A coordination lattice model for building urban resilience

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ABSTRACT

Common denominators emerge difficultly in projects bridging science and society or/and across disciplines. Managing crises require inter-organizational learning and citizen involvement, but, often such undertakings lead to bargain resulting in sub-optimal decisions. Building resilience into human communities demands complex projects, which further require good problem definition, starting with agreements on values and knowledge, as basis for further agreements on goals and methods. This paper spreads the Data-Information-Knowledge-Action-Result frame over a 4-level process to generate a *DIKAR_process* matrix and lattice that allows optimal orientation and coordination towards achieving a set of common denominators and coordinated action protocols. This framework allows sequences and cycles that can be formulated and pursued simultaneously, comparatively and iteratively, within any large, heterogeneous constituency of actors involved in building resilience in local communities. The model is illustrated and discussed in relation to urban sustainability issues and complementary methods like knowledge maps, mental models, social learning and scenarios.

Keywords

Resilient communities, Social learning, Data-Information-Knowledge-Action-Result, Foresight, Planning

INTRODUCTION

Dealing with crises requires inter-organizational learning and effective citizen involvement, but, in the absence of common denominators, these easily lead to bargaining resulting in sub-optimal decisions (Moynihan, 2008; Turoff et al., 2013). Resilience of human communities can only be built through complex projects, which in turn require good problem definition. This starts with agreements on values and knowledge, as a necessary condition for further agreements on goals and methods (Castle & Culver, 2013). However, developing a set of common denominators is a long-term activity that never stops, because it takes projects bridging science and society or/and involving different disciplines (Brand et al., 2013; Mauser et al., 2013; Polk, 2014; Janssen et al., 2015; Schimel et al., 2015). Getting partners on the same page requires a lot of uncertainty, investment of resources and experimentation, learning, conflict management and institutional building. Such projects and programs include a broad range of disciplines, social actors and contexts, each with its own issues, terminology and worldview. They are triggered by convergences of interests matching public demands or other types of opportunity, but most of the initial coordination efforts are dedicated to alignment of formal requirements. Essential contextual and conceptual mismatches are postponed to later stages, presumably to be addressed 'as per normal' or/and "one problem at a time". However, resilience can only be treated effectively as part of a holistic endeavor about sustainability, whereby disciplinary experts can't "just do one thing", but have to work together, learn from each other and make expert-decisions as a group, and engage in stakeholder collaboration and social learning (Clark et al., 2016). This starts with project preparation. Very often, and especially in the case of megaprojects, not the best projects are being funded, but those who look best on paper (Flyvbjerg, 2014). Especially when they haven't worked together before, intended partners can easily overestimate both their common grounds and their individual adaptability, at which point crisis becomes inevitable.

MODEL

To overcome inertia or project setbacks a group of actors and stakeholders (scientists, citizens, etc.) must recognize that they must avoid a situation of poorly-structured problem, i.e., one with latent disagreements on values (general rules of operation) and knowledge (general terminology, theories and models). If they don't, they have no realistic basis for meaningful and effective coordination on goals, and further on methods. This situation is particularly frequent in the case of pioneering, large and transformational projects connecting science and society (Mingers, 2004; Mauser et al., 2013; Midgley et al., 2013; Janssen et al., 2015, Schimel et al., 2015). Nonetheless, common denominators are difficult to come by in projects and programs covering the relations between science and society, but also between different disciplines or professions (Figure 1).

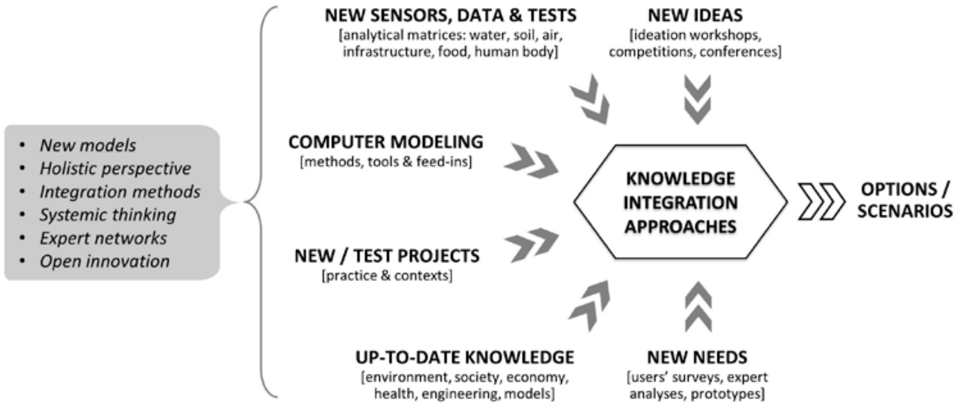

Figure 1. General representation of knowledge integration in communities – principles required (bullets of the left-hand side, on the small grey background) and practice (convergent categories on the right-hand side)

In the absence of a basis of common denominators, such a constituency is a group of agents locked in a situation of Prisoner's dilemma whereby, in order to avoid being duped, it is rational for each agent to make non-cooperative choices that will yield lower individual payoffs and the lowest payoff for the group as a whole. Drawing on practical experience and literature, this paper proposes for trials in different contexts a co-work simplifier design for developing common denominators in complex endeavors, i.e., for planning collaborative work in projects and programs aiming at building resilience in local communities (Figure 2).

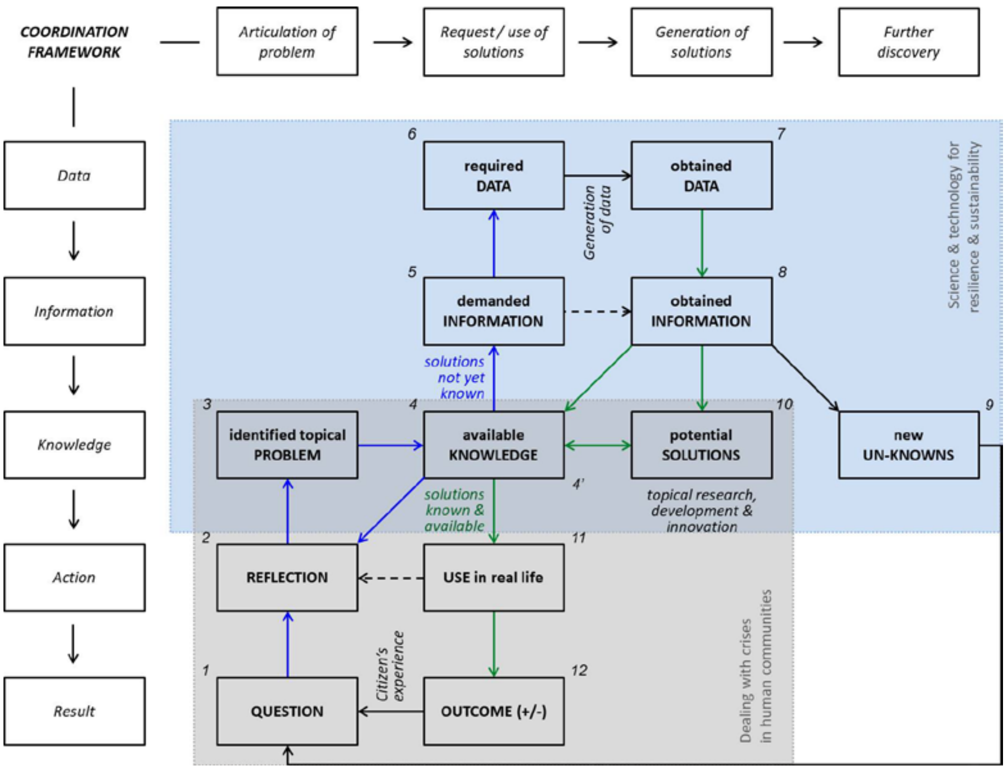

Figure 2. ***DIKAR_process*** **matrix for structuring collaborative work in a project and between work packages for building resilience in human communities. Numbered cases show co-work steps understood as "coordination rooms". Arrow indicates the the transformations taking place between steps, e.g., interpretation of new data results in new information. Arrow colors indicate sequences aiming at Strategic data acquisition and at Outcomes respectively.**

The model starts from a set of core definitions (Table 1): scientific but simple, inspired by practice and the basic principles of agent-based modeling (ABM) approaches, as applied to organization studies (e.g., Miller 2015).

Table 1. Basic (start) definitions used in the DIKAR_process model

DIKAR	Definitions	Example with urban (river) water pollution	Agent
Data	A measured or estimated value, i.e., a number *	A measured or estimated concentration of 2.5 $\mu g\ l^{-1}$ of atrazine, a common herbicide and endocrine disruptor (i.e., it can alter the human / natural hormonal system) in a river sample (water or/and sediments).	Scientists and supervised lab personnel.
Information	A result of the scientific / professional interpretation of Data items **	Telling whether the measured concentration of the target analyte (i.e. in analytical chemistry, the targeted substance) is above / below a certain threshold. From our Data item, three Info items can result: 1. It is above 0.1 $\mu g\ l^{-1}$ (0.1 microgram per liter), the legal threshold in the European Union (EU); 2. It is above 2.0 $\mu g\ l^{-1}$, the recommended threshold by the World Health Organization (WHO) 3. It is below 3.0 $\mu g\ l^{-1}$, the legal threshold in the United States of America (USA).	Usually scientists; depending on the context, relevant professionals.
Knowledge	The ability to 'connect the dots' in the Big Picture as described by theories and related models (i.e., every Information item is being combined and corroborated with other Information items), so as to:	(i) Identify options for action, (ii) Improve current models and theories, (iii) Renew the step of Reflection to update Problem co-definition within the agreed common set of social values, as needed, (iv) Request new Information items, or (v) Generate new Solutions. e.g., if similar loads of the analyte have been confirmed with alternative methods, in multiple samples (as described in a protocol), a studied water body <u>can</u> be identified as polluted (in the EU), not polluted (in the USA), or alarming (in countries using WHO standards). This identifies option (iii) above, then (i) per jurisdiction, e.g., (if in the EU) pursue protocol for polluted water; (if in a country using WHO standards); (if in the USA) do nothing until the next sampling as normally scheduled. If none of the five resolutions is possible, the result is a New Unknown, which in practice may (or may not) lead to a new topical Question, e.g., "Is the collected data item a result of a measurement error or signaling a one-off pollution event or a single point-source that easy to remove or a situation of diffuse pollution caused by atmospheric circulation or the effect of a decontamination treatment that diminished some previous concentrations until they arrived below the threshold of relevance in the USA?".	Those experts who are capable of generating and/or using relevant theories and models.
Action	Choices and proceedings on possible paths (i.e., scenarios and procedures)	The studied water body <u>is</u> identified as polluted (in the EU), not polluted (in the USA). This means path (iii) above <u>has been taken</u> and the Problem has been clearly identified and Knowledge has been updated. Further, a second round of action is as such: (i) per jurisdiction, e.g., (if in the EU) the protocol in place for polluted water is being applied (pursued); (if in the USA) nothing will be done until the next sampling as normally scheduled.	All entities that are undertaking action ***
Result	Any situation that is a basis for new experiences; evaluations; Questions	For example, the legal pollution thresholds at a given location / in a given country tend to correspond to up-to-date toxicological thresholds based on indicators of pollution impacts on human and/or ecosystem health. This means that the likely result of polluted water will be a number of cases of intoxications in the human population; also disturbances in the ecosystems.	All entities that are experiencing a situation; the stakeholders ****

* This means scientific data; but it can be adapted to include other types as needed, e.g., in informatics all digital records.
** The difference it makes (so it roughly corresponds to Shannon information) but it can be adapted to also include other types as needed, e.g. algorithmic information.
*** Citizens, companies, any institution pursuing their interests and obligations. Actions can be divergent or convergent, coherent or not, friendly or not, and coordinated or not. Agents have various degrees of freedom and can engage in competition, in cooperation or in both.
**** These entities may have participated or not to Action.

A basic user template is shown in Table 2. It can be extended as text, spreadsheets or/and diagrams, as needed.

Table 2. DIKAR_process user template for joint resilience-building endeavors that are bridging domains, disciplines and professions. Work steps take the form of coordination rooms, here illustrated with a would-be project and two work packages. Each complete cycle starts with a chosen topical question.

Step no.	COORDINATION ROOMS	*e.g., Would-be project: machine learning (ML) for building resilience in cities*	e.g., WP1: building alternative paths for clean water in cities	e.g., WP2: developing platforms for dialogues between citizens & experts
1	QUESTION	***Q1. How to use ML for catalyzing a high level of resilience in cities?***	**Q1.1. How to improve water safety, cost & accessibility?**	**Q1.2. How to improve the dialogue between experts & citizens?**
2	**REFLECTION**	*Resilience: key aspects in transitions to sustainability; urban adaptation to climate changes (Ciumasu 2013; another one, find review on resilience or/and climate).* *AI/ML multiplier effects in development of solutions*	Water management divided in separate sectors: supply, waste water, sanitation and storm water (Bach *et al*. 2014; Ntanou *et al*. 2014; Pahl-Wostl 2017) ML+ parameters can help create new, unified options.	Project co-involvement of can elicit convergence of perspectives (Van der Wal *et al*., 2014; Clark *et al.*, 2016). Health, safety is holistic, i.e., in dealing with crisis, sectors must co-work
3	**PROBLEM** (to be co-defined by project partners)	*The risks and opportunities of ML/AI are currently not well charted, which creates all kinds of hypes and fears*	Water governance failure, lacking tools, e.g., sensor architectures for unified water quality control	Science-society co-working failure due to lacking good tools for effective experts-citizens dialogues
4	**KNOWLEDGE** (if solutions known & available, jump to step 11. Else, continue to step 5.)	*EXPERT TEAM: with rules, theories, models; thematic networks & topical clusters; non-governmental bodies; relevant industries; etc.*	SCIENCE TEAM: ecology, water, analytical chemistry, toxicology, engineering, etc., with holistic & specialized models	SOCIETY TEAM: design, business, communication, sociology, informatics, law, arts, etc., with their holistic & special interface tools
5	**NEW INFORMATION demanded** (as coordinated across WPs)	*E.g., lists of needed info items; expert parameters;* *E.g., Lists of ML tools & utilizations in real life* *E.g., Details on evolving public perception of ML*	E.g., chemical, biological, eco-toxicological tests E.g., analyte loads & related toxic effects; E.g., ML-based techniques for sampling & analysis	E.g., lists of info items about water, with risks, etc. E.g., visual demo items with science / ML methods E.g., all cultural references & the public perceptions
6	**NEW DATA demanded**	*- Lists of raw data to be generated by a protocol* *- Lists of all potential ML options on all city topics*	- Lists of raw pollution data to be generated by protocol - Lists of all issues and ML options in water analytics	- Survey on public opinion about urban water pollution - Lists of all ML options on citizen-expert interaction
7	**NEW DATA obtained**	*- Lists of data items generated as per protocol*	- Lists of data items generated as per protocol	- Lists of data items generated as per protocol
8	**NEW INFORMATION obtained**	*- Lists of all new info items obtained from all new data*	- Lists of all new info items obtained from all new data	- Lists of all new info items obtained from all new data
9	**Potential SOLUTIONS**	*E.g., city model mapping topics, ML risks & benefits*	E.g., testing new sensor architectures by water uses	E.g., online interface with options, alerts & services
10	**NEW UNKNOWNS**	*E.g., new issues & topics as resulted from works*	E.g., costs of additional tools for city-scale uses	E.g., collateral risks; costs of technological choices
4'	**KNOWLEDGE (updated)**	*E.g., constant learning; updated models & toolbox*	E.g., new models: transport -energy-land-water nexus	E.g., new dialogue models, priorities & scenarios
11	**USE in real-life** (chosen solutions)	*E.g., clearer set of options involving AI/ML*	E.g., a best tools and infrastructure designs	E.g., web tool for citizen-expert interactions; projects
12	**OUTCOME**	*E.g., risks being +/-charted, ML/AI is explored (or not)*	E.g., ML-based, city-scale water quality monitoring	E.g., ML-based/-enhanced science-society activities.
NQ 1	**NEW QUESTION** (starting a new full-cycle iteration)	E.g., What long-term roles of ML in society/cities?	E.g., What best tools for promoting science?	E.g., What impacts of ML on education?

Intended to be applicable to all types of collaboration and workflows, this basic framework explicates the Data-Information-Knowledge-Action-Result (DIKAR) frame (Venkatamaran 2002; Bytheway 2014) along a work process that is carried out by explicit agents, e.g., the participants to a project, or agents participating in broader social transitions (Miller, 2015; De Haan & Rotmans, 2018). This results in a basic, bi-dimensional matrix within which one can identify a stream of work steps, i.e., “coordination rooms” for developing and managing common denominators. In those, a set of definitions (values and knowledge) are co-defined and agreed by a group of experts (or experts and citizens; all needed participants) through a set of commonly agreed qualitative and quantitative methods that end with various forms of collective expert decisions (e.g., Ciumasu 2013, Van der Wal et al., 2014; Pahl-Wostl, 2017). These are then recorded, used in a project as such and to insure alignment and coordination between its work packages and updated when needed, as needed.

In the general model, work begins with a chosen topical question and continues with a series of steps, paths and cycles which can be tested and iterated (2-n times) until the optimal routine is found for the intended use. There is no prescript number of iterations. The model allows optimal orientation and coordination towards achieving a commonly agreed set of action protocols, i.e., sequences and cycles that can be formulated and pursued simultaneously, comparatively and iteratively, within any large, heterogeneous constituency of actors involved in building resilience in cities.

By means of iterations, the described bi-dimensional matrix can add variations. Collectively, all these variations can be understood as conferring a depth dimension to the bi-dimensional matrix described in Figure 1, making it a de facto three-dimensional lattice that is charting all paths. Depending how we classify the depth variations, the three-dimensional lattice can be also generalized as multi-dimensional lattice. Once iterations started to happen, the lattice model describes a space of options that can be explicated in the sense of implicate/explicate order of David Bohm (2002), i.e., it can unfold to display practical details, so as to reflect priorities and any specific demand, e.g., as spreadsheets. The confirmed space of options growths with any variation of criteria or types (definitions) of data (e.g., various types of scientific data, informatics data) or/and types of information (e.g., Shannon’s or/and algorithmic).

DISCUSSION

Essentially, DIKAR_process, it is a lattice model of the type used in both natural and social sciences to make realistic approximations of various processes and various interactions between agents, and between agents (or groups of agents) and their environment. In terms of potential applications, DIKAR_process is a basic, start design for planning work and managing complexity in heterogeneous constituencies. This general model gives a large team constant visibility on the whole project: what matters, status of the project and status of the work packages, at any moment in time; how they got there (logical or/and process, ontological description), why, and what are the next coherent steps that are possible between the applied topical question (which is normally formulated holistically, as reflecting real-life concerns) and the detailed requirements of the technology and the protocol employed in data generation. For these reasons, the model is suitable for strategic data acquisition, as well as data-based scenario building, during the preparation phases of crisis management.

Urban resilience requires the development of common denominators (a) between different types of actors and (b) between professionals from different disciplines having different meanings for different notions. By preventing the development of common denominators, social dilemmas like the Prisoner’s dilemma undermine resilience building. DIKAR process helps solve such dilemma, thence it helps build the fundaments for co-development of a common understanding, which is a necessary condition for further development of scenarios and tools that can be used in situations of crisis. More often typically recognized, endeavors of human collaboration, notable those toward responses to crises and in general for the transition of cities to sustainability, are hampered by the fact that partners presume they mean the same thing when using a key term while in fact they assign different meanings that may overlap a bit or not at all; and they discover the mismatch later, often when it is too late, which results in very significant losses of project resources, of assets intended to protect or of both. The common understanding and common denominators in terms of notions, methods and tools must be developed before crises strike, as part of preparation of options for response.

The general model applies for all types of projects, with any question, it is adaptable to any context, and can be used with tools (software and hardware) of choice. This makes it useful for scaling-up collaboration in organizations of any size. This also allows optimization of planning and work processes at separate phases, e.g. during preparation, implementation and evaluation.

This paper is meant to be a concise introduction to the concept that will be further developed in a stream of subsequent papers. As key observation, there is a great deal of confusion in the literature on what constitutes Knowledge, Information and Data, and the terms are often used interchangeably or/and with different meanings in different disciplines or contexts. The idea of the model presented here is to start with a simple set of definitions that allow clear distinctions (and relations) between the three, and then adapt the definitions as needed in different context, provided – and this is a fundamental condition – that those definitions are negotiated and agreed by the participants to that particular project. As they have to start with something, the paper hereby can serve as starting platform if they choose so.

In brief, Knowledge ultimately means people - with their capacity to connect the dots using theories and models. For example, sustainability is now understood systemically. According to this, any economic system is a subsystem of a social system, itself a sub-system of a natural system (Giddings et al., 2002; Gowdy & Erickson, 2005). This nested inclusion relationship can be made operational in terms of sustainability filters that can be used to plan or assess risk management projects (Ciumasu et al., 2012), each filter being a list of items, as indicated in the user template (Table 2). There is no true resilience outside sustainability or a human community, but this means an amount of complexity that is overwhelming and this usually results in nothing significantly being done until crisis strikes. The DIKAR_process framework is a holistic model that can play the role of start platform for meaningful and fruitful collaborations in projects organized as clusters or networks (or both) and covering all disciplines and professions. To take the example of water, there is a need for large programs in water research, and partnerships with other societal actors; a need for more knowledge-to-action work in water under climate changes (Pahl-Wostl et al., 2013). A combination of structural and non-structural measures can be very effective in reducing flood risks, but they depend on socio-economic aspects and governance arrangements which requires participation of many stakeholders, e.g., building resilience by combining flood-related measures with land use, insurance and urban revitalization projects, e.g., with Rotterdam in the Rhine-Meuse-Scheldt delta (De Graaf & Van der Brugge, 2010) and London in the Thames estuary (Dawson et al., 2011).

In context, the model seeks to help articulate efforts to develop new roles of science in society and to help interaction between science and society, notably in the largely uncharted space that is widening between current scientific and technological advances and new societal needs (Lubchenco 1998; Scholz 2017). Progress follows big societal questions. For instance, the so-called "artificial intelligence" (AI) is omnipresent in major technology forecasts by Gardner, Deloitte, Accenture or governmental agencies. In terms of impacts in society, AI compares with electricity a century ago or steam engines three centuries ago, and is expected to generate transformations that equal a new industrial revolution. There are catchy but largely misleading commercial metaphors like "Data is the new oil" (The Economist, 2017) which are wrongly painting Data (rather digital records, not necessarily scientific data) as a commodity. In fact, useful data is a limited product, as generated through purposeful efforts under pre-defined requirements, e.g., as outlined in Fig. 2 with blue (ascending) arrows. Also, AI still only involves a small number of data types: the digital records that are being used for a narrow set of task automations that are currently feasible. But the role of data in science and society is quite broader.

By anchoring itself in all science, AI could widen its relevance and deepen its potential beyond this initial hypes and distrust, and achieve a more balanced discussion between qualitative and quantitative aspects. This can provide useful avenues for discussions about the connections between smart cities, urban metabolism models and sustainable cities / eco-cities (Ciumasu, 2013; Ntanou et al., 2014), and how AI can play a catalytic role in managing risks, crises and transitions in human communities. AI has the potential to have transformative impacts – provided that it manages to anchor itself in the whole of science. AI-aided holistic models can enable solutions to problems that have been impossible or excessively hard to address. One such example is the common-pool resources (CPR) dilemmas, also known as 'tragedy of the commons', that is, long-term collective destructions of shared natural resources (e.g., air, water, ecosystems) or products of civilization (e.g., common urban spaces and infrastructure) by self-interested short-term exploitations. DIKAR_process combined with AI can help partners in complex contexts and endeavors engage with each other in spite of the complexity of the situations (which usually pushes toward non-cooperative choice in the prisoner's dilemma). This model, when applied, can help participants understand each other and develop a common understanding and representation (mental model) of their shared resource, and how it evolves and operates, so as to distill optimal rules and to sustain reciprocity in a community of users (Ostrom et al., 1999; see also Pahl-Wostl, 2007). Often such overexploitations of ecosystems lead to disequilibria, and ultimately disasters (Gurjar et al., 2006). The main advantage of the general model is that it allows clear formulation (and therefore automation) of routine searches (of solutions) and activities. This can bring down coordination costs and thus free resources for qualitative interaction. This can make possible solutions to the tragedy of the commons type of situations which otherwise would not be possible due to overwhelming complexity and resource-intensity of coordination (making self-interested decisions more economically logical). This increased capacity to cooperate is what allows building solutions and paths and protocols into human and technological systems.

The paper hereby provides a structured state-of-the art review and a synthetic model for the managers of contributions to complex projects aiming at solving current problems (Ahern et al., 2014) and/or increasing urban resilience (Godschalk, 2003; Meerow et al., 2016) as component of the wider urban sustainability (e.g., Alberti & Marzluff, 2004; Ernstson et al., 2010; Ciumasu, 2013; Sellberg & Wilkinson, 2015; Meerow & Newell, 2016; Eakin et al., 2017). In-depth modeling and testing would go beyond the scope and space limitations of this paper but will be presented in further oral and written communications, using order theory (e.g., Monjardet 2003; Fu et al., 2010), category theory (e.g., Philips & Wilson 2010; Tsuchiya et al., 2016) and graph theory (e.g., Otte & Rousseau, 2002; Stell, 2014), Agent-Based Modeling (ABM) and the related Multi-Agent Systems (MAS) (Miller, 2015; Bloembergen et al., 2015). In brief, the DIKAR_process model is the core of a strongly connected direct graph (e.g., Otte and Rousseau, 2002) whereby a set of vertices (nodes; categories) are connected by directed edges (morphisms; transformations) that have a direction (arrows), so that every vertex (category) is reachable from every other vertex. It allows the formulation as steps, sequences of steps and loops that describe all possible interactions inside a group of agents. The model is issued from the synthetic formalization of the feedbacks from all the partners of Econoving project (a university-industry-government cluster) hosted at the University of Versailles (2008-2013) and focused on eco-innovation (i.e., innovation for sustainability, meaning it integrates environmental, social and economic aspects) and is currently used in the project ACE-ICSEN, a trans-disciplinary university cluster at the University Paris Saclay. The User Template (Table 2) was made at the request of the participants and managers of the ACE-ICSEN project, as part of the Author's role in the work package focused on trans-disciplinary integration of different thematic modules focused on cities, climate changes and health.

In practice, DIKAR_process is complementary to other models and approaches, e.g., problem structuring (Scholz et al., 2009; Ciumasu et al. 2012); comparisons of mental models to monitor shared understanding of a problem (Scholz et al, 2014); issue mapping (Cronin et al 2014); measures of social learning by different actors (Van der Wal, 2014); Delphi-based streamlining of priorities into scenarios (Ciumasu, 2013); technological revolutions and new techno-economic paradigms (Perez 2010). In addition, DIKAR_process is focused on coordination for systematic and consistent production of common denominators as a precondition for further success with methods such as those mentioned above. As illustrated in Table 2, negotiation rooms can host an unlimited range of views. Dealing with disagreements in various contexts is a theme *per se*. Because of the wide differences in terminology and methodologies, one cannot realistically hope to bridge semantic differences quickly. Instead, discussions should use available methods and aim at reaching collective expert decision; e.g., Delphi-based methods (Ciumasu, 2013), whereby views are collected and debated in rounds, until a common understanding is reached through informed voting resulting in an aggregated decision. This does not force a perfect common theory conciliating theories or/and preferences but to identify what is best "what to do next" as accepted by all participants, e.g., be it a definition, a list of priorities or/and scenarios. Another approach uses measures of social learning (Wal et al., 2014), whereby participants' world views (e.g., hierarchist, individualist and egalitarian) converge or diverge during a project.

Taking into account these examples and the rest of the literature, the paper is also an invitation to use the template and provide feedbacks about its applicability.

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