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.

Keywords: Collective Intelligence, Framework, Matrix, Solution Generation, Tools, Wicked Problems

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, thus the effort to solve one aspect may create other problems (Ackoff, 1974; Ritchey, 2011; Rittel and Webber, 1973).

Wicked problems are thus ambiguously bounded, since they can be considered as symptoms of other problems at a different scale. They are complex issues, large in scale and scope, which progress at a rapid pace and cannot be explained by considering each of the parts in isolation. The social costs of erroneous interventions can thus be prohibitive (Duckett et al., 2016; Ketter et al., 2016).

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 solutions. 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 YouTube), bookmarking and voting (e.g. Tumblr and Del.icio.us), tag cloud navigation (e.g. Flickr), R&D problem solving (e.g. Innocentive), money collection (e.g. Kickstarter), ideation (e.g. Spigit), design (e.g. Quirky), and due diligence (e.g. Seedups).

Although the potential benefits of large group participation are evident in many human activities, and deliberation in complex socio-technical debates is critical, today's social platforms do not completely support citizens or community managers to quickly grasp the state of a debate, know where to best contribute and effectively identify and pursue innovative ideas (De Liddo and Buckingham Shum, 2014).

Complexities derive from the difficulty to define the state of a multifaceted topic and to generate feasible 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 perspectives. The method proposed is mostly addressed to focus on complex or wicked problem resolution processes, which are of specific relevance and interest into the area of social and collective endeavors. Although the contribution may be of interest for the general application to problem solving, complex social issues (with their multi-stakeholder feature) represent a privileged field of application for the framework proposed. We adopt the perspective of collective intelligence for the conceptual investigation, and a systemic approach to integrate the multiple dimensions involved into complex problem solving processes. The contribution can be thus useful as design checklist and a basis for further technology development. We describe the functional elements of a collective intelligence system supporting the resolution of wicked problems, along with 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 conclusions that offer new opportunities 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 Kiew, 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).

Many papers have been written about group working and participative approaches to problem solving. In particular, the literature on group problem solving dates back to the studies of Marquart (1955), Hoffman (1965) and Maier (1970), with a predominant psychological focus into learning-related processes. Other contributions (e.g. Vidal, 2006) have focused on the collaborative and creative approaches adopted by communities, organizations and public institutions to face problematic situations. In the today's increasingly complex and interdependent society, participative problem solving becomes crucial and experimental research by social and cognitive psychologists has established that cooperative groups solve a wide range of problems better than individuals do. Lughlin (2011) explored basic concepts such as social combination models, group memory, group ability, and social choice to propose a set of generalizations and operational guidelines supported by theory and research, which are relevant for both decision-making research in social and cognitive psychology and into multidisciplinary and multicultural problem-solving in organizational behavior, business administration, management, and behavioral economics.

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 (Ackerman 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 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 research effort is positioned within such conceptual space, and intends to build a systemic view of problem solving as complex endeavor into wicked scenario, as well as to provide a platform for further theory development and practitioner development. Different efforts are being undertaken at worldwide level to increase awareness of citizens, communities and large groups to discuss and identify balanced solutions to complex problems. However, a systematization effort of processes, actors, strategies and tools, which can be adopted at such purpose is yet to be introduced. In particular, our works leverages collective intelligence principles to define a structured representation of problem solving “variables”, along with a management checklist to support initiatives and further development work in the area of collaborative systems for wicked problem solving.

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 steps, actors and 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 resolution 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). Problem solving is the act of identifying and defining a problem, determining its cause, designing, prioritizing and selecting alternative solutions, testing and prototyping solutions using a set of criteria, and implementing the most convincing solution (Beecroft et al., 2003). Moving from such extant views and classifications, the wicked problem resolution process may be thus described in terms of the following key steps:

1. *Problem identification and conceptualization* (key concepts and critical issues are defined and described, and a shared conceptualization of the problem is obtained);
2. *Problem analysis and study* (available information and experiences are gathered to support definition of hypothesis about problem causes);
3. *Problem synthesis and modelling* (key variables of the problem are defined to obtain a reference model of activities, actors, decision flows, constraints and metrics);
4. *Solutions proposition and definition* (possible actions and answers to the problem are presented along with design and feasibility elements and success evaluation criteria);
5. *Solutions prototyping and test* (alternative solutions are tested and filtered to obtain one single alternative which is modelled, tested and validated in a real context with users and target groups);
6. *Solution implementation* (the identified solution is implemented into a larger scale scenario);
7. *Solution maintenance* (solution is supervised and improved to be sustainable in the long term at socio-technical and economic level).

The execution of the different steps requires a bundle of knowledge and competencies that 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. In particular, the following macro-categories of stakeholders can be identified:

1. *Policy Makers*, i.e. actors involved in social planning, strategy design and administration-related activities devoted to set the specific institutional and policy background in which the problem resolution process is conducted;
2. *Scientists and Researchers*, i.e. actors involved in research and development activities to provide advancements in terms of knowledge useful to address wicked socio-technical and organizational issues;
3. *Technology Providers*, i.e. actors involved in the design and delivery of solutions, products, and other artifacts useful to support the process of solution generation and implementation;
4. *Data and Information Providers*, i.e. actors offering industry reports, data, case studies, best practices, state-of-art knowledge and other similar know-how or codified experience;
5. *Product and Service Providers*, i.e. industry actors that offer applications, artifacts and market solutions needed to accomplish tasks involved in problem analysis and resolution;

6. *Civil Society and Users*, i.e. the main customers of solutions identified, that include informed and engaged individuals, common citizens, experts and "insiders";
7. *Communities and Groups*, i.e. physical and virtual aggregations of individuals and organizations that represent specific interests and needs that should be taken in consideration for problem resolution, including NGOs, labor unions, market associations, and professional communities.
8. *Funders and Sponsors*, i.e. actors that can 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).

Although activities and actors represent two crucial elements of the problem solving endeavor, they are not sufficient to encapsulate all the different elements and criticisms that may emerge into the overall process execution effort. In fact, the design and implementation of a (potential) solution to a wicked problem is a complex and articulated task, which can benefit from the application of a systemic approach to process management and the adoption of criteria aimed to ensure that all the "dimensions" of the process are consistently addressed.

In such view, a systemic definition was provided (Margherita, 2014) which includes eight management areas, i.e. the scope of the process, integration with other processes, structure, resources and inputs needed, human resources and technology used, dependencies among activities, exceptions to handle, and overall performance. This taxonomy of management items is applied here below as a structure for discussing where and how to address attention to successfully manage the problem resolution process. The framework can provide a useful synthesis of critical management dimensions to address for achieving a comprehensive study of the problem solving process.

First, the *scope* of wicked problem resolution is concerned with (finding) a range of pertinent answers to the complex issue under analysis. Managing the scope is thus concerned with delineating the knowledge domains (and boundaries) that may provide the area of action (e.g., computer engineering, biology, sociology, etc.) as well as the nature of solutions to be identified (e.g. new rules, new technology devices, new competencies).

Second, complex problems are often interrelated and the emergence of an *external integration* with other problem solving processes is thus possible/needed. In line with a systemic view, managing integration should be aimed to identify and capitalize synergies with other problem solving attempts (e.g. solving urban mobility problems may have an integration with solving climate change issues).

The *structure* of steps characterizing the problem resolution process is quite complex and this raises the importance to optimize aspects such as the sequence of activities and the expected duration, and the feedbacks among the same (e.g. a tested solution may show weaknesses which are dependent from an incomplete problem synthesis and modelling).

The fourth management area is related to the key *resources* needed for undertaking the problem solving process, and thus money, pre-existing knowledge and artifacts, as well as emerging societal needs and policy inputs that generate new opportunities or constraints. Managing resources is thus concerned with ensuring that all the necessary inputs are available and have been considered or acquired into the process execution effort (e.g. a new law establishing limitations to the use of cars into urban areas).

Process execution is based on the use of relevant *systems* at technology, organizational, and human capital level. The main management concern is thus to acquire and integrate all the tools (e.g. decision support systems, platforms, software suites, communication devices, sensors), to coordinate individuals and teams involved, and develop the competencies/expertise (e.g. domain experience, project management skills, along with incentives and motivation drivers) needed to successfully undertake the problem solving process.

One further management area is related to the optimization of *dependencies*, i.e. the relations among process sub-parts in terms of resources used and/or outputs produced. Dependencies are of three types, i.e. “flows” between steps (sequence constraints), “fit” of activities to generate a unique output (e.g. collection of contrasting opinions about city crime and generation of a comprehensive unique definition), and “share” of resources (e.g. use of a collective database to feed multiple views about city crime).

The execution of a process is normally exposed to potential problems, or *exceptions*, due to known or emergent events. Managing exceptions is thus a matter of clearly identifying the human or technical factors that may generate such issues and establish proper handling or response strategies for each single exceptional event (e.g. setting turnover or replacement criteria in the case that one crucial actor involved into solution testing is no more available).

Finally, *performance* of the process should be measured in terms of key metrics, with the ultimate goal to assess critical success aspects and redefine correction actions accordingly. Examples of such metrics are the degree of actors’ involvement, the measurable effectiveness of a solution, the level of innovativeness of a solution, the level of acceptance by end-users, and the overall process cost, duration, and complexity.

We illustrate in Fig. 1 our representation of the problem resolution process, with related actors, activities and the eight management areas.

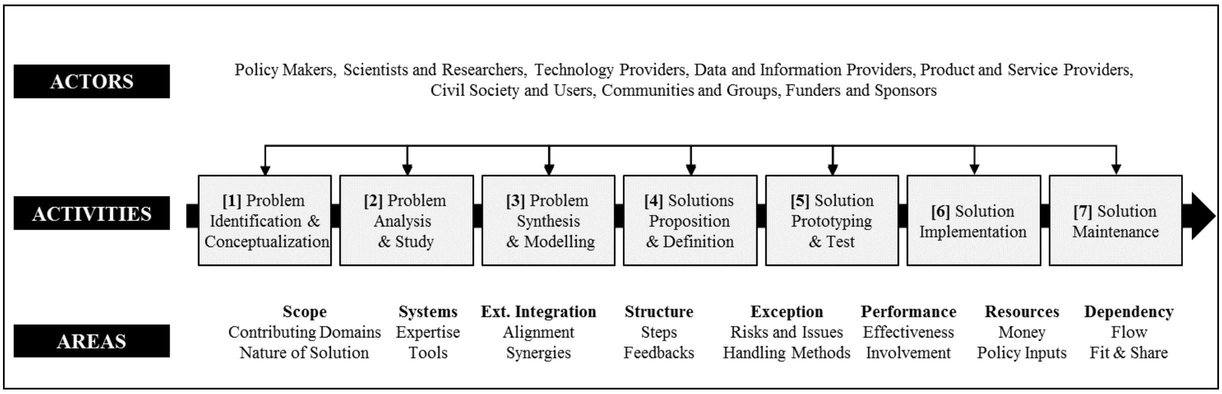

Fig. 1. Activities, Actors and Management Areas of the Problem Resolution Process

3.2 Problem Resolution Matrix

In their seminal work on collective intelligence genome, Malone, Laubacher and Dellarocas (2010) identified a relatively small set of building blocks that can be recombined in various ways in different collective intelligence systems. To classify these building blocks, the authors used four key questions, i.e. 1) What is being done in the system? 2) Who is doing it?; 3) Why are they doing it?; and 4) How is it being done? The answers to such questions allow to define the “genes” of the system.

By applying the approach to problem resolution, the four genes are related to: 1) the specific activities to be undertaken to solve the problem (what); 2) the categories of actors participating and contributing to the resolution effort (who); 3) the incentives that motivate participation of actors (why); and 4) the modality of activity execution with related roles of actors (how). Whereas the problem resolution process and the stakeholder analysis presented in the previous section has provided a possible definition of the first two elements (what, who), some further discussion is needed to define the “why” and “how” aspects.

For each stakeholder, different categories of motivations can be identified and three basic examples of “incentive” for participation (why) are: 1) *money* (M), i.e. the promise of financial gains and rewards through direct payments or increased likelihood of earning future payments; 2) *love* (L), i.e. intrinsic enjoyment, social gratitude, opportunity to socialize or contributing to a bigger cause without expecting monetary benefits; and 3) *glory* (G) or peer recognition and satisfaction (Malone et al., 2010; 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 modalities of activity execution (how) are strictly related to the role of each stakeholder into each activity of the process, and thus to the single tasks or requirements which are associated to the same. In such view, the methods and techniques used in project management can be a useful source of inspiration to define complementary contributions into a unified execution effort. Concerning the roles, the RASCI model (Hightower, 2008) used to assign project responsibilities and associated tasks defines five key roles, i.e.: *Responsible* (R), *Accountable* (A), *Support* (S), *Consulted* (C) and *Informed* (I). For each role, a number of more practical activities and tools that can be used has to be defined, and this represent the focus of section 4. A temporal dimension can be also addressed to include key issues such as duration of activities, handoffs, feedback and feed-forward flows among phases.

We have attempted to include the four elements of the collective intelligence genome (what, who, why and how), and the additional time factor (when) into a *problem resolution matrix*, which is represented in Figure 2. 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 undertaken. 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, risk of execution, and escalation. 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.

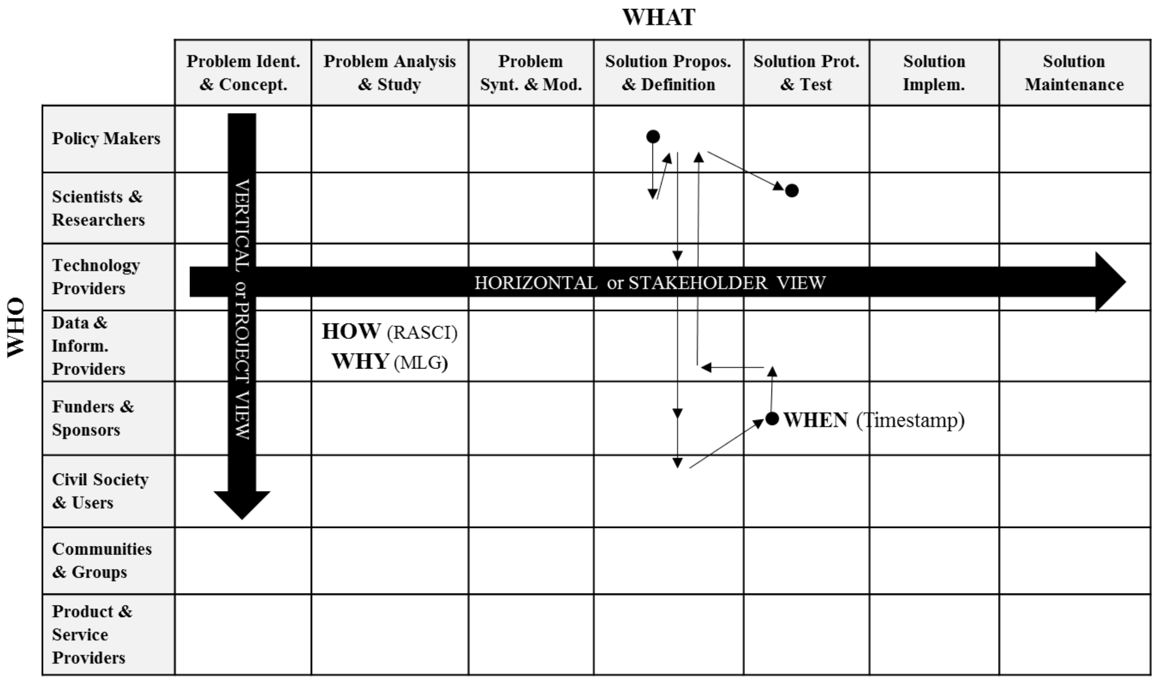

Fig. 2. Problem resolution matrix

An illustrative example can be used to better describe the “application” of the matrix and the operational meaning of the five components of the same. If the wicked problem to (attempt to) solve is represented by city crime, the application of the matrix would allow to build a comprehensive representation in which each of the 56 cells (7x8) shows the combination of *what*, *who*, *how*, *why* and *when* elements contributing to solve crime within a city. For example, at the intersection between scientists and researchers (*who*) and problem synthesis and modelling (*what*), the contribution of sociologists can be represented as accountable professionals (*how*) looking for visibility into a large-scale problem solving initiative (*why*). The contribution of sociologists into problem modelling can be also represented as a pre-condition or input (*when*) for successful analysis by policy makers (ordered hands-off) or an initial contribution stage, which is followed by a second involvement of the same actors into a future phase (e.g. solution implementation).

The matrix complements the process model defined in section 3.1 and prepares the ground for the design of an integrated system of “tools”, which is described in section 4. The main difference from extant studies is the use of an integrated or multi-dimensional view aimed to investigate the activity dimension, the stakeholder dimension, the project or realization dimension and the temporal dimension of complex problem solving. These dimensions are generally analyzed in separate investigations. The tool may thus serve practitioners as an integrative model or reference framework for further analysis and real-life implementation projects. The application of the matrix has positive implications and some drawbacks compared to analogous tools adopted for solving wicked problems. The advantages or implications are in terms of a holistic definition of elements to be addressed, and in terms of using a framework of collective intelligence, which provides a basis for technology and system development. A drawback in our work is the fact that we present a “linear” description of the problem solving process, which is not always realistic in innovation-driven or innovation-oriented scenarios, where most of actors and activities are indeed dynamically interacting and subject to change in the short term.

4. System for Collective Problem Analysis and Resolution

The resolution of wicked problems requires a multi-dimensional (different perspectives from different disciplinary contexts) and multi-stakeholder (many actors) approach. In such endeavor, collective intelligence may represent a relevant construct and provide an enabling infrastructure for such complex process. Collective intelligence can be thus purposefully "contextualized" to the specific goal, approach and method defined in our article. For the goal, the main objective of collective intelligence is to solve problems or doing activities in a better way than they are executed by single individuals. The application to wicked problem resolutions is thus native or natural. For the approach, the literature has suggested to identify the key building blocks to analyze if and when the genome of collective intelligence can be opportunely applied to wicked problem solving. In the matrix section, we have conducted such specific discussion work to demonstrate the applicability of the four concepts (plus time) to the resolution pattern of a complex problem. For what concerns the method, a collective intelligence system should 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 (Glenn, 2015).

At this purpose, we introduce in this section the foundational elements of a system to support wicked problem solving. In particular, we 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 key issues represent the fundamental constructs for the development of collaborative problem solving features. In Tab**.** 1 we show the result of such association work. The main value added is to provide an operationalization of constructs, where key issues represent functional design targets of an information system. Whereas extant literature on problem solving has focused on the description of phases and activities required to come up with a solution into complex problem settings, few attention was addressed to define design elements for the development of a system to support the overall lifecycle. In such perspective, the effort of creating a taxonomy of key design elements should be considered as a progress respect to existing literature.

Tab. 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*

For each step, we thus defined the core elements of a tool able to support the related activity, and 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.), although the work undertaken can be used as basic requirements for designing and developing purposeful software applications. The seven steps are presented here below, along with a set of illustrative examples of how one community member can use the system to contribute to solve the problem under analysis, e.g. city crime.

In the “*Problem Identification & Conceptualization*” step, the need is to gather multiple definitions, codified knowledge and perspectives about a problem, as they arise within the engaged community, along with “external” sources of knowledge. The wickedness of the problem reveals since its formulation, since reaching its agreed formulation represents a first challenging step for the resolution (Duckett et al., 2016). The ultimate goal is thus to create a common ground and a shared semantic of the problem. In such view, we envision the utility of a *semantic aggregator* able to *edit* contributions, i.e. to insert, modify, delete and save a new definition or statement, and to *link* contributions, i.e. associate, compare, and combine statements provided by different individuals. Voting and rating systems can support the process of collective conceptualization. The community member can thus include into the system his/her own definition of city crime, vote for definitions provided by other members and look at how the system aggregates definitions to obtain one single integrative description.

In the "*Problem Analysis & Study*" step, the goal is to build and share a comprehensive taxonomy of dimensions and parameters of the problem under analysis, a sort of cross-disciplinary cognitive map of key components (or sub-problems) needed to propose relevant solutions. We envision the utility of a *parameter tree generator* able to *add* items, i.e. to create a new branch or element within an existing tree, and to *generate* a new tree that consolidates the changes made by all the contributors in the community. The community member can thus suggest into the system a number of items or constructs associated to city crime (e.g. 911 calls, burglaries, citizen fear) and look at how the system aggregates concepts into a one single integrative conceptual tree.

In the "*Problem Synthesis & Modelling*" step, the need is to generate a graphical representation of the problem and its components, a casual map of the problem (Bryson et al., 2004) in terms of key constructs, causes/antecedents, effects, and relations. The map allow capturing argumentations and sharing views, in the aim to facilitate negotiation and achieve a common problem model. We thus envision a *problem visualizer* able to *correlate*, i.e. to create links among the nodes of the map, and *navigate*, i.e. to define logic patterns that provide possible descriptions or interpretations of the problem. The community member can thus suggest possible relations among constructs (e.g. between nighttime shopping statistics and thefts) and look at how the system aggregates concepts into a one single integrative conceptual tree.

In the "*Solutions Proposition & Definition*" step, the key objective is to gather all the potential solutions proposed by the community members, and evaluate them using a set of relevant (quantitative and qualitative) metrics into purposeful trade-off matrixes. This enables debate and negotiation among participants who can vote, provide support, discuss, and choose solutions by adopting scenario planning techniques. We thus envision a *solution matrix* endowed with a *solve* function, to propose the solution using a given format, and a *vote* function, which allows all the community members to grade solutions provided, also based on the outcome of the trade-off matrix. The community member can now present his/her own solution (e.g. gun control, poverty reduction programs), with related measures of expected improvement (e.g. impact in terms of reduced deaths) and rank other members' solutions to visualize the solutions best ranked within the community.

In the "*Solutions Prototyping & Test*" step, the goal is to define the basic (project) management aspects related with prototyping and testing the selected solution(s) into a controlled environment. Roles and tasks should thus be assigned, and key elements such as duration, budget and human resources, level of complexity and risks, and expected impact should be defined carefully. We envision the utility of a *pilot builder* endowed with a *staff* function, to assign tasks (with deliverables and deadline) to available actors, and a *candidate* function, to allow community members to spontaneously contribute to any of the planned activities. The community member can thus receive a request from the system or spontaneously candidate to become part of a small group of actors involved into the prototyping and testing of the solution best ranked by the whole community.

In the "*Solution Implementation*" step, the goal is to ensure real-time monitoring of implementation activities and results, thus providing key measures (e.g. number of involved users, geographic scope) for evaluating the effects of real-world application of the solution. We envision the utility of an *application monitor* endowed with a *coordinate* function, to ensure proper execution of activities, and *recommend* function, to suggest adjustments or improvements into the implementation process. The community member can now look at how the solution testing is being undertaking and propose real-time modifications or adjustments.

Finally, in the "*Solution Maintenance*" step, the goal is to measure key performance indicators of the implemented solution and use the same to design corrections or improvement actions. We suggest the utility of a *performance scorecard* which provides a *report* function, to generate a detailed report of the effects and performance achieved with implementation, and an *improve* function, to suggest amendments, further refinements or alternative solutions. The community member can finally read the statistics of solution implementation and resulting effects, so to define more structured changes or new solutions to be considered. In Fig. 3 we show the system for problem analyses and resolution, with the indication of steps and associated tools, functions and output.

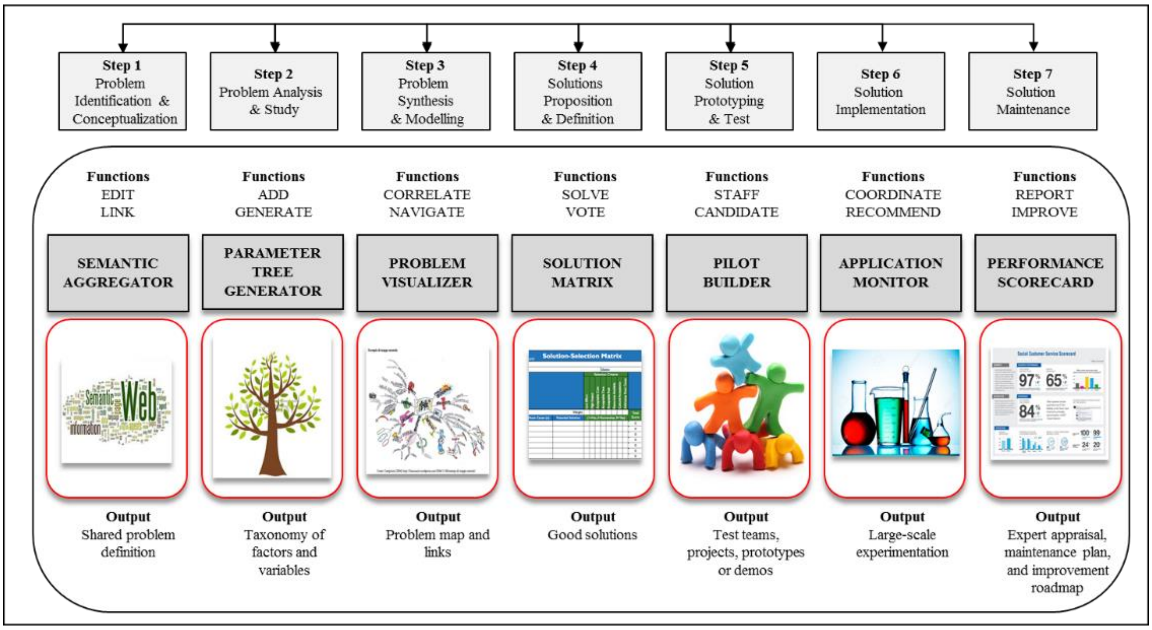

Fig. 3. Collective Intelligence System to support problem analysis and solution generation

The definition of goals, key constructs, and tools of potential use for each step is complemented by a checklist of activities and expected outcomes, which we represent in Tab. 2. The main value of the table, and key development respect to extant contributions, is to provide a comprehensive canvas for practitioners and a structured view of activities to undertake with associated outcomes. The analysis derives from the application of collective intelligence principles into the process and matrix development work and it can thus be a useful operating tool for individuals involved as coordinators, project managers, or simple facilitators into wicked problem solving initiatives.

Tab. 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

The system of tools is 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. Group decision making is today significantly 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 contributions 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.

The problem resolution process provides a structured sequence that starts with problem identification and conceptualization, which represents the first key challenge in the resolution of a wicked problem. In fact, wicked problems are “ambiguously bounded” (Duckett et al., 2016) and a number of strategies can be applied such as inter/transdisciplinarity, boundary spanning and systems thinking (van Bertalanffy, 1968). The ultimate goal is to create a common ground of knowledge, principles and values, and to accommodate multiple alternatives. In our model, we have addressed the relevance of shared or collective “definition” generation and semantic building. Besides, we have adopted a process management approach to identify the critical management areas to address in order to successfully undertake problem analysis and resolution generation process.

As for the resolution matrix, the integration of the stakeholder view with the project view is aimed to address the ambiguous boundaries of a wicked problem and highlight the importance to leverage interdisciplinary and transdisciplinary interactions among heterogeneous individuals (Tress, Tress, & Fry, 2004) into structured and implementations-driven initiatives. Moreover, the temporal dimension (when) embedded into the matrix stimulates discussion about scenarios and evolving dynamics, fore sighting and envisioning for imaging plausible futures and feasible solutions.

The system of tools associated to the seven steps of problem resolution provides a twofold contribution. From one side, the inclusion of modelling tools, scenario planning and emerging participatory approaches is addressed to cope with uncertainty typical of wicked contexts (Batie, 2008). Second, the inclusion of prpblem "decomposition" tools contributes to transform complex issues into more recognizable and smaller problems (Shindler & Cramer, 1999), thus locking down the problem definition (Conklin, 2010), aligning purposes and goals (Lazarus, 2009), and assessing competences. Besides, the adoption of dialogue mapping and deliberation tools (Conklin, 2010) encourages to adopt a participatory approach in the overall resolution process, so increasing equal empowerment (Brown et al., 2010), ownership through transparency (Mascarenhas, 2009), continuous debate (Whyte & Thompson, 2012), and rational collaboration (Innes & Booher, 2010).

Earlier contributions have discussed the role of group learning, team composition, visual analytics approaches and scenario planning techniques to support interactive problem solving. Our work has elaborated an integrated architecture of constructs and tools that may support the execution of tasks involved into large-scale and complex solution generation efforts, where the extended number and variety of stakeholders and the distinguishing multi-domain nature of complex social issues requires to define systemic views and models.

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 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. Considering the data-intensive nature of wicked social issues, the proposed framework can be further extended by including the emerging paradigm of big data and analytics, which allows to discover and analyze a wide variety of data to support decision making (Ketter et al., 2016).

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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