Urban Resilience and Agent Based (AB) Simulation-Literature Review

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Increasing Urban Resilience to Large Scale Disasters: The Development of a Dynamic Integrated Model for Disaster Management and Socio-Economic Analysis (DIM2SEA)

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Vulnerability of Cities: the ability of cities to cope with unanticipated disasters is an issue high on the urban agenda (UNISDR, 2012; Masterson et al., 2014). Over the last few decades cities have been subjected to ever-increasing disastrous events resulting in casualties and extensive property damage (Wamsler, 2004). As cities increase in size and complexity they also become increasing vulnerable to unanticipated events, both natural and anthropogenic (Deppisch and Schaerffer, 2011; Godschalk, 2003). As city populations and densities continue to rise, it is reasonable to assume that the trend of increasing damage from such events will intensify (Quarantelli, 1996; UNISDR 2012). Given the magnitude of the potential catastrophes and also the expanding availability of data, tools and knowledge, increasing multi-disciplinary effort is being focused on mediating the hazards facing cities and bolstering their resilience (Zolli and Healy 2012).

The concept of resilience: emerged in the study of ecology in the early 1960's and the 1970's (Folke, 2006). One of the first definitions of the term sees resilience as a property of a system that has high probability of persistence in form and structure, embodied in an ability to absorb changes to its variables and parameters (Holling 1973). This definition has been further elaborated to include the self-organizing ability of a system, as well as the ability to adapt and learn (Folke et al., 2002). This dynamic conceptualization of resilient systems extends the previous focus on the ability to restore equilibrium after a temporary disturbance (Holling 1973, 1996; Adger, 2000; Folke, 2006), The latter, sometimes referred to as 'engineering resilience', is criticized as static and deterministic, ignoring the possibility that the pre-shock state is only one of several states the system could present (Holling, 1973).

The notion of resilience has been imported by other fields of research including urban planning and disaster management. However, the ideal of a 'resilient city' is still a concept lacking universal definition and acceptance. Some authors follow Holling's definition and regard the resilience of a city as the degree to which it can sustain a shock before shifting to a new state (e.g. Alberti & Marzluff, 2004; Alberti et al., 2003). Others ascribe to the notion of to the city's ability to reorganize (e.g. Cruz et al., 2013). Others still adopt the 'engineering resilience' conception of rebounding, "bouncing-back" to pre-disaster stage, and restoration (e.g. Campanella, 2008; Godschalk, 2003; Müller, 2011).

Equilbriun View Challenged: All views can be justified. On the one hand, as market mechanisms of supply and demand are involved in the behavior of many of the urban sub-systems (such as the housing and employment markets), the equilibrium-stability view seems to be valid. Yet, cities are complex systems whose state depends on many decisions by a wide assortment of agents and entities (Cruz et al., 2013; Godschalk, 2003; Müller, 2011). Thus, this equilibrium view of resilience has been challenged in the context of urban recovery (Martin 2012, Davoudi 2012). The first claim is that cities are not as mechanistic and predictable as the equilibrium view purports. Second, recovery to a former state may not be desired goal for those urban areas whose pre-disaster state was unattractive in the first place. Finally, the equilibrium view ignores 'the intentionality of human actions' (Davoudi op cit., p305) implying that human intervention through regulation, planning and policy is effectively ignored.

Difficulties in Operationalization: When operationalizing resilience and designing recovery strategies, both of these concepts present difficulties. The rigid policy options associated with rebounding and derived from the equilibrium view may paradoxically tilt the system away from stabilization by not allowing the freedom needed to achieve steady state (Folke et al., 2002). On the other hand, viewing cities as complex systems, leads to confusion regarding the processes and factors promoting urban resilience and to great difficulty in formulating absolute resilience strategies (Müller, 2011; Allan et al., 2013). As systems differ in terms of inputs, outputs, agents, and parameters, no two urban areas are alike and even the same urban space can change character over time.

Generic Solutions: The tendency of the discussion on resilient cities and urban recovery to "focus on process rather than place and form" (Allan et al., 2013, p. 244) only aggravates the situation. Portraying a picture of a general process, for example a shock leading to loss of lives, damage to property and infrastructure, diminishing accessibility and provision of services, may promote generic perceptions of the recovery process. These are expressed in the common conception that recovery is proportionate to the magnitude of the effect (Chang and Rose, 2012). As such, it tends to highlight either mitigation measures (Fleischauer, 2008; Godschalk, 2003) or 'bouncing back' strategies to regaining pre-disaster conditions (Chang, 2010), and in the typical knee-jerk reaction to disaster that involves "time-compressing" rebuilding and rejuvenation measures (Olshansky, Hopkins & Johnson, 2012).

Criticism of Generic Solutions: In the context of the long term urban effects of shocks like an earthquake, The general acceptance of direct relationships like Chang and Rose (2012) suggestion, are hard to justify. These well-intentioned activities do not consider the existence of multiple and unstable equilibria resulting from different activities recovering at different rates. Neither do they consider the possibility of incongruence between the location of the event and the point of recovery: pre-shock state is just one of many possible unstable equilbiria states. Beside the bounce-back scenario there is the possibility of reorganization under a new state (i.e. 'bouncing-forward', see Grinberger and Felsenstein, 2014): disaster can (perversely) offer opportunity for change and renewed growth. For example, the devastation wrought by World War II bombing on cities in Germany and Japan has been shown to have "bounced forward" the economies of the devastated cities (Brakman, Garretsen and Schramm, 2004; Davis and Weinstein 2002). This undermines much of the popular literature promoting a 'one size fits all' approach to both urban mitigation and rejuvenation and neutralizes the standard checklist approach to disaster management mechanisms, which while well-intentioned may be misleading (Prasad et al., 2009; UNISDR 2012).

As the urban environment is fashioned by the interaction of many agents such as residents, workers, local governments, developers and by sub-systems such as housing markets and transportation networks (Cruz et al., 2013), unraveling the key to urban resilience becomes extremely difficult (Müller, 2011). Local shocks may have global effects and innocuous, short-term perturbations may cause long term change. The result can be a shift of the entire system to one of a few possible unstable equilibria states. This situation plays havoc with attempts to formulate generic post-disaster urban resilience solutions without consideration of context (Kartez, 1984; Kartez and Lindel, 1987).

Agent Based (AB) Simulation: Unanticipated disasters have attracted considerable agent based modeling attention. AB models are based upon three elements: the environment, the agents and a set of rules guiding agent-agent and agent-environment interactions (Macal et al., 2005). The latter may be defined within the model based on social, economic and spatial decision rules. The first two however are exogenous starting conditions of the simulation. The long-term indirect effects of an event are reflected in the behavioral responses of the agents. "Shocks" generated by a disaster are mediated through the aggregate behavior of 'agents' (households, workers, land developers, firms, city authorities and intervention agencies). AB models were used on numerous subjects, like flooding (Dawson et al. 2011), fires (Chen & Zhan, 2008), earthquakes (Crooks & Wise, 2013, Grinberger & Felsenstein, 2015), terrorism (Park, Tsang, Sun & Glasser, 2012) and industrial accidents (Salze et al., 2014). Much of this interest is in the short-term, evacuation and recovery aspects of the disaster with an emphasis on route optimization and emergency management (Zimmerman et al 2010; Chen, Kwan, Qiang & Chen, 2012).

Studies that take a longer-term view of urban recovery often approach this issue from a more fully articulated theoretical base. Recent efforts have seen agent based models fuse the rich detail embodied in agents with more sophisticated micro economic behavior protocols. These can be exploited to understand broad urban processes such as suburban sprawl, leapfrog development, economic deconcentration and gentrification. This has given rise to AB models that try to represent the full working of markets with supply and demand schedules, price emergence and market clearing effects (Magliocca, Safirova, McConnell & Walls, 2011; Ettema, 2011; Filatova, 2014; Magliocca, McConnell & Walls, 2015; Olner, Evans & Heppenstall, 2015). Agents are represented with increasing sophistication. They are governed by behavior rules that account for preferences, competitive bidding, resource and budget constraints, utility and profit maximization and search behavior. In some models, supply and demand schedules and price emergence are fully endogenous processes (Ettema, 2011). Invariably, these AB initiatives are more about urban growth and expansion than urban recovery and rejuvenation (Huang, Parker, Filatova & Sun, 2014). While there are studies that account for change within the city, such as gentrification (Torrens & Nara 2007; Jackson, Forest & Sengupta, 2008), most of the emphasis is on land use change and its feedback effect on agent activity at the urban fringe.

Synthetic Big data for Agent based (AB) Simulation: While other modeling frameworks exist for disaster analysis (see for example, the suite of applications of multi-regional input-output modeling in Richardson et al., 2014), the value of AB models lies in their ability to create high-resolution representations of the urban environment. additionally, AB models can represent dynamics at high levels of temporal resolution and be use to simulate the long-term consequences of a disaster and generate Geo-information. But, as spatial socio-economic and urban data is usually available at aggregates such as census tracts, agent-level data must be generated synthetically. The literature offers a number of data disaggregation techniques. These include population gridding (Linard et al., 2010), areal interpolation (Reibel, 2005), dissymmetric representation (Eicher & Brewer., 2001; Mennis, 2003) proportional iterative fitting (Beckman et al., 1996; Pritchard & Miller, 2011), dynamic population modeling (Bhaduri et al., 2007; Martin et al., 2015) or combining administrative data available at a coarse spatial level and a detailed buildings GIS layer in order to create spatial representations of individuals and households within buildings and allocate synthetic socio-economic values to them (Lichter & Felsenstein, 2012; Harper & Mayhew,2012). Grid representation, which relates one specific value to a unit of space, is common to agent-based modeling (Brown et al., 2005) but using a synthetic big database, one may characterize the starting conditions of the urban simulation in terms of both environment and agents, with more detailed representation which characterizes individual buildings and the road network connecting them. Each synthetic representation of an individual and a household is transformed into an agent (Lichter & Felsenstein, 2012; 2015). Agent profiles are translated into behavior expressed through the operation of basic logical decision rules and constraints: they are rational, utility-seeking entities whose preferences can reflect a mix of behavioral assumptions like satisficing behavior (Simon, 1955), residential segregation (Schelling, 1971), and risk evasiveness.

Comunicating Simulation Outcomes by Web-Mapping (GIS): AB modeling and geo-information can be combined in a framework that goes beyond improving disaster response and can contribute to the wider organizational realms of training, awareness enhancement and team building. Little *et al* (2015), show how web-based geovisualization tools can both encourage stakeholder involvement and public input into emergency management, Hagemeier-Klose and Wagner (2009) evaluate the use of web mapping services in communicating flood risk, and Kwan and Lee (2005) analyze the potential use of real-time 3D GIS in the case of terror attacks. As maps are an intuitive and user-friendly medium for communicating risk (Dransch et al., 2010) And public participation in planning and decision-making is gaining increased currency

(Dunn, 2007; Elwood, 2008), web GIS has been is a key component in hazard management and vulnerability assessment (Tate et al., 2011; Kawasaki et al., 2013).

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