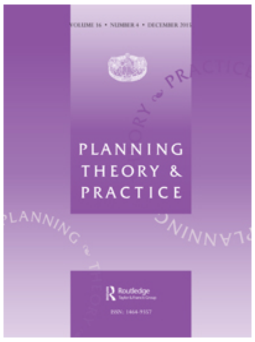

Planning Theory & Practice

ISSN: 1464-9357 (Print) 1470-000X (Online) Journal homepage: http://www.tandfonline.com/loi/rptp20

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Planning Theory & Practice, 2015
Vol. 16, No. 4, 457–478, http://dx.doi.org/10.1080/14649357.2015.1084360

Routledge
Taylor & Francis Group

Planning for deep-rooted problems: What can we learn from aligning complex systems and wicked problems?

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(*Received 16 May 2014; final version received 14 August 2015*)

An earlier generation of planners turned to Rittel & Webber's 1973 conception of "wicked problems" to explain why conventional scientific approaches failed to solve problems of pluralistic urban societies. More recently, "complex systems" analysis has attracted planners as an innovative approach to understanding metropolitan dynamics and its social and environmental impacts. Given the renewed scholarly interest in wicked problems, we asked: how can planners use the complex systems approach to tackle wicked problems? We re-evaluate Rittel and Webber's arguments through the lens of complex systems, which provide a novel way to redefine wicked problems and engage their otherwise intractable, zero-sum impasses. The complex systems framework acknowledges and builds an understanding around the factors that give rise to wicked problems: interaction, heterogeneity, feedback, neighbourhood effects, and collective interest traps. This affinity allows complex systems tools to engage wicked problems more explicitly and identify local or distributed interventions. This strategy aligns more closely with the nature of urban crises and social problems than the post-war scientific methodologies about which Rittel and Webber had grown increasingly sceptical. Despite this potential, planners have only belatedly and hesitantly engaged in complex systems analysis. The barriers are both methodological and theoretical, requiring creative, iterative problem framing. Complex systems thinking cannot "solve" or "tame" wicked problems. Instead, complex systems first characterize the nature of the wicked problems and explore plausible pathways that cannot always be anticipated and visualized without simulations. The intersection of wicked problems and complex systems presents a fertile domain to rethink our understanding of persistent social and environmental problems, to mediate the manifold conflicts over land and natural resources, and thus to restructure our planning approaches to such problems.

Keywords: complex systems; wicked problems; planning theory; history of planning methodology; agent-based modelling

1. Introduction: what happens when one brings complexity to wicked problems?

In their seminal article, Rittel and Webber (1973) locate planning within the domain of "wicked problems" as opposed to the "tame" problems that science is prepared to tackle. Their 1973 article, which encapsulated several years of writings and seminars (Churchman, 1967; Protzen & Harris, 2010; Rith & Dubberly, 2007; Skaburskis, 2008; Verma, 1996), has had a remarkable resonance and longevity, including a recent resurgence (see, for example, Batty, 2014; du Plessis, 2009; Rayner, 2006; Wexler, 2009). If Rittel and Webber were responding to the inability of "scientific" policy to address the urban crisis during the 1970s era of suburbanization, deindustrialization, the NASA space age and the Vietnam War, we now use the "wicked problem" moniker in response to an era of megacities, globalization, climate change, terrorism, sustainability, communicative action and anti-science backlash. Long after many theories from that era have

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aged poorly or been forgotten altogether, the concept of "wicked problems" still carries relevance and weight, not just in planning, but in many seemingly distant fields (such as climate change). One source of the article's power is its unequivocal writing and explicit argument: that we have tried to confront (urban) social problems with the wrong tools because we have misunderstood the very nature of the problems.

We began this project with the simple observation that the characteristics of wicked problems intriguingly resonated with the contemporary definition of complex systems. Both approaches emphasize a world of diverse, pluralistic and dynamic changes that is ill suited to traditional optimization and equilibrium modelling. We now take the connection between wicked problems and complex systems a step further: the complex systems underlying human settlements (encompassing their social, biological and built infrastructure) *generate* wicked problems through interactions, heterogeneity, feedback, neighbourhood effects, and tensions between individual and collective interests. Conversely, planning can use the tools of complex systems (i.e. planning in its best sense) to more effectively mitigate and adapt to these wicked problems. There is an engaging symmetry here: complexity is both the source of intractable wicked problems and a way to trace the pathway out.

In this article we have therefore used the complex systems structure, summarized in section 2 below, to re-evaluate Rittel and Webber's claims (section 3) about the difficulties of "solving" the problems of open social systems. As we will see, many of Rittel and Webber's original statements about wicked problems align well with complex systems thinking, e.g. "wicked problems have no stopping rule," (Rittel and Webber, 1973, p. 162) and "wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions" (1973, p. 164). But complex systems analysis also advances our understanding about social problem-solving beyond the 1970s wicked problems perspective. Importantly, Rittel and Webber's insistence that "the planner has no right to be wrong" (1973, p. 166) (echoing the NASA lunar mission credo, "failure is not an option") now sounds antiquated in our current era of "fast fail" innovation and misses the trial-and-error/feedback of current adaptive planning processes.

This last point reveals a generational shift in planning thought: contemporary planning scholars approach complex problems with tools and cultural norms that would often be strange to planners in the 1970s. Indeed, the shift in planning language from Rittel and Webber's "wicked problems" to today's "complex systems" is a proxy of the larger changes in planning theory over these 40 years. We therefore do not view today's complex systems thinking simply as the resuscitation or elaboration of the 1970s wicked problems framework (i.e. old wine in new bottles). Instead, complex systems present an adaptation and transformation of wicked problems thinking in a new era of planning and, more broadly, in a new era of relationships between problem definition, scepticism, policy, science, and beliefs in progress. Rittel and Webber were responding to a Cold War overconfidence in the universal applicability of scientific problem-solving (and perhaps to the waning overconfidence in American political-technical dominance). Today's planning scholarship works in a more bifurcated (if not schizophrenic) era of healthy scientific scepticism (arising both from environmental and community activism), troubling anti-science (e.g. right-wing attacks on climate change modelling), and a new era of (over)confidence in information-age problem-solving (Big Data, networking, personal device connectivity, geographic information systems, the "Internet of things", and so-called "Smart Cities"). Rittel and Webber wrote in the early 1970s when tensions between comprehensive planning, community advocacy, and cautious incrementalism fuelled planning theory debates over urban renewal, traffic congestion, white flight and the urban crisis. Today, complex systems scholars write in an altered planning theory landscape. First, new theoretical tensions arise between communicative action (Habermas and beyond), power (Foucault), market-based planning (Hayekian or otherwise), spatial justice, local–global polarities, and ideas of self-organizing systems. Second, the field has survived a bruising journey through anti-modernism, postmodernism and rehabilitated modernism. Third, the overlapping collapse of Marxist–Leninist communist states and rise of strong developmental states (especially in booming Asian megacities) have rewritten the planning–market–state relationships and our existential notions of "planning" (though these impacts have been often underestimated). Overall, then, we have identified both continuity and change: complex systems echo the enduring challenges of wicked problems identified by Rittel and Webber, but complex systems also represent a new era of theory and methodologies given all the fundamental changes to planning and the urban world since 1973.

We then asked: How can recent developments in complex systems analysis help planners effectively address wicked problems? While complex systems thinking shows promise in tackling and taming challenging planning issues like climate change and flooding, this framework has not been actively integrated into mainstream planning education and practice. Planning and geography scholars, especially in Europe, have developed an extensive and often sophisticated literature that acknowledges, classifies and theorizes the complexity of urban systems (Batty, 2005, 2013; de Roo, Hillier, & Wezemael, 2012; de Roo & Silva, 2010; Lai & Han, 2014; Marshall, 2012; Portugali, Meyer, Stolk, & Tan, 2012). But there remains a persistent gap between these considerable conceptual accomplishments and their sporadic adaptation into daily planning practice. Some of these gaps are simply the inevitable time lag between theory, modelling and practical implementation. But we also identified substantial theoretical and methodological barriers that prevent this integration from happening (section 4). We conclude with recommendations to bring complex systems tools into wider use by planners (section 5).

2. Complex systems and planning

A complex system is composed of multiple, often heterogeneous parts that selectively interact with each other, giving rise to a coherent organization with its own attributes, behaviours and trajectory. Cities are superlative examples of complexity, where different actors interact with each other and their environment to collectively (and often unconsciously) compute daily traffic flows, market prices, long-term land use arrangements and resource-extraction patterns. Fluid decisions made today solidify into the fixed built environment of tomorrow, which in turn shapes a new generation of interactions. The long-term behaviour of the system cannot be readily anticipated from aggregating the behaviour of the parts (e.g. through a statistical analysis of commuting speed or residential density), but rather emerges from the interactions of its parts, which affects future interactions and behaviours (Axelrod & Cohen, 1999: p. 1-31.). A complex system is adaptable and robust, retaining its integrity and coherence over long periods of time, even when its constituent parts cease to exist (e.g. people leave the city, buildings are demolished, new officials are elected). The system's ability to self-organize despite constant change relies on the selective and decentralized flow of matter, energy and information among its parts.

Small perturbations, however, can be amplified through the decentralized interactions, causing trajectory bifurcations, sending cities down alternative historical paths with varying degrees of adaptive success (think once seemingly similar US Midwestern industrial cities like Chicago, St Louis, Pittsburgh or Detroit). Feedback mechanisms can thus contribute to both stability and upheaval. This feedback, often time-lagged and spanning spatial scales, also limits the constituents' awareness of the state of the system to which they belong (e.g. downstream flooding as a consequence of land-cover changes upstream, spurred by development pressures and financial incentives), contributing to unintended and unpredictable consequences (Arthur, 1988; Axelrod & Cohen, 1999; Holland, 1995, 1998; Prigogine, 1996).

Complexity has long been recognized in planning (both overtly and by other names), even before the study of complexity was well established as a scholarly field. Jane Jacobs (1961) describes cities as problems of "organized complexity" in the final chapter of *The death and life* *of great American cities* ("The kind of problem a city is"), closely replicating Weaver's (1948) typology of problems: simple; disorganized complexity; organized complexity. Indeed, contemporary complexity scholars frequently evoke Jane Jacobs, the alternative godmother of city wisdom, to emphasize this dormant thread of complexity underlying the last half-century of urban theory.

More recently, Judith Innes has been an important voice addressing complexity in planning, focusing mostly on its social dimension. In *Planning with complexity,* Innes and co-author David Booher describe planning as a collaborative, interactive and communicative approach that can generate the coordination and innovation necessary to respond to complex problems (Innes & Booher, 2010). They emphasize the qualitative aspects of planning, including the role of local knowledge and collaboration, in response to the past over-reliance on rational linear reasoning that poorly fits with systems far from equilibrium. Complexity in planning also focuses on the complicated, diverse, open political process that forms the context for planning practice (Forester, 1999), and the challenges of planning in a spatially multi-scaled world of governance (Healey, 2007) and government (Christensen, 1999). Other theoretical discussions tend to transfer complex systems characteristics (e.g. fractal organization) to understand complex phenomena in urban planning (e.g. self-similarity in the organization of policies across scales) (Chettiparamb, 2006, 2014).

2.1. Complex systems analysis as an element and extension of collaborative planning?

The contemporary engagement with communicative action has opened important new pathways in planning theory and practice. Collaborative planning encourages groups to collectively negotiate, make deeper interests explicit, and shift from starting positions towards both compromise and creative new solutions. This scholarly focus on dialogue, debate and deliberation has both acknowledged what many planners had already recognized as their primary professional daily activity, and spurred exploration and experimentation into new communicative practices. But what if the participants' collective knowledge and discursive problem-solving skills are not enough to address the scientific, technical, economic, or institutional complexity of the problem? How can planners employ complex systems tools to expand and extend the range of communicative action planning?

The inevitable, and often disproportionate criticisms of communicative planning have condemned the heroic prerequisites needed for ideal community deliberations, including that all participants come to the negotiation table with equal voice and influence and feel bound to the negotiated outcomes. Complex systems analysis cannot resolve these challenges of uneven political power and resources. But complex systems tools can assist planners with other barriers to implementing communicative action: scalability, multiple forms of knowledge, highly technical information, cumulative impacts, and unintended consequences. The planning worldview emphasizes the importance of seeing the long-range impact of today's decisions, anticipating surprises, and evaluating trade-offs/opportunity costs. These are hard for most participants at public meetings to envision fully; such forums typically work best with a small number of participants who can express all interests explicitly and verbally (Pennington, 2002), and focus mostly on a limited set of alternative scenarios with distinctive, immediate consequences.

In particular, complex systems tools can help planners overcome our current limitations in evaluating whether collectively negotiated solutions will lead to good long-term and system-wide outcomes. Participants in collaborative planning have generally been better at judging the short-term success of public deliberations: is the process fair, inclusive and converging towards consensus (Deyle & Slotterback, 2009; Schively, 2007)? Yet measuring the substantive success of distant outcomes often requires leaps of faith with great uncertainties. A productive and fair collective process can still lead to environmental and social deterioration if participants cannot jointly make sense of the complexity they are dealing with and plan accordingly. When complexity overwhelms common sense and expertise, untested beliefs and political mandates override good judgment, even if consensual. Complex systems models can help envision the substantive outcomes and consequences of the agreed-upon solutions. They can serve as prosthetic devices to extend planning's reach (Hoch, Zellner, Milz, Radinsky, & Lyons, 2015): to help organize existing knowledge, to augment group knowledge with diverse information, to keep track of relevant interactions, and to visualize how these interactions might influence the various outcomes of interest.

Building complex systems models provides an analytical structure to define human activity in its social and natural environment, and to reason about and understand the dynamics of development trajectories and path dependence through simulations. The appeal of the modelling tools (e.g. cellular automata, agent-based modelling, network modelling) is that they can help trace system change over time and space as a consequence of discrete, localized actions and interactions. Such models can integrate multiple forms and scales of information (quantitative and qualitative, behavioural and environmental), and generate a variety of outputs that can be examined from different views (scales, interests, dimensions) (Epstein, 1999; van der Leeuw, 2004; Miller & Page, 2007; Railsback & Grimm, 2012). In planning contexts, complexity-based models can allow users to explore how policies can shape development and its regional impacts by influencing local actions and interactions (Batty, 2005; de Roo et al., 2012; Zellner, 2008).

An early inspiration was the economist Thomas Schelling's stylized segregation model (Schelling, 1969, 1978), first implemented with coins and later as an agent-based model (Wilensky, 1997, 1999). In this model, agents of two kinds decide whether to stay or relocate to a random location depending on the proportion of neighbours of the same kind. The power of this model lies in showing that with very simple behavioural rules, segregation emerges even in tolerant populations, i.e. with agents who would be happy with a minority of their neighbours being similar to them (Figure 1). Implications of this model can be transferred to housing, to understand how unintended consequences of housing policies may arise.

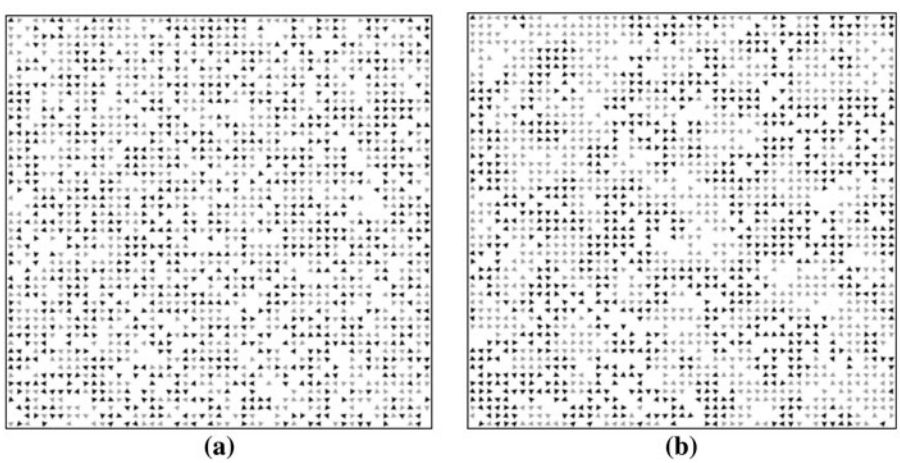

Figure 1. Schelling's segregation model (adapted from Wilensky, 1997): (a) initial random distribution of two types of agents (black and grey), (b) final distribution with a preference for 30% of similar neighbours.

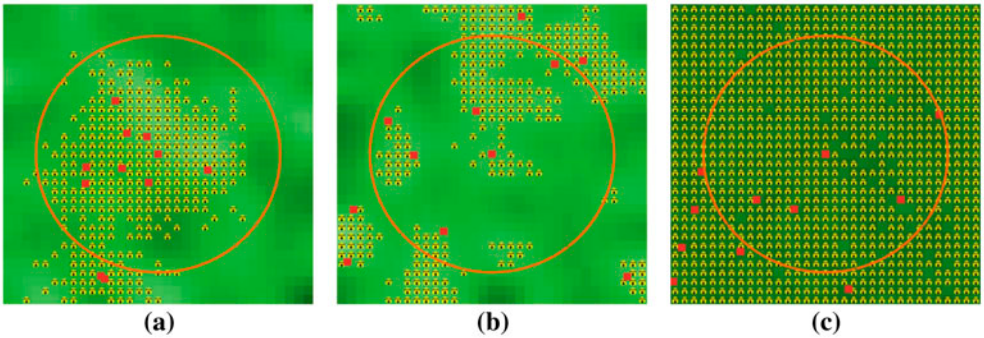

Figure 2. SOME simulations (Zellner, 2011) of exurban development with: (a) residents' (shown in yellow) equal preference for natural beauty (increasing with lighter shades of green) and for proximity to commercial centres (shown in red), (b) preference for only natural beauty, (c) preference for only natural beauty with feedback from ecological deterioration due to development.

Beyond stylized models, examples abound of land-use and land-cover change models, initially aiming at identifying drivers (e.g. individual preferences, infrastructure development, landscape characteristics). A simple example is the SLUCE Original Model for Exploration (SOME) first developed at the University of Michigan, and later implemented in Netlogo modelling software (Jun, 2004; Zellner, 2011). The SOME model shows how different exurban patterns of development emerge from small changes in residential and commercial preferences, in landscape feedback and zoning (Figure 2) (Rand, Zellner, Page, Riolo, Brown & Fernandez, 2002; Zellner, Riolo, Brown, Page & Fernandez, 2010). Such models can then be overlaid with simple representations of groundwater flow, for example, to understand how urbanization patterns may shape water depletion (Zellner, 2007). While the cases shown here do not provide the whole picture of sprawl and their environmental impacts, they provide powerful and relevant insights as to how localized changes (e.g. location preferences, road expansion) can contribute to a system-wide transformation (e.g. regional water depletion, deforestation).

More sophisticated models have been developed to replicate actual (rather than stylized or archetypal) cases, increasingly focusing on studying environmental and social impacts of human settlements such as ecosystem function and resource depletion (Deadman, Robinson, Moran, & Brondizio, 2004; Robinson et al., 2013; Zellner & Reeves, 2012). Others have more directly studied the planning and policy implications from development patterns and structures emerging from the influence of zoning, infrastructure development decisions, and support of creative industry (Hanley & Hopkins, 2007; Kii & Doi, 2005; Liu & Silva, 2013; Zellner, 2007). This experience has encouraged the incursion into other realms relevant to planning, such as gentrification (Torrens & Nara, 2007) and the dynamics of urban and agricultural land markets (Filatova, Parker, & van der Veen, 2009; Magliocca, Safirova, McConnell, & Walls, 2011). That said, most of this work is carried out by scholars in disciplines other than planning, such as geography, economics, biology and ecology. Even fewer examples exist of applications by practising planners; they rely on research experts and their computing facilities to conduct such modelling exercises.

In the next section we compare complex systems thinking and modelling with the structure of wicked problems, and consider the barriers that have not allowed complex systems to support planners more fully in engaging with wicked problems. In the article's final section, we propose ways to overcome the barriers.

3. Examining wicked problems through the lens of complex systems

Rittel and Webber wrote their 1973 paper during a lively and turbulent era of planning scholarship. Though the field was expanding and ostensibly gaining new scholarly rigour and scientific authority in academic and policy circles, it was also getting criticized for its inability to efficiently and methodically solve the "urban crisis" (inner-city decline, urban poverty, inequality, deindustrialization, and urban violence). Planning scholarship had sought academic legitimacy through embracing quantitative methods, rational problem-solving, and large-scale modelling, in part to emulate the more established disciplines on campus. But planning could not fully assimilate into an "applied social science", and the scientific basis sought was being attacked by the anti-professionalism and anti-expertise of the time (Skaburskis, 2008).

Rittel and Webber provided an alternative explanation of planning's crisis. The deficiency was not that planners lacked the intelligence, methodological skills or scientific rigour to solve urban problems. Instead, the challenge lay in the nature of planning problems themselves. "We shall want to suggest that the social professions were misled somewhere along the line into assuming they could be applied scientists – that they could solve problems in the ways scientists can solve their sorts of problems. The error has been a serious one" (Rittel & Webber, 1973, p. 160). Their reinterpretation of the field's crisis was a sobering acknowledgement that urban planning faced an unruly collection of intractable challenges. But it was also a reassuring argument: the criticisms of our profession as too immature and ineffective were misplaced and arose from an impatient and inappropriate application of scientific standards from the natural sciences and engineering to social policy. The article carried the hopeful implication that recognizing wicked problems would lead planners to strategically reorient their problem-solving methods.

In the 40 years since Rittel and Webber's publication, both planning's theoretical culture and the nature of urban problems have profoundly changed. Nevertheless, their idea still finds relevance today. The field now uses the "wicked problem" moniker in response to an era of megacities, globalization, climate change, terrorism, sustainability, and communicative action (several of many examples include Allen, 2013; Hughes, Huang, & Young, 2013; Hutchinson, English, & Mughal, 2002; Levin, Cashore, Bernstein, & Auld, 2012; Murphy, 2012; Seager, Selinger, & Wiek, 2012; Wexler, 2009). The relationship between science and planning has also changed. While in the 1970s the frustration arose from the difficulty in translating technological and scientific progress elsewhere into social planning and policy, contemporary expectations about science and urban planning are more nuanced if not contradictory. Some in the field have embraced a qualitative, narrative approach to planning as discursive collaboration or urban design, while others have embraced geographic information systems (GIS), spatial analysis, "big data," and quantitative evaluation. Perhaps there is no longer an expectation or need to articulate a singular stance towards scientific methods in planning.

This is the context in which we examine complex systems analysis and wicked problems, as a juxtaposition of two overlapping sets of ideas from two eras of planning analysis. Although not always an identical match, most elements of complex systems align well with their wicked problems antecedent. The convolutions and uncertainties that characterize urban and regional systems – the very qualities that led Rittel and Webber to dismiss traditional technical-scientific problem-solving – resonate with complex systems approaches. Complex systems cannot "solve" wicked problems in the conventional deterministic sense. But complex systems can help redefine wicked problems, and unravel them while retaining their diversity, interdependence and "messiness". The very characteristics of wicked problems that trip up traditional statistical and mathematical analysis become prolific ingredients for complex systems analysis. In this section we have revisited Rittel and Webber's often-cited 10 characteristics of wicked problems (numbered below), combining them into five clusters, and comparing them to complex systems.

"1. There is no definitive formulation of a wicked problem." (Rittel & Webber, 1973, p. 161.)

Rittel and Webber begin by challenging the tidy sequence of the "systems approach" to problem-solving (define problem, evidence, analysis, synthesis, solution). Their scepticism that a precise problem statement will efficiently lead to a logical solution resonates with the process of emergence in complex systems, in which knowledge of starting conditions cannot lead to accurate predictions of outcomes. Wicked problems upend this unidirectional systems sequence, requiring instead a back-and-forth, often simultaneous shaping of problem and solution. Rittel and Webber call for an alternative iterative process of collective argumentation that presciently anticipates the communicative action model a generation later, "a model of planning as an argumentative process in the course of which an image of the problem and of the solution emerges gradually among participants" (Rittel & Webber, 1973, p. 162).

Here one can see convergence between communicative planning and complex systems thinking: the problem-solving process is one of on-going exploration and discovery, where the system is understood by trying to define and explain it through explicit representation, simulation, and evaluation and reflection from a variety of perspectives and with a variety of tools (Bankes, Lempert & Popper, 2002; de Roo et al., 2012; Miller & Page, 2007; Railsback & Grimm, 2012; Zellner, 2008). The field of complex systems offers conceptual and computational modelling tools to facilitate this iterative exploratory process. This approach forces users to be explicit about the relevant aspects of the problem and how they relate to each other, bringing the problem and its consequences into sharper focus. Multiple forms of knowledge can be integrated into these tools, and outputs can be examined from different angles in the search for robust approaches to wicked problems (Bankes, 2002; van der Leeuw, 2004; Miller & Page, 2007; Zellner, 2008).

"2. Wicked problems have no stopping rule." AND "4. There is no immediate and no ultimate test of a solution to a wicked problem." AND "8. Every wicked problem can be considered to be a symptom of another problem." (Rittel & Webber, 1973, pp. 162, 163, 165.)

Unlike solving tame problems, engaging wicked problems characteristically lacks clarity and closure: it is neither self-evident that a proposed solution is correct, nor do you receive a straightforward signal that you have finished your work and can stop. Uncertainty means there are no definitive answers and no permanent solutions. The system is open, interdependent and continually evolving, and the pursuit of a solution to one problem invariably uncovers more problems in unexpected areas. There is no "eureka" moment: activity stops because of external constraints (budgets, deadlines) or simply because politics or institutions compel closure.

Complex systems similarly elude equilibrium: as open systems, they are constantly pushed and redirected by outside forces and agents. Every intervention will unlock a series of effects over time. While Rittel and Webber suggest that we could potentially wait for the repercussions to die down, from the complex systems perspective, this would never truly happen. The interactions activated by these interventions would lead to future changes. For this reason, the search for best estimates and optimal solutions is too costly, narrowly conceived, and ultimately misdirected.

Where complex systems and wicked problems also diverge is in the relationship between scale and the difficulty of solutions. Rittel and Webber wrote in an era where the comprehensive–incremental debate (and the related top-down/bottom-up debate) constrained the field in a self-imposed scalar dichotomy. Rittel and Webber assumed that higher levels of problem formulation made it harder to be specific about solutions. By contrast, contemporary complex systems thinking is far more tolerant of engaging multiple scales simultaneously: higher levels of a complex system require the definition of their own constituent units and transition functions or mechanisms that result in a behaviour at that specific level (Miller & Page, 2007). This does not imply that the system and the interventions at that level become more vague. Quite the contrary: interventions target the specific behavioural rules at that level (e.g. federal policies of regulating oil production, transport and refining, and local land-use policies regulating alternative decentralized energy production and transmission). Rittel and Webber asserted that "one should not try to cure symptoms: and therefore one should try to settle the problem on as high a level as possible" (Rittel & Webber, 1973, p. 162). In complex systems, interventions at lower levels may prove more effective in terms of the system-wide transformations they can activate through the mechanisms of emergence.

These 1970s constraints about scale and problem-solving may have led Rittel and Webber to be critical of traditional incrementalism of successive limited comparisons (Lindblom, 1959), because a low-level corrective intervention might make things worse at higher levels: "Marginal improvement does not guarantee overall improvement" (Rittel & Webber, 1973, p. 165). The Lindblomian version of incrementalism is rather cautious in its ambitions and limited in its ability to learn and adapt. Incrementalism leads to first-order learning: mid-course corrections on the path towards a predetermined goal. By contrast, complex systems analysis is built upon an exploration of cross-scale feedback, allowing for the continual re-examination and revision of both values (second-order learning) and paths to realizing them (first-order learning).

Both complex systems thinking and incrementalism assume that no individual can ever know all the relevant planning information up front. But at that point they diverge. Lindblomian incrementalism is sceptical and defensive: it bumps up against the limitations of information access and processing in a complex world, and defaults to marginal, short-term corrective actions. Complex systems thinking is more ambitious and expansive: like communicative action planning, it seeks to overcome the limitations of individual knowledge and cognition through the collaborative exploration of group knowledge, collective learning and adaptation. Complex systems tools can help planners trace the consequences of individual/localized decisions on system-wide effects over time. Complex systems thus encourage planners to consider not only how planning strategies might be corrected, but also whether the chosen direction should be changed or eliminated altogether. (For example, asking not only "where should growth occur?" but also "should growth occur at all?"). This contrast leads to an important distinction between *incremental* change (an atomistic and linear approach) and *interactive* change (an approach that recognizes interdependence and ripple effects). It is for this reason – not the level of intervention as Rittel and Webber suggest – that incrementalism stifles adaptation towards structural improvement.

The flipside of this flexibility is indeterminacy. Sceptics might criticize complex systems analysis as failing to provide definitive, explanatory answers, and instead merely offering description, probabilities and exploratory insights. Complex systems analysis can produce a wide range of outcomes that can be analysed by established (e.g. ecological footprint) and newer indicators of social and environmental trends (e.g. based on information theory such as Cabezas, Pawlowski, Mayer & Hoagland, 2005; Randolph, 2012). These indicators enable planners to identify better or worse simulated trajectories and outcomes of specific policies (Zellner, Theis, Karunanithi, Garmestani, & Cabezas, 2008). This approach neither eliminates the open-ended nature of the wicked problem nor diminishes the need for planners and communities to engage in an on-going process of exploration, evaluation, questioning, and innovation. What complex systems tools provide is a way to understand the likely causes of wicked problems and examine the plausible cross-scale consequences of solutions proposed in such open-ended processes.

"3. Solutions to wicked problems are not true-or-false, but good-or-bad." AND "6. Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into

the plan." AND "9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution." (Rittel & Webber, 1973, pp. 162, 164, 166.)

These characteristics of wicked problems arise in the presence of three conditions: an unclear (and incomplete) set of possible solutions; multiple, divergent causal models linking problems to solutions; and normative consequences for any solution implemented in a pluralistic society. Solutions therefore cannot be judged against an objective, universal standard; solutions are satisfactory – contingent on specific interest groups, times and locations.

Complex systems modelling allows for the explicit representation of these contingencies: starting conditions, multiple causal links across diverse dimensions (e.g. preferences, land-cover, environmental dynamics), data formats (e.g. digitized land cover, demographic distributions, social norms of interaction, resource flows), and outcome variables (e.g. distribution of wealth and resources, environmental quality). The choice of initial conditions and causal dimensions, data and variables of interest depends on the composition of the group of planners, policymakers and stakeholders, as well as on the existing knowledge about the structure of the problem (scientific, practical or anecdotal).

Complexity, like wicked problems, recognizes the limitations of predicting future outcomes and making fully informed decisions given this contingent nature of social and environmental problems. We need to run the complex systems model to see what emerges (Epstein, 1999), and then discuss the trade-offs inherent in the outcomes (Zellner, 2008). Some dimensions of the problems may not seem relevant at the start, but rather emerge from the systematic study of the wicked problem in question with tools that allow us to visualize and deliberate about the benefits and costs of potential outcomes, and further discover and formulate new goals (Miller & Page, 2007). Given this lack of "an enumerable (or an exhaustively describable) set of potential solutions" (Rittel & Webber, 1973, p. 164) at the start, a participatory planning process needs the flexibility to introduce and negotiate new ideas and solutions midway. It is still up to the group to negotiate which dimensions and solutions to bring forth.

The computational tools developed for complex systems analysis allow planning groups to "put [a hypothesis] to a crucial test" (Rittel & Webber, 1973, p. 166), by representing in a virtual world the factors and mechanisms that participants consider important, and showing how they are or are not relevant to the complex problem studied. If they do not prove as relevant as first thought, participants can re-examine assumptions, generate new hypotheses and test them via simulation. Still, we cannot escape the reliance on judgment to select a valid explanation and solution for complex problems, which will depend on the beliefs and attachments held by the planners and stakeholders (Hoch et al., 2015; Zellner et al., 2012). Again, complex systems analysis can only offer a way to study the implications of these judgments.

"5. Every solution to a wicked problem is a 'one-shot operation'; because there is no opportunity to learn by trial-and-error, every attempt counts significantly." AND "10. The planner has no right to be wrong." (Rittel & Webber, 1973, pp. 163, 166.)

Rittel and Webber saw no tolerance in planning for the repeated hypothesis testing that governed the Popperian scientific thinking of the time. They emphasized the critical importance of making correct plans the first time around. The planner's task was not to seek the truth through repeated experimental trial-and-error, but rather "to improve some characteristics of the world where people live" (Rittel & Webber, 1973, p. 167). The social and environmental costs of mistakes arising from "real-world" experimentation could be tremendously high, and the reinterpretation of modernist urban renewal programmes as "failed social experiments" was forefront in planners' anguished minds at the time of Rittel and Webber's writing. Arguments against trial and error could take on several dimensions: scale (too big and therefore too risky), the ethical barrier to "experimenting with people's lives", the lack of feedback/learning from the process, and the danger that the decisions were irreversible (e.g. large-scale slum clearance to make way for public housing), particularly with growing scales of intervention (e.g. Krieger, 1986; Whiteman, 1983).

It is here that complex systems analysis crucially departs from Rittel and Webber's sombre pronouncements from 1973. Given the contemporary preoccupation with collective deliberation, diversity and adaptation to multiple desires and values, their imperative of getting it right the first time is both highly unlikely and usually unnecessary. The study of complexity can make its strongest and most valuable contribution addressing these very real concerns. Computational complex systems models provide planners and communities with the opportunity for trial and error in less risky, virtual environments – and thus allow for exploration of innovative alternative scenarios. (The contemporary refrain among Silicon Valley tech firms is that "failing fast" leads to rapid learning, adaptation, and eventual success; the same likely applies to complex systems modelling.)

Rittel and Webber equate these exercises to scientific endeavours that do not apply to planning, but we disagree. There is a place for these simulations, if they can effectively bridge science and policy, as evidenced in the extensive literature of applications to policy exploration (Axelrod, 1997; Bankes, 2002; Miller & Page, 2007; Zellner, 2008). Just as trial and error and adaptation forms the core learning mechanism in complex adaptive systems, virtual failure could serve the same role in planning but without the risk. The challenge is to craft a simulation process that generates accessible and compelling outcomes that planners and citizens can credibly translate to meaningful decisions in the real world (otherwise participants will simply dismiss the simulations as entertaining but irrelevant, concluding, "Clever modelling exercise: but let's get back to the real world of making decisions based on the rules, practices and property markets that we know.").

This tension between the long, time-consuming process to explore innovative ideas and solutions, and the urgency to get the right answer and the right policy on the first try, continues to bedevil planning. Planners are caught in a difficult position in dealing with complexity: community members recognize the uncertainty of unintended consequences, but still impatiently expect that, given accurate and complete information, the "right" solution to a planning problem can be found. Planners are then either forced to engage in sophisticated analysis, or hire an outside consultant who will conduct it and provide the optimal answers demanded (Zellner, 2008). The demand for immediate success and the extreme aversion to failure that accompanies it give little room and patience for exploration and learning. An open attitude towards learning is often trumped by the pressure to collect ever more data to reassure us of the certainty of our success, which ironically slows down the search for and implementation of a good-enough solution. At best, this process promotes cautious incrementalism, and at worst, stagnation and the reinforcement of beliefs that remain unexamined.

Is there a way out of this conundrum? Yes, if planners use tools that allow us to fail without major consequences, other than understanding the sources and consequences of our mistakes, and gaining insights and reasoning capabilities that can be applied to the complex problem at hand and transferred to other realms. Complex systems modelling is not infallible; indeed, the nature of the process is one of imperfection–learning–adaptation. If done well, complex systems analysis allows for learning and improvement over time in an open, diverse, changing society with emergent values and priorities.

"7. Every wicked problem is essentially unique." (Rittel & Webber, 1973, p. 164.)

Discovering the universal patterns beneath the surface variations among individual cases is an integral part of scientific study: to separate the "signal" common to all cases from the disparate "noise" coming from individual cases. The aspiration is to not only discern consistent patterns in the data, but also infer that these patterns arise from underlying laws of nature (e.g. Newtonian physics). Numerous scholars have challenged this assumption (such as Cartwright, 1983, 1999), both in the practice of science in general and particularly in the social sciences. The implications for urban planning are unmistakable: the lack of a reliable universality across planning problems undermines the credibility of traditional scientific problem-solving in open social systems. A consequence is planners' long-running lament that the profession lacks the systematic, cumulative knowledge-building process found in the natural sciences (Kuhn, 1962).

In this vein, Rittel and Webber recognize an aspect of social systems that complexity theorists also recognize: the dependence on context. Even two apparently identical cases will play out different histories: the complexities of context and interactions will lead the two cases to diverge (Ragin & Becker, 1992), or in the words of Rittel and Webber (1973), "one can never be certain that the particulars of a problem do not override its commonalities with other problems already dealt with." Moreover, it is unlikely that even the *same* system will behave in the same manner over time: the system may, at a critical juncture, pursue one trajectory over another equally likely one. The benchmark for scientific confidence – replication through achieving the identical outcome with the identical starting conditions – is thrown into doubt as equally viable future pathways present themselves.

Yet complexity theorists have made peace with this apparent unpredictability. Even if the same components and mechanisms of complex systems lead to different outcomes, one can, in fact, establish regularities and gain understanding as to how the range of outcomes emerge from these components and mechanisms coming together. The regularity is in the way these systems work (and how we study them), not in a singular outcome. While the importance of context can render "best management practices" ineffective, one can still identify policies that are robust in a range of possibilities (Bankes et al., 2002). The future is no longer deterministic, but probabilistic.

Complex systems analysis enables us to extract some regularities across systems, transferring insights from one realm of complexity (e.g. social contagion) to another. We can apply insights from forest fire dynamics emerging from the connectedness in vegetation, to the collapse of financial systems (Miller & Page, 2007) or to the adoption of innovations (Gilbert & Troitzsch, 1999). The role of limited resources in dampening the booms and busts of predator-prey populations (Wilensky, 1997) can translate into useful recommendations to maintain healthy financial markets. This focus on complexity allows us to identify certain "building blocks" (Holland, 1995) and classes of problems that planners can recognize as they evaluate and plan for wicked problems.

Considered together, the Rittel & Webber wicked problems of 1973 and today's complex systems articulate the shortcomings of conventional systems optimization and prediction, and point towards alternatives to address the complexities of open, interdependent systems in pluralistic societies. Both conceptualize problems not as self-contained logical puzzles, but instead as embedded in larger, dynamic open systems. A problem may be wicked or complex not simply due to its intrinsic qualities, but also due to its interaction with the larger socio-ecological context: the technologies, institutions, culture, and environment of the time. These circumstances are not static; they change and evolve over time and in space. Rittel and Webber focused more on the barriers that such problems posed towards conventional scientific solutions. By contrast, complex systems thinking provides techniques to approach such problems and explore alternative pathways forward. The study of complex systems does not offer the promise of solving or "taming" wicked problems. Instead, it explicitly acknowledges and builds on these "wicked" characteristics to address them through simulation, learning and innovation.

4. An untapped potential: barriers to widespread adoption of complex systems reasoning and tools in planning

Given all these promising potential applications, why have relatively few planners embraced complex systems analysis? We have observed a discouragingly low adoption rate of complex systems reasoning and tools in planning scholarship to date, and even more so in planning practice. We have identified several primary causes, both methodological and theoretical, and offer strategies to increase adoption.

4.1. Methodological challenges

Recent trends in planning education show a shifting away from requiring quantitative analytical skills, simultaneously expanding the repertoire into areas of communicative skills including visualization, negotiation, conflict resolution and public presentations (Edwards & Bates, 2011; Kaufman &, 1995; Klosterman, 2013). The recent emphasis on collaborative/communicative planning parallels this shift in methodological priorities, and feedback from planning alumni often reinforces the need to better align skills taught and skills used in the labour force.

Many planning programmes continue to require courses in statistics and economics, and have sometimes expanded coursework in finance, for example. Yet relatively few master planning students take rigorous quantitative methods courses beyond the core requirements, let alone computational modelling. To richly take advantage of complex systems analysis, a planning student requires *both* quantitative/computational methods beyond the standard core courses (i.e. a fluency in modelling) and the newer methods of planning analysis (i.e. communication and negotiation in a pluralistic world).

4.1.1. The adoption of GIS methods as a model for complex systems?

One might hypothesize that the history of GIS use in planning is a model for complex systems, and that planning's learning curve for complex systems analysis will follow that of GIS: (a) early, informal exploration by "data geeks" with deep knowledge of coding; (b) formalization in an elective course as the software gets easier; (c) finally, incremental integration into the larger curriculum as software approaches the ease of spreadsheets. But as popular as GIS has become in planning, its use in practice is often illustrative and descriptive, driven more by the aesthetics of visualization rather than rigorous and sophisticated analysis of spatial (Göçmen & Ventura, 2010; Göçmen, 2013) Moreover, there seems to be confusion between the proficiency in the use of the software and the proficiency in the *reasoning ability* that the tools are supposed to enhance. The important distinction between GIS as software versus a methodology for spatial analysis remains muddled. Increasingly sophisticated technology cannot substitute for reasoning ability. As fewer resources are dedicated to analytical training, analysis ends up being outsourced to consultants (either private or academic) who often develop tools that communities will have a hard time using effectively, or that provide answers that users cannot examine and contest because they have not been trained to do so.

Additionally, learning complex systems is not like learning GIS. Unlike GIS, complex systems analysis does not have standardized steps to follow that can be easily documented in a tutorial. GIS is easier to use and accessible with less explanation, with solid and stable outputs that are visually appealing. Students can begin GIS work through simple descriptive mapping, a standard foundation of planning practice that is rooted in land use and street maps, and readily familiar to end-users through the long history of cartography. Sophisticated spatial analysis, however, requires extensive training that is typically taught in advanced classes and remains the domain of experts.

By contrast, complex systems analysis places far more emphasis on defining (and redefining) the problem, representing the system, and assigning behaviour to agents. There are fewer canned, pre-packaged tools. Complex systems analysis requires more intricate engagement with temporal dynamics and interaction, feedback effects and change over time. There is not a clear-cut set of final products representing a stable, fixed outcome (e.g., GIS's thematic map). Instead, learning complex systems requires more improvisation, adaptation to specifics, and interpretation. It demands more interaction between user and model, a greater understanding of the internal dynamics, and a higher tolerance for the interplay between problem definition and solution. In this way, the learning of complex systems mirrors the nature of complex systems themselves. In summary, we believe that it will take more than time and friendlier user interfaces for complex systems analytical tools to approach the popularity of GIS.

4.1.2. The art of reasoning with complex systems

As with other analytical approaches, the effective use of complex systems analytical tools requires training in appropriate modelling: defining a problem and questions, and deciding what to include and what to leave out in relation to the problem and questions. This is not a preliminary, trivial activity, and requires a rich knowledge of the problem and context. It also requires the development of unique complex systems reasoning to recognize and conceptualize complexity: appropriately defining actors, their attributes, their actions and rules of interaction, the patterns that need to be represented at various levels of organization, and how they are relevant to the emergent patterns of interest. Effective complex systems work also means developing an appropriate coding and programming practice: ensuring the valid transfer between conceptual model and code implementation, gradually constructing and testing the model, running sensitivity analysis, and developing adequate documentation. Finally, complex systems analysis means conducting valid reasoning with these tools, i.e. designing relevant simulation experiments and extracting valid interpretations and insights from the results.

If such training and skills remain in the expert domain, there is no clear advantage to engaging in this type of endeavour, as communities will still outsource analysis and hand over the power of decision-making to tools they cannot understand or question. Applying complex systems analysis to solve wicked problems is therefore labour-intensive and requires on-going, sustained effort by communities to learn how to reason with complex systems tools to understand the complexity of the problems they are confronting and to come up with solutions.

4.2. Theoretical challenges

Beyond mastering the modelling and the coding, effective complex systems reasoning requires a new approach to theorizing the research problem itself. To frame our observations, develop our methodological approach, give meaning to our insights and not get lost in complexity, it is vital to establish "anchors:" crisply define the problem, the research questions and the planning questions. This is not different from the rigour that should exist in any research or planning endeavour. What becomes distinctive to complexity is that this sequence is an open-ended, iterative process in a cumulative spiral of learning and adaptation. This creates a tension for planning: though we readily acknowledge that the systems of interest to our scholarly and professional communities are complex, we constantly encounter impatience and pressures (both internal and external) to deliver quick fixes. We can fix or solve specific problems at certain points in time, but we cannot ultimately "solve the city" (Bettencourt, Lobo, Strumsky, & West, 2010; Bettencourt & West, 2010; Lehrer, 2010). Not only will new issues constantly emerge (it is, after all, an open system), but also the "solving" claim is theoretically and methodologically misplaced.

We define problems, we model systems relevant to these problems, and we plan to affect components of the system so that the specific problems are solved … and then new ones arise. We may sensibly construct a model of a city (in the conventional sense of the term model as “simplifications with a purpose”) to understand the city’s mechanisms and explore various scenarios; but to construct a model to deterministically predict the urban future is as theoretically and methodologically untenable as it is to try to solve it.

It is tempting to believe that, had we sufficient data, information and accuracy, then we would be able to eventually find tame solutions to complex problems. This is an illusion in complexity (Bankes, 2002). In complex systems, present interactions continuously change what the future might look like (Axelrod & Cohen, 1999), and in wicked problems, humans value the possible outcomes in different ways at different times. There is an intrinsic barrier to accuracy when dealing with a moving target. Complex systems thinking prioritizes exploration over prediction, and robustness to uncertainty over optimization. One cannot be an *efficient* innovator; one can be an *effective* innovator if allowed to fail and try again. This shift in problem-solving begins with how we train practitioners to creatively use this mind-set, and the tools that come with it. Our expanding analytical arsenal (e.g. massive computational power, GIS, multivariate meta-analysis, 3D data visualization) needs to be matched with strong theoretical innovation, problem framing and problem-solving.

Understandably, the lack of traditional markers of accuracy, efficiency and reliability will make many planners, researchers and stakeholders unsettled. Complex systems advocates are, in a way, asking planners to enter unfamiliar territory. The assurance that a time-intensive engagement with complex systems modelling will provide “insight” may well not be enough for those who want their methods to provide “solutions” and a “fix”, sending them back to familiar planning methods. This scepticism is not a trivial barrier. Complex systems advocates need to more directly address these questions of confidence and veracity. Otherwise, many planners will judge complex systems to be a clever exploratory tool at best, an obscure black box at worst, but not a serious analytical tool.

A recent example illustrates this challenge. In leading community participants in exercises involving complex systems modelling, we encountered an unsettling paradox: some participants stated that they had learned a lot about the planning issue at hand, but still found the exercise useless. This disconnection highlights the gap between gaining insights and translating into better decisions: complex systems learning does not automatically lead to complex systems planning. (This parallels a criticism of communicative planning: an overemphasis on discussion and exploration without always a clear connection to individual and collective decision-making.) Our culture is often uncomfortable with this uncertainty, expecting models to provide accurate answers, rather than support the discussion and negotiation of answers emerging from users as they explore the problem with models.

5. Strategies to incorporate complex systems in planning education and practice

We began with several observations. First, the idea of wicked problems, though over 40 years old, continues to find resonance (and new enthusiasts) today. Planners and other scholars still evoke the term “wicked problems” because it cogently captures the world we work in, sharply articulates the gap between natural science and social science problems, and has yet to be overtaken by a more compelling term. Second, complex systems analysis, though not a direct descendant of wicked problems, may nevertheless provide a path to redefining and updating wicked problems. Both share a kindred worldview of open, diverse socio-ecological systems.

So we return to our original questions. First, what do we gain by overlaying the complex systems approach onto the earlier map of wicked problems? Second, if this approach is promising, how do we overcome the obstacles in integrating complex systems analysis into planning education and practice?

Developing innovative, ambitious complex systems approaches in planning runs into significant methodological barriers. Methodological rigour is vital, but planning, as a field, is not very good at promoting it (recent PLANET listserv discussions among planning faculty members about deficient methods training among students illustrates this point), and the learning curve is steep. Beyond mastering the computational programming, effective use of complex systems requires a new approach to theorizing the research problem itself.

Approaching wicked problems as complex requires a way of thinking that is closer to playing than to optimizing or forecasting. By "play" we do not mean frivolous, non-essential behaviour. Games are work; they are the productive, open-ended, and interactive exploration of co-evolving processes. Games encourage participants to tackle challenging problems in diverse, tangible, creative ways. Playing allows for learning and recovery from failure, mid-course intervention, and innovation necessary to transparently address the surprises inherent in complexity (Kapp, 2012; McGonigal, 2011). Games are "the voluntary attempt to overcome unnecessary obstacles" (Suits, 1978, pp. 54–5) – and one can cautiously substitute the term "wicked problems" here for "unnecessary obstacles." Our field has yet to fully develop the strategies to train practitioners to use these tools creatively.

Complex systems analysis offers great promise, but we are very aware of both the challenges in bringing it to planning and the legacy of other once-touted methods for planning that evaporated. We conclude with four recommendations below.

5.1. *Working with complex systems requires sustained interaction and effort*

Despite the interactive, open design of complex systems analysis, too many planners and stakeholders instead view the approach as a closed "black box". Complex systems will remain a black box unless we can open it up, tinker with it, and understand the significance of interdependence and intermediate steps in affecting the outcome. This is not for the impatient or faint of heart. Importantly, employing complex systems in planning works best when done locally by planners working closely with the community. When outsourcing analysis, communities have no way of knowing what an in-depth analysis involves. Consequently, when directly engaged in complex systems analysis, community participants have very unrealistic expectations of, and are frustrated by, how much effort and time it takes.

5.2. *Bring numbers, risk and critical problem-definition back to planning education*

We recommend reversing the trend of eliminating quantitative and computational skills from the core curriculum and from specializations. If planners want to deal with complex problems, then they need to develop strong quantitative and computational skills in addition to negotiation and communication. Moreover, these two should not be dissociated, since there is little use for rigorous analysis if it cannot be effectively communicated to inspire the necessary changes. We therefore do not pose complex systems as an oppositional alternative to communicative action, but rather as an extension and technologically-assisted enhancement of communicative action.

But it is not just bringing back numbers, quantitative analysis and conventional inferential statistics courses. It is also bringing "failure" back into planning, or more precisely, allowing planners to get beyond their fear of failure and to engage in more innovative trial-and-error in the relatively safer context of computer modelling. Complex systems reasoning means logical, interactive, critical problem-definition: taking risks to fail, to explain, to redefine, and to remodel, a significant but necessary effort to deal with wicked problems. Finally, complex systems analysis allows us to creatively, courageously and explicitly engage with the future, planning's *raison d'être*, though we too often shy away from it (Isserman, 1985; Klosterman, 2013; Myers, 2001; Wachs, 2001).

The current structure of professional planning education gives little room for the development of complex systems reasoning. While this problem could be resolved through curricular restructuring of planning programmes – a challenge in itself – there is also the question of whether complex systems should remain within the domain of experts only, or if this approach could be extended to general public education. The purpose would be two-fold: (1) allowing future practitioners to start earlier and thus have more time to develop this reasoning skill throughout their grade school, undergraduate and graduate training, and (2) educating the citizens to reason about complexity so that they can more effectively participate in planning processes in which they have a stake (more on this below).

5.3. Educate citizens to reason about complex systems

Complex systems analysis cannot remain the domain of experts if we are to communicate effectively with the communities we want to serve, and inspire them to engage in their own transformation. Wicked socio-ecological problems cannot escape the need for stakeholder engagement, as they need to make value judgments around an understanding of their own role in the problem (either as a cause or as a consequence) and in advancing solutions. Their judgments, however, must be informed by an analysis they can dissect, criticize and contribute to. This is a tall order, but the tools made available by complex systems have the potential to open up the access to modelling by non-experts. Advancements in computer interfaces are needed, however, to facilitate this access (Zellner et al., 2012). The tools here play the role of a prosthetic device to support complex systems reasoning (Hoch et al., 2015), but the goal is the reasoning, not the mastery of software or modelling code. There is substantial published work in the learning sciences literature regarding the support of complex systems reasoning with models, mostly concerned with learning in formal classroom settings (Hmelo, Holton, & Kolodner, 2000; Jacobson & Wilensky, 2006). Recent changes in educational standards have been supported by a commitment to interdisciplinary understanding, particularly around environmental problems, and to the use of modelling tools to advance this understanding (College Board, 2009). While these trends are auspicious for formal education, complex systems modelling remains marginal to mainstream educational practices, let alone to citizen education within an informal setting like a planning process. More resources should be directed towards these efforts.

5.4. Educate planners and citizens on systematic problem-solving

Appropriate problem definition is a critical guide to our research and our practice. Problem definition is a never-ending progression of exploration, thoughtful critique, and solution-building, going through the "ugly" failures and partial representations of the problems and solutions before we get to the more appealing and "successful". This activity takes time (Hmelo et al., 2000; Jacobson & Wilensky, 2006; Zellner et al., 2012). In this approach, success is not measured in terms of a model's ability to accurately reproduce observations, but instead in the ability to promote understanding of how interactions lead to a wicked problem, of the uncertain and cross-scale effects of specific interventions, and of the robustness of proposed solutions, given this uncertainty. Such understanding can support collective deliberations about more explicit trade-offs and move us forward in our negotiations. As is often recommended in planning – but hard to fund in practice – monitoring and evaluation of social and environmental variables of interest are key components to feed back into the continuous cycle of problem-solving and adaptation.

5.5. *Final thought*

Rittel and Webber shrewdly used the provocative term "wicked" (and not "convoluted" or "complex") implying an intractable barrier, and focused on characterizing wicked problems and their structures. In contrast, complex systems modelling supports candid representations of the "organized complexity" (Jacobs, 1961) of socio-ecological systems to characterize the nature of wicked problems, think about them and explore potential solutions that are not readily visible. Sceptics might argue that complex systems analysis is but the latest false promise of comprehensive urban modelling, which will do as little as systems thinking and cybernetics did for understanding wicked problems a generation ago, and cite Doug Lee's pivotal "Requiem for large scale models" as still relevant today (Lee, 1973). We would agree if monolithic comprehensiveness were the goal of complex systems thinking, but its promise lies elsewhere: it illuminates wicked problems by identifying crucial actors and intervention points for system-wide transformations in a diverse, adaptive, multi-agent world. Despite the substantial barriers, the intersection of wicked problems and complex systems presents a fertile domain to rethink our understanding of socio-ecological systems, to mediate the manifold conflicts over land and natural resources, and to restructure our planning approaches to such problems.

Acknowledgements

We are grateful to our colleagues Mike Teitz, Dowell Myers and Robert Goodspeed, and three anonymous reviewers, for providing feedback on earlier versions of this paper, which was presented at the 2011 ACSP Conference in Salt Lake City. We also appreciate the valuable comments of participants at the "Wicked Problems in Socio-Ecological Systems Symposium" held at the University of California, Berkeley, in October 2013. The reflections in this paper result from the collaborative research on participatory modelling conducted by Moira Zellner with Charlie Hoch, Leilah Lyons, Josh Radinsky, and Dan Milz at the University of Illinois at Chicago, who have greatly enriched this field of study with their unique perspectives, and helped us envision the potential of this approach for planning.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research has been supported by the following funding sources and institutions: the Great Cities Institute Faculty Fellowship, the Faculty Scholarship Support Award, the Institute for Public and Civic Engagement, and the Chancellor's Discovery Fund at the University of Illinois at Chicago; and the National Science Foundation 11-515 Cyberinfrastructure Training, Education, Advancement and Mentoring Program award number OCI-1135572. Last, but not least, we thank our respective units in Chicago and Ann Arbor for providing funding to attend the Berkeley workshop.

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