical confusion. There are a few linked terms and concepts such as resistance, vulnerability and sustainability, coping capacity and etc. in disaster studies which have to be defined carefully to avoid using them in incompatible ways. Norris et al. (2008) make a distinction between resilience and *resistance*. In their terminology resilient communities and people bounce back from disasters, while *resistant* communities and people do not suffer harm from hazards in the first place. Tierney believes that community resilience acts to counter vulnerability. A high level of vulnerability does not necessarily mean that a community is not resilient; however vulnerability is often indicative of an inability to resist or respond to disaster (Tierney, 2009). In Cutter's adopted definition, vulnerability and resilience are not totally mutually exclusive, nor totally mutually inclusive. Vulnerability is the pre-event, inherent characteristics or qualities of the systems that create the potential for harm (Cutter et al., 2008b). Vulnerability is a function of the exposure (who or what is at risk) and sensitivity of system (the degree to which people and places can be harmed) (Adger, 2006, Cutter, 1996). In contrast, resilience is the ability of a social system to respond and recover from disasters and comprises those inherent conditions that allow the system to absorb impacts and cope with an event, as well as post-event, adaptive processes that facilitate the ability of the social system to re-organize, change, and learn in response to a threat (Tierney 2007).

The concept of sustainability is central in resilience studies since it is inseparably linked to the condition of the environment and the treatment of its resources. Sustainability, within the context of natural disasters is defined as the ability to ''tolerate—and overcome—damage, diminished productivity, and reduced quality of life from an extreme event without significant outside assistance''(Mileti, 1999) Unsustainable practice may cause more severe environmental hazards. Large-scale deforestation, for example, was a factor in increasing the flooding hazard in the 1998 floods in China, and loss of coastal wetlands is a contributing factor to the severity of impacts of tropical storms and hurricanes on coastal Louisiana (Wisner et al., 2004).

There are also diverse views about the relationship between the concepts of adaptive capacity and resilience which makes the actual linkage very unclear. As mentioned by Smit and Wandel (2006), some authors equate adaptive capacity with resilience and social resilience. Gunderson (2000) defines adaptive capacity as system robustness to changes in resilience; Carpenter et al. (2001) use adaptive capacity as a component of resilience that reflects the learning aspect of system behaviour in response to disturbance (Gallopín, 2006).

Methodology: Resilience models comparison

In order to bring together and evaluate the existing frameworks in disaster resiliency, and to answer the questions of what indicators can be used to measure community resiliency, we conducted a critical literature review including a wide range of disciplines comprising of environment, geography, planning and disaster, hazard and risk management. The eight most cited models and frameworks for measuring and assessing disaster resiliency were selected.

For the evaluation of disaster resilience models, an idealized disaster resiliency model has first been sketched out as a benchmark by which the existing models can be evaluated. Five types of resilience components are distinguished form literature for urban resiliency (See Figure1). The circles show the performance level of the urban system which in the event of a disturbance falls to a lower level depending on the resistance of the system. Each component of urban resiliency will have a particular level of resistance, transitioning period and recovery time to rebound to previous level of structure and functioning or to an upper

level of system's performance. The response to disturbance depends on different factors in each part of subsystems which are interrelated and this makes it more difficult to get quantified. It may vary from system to system and from one kind of disturbance to another. In the following sections, we will examine properties of the models based on eight criteria.
Since the principal motivation for understanding the drivers and processes of disaster resilience is to develop management plans to improve resiliency, assessments need to evaluate not only the baseline conditions but also adverse impacts, and factors that inhibit effective response (Clark et al., 1998). The transition from conceptual models to resilience measurement and assessment is challenging due to the multifaceted nature of resilience (Cutter et al., 2010).

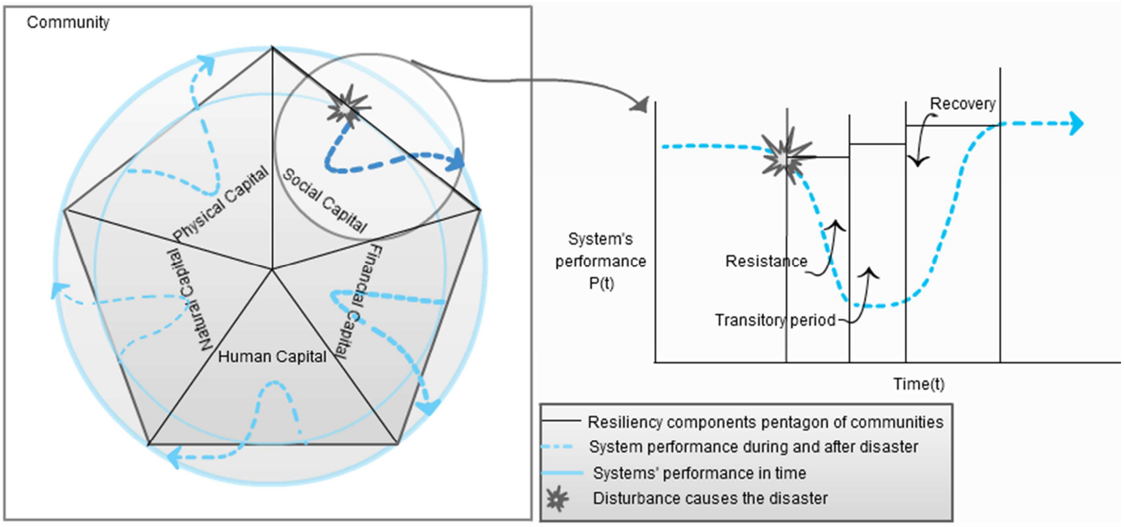

Figure 1: A model of disaster resilience models

The majority of assessment techniques are quantitative and use indicators or variables as proxies since it is often difficult to quantify resilience in absolute terms without any external reference with which to validate the calculations (Schneiderbauer and Ehrlich, 2006). As a result, indicators are typically used to assess relative levels of resilience, either to compare between places, or to analyse resilience trends over time (Birkmann, 2006). The selected eight models will be evaluated according to the following criteria: comprehensiveness, structure and indicator building methods, scale and unit of analysis, dynamic, data requirements, validation and operationality, and actual and potential applications.

Comprehensiveness

The comprehensiveness of disaster resilience models can be assessed based on different dimensions of resiliency included in the models such as built environment, economic, social, organizational and different temporal phases of disaster (mitigation, preparedness, response, recovery) for different types of disasters (such as geological, climatic,…). Yet it doesn't mean that the comprehensive model is necessarily better and more useful for policy making and planning purposes as it may result in too much complexity and serving too many purposes at one time.
PEOPLES stands for seven dimensions of disaster resiliency in this model: Population and Demographics, Environmental, Organized Governmental Services, Physical Infrastructure, Lifestyle and Community Competence, Economic Development, and Social-Cultural Capital.

As the third column of the Table 1 shows, DROP, CDRF and CDRI consistfive dimensions of aforementioned asset pentagon but DROP and CDRF disregarded the ecological resilience purposefully due to complexity or data inconsistency and relevancy (Mayunga, 2009).

DROP, PEOPLES, ResilUS, CDRF and Systems diagram are comprehensive in the sense that they address at least four dimensions of resiliency. They all encompass the technical, social, economic, organizational dimensions. NIRA focuses on the technical dimension of urban networked infrastructure. All of the models except for systems diagram and URF are multi hazard models whereas systems diagram is a seismic specific model and URF basically has been developed for climate change resiliency and thus not consider the risk as an abrupt change to urban systems but a slow onset challenge. All of the models have considered the pre and post disaster conditions but only CDRF has specifically emphasized preparedness and response phases, which are neglected by others (Mayunga, 2009).

Structure and indicator building methods

A proper resiliency index should identify the distinct dimensions and related key indicators and also aggregates the dimensions in ways that reflect community realities. PEOPLES seems to be the most successful model in this aspect. It uses a geospatial-temporal distribution within its influence boundaries to define components of functionality. And then uses the interdependencies between and among these components to determine the resilience indicators of communities (Renschler et al., 2010a, Gilbert, 2010). For example, the physical infrastructure dimension in PEOPLES includes both facilities and lifelines. In the facilities category, they include housing, commercial facilities, and cultural facilities. But for lifelines, they include food supply, health care, utilities, transportation, and communication networks (Renschler et al., 2010c). In this particular dimension, historical and continuously gathered information through remote sensing and also Geographic Information Systems (GIS) plays a major role in assessing the resilience of all integrated urban systems and feed a predictive resilience model (Renschler, 2010).The third and fifth column of table1 has summarized the main properties of models and comparison for the most important aspects of these criteria.

In DROP, two main qualities have been considered for resilience of communities: inherent (functions well during non-crisis periods); and adaptive (flexibility in response during and after disasters). Cutter's social vulnerability index, SoVI, in DROP has been used by PEOPLES to measure the social dimension of the resiliency. It integrates exposure to hazards with the social conditions that make people vulnerable to them to show the socioeconomic status of the community (Cutter et al., 2003, Cutter, 1996). They have also considered "Community competence" metrics in their index which represent how well the community functions pre-and post-disaster including a sense of community and ideals as well as attachment to place and the desire to preserve pre-disaster cultural norms and icons (Gilbert, 2010).

Metrics for measuring economic resilience have classically employed loss estimation models to measure the property loss and the effects of business disruption after disasters (Rose, 2004, Chang, 2010). PEOPLES, on the other hand, assesses both current economic activity and dynamic growth economic development (Renschler et al., 2010c).

ResilUS uses probabilistic methods within its loss and recovery modules. Each model state in ResilUS, is calculated through a comparison between a uniform random number and aggregation of all input variables which are stated as probabilities (e.g., the probability of restored water service in a neighbourhood) (Miles and Chang, 2011).

The key indicators in the Systems diagram are developed under the three complementary themes of resilience: ‘‘reduced failure probabilities’’, ‘‘reduced consequences from failures,’’ and ‘‘reduced time to recovery” which in conjunction with four aspects of resiliency: robustness, redundancy, resourcefulness; and rapidity have been organized in three horizontal layers. These layers are representatives of situations where in the bottom layer no intervention is made, in the middle first level of action and decisions and in the top layer multi attribute information is collected and used for decision making (Bruneau et al., 2003). On the other hand, the key elements of the urban resilience framework (URF) are urban systems and social agents(Tyler et al., 2010a)

Organizational dimension indicators include the number of available response units and their capacity. It means in addition to personnel and equipment, organizational resilience also includes elements that measure how organizations manage or respond to disasters such as organizational structure, capacity, leadership, training, and experience (Tierney 2007).

Scale and unit of analysis

Disaster resilience is often allocated to *technological units* and *social systems*. In smaller scales like when we consider critical infrastructures, the focus is mainly on technological aspects. And in larger scale like when we consider the whole community, the scope will be expanded to include the interaction of multiple systems – human, environmental, and others which together add up to ensure the resiliency of a community (Renschler et al., 2010c).

As column 4 of Table 1 shows, except from NIRA, which is only focused on networked infrastructures, all other seven models are at community level (Mayada, 2010). Systems diagram is developed for community level resiliency assessment and also for infrastructure networks systems. At community level, the human component is central, because in the case of a major disruptive event, resilience depends first on the actions of *people* operating at the individual and neighborhood scale. Community resilience also depends heavily on the actions of different levels of government and its agencies at the local and regional scales when a disruptive extreme event occurs.

In general PEOPLES *Resilience Framework* is based on basic community organizational units at a local (neighborhoods, villages, towns or cities) and regional scale (counties/parishes, regions, or states). Thus it can be considered as a multi scale model like ResilUS which is scalable to any number of neighbourhoods or socio-economic agents, and community. Among these community level models, URF and CDRI use city as their unit of assessment while DROP and CDRF model’s unit of analysis is county. They have chosen county as a reasonable unit of analysis mainly because of easy data availability and because it is where hazard mitigation plans and risk reduction programs are directed in the US (Mayunga, 2009).

Dynamics

Resilience can be considered as dynamic quantity that changes over time and across space. The conditions defining resilience are dynamic and ultimately change with differences in spatial, social, and temporal scales (Renschler et al., 2010a). A society may be deemed as resilient to environmental hazards at one time scale (e.g. short-term phenomena such as severe weather) due to mitigation measures that have been adopted but not another (e.g. long-term such as climate change). The temporal scale at which resilience is measured is an important issue, since it will affect the selection of variables and parameters in index construction. Although resilience is a dynamic process, but for measurement purposes, it is often viewed as static phenomena (Cutter et al., 2008a). In all eight models, there are signs which indicate the dynamic or quasi dynamic nature of the models. For example the post-event processes embedded within the DROP model allow the conceptualization to be dynamic, yet the antecedent conditions in this model can be viewed as a snapshot in time or as a static state (Cutter et al., 2008b). In PEOPLES model the community resilience indices are integral of the geospatial – temporal functionality of components of resilience. And it is supposed to continuously measure and monitor the functionality of the systems over time (Renschler et al., 2010a). The closed loops in systems diagram and iterative processes of diagnosing vulnerability, planning and implementation indicate the requirement for an iterative dynamic process to achieve a higher level of resiliency in systems (Bruneau et al., 2003). Dynamic of ResilUs is represented by pre/co-event and post-event models. For a particular dynamic (time-based) output, each model state is calculated as a comparison between a uniform random number and the aggregation of all input variables(Miles and Chang, 2011).

Data requirement

Researchers in this area often meet the difficulties in gathering data on resilience indictors for input into their models (Cutter et al., 2008a). However the availability and accessibility of the data has been one of the most important criteria for indicator construction (Mayunga, 2009). In general, data for these models fall into four types: case studies, insurance claims, direct measurements, and survey methods (Gilbert, 2010).

A huge part of the data for these models, particularly in DROP, URF,CDRF and CDRI primarily comes from the secondary datasets such as census (Cutter et al., 2008b, Tyler et al., 2010b, Mayunga, 2009, Shaw, 2009). The PEOPLES resilience framework requires the combination of qualitative (like pre/post disaster detection analysis; object oriented classification; change detection analysis of RS imagery) and quantitative data sources at various temporal and spatial scales (like voters registration, mortgage rates, saving rates, court reports, crime reports,..), and as a result, information requires to be aggregated or disaggregated to match the scales of the resilience model and the scales of interest for the model output (Renschler et al., 2010c). On the other hand, in ResilUS because of the large number of model variables and their interrelationships, the behaviour of this model is complex and it needs more simulated, aggregated and micro-data in addition to census data. However, its modularity helps to substitute a data source for a model reference. For example, rather than modelling lifeline restoration, actual lifeline restoration time-series data can be used (Bruneau et al., 2003).

Table1. Summary of the main properties of the models

Disaster resilience model	Developer/ Affiliation	Components	Scale/Unit of analysis	Methodology	Data sources	Application
DROP Disaster Resilience Of Place	Cutter et al. HVI- University of South Carolina/ 2008	Social Technical Economic Organizational	community/ county	Spatial mapping; Weighting; aggregation; Multivariate analysis; Sensitivity Analysis	Census; American community survey	Information gathering Comparison of the resiliency of different counties
PEOPLES MCEER's resilience framework	Renschler et al. MCEER- University at Buffalo/ 2010	Population &demographics Environment Organized governmental services Physical infrastructures Lifestyle & community competence Economic development Social cultural capital	Community (can be adapted to multi scale)/county	Spatial (time dependant community functionality maps); Visual inspection of RS imagery; quantitative and qualitative models for any or a combination of dimensions. E.g. SoVI for social resilience.	Census ; Quality of life surveys; Utility usage; Mortgage rate; Voter registration; Home price indices; Unemployment rates; SEC filings; Content Ground trothing interviews; pre/post disaster detection analysis; Object oriented classification; change detection analysis	Information gathering; Comparison of resilience between Counties; Empowerment of people; After complete development, it can be used as a geospatial and temporal decision support software tool
Systems Diagram Quantitative framework for seismic resilience assessment	Bruneau et al. MCEER- Univeristy at Buffalo/ 2003	Conventional systems System assessment and actions Resilience assessment	Community level, infrastructure networks	Scenario based resilience assessments	---	---
ResilUS A community-based disaster resilience Model	Miles & Chang et al. University of British Columbia & MCEER/ 2007	Recovery module Loss estimation module	Scalable to any number of neighbourhoods or agents/PUMA (Public Use Microdata Areas)	Spatial; probabilistic methods; Spread sheet-based Fragility Curves to model loss; Markov chain to model recovery; Survey based assessment	Poll results; general observations from previous studies; Zip Code Business Pattern data; Surveys from previous studies; some simulated data; Public use micro data series; USGS shake map data	Information gathering; education, training, public awareness; Resilience Comparison between different
CDRF Community Disaster Resilience Framework	Joseph Mayunga HRRC - Texas A&M University/ 2009	Human Capital Social Capital Economic Capital Physical Capital	Regional/ County	Spatial; GIS based Composite indicators; Correlational analysis; Regression analysis; Incremental validity	Census, Insurance datasets; County business patterns; Spatial Hazard Events and Losses database for US (SHELDUS); US Fire administration;; Centre for Disease control and prevention(CDC)	Information gathering; Enhance local community coping capacity; comparing disaster resiliency of communities; operationalize the disaster resilience concept to support planning, management and decision making
CDRI Climate Disaster Resilience Index	Rajib Shaw "Human Security Engineering for Asian Megacity" of Kyoto University/ 2009	Physical Social Economic Institutional Natural	City	Non spatial; Spreadsheet – based; Questionnaire survey	Surveys; Secondary data	Information gathering; Priority setting and policy recommendations based on level of resiliency in each dimension;
URF Urban Resilience Framework	StephenTyler Marcus Moench Jo da Silva ARUP + ISET/ 2009	Urban Systems (ecosystem, infrastructure, institutions, knowledge) Social agents	City/ Wards (communes)	Shared Learning Dialogues(SLD) workshops; GIS enabled sampling and aggregation method; Hazard, Capacity and Vulnerability Assessment(HCVA)	Identification of homogeneous socio-economic clusters by satellite imagery verified with rapid ground survey; Secondary data	Information gathering; Interpretation; Collaboration; implementation
NIRA Networked Infrastructure Resiliency Assessment	Omer, Mayada Stevens/Institute of Technology/ 2010	Urban Network Systems	Infrastructure networks	Spread sheet-based; System mapping; Network flow analysis; Disruption scenarios	State of New York department of Transportation; Highway capacity manual	Resiliency assessment; Resiliency strategy evaluation

Validation and operationality

Many researches in developing composite indices in resilience studies, fail to empirically validate the measures especially in terms of incremental validity. This is one of the major flaws of using composite indexes as there is no simple way to get scientific validation of a particular index (Davidson and Shah, 1997). The absence of validation is a major concern. In many circumstances, the index relies on empirical data that is far from perfect. Many assume that because numbers have been derived using some basic statistical procedure, the overall results of the index is valid and reliable. However, some qualitative methods such as in-depth surveys and case studies can be used to validate the index. Actually the best way that any sort of metrics related to the disaster field could be validated would be to continually test them after major events and refine them accordingly. This would take a considerable amount of time (Simpson and Katirai, 2006). Chang and Miles for example, have had several attempts like this to validate ResilUS (Chang, 2010, Miles and Chang, 2008). It has been applied for modeling recovery of Kobe after 1995 earthquake (Chang, 2010) and also1994 Northridge earthquake disaster (Miles and Chang, 2008) in order to calibrate several output variables with empirical data. ResilUS is currently being developed to better represent socio-cultural, personal, and ecological capitals to assist in modeling the resilience of the Gulf Coast area of Louisiana in association with the 2005 Hurricane Rita disaster (Miles and Chang, 2008).

NIRA, CDRI, URF have not been scientifically validated. However, NIRA has been applied to four types of critical infrastructure systems. These case studies probe the resiliency of the studied infrastructure systems in the face of specific disruptive events: telecommunication, transportation, maritime transportation and organizational networks. CDRI and URF has been applied to relatively 9 and 10 Asian cities for measuring their resiliency and providing some policy recommendations based on their expected level of resiliency (Shaw, 2009, da Silva and Moench, 2010).

Among all models, CDRF as a PhD project has had a full internal model validation process for its content by construct validity, predictive validity and reliability validity and plausible results were obtained (Mayunga, 2009). Based on our recent email contact, Cutter et al. are validating DROP through a case study from Mississippi Gulf Coast. PEOPLES has been partially applied for 2010 Haiti earthquake (Landscape-based Environemntal System Analysis and Modelling, 2012).

Actual and potential applications

Considering the range of issues facing communities in the event of disasters, the spectrum of applications which can be addressed by current models is not broad. These issues can be categorized into two major groups in loss reduction and quick recovery after disaster (Gilbert, 2010). The resiliency models can be utilized to assess the strategies, actions and policies for loss reduction and recovery acceleration through different scenario development or by modifying land use plans and building control arrangements. This can help to not only mitigate the exposure but also to maintain functioning of the urban system during and after a disaster (Coaffee, 2008, March et al., 2011)

PEOPLES, CDRF, DROP and CDRI by quantifying the disaster resiliency and generating hotspot maps or diagrams provide the ability to compare communities with one another in terms of their resilience, and determining whether individual communities are moving in the direction of becoming more resilient in the face of various hazards. In general, the disaster resilience determinants identified in these models, can be utilized to analyze the resiliency of each place and find the weaknesses and strengths to enhance the resiliency of place (Mayunga, 2009, Renschler et al., 2010a, Cutter et al., 2008a, Shaw, 2009).

However in ResilUS, the model's limitations make it more appropriate for education, training, and public awareness purposes rather than the actual planning purposes (Miles and Chang, 2011). On the other hand, URF seems to be more practical framework for resilience planning which in conjunction with SLD's (Shared Learning Dialogue) framework integrates resilience thinking into planning procedures in order to enable the vulnerable groups to anticipate, respond to and recover from projected climate change impacts. It will also provide resilience-related information to state and local mission partners that will support their risk-based resource decision-making process (Tyler et al., 2010a). NIRA by investigating the reaction of the networked infrastructure systems to disruptions, allow the decision makers to investigate the different resiliency strategies by adopting different scenarios.

Practicality of the resiliency quantification results depends on the level and scale of the assessment. At larger scale it is limited to public awareness and education. At regional scale, on the other hand, it can be more useful for disaster managers and policy makers to direct the resources to most vulnerable areas and where management and planning actions are needed. Resiliency models at local level by identifying more contextual determinants of resiliency of place can provide a tool for urban designers and planners to assess their designs and plans in terms of their resiliency. Several studies (Allan and Bryant, 2011, Bryant and Allen, 2011, March et al., 2011) suggest that the resilience is linked to the built environment indicators on spatial morphologies that encourage response and adaptation, such as a diversity of open spaces, redundancies in connectivity, self-sufficiency (food from urban gardens, multiple sources of water) and local urban spaces that can quickly be adapted to encourage communication and response. They note that recovery also has a spatial dimension and resilience theory suggests that design, form and space, as well as, process could influence recovery.

Conclusion

This paper has analyzed some of the most well cited and prominent resiliency models. Resiliency is a broad and complex concept which is very difficult to define and measure comprehensively. This review revealed that most of the frameworks for measuring disaster resiliency are generic and broader in the context of environmental hazards. Defining a proper context and scale for resiliency models seems necessary to take the most useful and applicable output of the model and also to provide a consistent basis for data development required for assessment. More specifically the variables and attributes of some of the frameworks are very broad and often not workable at the community level for measurement purposes. Therefore their application becomes clumsy at this level particularly where availability of data for certain indicators at the local level is a great challenge. The existing indicators can also be criticised for difficulty of meaningful interpretation or the lack of causal linkages between the indicator values and the policy relevance of outcomes.

This critical review also points out a number of gaps in measuring disaster resilience literature. First, a large portion of the resiliency literature is mostly conceptual with excessive emphasis on resilience in socio-ecological systems. In this context, there remains a lack of robust case studies which can test or validate the models and their theories. Second is the lack of policy relevancy of the outputs. In this regard, the potential applications which were mentioned in earlier parts of this paper deserve more attention by researchers in this field including specific urban design and planning measures which can influence the resiliency of place such as incorporating flood attenuation as part of an integrated urban form. Open spaces, such as recreational parks and ovals to manage and reduce potential flood hazards and other applications such as improvement in construction practices, building codes, and mitigation of homes (retrofitting or elevating) are measures that enhance resilience as is the building of redundancy in critical infrastructure and also acting as a management or decision making tool are seem to be in reach by further developing and integrating the existing frameworks. To sum up, for making our communities disaster resilient we need tools for evidence-based policy making, analysis and evaluation of a large variety of issues and criteria. Existing experience shows that developing indexes, typology approaches and benchmarking can be of great help in research as well as for practitioners for making our communities resilient.

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