A review of methods for modelling shared decision-making process in a Smart City Living Lab

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***Abstract*— Living lab is becoming a popular concept to design integrated solutions through the integration of users in the each stages of an innovation process. This study uses the systematic literature review methodology in order to research the suitable methodology for modelling a Living Lab decision- making process that enabling multi-stakeholders, especially citizens of Smart City projects leading to the research agendas for the coming years. Finally, a conceptual framework of collaboration involving multi-stakeholders to follow the share decision-making process in a Living Lab platform is proposed.**

Keywords— Smart City; Living Lab; decision- making; collaboration; multi-stateholders

I. INTRODUCTION

Cities are increasingly growing to become larger and more complex than ever. As a consequence, dealing with issues such as mobility, pollution, health risk or new infrastructure among others, couldn't be treated anymore by city authorities, merely with traditional top-down approaches, but also integrating active participation of user and other stakeholders. In recent decades, the concept of "Smart City" has considered as a city functioning by Information and Communications Technology (ICT)- based solutions for public issues and on the basis of public–private–people partnerships (4Ps) of multi- stakeholders [1]. Because of ICT development, citizens of smart cities have more chances to access information and public data. This context brings opportunities for them to interact, collaborate and be engaged on their city's projects.

Living lab approach has emerged as a methodological support to the interaction of stakeholders, including users, in order to create new services, products and innovation in general. Juujärvi and Pesso underlined the differences stakeholders' roles and their outcomes on such projects [2]. However, dealing with a Living lab project is a complex task because of its own nature (multi stakeholders, dynamic interactions, independency but interaction...) that make it difficult to steering successfully those projects.

Formal representations of decision-making and interaction process in complex systems will enhance the comprehension of the dynamics of the collaborative projects and its implications on the project outcomes and its success or fail. Several modeling approaches have been proposed in the literature such as multi-agent system (MAS) [3], System Dynamics (SD) [4], Multiple-criteria decision-making (MCDM) [5], Fuzzy Cognitive Maps(FCM) [6], Bayesian networks (BNs) [7] among others.

However, there is not a general approach to decide the best representation tool regarding to the level of decision, stage of the project and context.

This paper proposes a systematic literature review of the formalization tools of a collaborative smart city projects within the framework of the living lab approach, in order to pinpoint their relevance, advantages and scope are exposed. Moreover, a discussion will be made toward a general approach in order to select the more adapted tool.

Results show that there is a gap between modeling the decision- making processes and experimenting and evaluating such models in complex systems. MAS offers a conceptual and methodological approach to involve multi- stakeholder into dynamic models of decision- making process.

The paper, after this introduction, is organized into five sections. Section 2 defines Living lab concept, smart city as well as collaboration and decision-making process in complex systems as smart city projects under the living lab approach. Section 3 presents the systematic literature review methodology for this system study. Describing in the section 4, findings of this study include the existence decision making tools that could be integrated for Living lab decision- making process and a conceptual framework of collaboration between multi-stakeholders in multi contexts. Finally, section 5 discusses about the proposal and the perspectives in next further researches.

II. LITERATURE REVIEW

A. Living lab concept and Smart City

Living Lab started to emerge in the beginning of 2000 and has been defined as an environment, a methodology or a system [8]. In this research, we will focus more on the methodology perspective that considered Living Lab concept as methods of user-centric design that involving communities of user in every stages of an innovation process. Living lab provides collaborative workspaces for different groups of stakeholders, especially users, working together and sharing

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knowledge and decisions. Diverse competencies, priorities and interests of participating stakeholders often make Living Lab projects complicated and volatile [9]. Regarding to these complexities, collaboration and interaction among stakeholders in real-life environments are considered as the core rationale for setting up living labs. The theoretical "distributed collaborative ecosystem" model has developed and experimented in Living Lab projects [10], [11]. At the first level, separate elements are concentrated and then following by interactions and factors which allow interactions at the second level. Finally, parts and links can then be observed as a whole at the third level. This process not only includes communication and collaboration between stakeholders but also their negotiation, combination and integration.

The Living Lab concept has been applied to different fields such as well-being, education, rural areas among others. But, maybe the field where this concept has been more adopted and applied is "Smart City". Smart City is considered as a city seeking to address public issues via ICT-based solutions on the basis of a multi-stakeholder and municipally based partnership [1]. Several project management researches and urban studies have concerned citizens as users and stakeholders of urban projects [12]. In Smart city, citizens are not only engaged and informed in the relationship between their activities, their neighborhoods, and the wider urban ecosystems, but are actively encouraged to see the city itself as something they can collectively tune, such that it is efficient, interactive, engaging, adaptive and flexible. They are active contributors within innovation and design communities.

Since the ERPI laboratory investigate urban transformation, we have developed research, pedagogic projects, and experiments in real life with citizens, and tools to support financial or technological needs that we called demonstrators [10]. Each project has a specific added value and gives us characteristics to analyze Smart City:

1. User-driven approach is qualified by end-users' integration in the design process: from strict delivery without integration (for) to end-user as product co-designer (with) or designer (by) [13].

2. Solution's design process gives a level of collaborative process [14]: stakeholder works alone on its project; several stakeholders work in parallel on parts of different projects (distributed); stakeholders collaborate on a long-term, project (collaborative); several collaborative groups work in parallel on a complex project and interact regularly (distributed & collaborative).

3. Level of integrated solution depends on its sustainability and viability, i.e. the number of dimensions taken into account by a solution. According to circles of sustainability, we reveal four dimensions for sustainable development (SD): Economics, Ecology, Politics, Culture, and Governance as a dimension connecting the other four.

4. Solution's representation level is defined by demonstrator proximity with final form (marketable or completely adopted by users)

5. Spatial scale level indicates number of concerned scales. An example of scale of study can be at product, an apartment, a building, a block, a neighborhood, a city, or a region level.

6. PPPP (Public Private People Partnership) level shows how various stakeholders are involved in co-design. We can find universities or academics, local authorities or elected representatives and territorial engineers, companies or industrials, and finally citizens.

However, dealing with a Smart City project under the Living lab approach is a complex task; decisions along the project and after the project must be taken. The mechanisms, metrics and implications of type of projects aren't yet well known as it implies several stakeholders and levels of decision during its deployment.

B. Communication by ICT and collaboration in a complex system

Mila Gascó made a contribution to understand the concept of Living labs as open innovation intermediaries in public service sector [15]. Innovation, in the theory concept of some papers, is considered as a complex process embedded in a social and cultural territory, occurring by the numerous interactions of a various individuals and collaborations between organizations [12]. Several Living Lab case studies, especially urban transformation and innovation projects, has provided ICT interfaces between stakeholders in order to support the urban design process where user is considered as a potential active actor [16], [11]. The mass- deployment of ICT solution has brought users into the system of innovation with larger mass of idea and knowledge.

In term of engineering systems, the city is understood as a set of elements which are related to each other [14]. In 2014, Longo et al have presented a model for smart cities that was called Intelligent Distributed Autonomous Smart City (IDASC). Cities generally defined as "smart", also require connectivity, automation and coordination between elements to enhance transmitting and distributing data system [17]. IDASC involves multi-agent systems (MAS) and IoT (Internet of Things) to enable observation, audit and performance of the system.

Within this context, Multi-agent system (MAS) consists of a set of agents representing organizations or interest groups involved in a problem of urban management. By using multi-agent framework, the model of city is discussed by active autonomous agents. Each agent is responsible for a specific function and for a specific portion of the smart grid of infrastructure. Different autonomous decision-making agents have to facilitate, communicate, exchange knowledge, and cooperate in order to achieve common goals. By transmission and distribution data, the multi-agent system is to break down a complex problem handled by a single entity – a centralized system – into smaller simpler problems handled by several entities – a distributed system.

C. Decision- making in complex system

According to Rushton and Oxley (1989), a hierarchy level of decision - strategic, tactical and operational - based on the time horizon for activities, the pertinence of decisions and the

influence of different levels of management. Strategic level deals with the long- term decisions at the top- level management decisions. Tactical level considers the medium term decisions on mid-level in order to achieve results specified at the strategic level. Lastly, operational level involves short- term decisions data and assesses the results of low- level managers.

In complex systems as living lab projects, there is a demand to representing decision-making and communication processes of different stakeholders. This study will review several modeling methods proposed in literature review such as multi-criteria decision analysis (MCDA), system dynamics (SD), fuzzy cognitive maps (FCM), multi- agent system (MAS) among others, in order to highlight their main contributions, advantages and limits to this field.

MCDA is a multi-step process consisting of a set of methods to structure and formalize decision-making processes in ecosystem service assessments. [5] However, MCDA is considered steady-state method whereby providing snapshots of hotspots based on historical data. This method does not provide projections, trends in the future or take into account the interactions of different metrics, outputs and parameters over time. To make the results more useful for decision and policy makers, we need to model the dynamic interrelationships of these variables over time [18]. In order to deal with dynamic and complex problems, Stave discussed the use of system dynamics as a methodology to improve public participation in environmental decisions [4]. Nevertheless, this decision-making approach is not suitable for operational problems in integrated solution management [19]. FCM is considered as a visual representation method for modelling and simulating dynamic system that is applying widely as an advance decision support system [6] to capture the point of view of individual stakeholders and identify conflicts among stakeholders interests [20]. This means FCM is well- adapted for issue identification phases in a decision-making process. Bayesian networks (BNs) are modelling technique using Bayes' probability theory to replicates the essential features of reasoning in conditions of uncertainty. However, BNs are well suited for modelling system components where knowledge is unstructured that is definitively unsuitable when the reasonable alternatives of systems have to be determined via negotiations [7]. Among types of modelling method above, MAS seems interesting and promising in the domain of complex and high-interactive systems. MAS approach represents a system as many autonomous interacting agents, which adapt and co-evolve based on the information received from the environment and each other.

The table below presents a comparison of several modelling methods representing a decision-making process in complex systems regarding to requirements that are further developed from the analysis of Rahimi et al [6].

In order to select the more suitable method in collaborative smart city projects within the framework of the living lab approach, a deeper analysis will be proposed in the next sections of this study.

TABLE I. COMPARING THE MODELING METHODS IN TERMS OF EQUIREMENTS DEMANDED

Method	**Requirements in representing a complex system**			
	Modelling dynamic relationships	***Ability to evaluate the uncertainty***	***Directed graph with cycles***	***Operational problem management***
MCDA		x		x
SD	x		x	
FCM	x	x	x	
BNs	x	x		
MAS	x	x	x	x

III. RESEARCH METHODOLOGY

To deal with complex task and decisions in collaborative projects, as smart city projects under living lab approach, the objective of this study is to determine the formal representations of decision-making and interaction process. A systematic literature review methodology has proposed by a search strategy and analysis of the collected documents has been deployed:

In order to determine which decision-making approaches are relevant to different stages of collaboration project, a systematic literature review methodology composed by a search strategy and analysis of the collected documents has been deployed. First of all, a search strategy considers journal articles and conference proceedings searched in scientific databases, especially, in Scopus and Web of Science. The researchers are initially selected including keywords regarding to the share decision- making process in complex, dynamic collaborative systems such as ecosystem, urban management or organizational projects. The period of document selection is more focused since the beginning of 2000 when the concept of Living Lab started to emerge [8].

After the filter, the descriptive analysis of the state of the art was made in order to inquiry different decision-making methodologies in urban collaboration projects. A typical Living Lab process includes several iteration cycles: concept, prototype and experiment in real-life. Based on this development process, the levels of model using to representing the decision making process in the research were analyzed for comparison and selection.

IV. FINDINGS

A. Decision- making approaches in urban collaboration projects

The awareness of the importance of a shared decision process in complex domains, like urban collaboration projects, recently studies effort to involve participatory of stakeholders in negotiation and interaction processes [21]. This study will review different methods representing the cooperation and shared decision- making process in complex and collaborative projects based on four levels (table II). First of all, at the conceptual level, the model is formed after the first stage of Living Lab process [22].

TABLE II. REPRESENTATION OF DIFFERENT DECISION-MAKING METHODOLOGY IN SOLUTIONS OF URBAN COLLABORATION PROJECTS

Ref.	Domain	Method	Findings	Level of representation model			
				Conceptual model	*Logical model*	*Prototype in real-life*	*Experiment in real-life*
[24]	Simulating knowledge sharing in spatial planning	MAS	A model of collaboration and decision making for exchange of information		x	x	
[25]	Simulating smart grid of energy system.	MAS	A simulator of a dynamic infrastructure (discrete heterogeneous devices) in smart cities		x	x	
[26]	Virtual Community Management System in smart city	MAS	Virtual spaces to build collaborations and exchange knowledge between people sharing similar interests or goals				x
[27]	Conflict resolution in choosing a suitable technology	MAS	A platform of solving conflicts in smart city management		x		
[23]	Collaborative environmental planning in river management	MCDM	A framework for discussions of multi-stakeholder about long-term river management possible	x			
[5]	Ecosystem service assessments and urban planning	MCDM	Using MCDA to accommodate conflicting stakeholder perspectives and to address trade-offs between ecological, social and economic values	x			
[19]	System Dynamics Simulation in Water Resources Management	SD	Applications of system dynamics simulation combined with stakeholder involvement methodology	x	x		
[4]	Using system dynamics to improve public participation in environmental decisions	SD	Group model building to support a stakeholder advisory group and add the information feedback to the advisory process		x	x	
[6]	Risk assessment of complex and dynamic systems	FCM	Decision support tool using FCM to represents and analyzes the dynamic behavior of complex systems	x	x		
[20]	Issue identification in a water resources conflict resolution system	FCM	A community decision support system is propose to simulate real conflict and negotiation proces	x	x	x	

The MCDA method has applied widely at this level for modeling fundamental principles and basic functionality of in decision- making and discussion process of multi- stakeholders [5], [23]. Meanwhile, there are several applications of system dynamic method combined with stakeholder involvement for simulating dynamically complex problems [4], [19]. System dynamic is used as a suitable representation of a system to creating logical model and prototype in real-life that allowing visualization of internal relationships within Living Lab platform. An alternative tool is found in Multi-Agent Systems (MAS) that offer a methodology to involve multi- stakeholder into dynamic models of decision- making process that able to experimenting in the real-life [24], [25], [26].

It can be realized from the table II that within the domain of collaboration and decision- making in complex system, modeling methods are mostly used to creating conceptual and logical models. Meanwhile, there is a lack of decision- making models been prototyped or experimented in the real- life. This leads to a demand of methodologies enabling to integrate simulations of different representing tools in complex and dynamic system.

To conclude, MAS is an appropriate method proposing models, executing them in the real-life of Living Lab Platform and finally, adjusting and evaluating. MAS is the most relevant representation tool of decision- making process in multi-context and during the whole stages of the urban living lab.

B. A toward conceptual framework of collaboration and decision- making process in a Living Lab

A sustainable process of urban transformation into a smart city requires co-operations between ICT infrastructure and soft approaches, such as collaborations between multi-stakeholders in multi contexts. In this regard, the city can be seen as an enabling platform, an environment where different stakeholders work actively together. In smart city projects, the living lab environment plays a central role as innovation intermediary in the ecosystem. The framework of the living lab approach solves problems of varying complexity and facilitates to link user and other stakeholders in a collaborative and open access network of smart cities. However, each of stakeholders has dissimilar background, knowledge and objective. This leads to the demand of building a conceptual framework of collaboration and group decision- making process in Living Lab platforms.

Dealing with this context, Ligtenberg has offered a conceptual framework for decision- making process involve multi- stakeholders in a spatial planning based on Multi-agent Systems method [24]. During this decision- making process, stakeholders communicate and negotiate their preferences with others. They try to influence, convince or co-operate whenever necessary to improve the position of their preferences on the decision market.

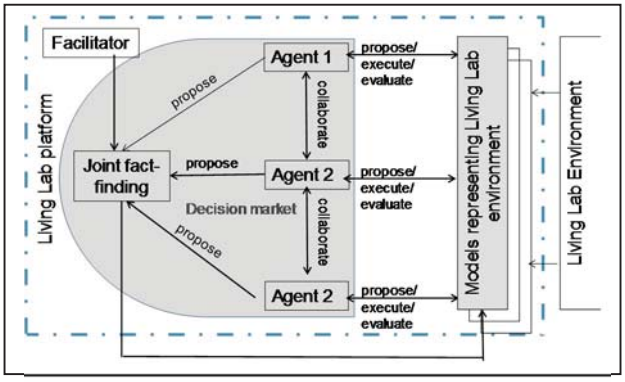

Fig. 1. Conceptual framework of Living Lab Decision- making process by Multi-agent system model.

Developed from the research of Ligtenberg, we proposed a conceptual framework for the collaboration and decision-making process of multi- stakeholder in the Living Lab platform by Multi-agent Systems approach.

As can be seen in the fig. 1, in a Living Lab platform, an agent is responsible for a representative of stakeholders. Stakeholders sequentially propose, execute or evaluate models representing the Ling Lab environment through collaboration and negotiation. The preferences and goals of each individual stakeholder are input in the process of joint fact- finding. The important role in this process is belong to facilitator, a special agent, whose main tasks are to maintain the process of joint fact- finding in order to achieve consensus and reconcile conflicts. The intermediate results of the joint fact- finding are adjustments for models that are continue to execute or evaluate by stakeholders. Therefore, in this framework, the Living Lab decision- making process operates as an iteration cycle, where different levels of model are created and modified.

In order to develop from conceptual to operational framework and facilitate for the simulation process, it is necessary to experiment and validate the framework by different case studies. Recently, several real-cases of Smart City projects under Living Lab approach have studied, supported and developed by the Lorraine Smart Cities Living Lab and the Chaire REVES project with its Smart City demonstrators [10]. This is the foundation for modeling the decision- making process in Smart City projects, toward solving conflicts and negotiation of multi- stakeholders and involving citizens in an active way.

V. CONCLUSION

Smart cities have been researched for over a decade as complex and dynamic networks formed by communities of interacting organisms and their environments. In a Smart City Living lab, collaboration and interaction face numerous difficulties to achieve common goals and make a final decision. In this context, our study explored the application ability of different methods for modeling the share decision- making process in a Living Lab Smart City project. Regarding to the levels of representing model and the development stages of Smart City Living Lab projects, multi- agent system is considered as a suitable method representing the share decision- making process as a conceptual model, then executing and finally, experiment solutions in the real-life. A collaborative framework of multi- stakeholders in Living Lab platform has built based on principles of multi- agent system approach where stakeholders, especially citizens, not only able to access information and public data but also involving as active actors of innovation process. In urban innovation process, Living Lab platform could bring the collaborative environment to make links of communication and negotiation. We do believe that the ideal of Living lab methodology is potential to deal with complex projects of smart citizens.

The MAS methodology is well- adapted to strengthen the collaborative dimension of the urban transformation. But, it could be interesting to continue to explore tools supporting and developing the MAS method for simulating and modeling collaborative platforms.

Besides, our research is still a conceptual proposition. Its research scope does not include yet practical case studies that will be mentioned in next further researches. In Lorraine, we have conducted several innovation projects supported by a Fab Living Lab platform (LF2L, founded in 2014). The share decision- making process for multi- stakeholders could spread on solving difficulties in an Urban Living Lab project to transform “shared diagnosis” to “shared action” stages.

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