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Can we solve wicked problems? A conceptual framework and a collective intelligence system to support problem analysis and solution design for complex social issues

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ABSTRACT

Wicked problems are complex and multifaceted issues that have no single solution, and are perceived by different stakeholders through contrasting views. Examples in the social context include climate change, poverty, energy production, sanitation, sustainable cities, pollution and homeland security. Extant research has been addressed to support open discussion and collaborative decision making in wicked scenarios, but complexities derive from the difficulty to leverage multiple contributions, coming from both experts and non-experts, through a structured approach. In such view, we present a conceptual framework for the study of wicked problem solving as a complex and multi-stakeholder process. Afterwards, we describe an integrated system of tools and associated operational guidelines aimed to support collective problem analysis and solution design. The main value of the article is to highlight the relevance of collective approaches in the endeavor of wicked problem resolution, and to provide an integrated framework of activities, actors and purposeful tools.

1. Introduction

Many relevant problems in the real world are "wicked" as they have no single or definite computational formulation or a set of valid solutions or right answers, but only answers that are better or worse from different angles. Wicked problems are unique, multi-causal and generate a contradictory and changing requirements situation that is difficult to diagnose. They are messy and devious systems of interacting problems and the effort to solve one aspect may thus create other problems (Ackoff, 1974; Ritchey, 2011; Rittel and Webber, 1973).

West Churchman (Churchman, 1967) has firstly used cases such as global warming, climate change, health care, poverty, education, and crime to introduce examples of wicked problems. More recently, the US National Academy of Engineering (NAE) has studied a family of "grand challenges" that address complex or wicked issues (e.g. improvement of urban infrastructures, pollution reduction, and enhancement of cyberspace security). In 2015, the United Nations have identified seventeen sustainable development goals related to a set of universal, integrated and transformational problems that cover global and complex issues such as poverty, nutrition, instruction, sanitation, employment, climate change, preservation of natural resources, and justice (ICSU, 2015). The term wicked problem has been also used in the business world to refer to the complexity of some strategic planning processes (Camillus, 2008).

The attempt to find possible solutions to critical human issues has been a major driver for undertaking research in the field of participatory approaches as an effective decision-making strategy. This is in line with the tendency to ascribe superior value to decisions when people with different interests, expertise, worldviews and values are involved in deliberations (Nogueira et al., 2017). In fact, wicked problems involve constellations of stakeholders, which may have conflicting interpretations as well as different life experiences, competencies, goals, and values. Their strategies to address the problem are based on the perceptions of the problem and its solutions, which may differ from the view of others (Van Bueren et al., 2003).

Today, the open contribution and participation of large groups is facilitated by the Internet and social networking, which have driven the emergence of the "wisdom of crowds" (Surowiecki, 2005) as a foundation of open innovation (Gassmann et al., 2010; von Hippel, 2005) and collective intelligence (Lévy, 1994; Pór, 1995). In particular, collective intelligence systems (Malone et al., 2010) allow harvesting knowledge and experience possessed by potentially thousands of individuals to support better decisions or generation of novel knowledge, ideas and products. Examples of collective intelligence "in action" (Alag, 2008) include ratings, reviews, recommendations (e.g. Trip Advisor and Amazon), user-generated content (e.g. Wikipedia and

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YouTube), bookmarking and voting (e.g. Tumblr and Del.icio.us), tag cloud navigation (e.g. Flickr), R&D problem solving (Innocentive), start-up creation (e.g. Kickstarter), and idea crowdsourcing (e.g. Spigit).

Although the potential benefits of large group participation are evident in many fields of human activity, the application of collective intelligence principles for public good is still poorly supported by collaborative social platforms (De Liddo and Buckingham Shum, 2014). Complexities derive from the difficulty to define the state of a multi-faceted topic and to generate feasible ideas and effective actions by engaging all the stakeholders that can contribute in devising possible futures. The effectiveness of decision-making relies on the capacity to link the varied contributions of the involved agents, which depend on their different interests and expertise, points of view and values, and the way in which the process of decision-making is conducted (Nogueira et al., 2017). For socially relevant decisions, it is necessary to combine multidisciplinary knowledge and a variety of actors, organize information, generate consensus and legitimate collective action into structured approaches. Finally, it is important to understand the boundaries between the role of idea crowdsourcing and expert decision, as well as to identify the specific nature of the problem to be solved, which has an impact on the approach to problem solving.

In such endeavor, we aim to present a conceptual framework for the study of wicked problem solving as a complex and multi-stakeholder process characterized by a number of different interrelated perspective or dimensions. Based on that, we describe the functional elements of a collective intelligence system to support the resolution of wicked problems. In particular, we present a set of tools and associated operational guidelines aimed to support collaborative problem analysis and solution definition in complex social endeavors. At this purpose, we first present extant research in the area of group/collaborative problem solving and the adoption of collective intelligence. Next, we describe a process of problem resolution and a problem resolution matrix attempting to integrate different dimensions involved with complex problem solving. In Section 4, we introduce a set of tools and methodological guidelines for the implementation of the resolution process; finally, we provide in Section 5 some discussions and conclude the article with avenues for further research.

2. Problem solving and collective intelligence

The literature on problem solving is rich and differentiated. Most general contributions have analyzed *strategies* such as abstraction, analogy, brainstorming, lateral thinking, morphological analysis, root cause analysis or trial-and-error (Wang and Chiew, 2010), and *methods* like APS (Applied Problem Solving), GROW (Goal, Reality, Obstacles/Options, Way forward), OODA (Observe, Orient, Decide, Act), TRIZ (the "theory of inventive problem solving"), and SPS (Systematic Problem Solving). With a more specific focus on systems enabling problem analysis and related decision making, group decision support systems (GDSS) have emerged as interactive computer-based systems facilitating the solution of unstructured problems by a group of decision makers (DeSanctis and Gallupe, 1987). A GDSS includes a set of software, hardware, language components, and procedures that support a group of people engaged in a decision-related meeting (Huber, 1984).

Group decision and collaboration is today impacted by the research conducted at the crossroads of computer science, behavioral science, and management science. The development of information systems for wicked problems (Schoder et al., 2014) benefits from advancements in areas such as collective intelligence and social media, with a relevant challenge being related to how to canalize the large participation and get the best contributions from the crowd. Information systems for group problem solving have been improved thanks to major research findings in the fields of dialogue and casual mapping, argumentation, and knowledge representation. In contrast to restrictive structures, dialogue mapping facilitates group intelligence to emerge (Conklin, 2005), whereas causal mapping methods support the analysis of complex tasks, with examples in engineering and construction projects (Ackermann and Eden, 2005).

In a collaborative setting, the relevance of the argumentative process has been highlighted as effective way to tackle wicked problems (Rittel and Webber, 1973). An argument is a structured connection of claims, evidence and rebuttals, and it is part of the route that goes from unshared individual knowledge to shared team knowledge and common ground (Beers et al., 2006). Argumentation systems have been applied to improve the GDSS prediction ability of market trends, with examples in the housing market (Introne and Iandoli, 2014), and to support discourse among decision makers (Karacapilidis and Papadias, 2001). Argumentation platforms have been described as systems through which users can quickly and comprehensively explore the debate on the discussion topic (Gürkan et al., 2010) whereas Information Aggregation Markets are effective tools for idea generation and evaluation (Bothos et al., 2012). Finally, knowledge representation techniques can support problem resolution by reducing environmental complexity and facilitating the shared understanding of concepts, variables and mutual interdependencies. Some applications can be found in the fields of education (Munneke et al., 2007) and innovation (Adamides and Karacapilidis, 2006).

Explicit applications of collective intelligence for domain-specific problem solving can be found in studies focused on developing recommender systems to support differential medical diagnosis (Pérez-Gallardo et al., 2013), open computer aided innovation (Lopez Flores et al., 2015), and national strategy exploration and scenario planning (Glenn, 2015). Other interesting contributions can be found in the fields of crisis and emergency management, with the analysis of multiple stakeholder perspective (Hernantes et al., 2013; Turoff et al., 2013), and the development of resiliency strategies for ports in case of adverse weather events (Gharehgozli et al., 2016).

Two examples of collective intelligence systems that leverage social networking and expert contribution to support the resolution of wicked problems are Open Ideo (www.openideo.com) and the Climate CoLab (www.climatecolab.org) (Introne et al., 2013). The systems tackle social challenges through the creation of a space for community members to contribute, by providing tools and resources for on-line voting, supporting, contributing and expert mentoring in the solution ideation and description endeavor. The key focus is on key actions such as share stories on specific challenges, ideation and community sharing of ideas, idea refinement for designing solutions, community feedback and solutions testing, selection of top ideas and community search for collaborators.

Other examples of tools supporting collaborative problem discussion are *Compendium* (http://compendiuminstitiute.net) for visual mapping and management of ideas and arguments, *CoPe_it!* (http://copeit.cti.gr) for argumentative collaboration and decision support, and *Debategraph* (http://debategraph.org) for supporting individuals and communities to deliberate and take decisions on complex issues. It can be also relevant to mention the EU2020 "Catalyst" project, a large-scale research effort aimed to generate and apply open tools for collaborative knowledge creation for public good, the CogNexus Institute, working on wicked problems and dialogue mapping, and the Swedish Morphological Society, on wicked problems and social messes.

Most of the existing approaches are focused on specific tools and services fostering collaboration, such as dialogue mapping, argumentation and information sharing, whereas the holistic perspective and system view of the entire problem resolution process (with phases, activities and roles) is not completely addressed. In such view, there is room for new contributions aiming to develop a more structured and integrated view of problem analysis and solution design for wicked problems, as well as to introduce a set of tools able to streamline the aggregation of controversial points of view and contributions of many stakeholders in multi-causal problem scenarios. Our work is focused on such major research direction.

3. A framework for wicked problem resolution

In this section, we present an integrated framework for wicked problem solving. We describe two components: a) a problem resolution process, with the identification of eight management areas for successful undertaking of the process; b) a problem resolution matrix, which provides a comprehensive view of the solution generation process (lifecycle) and categories of actors involved, along with motivation, roles and time-related insights.

3.1. Problem resolution process

In a general perspective, the problem solving and decision-making process includes three sub-activities, i.e. represent and analyze the problem, find alternatives, and make choices (Antunes et al., 2014). These stages include further activities such as problem setting, problem examination, solutions generation, solutions evaluation, and decision taking. Steps are not necessarily followed in turn, as decision makers have to go often back and forth (Simon, 1987; Simon, 1997). More in details, problem solving is the act of defining a problem, determining its cause, identifying, prioritizing and selecting alternative solutions, testing and prototyping solutions using a set of criteria, and implementing the most convincing solution (Beecroft et al., 2003).

The design and application of a (possible) solution to a wicked problem is a complex and articulated task, which can benefit from the application of process management elements with the goal to undertake successful problem analysis and resolution. A system view of business process management addresses the fact that successful execution of a generic process should include eight key elements or areas. Such areas are related to the scope of the process, its integration with other processes, the structure, the resources and inputs needed, the human and technology systems applied, the dependencies among activities, the likely exceptions to handle, and the overall process performance (Margherita, 2014).

For the problem resolution process, the *scope* is concerned with (finding) the range of pertinent solutions into the specific problem domain. One major characteristic of wicked problems is their extended area of interest and the co-existence of multi-domain components. The key challenge is thus to identify the area of action and the nature of solutions to be identified. The problem resolution effort should also address the existence of possible interactions and *external integration* with other problem solving processes. In line with a systemic search for problem resolution, one single initiative should indeed identify synergies and positive externalities with similar initiatives.

The *structure* of a generic problem resolution process includes different steps. First, the problem should be clearly defined and described. The interpretation and conceptualization of the problem are indeed crucial activities for achieving a basic consensus. The problem is then analyzed in details by gathering all of the available information and experience that support hypothesis on possible causes. Third, problem synthesis and modelling are needed to identify a set of key variables or parameters, and to obtain a reference model in terms of activities, knowledge, stakeholders, decision flows, constraints and metrics. Fourth, a set of alternative solutions can be proposed with design elements, required actions and evaluation criteria. Based on that, the fifth step is aimed to develop a prototype of alternative solutions to test in a real context with users and target groups. The last two steps concern the implementation of the "best" solution identified (also based on the evaluation of expected impact for large-scale adoption) and its maintenance (supervision and improvement) in order to be sustainable in the long term at socio-technical, economic and environmental level. Concerning *resources*, major inputs for undertaking the process are represented by specific emerging needs or constraints and policy inputs, as well as the availability of funds, pre-existing knowledge and artifacts on the topic under analysis, or opportunities that can be early envisioned and properly picked.

Process execution is based on the use of relevant *systems* at technology level (mostly ICT tools) and human level (actors and stakeholders). Technology systems include decision support systems, platforms, software suites, communication devices and similar, whereas human systems refer to domain-related expertise, problem solving and process/project management skills as well as the set of incentives and motivational instruments. Such competencies can be found in different categories of "contributors" or stakeholders. Stakeholder theory (Donaldson and Lee, 1995; Freeman, 1984; Friedman and Miles, 2002) has been applied in several fields related to the management of corporations, living labs, ecosystems, and social networks as well. In the problem resolution endeavor, the family of *stakeholders* includes all the actors participating to, influencing, or which can be impacted by the solution design and implementation activities. First, *Policy Makers*, i.e. actors involved in social planning, strategy design and administration-related activities are needed to set the specific institutional and policy background in which the problem resolution process is conducted. Second, *Scientists and Researchers*, i.e. actors involved in research and development activities are crucial to provide advancements in terms of knowledge useful to address wicked socio-organizational issues. Third, *Technology Providers* are needed to design and delivery of solutions, products, and other artifacts useful to support the process of solution generation and implementation. *Data and Information Providers* include actors offering industry reports, data, case studies, best practices, state-of-art knowledge and other similar know-how or codified experience. *Product and Service Providers* are industry actors that offer applications, artifacts and market solutions needed to accomplish tasks involved in problem analysis and resolution. *Civil Society and Users* represent the main customers of solutions identified and are thus a key category of stakeholders, including informed and engaged individuals, common citizens, but also experts and "insiders". Beside single contributors, the role of *Communities and Groups* should be taken in consideration for problem resolution. Such groups include think tanks, NGOs, market associations, labor unions, communities of practice and other aggregations created with the purpose to represent specific interests and needs. Finally, *Funders and Sponsors* are crucial to provide the financial support as well the commitment to sensitize the large audience and attract the interest of other stakeholders (e.g. testimonials and opinion leaders).

The management of the problem solving process also includes managing dependencies, exceptions and performance. The management of *dependencies* is aimed to optimize the relations among activities in terms of resources used and produced. In the problem resolution process, optimization should be in terms of flows between steps (including feed-backs and feed-forwards), fit among contrasting stakeholder opinions and contributions, and sharing of knowledge and ideas produced with the purpose of problem solving. Concerning *exceptions*, management issues may originate at human level (e.g. skill shortage in the team, or incapacity to reach an agreement) or technical level (e.g. instable solution, or functions not completely coherent with the process requirements). Proper handling or response strategies should be thus identified for each single exceptional event. Finally, *performance* of the overall problem resolution process should be managed in terms of key success metrics such as degree of actor involvement, knowledge generation and sharing, functional coverage, matching between problem's and solution's scope, degree of solution effectiveness, level of solution applicability, levels of creativity, level of acceptance by the end-users, and overall process costs and time. We illustrate in Fig. 1 the problem resolution process, with activities, actors and management areas.

3.2. Problem resolution matrix

The problem resolution process (*What*) and the involved stakeholders (*Who*) are two basic components to build a "process/actor", or problem resolution matrix. The matrix can be used to present the different levels of engagement and responsibilities of stakeholders respect

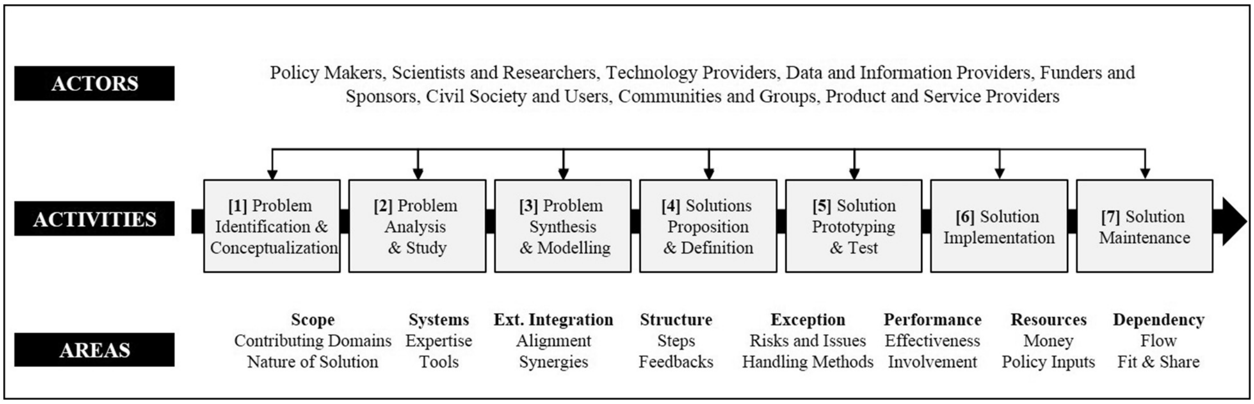

Fig. 1. Activities, actors and management areas of the problem resolution process.

to each phase of the problem solution process. Building on the RASCI model (Hightower, 2008) used in project management to assign roles and responsibilities, each cell of the matrix can be used to show *How* each stakeholder participates in problem resolution, with which responsibility or role, i.e. *Responsible* (R), *Accountable* (A), *Support* (S), Consulted (C) or *Informed* (I).

The matrix can also congregate information related to the key motivation of each stakeholder when contributing into problem resolution activities. Three basic examples of incentives for participation (*Why*) are: 1) *money* (M), i.e. the promise of financial gains through direct payments or increased likelihood of earning future payments; 2) *love* (L), i.e. intrinsic enjoyment, opportunity to socialize or contributing to a bigger cause without expecting monetary benefits; and 3) *glory* (G) or peer recognition (Malone et al., 2010). An alternative classification includes satisfaction, rewards and social gratitude as possible motivators (Estellés-Arolas and González-Ladrón-de-Guevara, 2012). In most cases, motivation of stakeholders can derive from a combination of different types of incentives.

Finally, the temporal dimension can be included in the matrix to monitor key issues such as duration of activities but also actor handoffs, feed-back and feed-forward flows among phases, number and roles of actors for each step. Fig. 2 shows the problem resolution matrix with columns and rows showing the *What* and *Who* dimensions, and cells indicating the *How*, *Why* and *When* of stakeholders participation.

The matrix supports a "horizontal view" and a "vertical view". The horizontal view is a *stakeholder view* as it shows the activities in which each actor is involved, and the specific role or responsibility. The vertical view is a *project view*, since it shows all the stakeholders involved in each activity, thus providing a basis to evaluate management and implementation issues like time, cost, ownership and risk of execution. Both columns (activities) and lines (stakeholders) of the matrix can be broken down into more fine-grained components with the purpose to define organizational charts or competence maps, and properly assign tasks and responsibilities for successful problem analysis and resolution. The key challenge is then to identify the specific activities to be undertaken at each single step and the related output, and to provide an operational method and a set of tools to execute those activities. We describe this functional analysis and design work in the next section.

4. System for collective problem analysis and resolution

Collective intelligence systems include three interrelated elements, i.e. the exchange and generation of data/info/knowledge, the use of software applications, and the participation of expert individuals

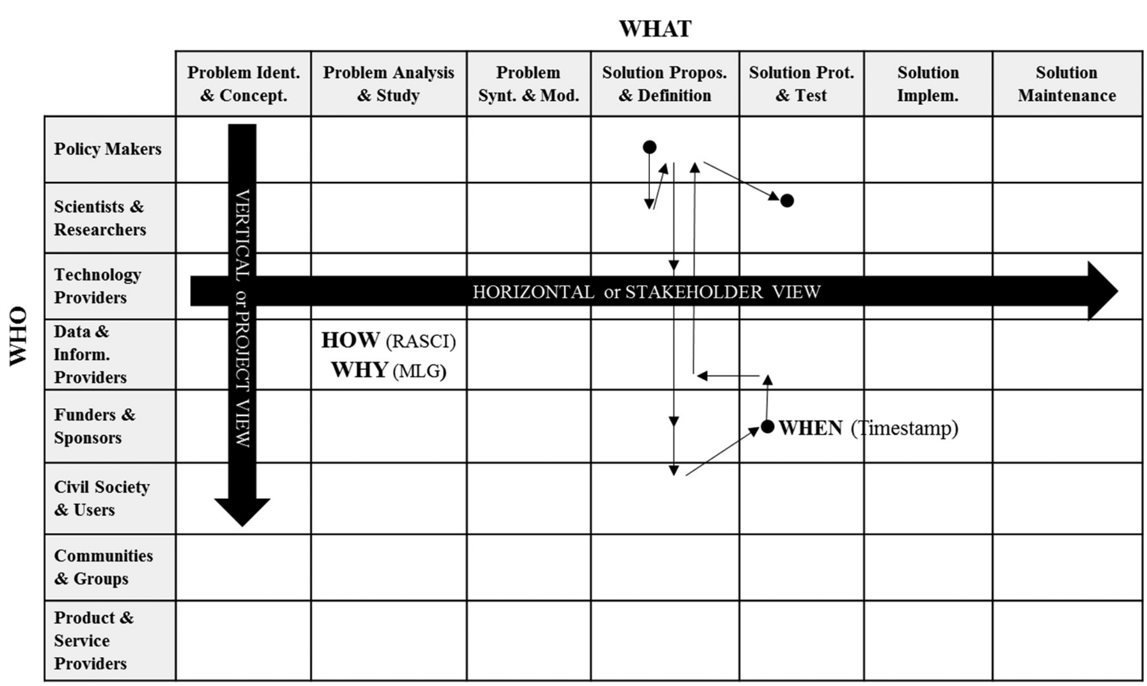

Fig. 2. Problem resolution matrix.

(Glenn, 2015). Based on the framework presented in the previous paragraphs, we introduce in this section the foundational elements of a collective intelligence system for wicked problem solving. In particular, we aim to describe the process of knowledge creation and sharing that happens within a community of expert and non-expert individuals, along with the functional aspects of a set of technology tools aimed to streamline the execution of the different steps of problem analysis and solution definition.

For the development work, we have adopted a design science approach (Hevner et al., 2004) that includes the steps of problem identification, objectives definition, artefact development, and preliminary solution demonstration and evaluation. The key problem addressed is the enhancement of collaborative and robust solution generation in wicked scenarios, with a set of specific objectives that have been defined in terms of critical design criteria:

a) The design and development process is based on problem breaking, solution impact prediction, and best solution selection (Introne et al., 2013) – The tools should thus support problem decomposition, identification of major perspectives and related variables, and solution measurement and comparison.
b) Systematic solution exploration is addressed to accommodate multiple alternative perspectives (Rosenhead, 1996) – To deal with complex problems, the tools need to foster multi-actor participation and group interaction through a transparent and structured idea exchange, also based on a visual approach to problem presentation and solution discussion.
c) Negotiation among actors needs to be grounded on a rigorous formalism and support distributed presentation of perspectives and contributions through a verification process that elaborates them by either adding information, agreeing, disagreeing, accepting, rejecting, or summarizing (Beers et al., 2006) – The tools should enable multiple loops of individual contribution and group validation, so to ensure that all possible suggestions and perspectives are gathered into the discussion, and all possible interactions have been made to accept, improve or discard each single contribution.

In the development work, we firstly associated goals and relevant issues to each step of the problem resolution process. Goals to achieve are strictly derived from the role of each step into the overall process and the design criteria discussed above, whereas issues represent the key constructs for the development of collaborative problem solving features. In Table 1 we show the result of such association work.

For each step, we thus defined the core elements of a tool able to support the related activity, and thus to explain "how" to achieve the goals illustrated in Table 1. In this paper, the concept of tool is elaborated as *methodological* tool (i.e. instruction, guideline, checklist, form, template, etc.), even if the work undertaken can be used as basic requirements for designing and developing purposeful software applications.

In the "*Problem Identification & Conceptualization*" step, a *semantic aggregator* is needed to gather multiple definitions, codified knowledge and perspectives of a given problem, as they arise within the community of experts engaged to solve the wicked problem. The main goal here is to allow individual contributors to introduce personal and unshared statements about the problem and come up with a predominant shareable perspective. In this process, external sources of knowledge can be also included and new relevant information collected, in order to create a common ground upon which building a shared understandable semantic of concepts. The tool should thus allow to *edit* contributions, i.e. to insert, modify, delete and save a new definition or statement, to *link* contributions each other, i.e. associate, compare, combine and aggregate statements provided by different individuals, as well as to include and refer external knowledge sources, statements and individual expertise. Finally, through voting and rating systems, participants bring out a shared definition and conceptualization of the problem.

Table 1
Process steps, goals and key issues.

Process steps	Goals to achieve	Key issues
Problem Identification & Conceptualization	Ensure comprehensive and shared *Definition* and understanding of the problem, its *Meaning* and related issues	*Definition* *Meaning*
Problem Analysis & Study	Identify all possible intertwined *Components* (factors and dimensions) of the problem, with *Hierarchy* and relations	*Components* *Hierarchy*
Problem Synthesis & Modelling	Represent semantic tree and process view of the problem, and related aspects with *Nodes* and *Links*	*Nodes* *Links*
Solutions Proposition & Definition	Drive creative *Solutions* proposal through extended idea acquisition and balanced evaluation *Metrics*	*Solutions* *Metrics*
Solutions Prototyping & Test	Build a pilot project with *Assignment* for each solution application or simulation, and *Feedback* collection	*Assignment* *Feedback*
Solution Implementation	Allow large-scale application, *Execution* and empirical *Validation* within a target community	*Execution* *Validation*
Solution Maintenance	Offer ongoing performance *Measurement* for solution fine tuning, enhancing or reengineering *Actions*	*Measurement* *Actions*

In the "*Problem Analysis & Study*" step, a *parameter tree generator* is required to build and share a comprehensive taxonomical tree of dimensions, perspectives and parameters related to the problem under analysis. In order to introduce major flexibility into the process, priorities and preferences can be associated to each element of the taxonomy. The key goal is to provide a multidisciplinary and multi-stakeholder perspective to the problem represented by a cognitive map, which determines all the components and criteria needed to propose informed and relevant solutions that encompass all the views of the problem. The tool should thus include an *add* function, to create a new branch or element within an existing tree, and a *generate* function to create a new tree which consolidates the changes made by all the contributors in the team.

In the "*Problem Synthesis & Modelling*" step, a *problem visualizer* can be used to generate a graphical representation of the problem based on the outcome of previous steps, and thus using the consolidated problem definition and the final parameter tree. Whereas the tree is a list of items to be included in the analysis, the visualizer aims to generate a casual map of the problem (Bryson et al., 2004) in terms of key constructs, causes/antecedents, effects, and relations. The map allows capturing argumentations and sharing views, in the aim to facilitate negotiation and achieve a common problem's model. The tool should thus include a *correlate* function, to create positive or negative links among the nodes of the map, and a *navigate* function, which allows to define logic patterns that provide possible descriptions or interpretations of the problem.

In the "*Solutions Proposition & Definition*" step, a *solution matrix* can be used to gather all the potential solutions proposed by the community members and to evaluate them using a set of relevant metrics. The evaluation is then completed by comparing the solutions identified using a trade-off matrix in which strengths and weaknesses of each solutions are shown and shared. The comparing process relies on both qualitative and quantitative measures, and grounds on an important negotiation process involving all the participants who vote, provide support, discuss, contribute, define and choose the most valuable solutions to explore further. The tool should thus include a *solve* function, to propose the solution using a given format, and a *vote* function, which allows all the community members to provide an evaluation to solutions provided, also based on the outcome of the trade-off matrix.

In the "*Solutions Prototyping & Test*" step, a *pilot builder* is needed to define the basic project management aspects related with prototyping and testing the selected solution(s), with the ultimate purpose to gain feedback for selecting that solution candidate for the large-scale implementation. Roles and tasks should thus be assigned to specific actors, and key elements such as duration, required budget and human resources, level of complexity and risks, and expected impact and sustainability should be defined carefully. The tool should include a *staff* function, to assign tasks (with expected deliverables and deadline) to actors who have previously communicated their availability, and a *candidate* function, which allows community members to spontaneously contribute to any of the planned activities.

In the "*Solution Implementation*" step, the *application monitor* is conceived as an interactive dashboard aimed to support real-time monitoring of solution implementation, thus providing key measures (e.g. number of involved users, geographic scope) for evaluating the effects of real-world evaluation of solution application. The tool should include a *coordinate* function, to ensure proper execution of activities, and *recommend* function, to suggest adjustments or improvements into the implementation process.

Finally, in the "*Solution Maintenance*" step, a *performance scorecard* should allow to measure key performance indicators of the implemented solution, in terms of the parameters defined at the outset and goals to achieve. The tool includes a *report* function, to generate a detailed report of the effects and performance achieved with solution implementation, and an *improve* function, to suggest amendments to the solution applied for further refinement or adoption of alternative solutions. In Fig. 3 we show the collective intelligence systems for problem analyses and resolution, with the indication of process steps and associated tools, functions and output.

The definition of goals and key constructs for each step, and the general description of tools and related features, is complemented by a checklist or canvas of activities and expected outputs, which we represent in Table 2.

The system of tools is thus integrated with a set of activities aimed to support a creative conceptualization of the problem and a gradual implementation of the "best" solution. In Sections 3 and 4, we have introduced a structure of the problem resolution process and some guidelines for applying collective intelligence principles to generate expected outcomes. The application of the integrated approach should leverage an extended community of individuals and experts who exchange knowledge and viewpoints, and activate informal and unstructured learning processes. The interaction should favor the effort of comprehensive problem analysis, solution analysis and refinement into an ongoing and dynamic process based on collaborative and competitive behavior of participants motivated by tangible or intangible incentives.

5. Discussion and conclusion

Wicked problems have no single solution and are perceived by different stakeholders through contrasting views. Many social issues are wicked in this sense and there is thus a research interest to design novel approaches to support or streamline the process of collaborative analysis and identification of possible answers. The field of group decision is today strongly impacted by the emergence of collective intelligence platforms able to combine distributed efforts of large groups of people to solve complex and multifaceted problems (Malone et al., 2010). However, a number of complexities derive from the difficulty to identify, capture and aggregate multi-stakeholder contribution through a structured approach able to leverage synergic or contrasting perspectives into a unique analysis and solution definition process.

In such endeavor, we have presented a framework for problem analysis and solution design that includes a structured process and a multi-dimension matrix. We have discussed the process in terms of seven steps (problem identification, analysis and modelling, solution definition, prototyping, implementation and maintenance) and eight management areas (scope, resources, external integration, dependencies, structure, exceptions, systems, and performance). We have then presented a matrix aimed to support multiple considerations related to the involvement of actors into the process (type/nature of involvement, motivation, and timing), allowing a horizontal (or stakeholder) view and a vertical (or project) view. Based on the framework, we have then described a set of tools and a detailed canvas to drive the different phases of the problem resolution lifecycle.

This article is an attempt to advance the discussion on wicked problem solving through a collaborative and process-driven approach aimed to combine a structured method with creative thinking and idea generation. In particular, the major theoretical contribution is to integrate problem solving, process management and decision support

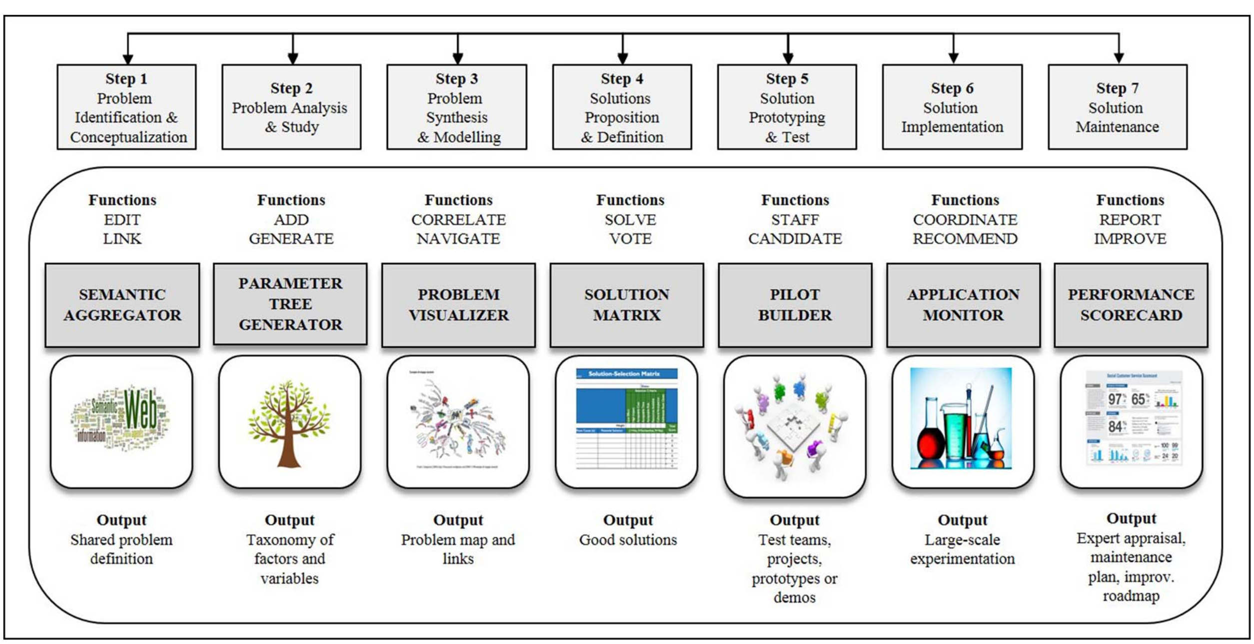

Fig. 3. Collective Intelligence System to support problem analysis and solution generation.

Table 2
Checklist of activities and key outcomes.

Step	Activities and outcomes
Problem Identification & Concept. (*semantic aggregator*)	[1] Presentation of the problem to solve, with phases and expected goals [2] Problem definition statement by community members and experts [3] Presentation, extension, reorganization and discussion of definitions provided [4] Description, debate, selection and sharing of aggregative problem definitions [5] Open collection of feedback to build a shared problem definition
Problem Analysis & Study (*parameter tree generator*)	[1] Open listing of descriptive factors, issues or parameters of problem [2] Design of a first-level taxonomy of elements collected [3] Collection of suggestions and feedback to improve the taxonomy [4] Extrapolation of key impact areas [5] Sharing of final taxonomy of the problem under analysis
Problem Synthesis & Modelling (*problem visualizer*)	[1] Design of a conceptual map with nodes and links based on taxonomy [2] Collection of feedback and reactions after open discussion [3] Elaboration of an improved schema [4] Community sharing of final schema
Solutions Proposition & Definition (*solution matrix*)	[1] Collection of potential solutions by community members [2] Aggregation and consolidation of comparable solutions [3] Definition of key performance indicators (KPI) for solution evaluation [4] Assessment/comparison of solutions based on trade-off matrixes [5] Voting and selection of the "best" potential solutions to prototype and test
Solutions Prototyping & Test (*pilot builder*)	[1] Definition of a project management plan for solutions implementation [2] Open discussion and collection of community availability for plan activities [3] Realization of demos/simulations of solution prototypes and data collection [4] Solutions comparison through trade-off matrix analysis [5] Reporting and sharing of test results and decision about large-scale adoption
Solution Implement. (*application monitor*)	[1] Large scale development of validated solution/prototype [2] Solution implementation and monitoring [3] Ongoing feedback collection and KPI measurement [4] Sharing of implementation report with results and possible evolutions
Solution Maintenance (*performance scorecard*)	[1] Collection of insights and recommendations on the solution implemented [2] Sharing of performance measures related to solution impact [3] Design of fine tuning or reengineering actions on the solutions [4] Sharing of maintenance plan for the solution implemented

components into an integrated and systemic view. By a practitioner perspective, the work offers a method to conduct problem-solving initiatives and projects into the scenario of the so-called *projectification* of society (Gemünden, 2013). Besides, the article provides a preliminary functional analysis to drive the development of proper software components and applications.

Our work has one main area of discussion and two limitations. The area of discussion concerns the existence of boundaries between crowdsourcing and expert decision, with limitations of both according to the nature of the (wicked) problem. The use of open participation and democratic contribution can be, in some cases, ineffective when it comes to analyze and suggest solutions to problems of relevant complexity and socio-technical consequences. In this case, expert decision (e.g. obtained through focus groups and Delphi panels) is a predominant strategy to adopt compared to extended and large-scale contribution. Since many wicked problems, and especially social wicked problems such as climate change, poverty, pollution and homeland security, are very complex issues, the role of collective intelligence and large group contribution can be envisioned as a preliminary step to be followed by a second phase of expert evaluation and final decision.

An alternative strategy can be applied for the simultaneous involvement of a large mass of people and a crowd of experts, in the aim to form a network of working groups that, thanks to a proper reward system, compete and cooperate at the same time to analyze the problem and devise possible solutions. The access to all the results generated by the working groups can stimulate a further tuning or completely rethinking of the solutions proposed, in order to elaborate new ones. Around these solutions, the working groups can be merged by adopting some aggregative functions (e.g. voting, supporting, contributing, mentoring). The result is a gradual reduction of the number of working groups and therefore of the possible solutions, that can be finally selected by involving only experts or the community.

In our research, we have presented a general-purpose model that can be applied to any complex problem-solving endeavor, but it is important to highlight that, as any model, the approach has to be contextualized to each specific case or issue.

Concerning limitations, the article lacks an investigation about the emergence and management of conflicting situations into the problem solving process. The lack of consensus is indeed a critical issue, which can easily happen into a wicked problem scenario. The analysis of single process phases should be thus discussed in terms of such adverse event that can undermine the successful undertaking of some or all the tasks of the problem solving lifecycle. For example, the investigation of response strategies and conflict management actions can be conducted using frameworks and techniques applied in fields such as project management (e.g. avoid, conflict, accommodate, reconcile, force or collaborate actions). The second limitation is also one future research direction for the study. Although the article is mostly a conceptual contribution, an extended real-life application of the same is required in order to test the process and the matrix, and define possible avenues for prototyping the tools, with the ultimate purpose being to experiment and validate the model and the method into a real life wicked problem resolution initiative.

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