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# From “shared diagnosis” to “shared action”: how Living Lab process can support decision-making process involving citizen for Smart City

Tran Thi Hoang Giang

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**UNIVERSITÉ  
DE LORRAINE**

**SIMPPÉ**



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PRODUITS, DES PROCÉDES ET DE L'ÉNERGIE

**Laboratoire : ERPI**

Equipe de Recherche sur les Processus Innovatifs

**D'un « diagnostic partagé » à « l'action partagée »  
: comment le mode projet Living Lab peut alimenter le  
processus d'aide à la décision du « faire la ville » en  
intégrant les citoyens pour une ville intelligente**

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**Thesis defended Novembre 13, 2019**

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## General introduction

Research on decision support tools is positioned at the intersection of several disciplinary fields which concerns psychology, sociology, science management, economics, law, but also mathematics or the operational research. Furthermore, cities are complex and this complexity asks for new knowledge and science to understand and manage them (Batty et al., 2012). In this context, Smart City concept appears at the frontier of new technologies, management methods and knowledge. Our study will focus more specifically on the shared decision of stakeholders in Smart City projects. Although we do not avoid using many of these disciplines, our study is more specifically focus on science management and operational research under the vision of the project and decision engineering.

### The scope and research problem

Since more than a decade, Living Lab is becoming a popular concept to design new solutions through the integration of communities of users. These solutions are then, co-designed, tested and evaluated within the natural environment of the users. 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 the smart cities (Bakici et al., 2013; Cardone et al., 2014; Cosgrave et al., 2013; Dupont et al., 2014; Naphade et al., 2011; Pallot et al., 2010; Skiba, 2014).

Having a central role of infrastructure in Smart Cities, technology should be at the service of citizens helping to produce and transfer knowledge and creating values but not only through the market. Information and Communications Technologies (ICT), regarding the Smart City concept relates to smart embedded devices; ranging from smartphones to sensors, smart meters and other instrumentation sustaining the intelligence of the city. Data coming from these sensors, or integrated networks, can provide citizens with real-time and location-based information. Furthermore, the open data from government entities create additional opportunities for developing new services that citizens can use to add relevance and value to the information and create applications.

The role that ICT plays in cities is the same one that these technologies have in organizations and that has been largely described in Information Systems literature and organization studies: improving productivity (i.e. output divided input) through automatic routine processes and by powering managers' decision-making, planning and control activities.

Living in a wide ecosystem of a Smart City, citizens can be in a permanent relationship with their neighborhoods. As a consequence, citizens are not only engaged actively into urban problems but also informed to see the city itself "as something they can collectively tune, such that it is efficient, interactive, engaging, adaptive and flexible" (Cities, 2010). In a complex and multi-scalar context of Smart City, stakeholders face an overflow of information. The huge and available information is not only an advantage condition for stakeholders but also be a challenge for wiser management of authorities. Several current research on the Smart City concept have emphasized the level of engagement of stakeholders, especially citizens, in the co-production of services and the decision-making

process. Making decisions under these rapidly changing conditions of Smart City requires a holistic understanding and ability of systemic thinking. However, discussions about decision-making processes and collaboration in Smart City projects still lack an overall picture and systemic understanding (Eräranta and Staffans, 2015).

There are several research questions have raised, such as:

- How many steps are needed in the co-creating process supported by a Living Lab towards the realization of Smart City projects?
- How to build a group decision- making process involving groups of stakeholders with different roles, skills knowledge and expertise?
- Which modeling technique is the most relevant to represent a system of Smart City?
- How to support close to a real-life environment while providing a higher level of stakeholder's engagement during the co-creation stage of the innovation process supported by a Living Lab?
- How to keep the key role of citizens in every stage of the co-creating process supported by a Living Lab towards the realization of Smart City?

## **Objectives of the research**

The main goal of the study will be the research of the methodology for decision-making processes that involve citizens in an active way and to propose and operationalize a conceptual framework enabling project stakeholders to follow the decision-making process within a Living Lab Project.

In order to reach this main goal, several particular objectives have listed that must include at least:

A state of the art on how ICT and interoperability are changing the citizen engagements and the way the cities are managed

A descriptive on how Living Lab group decision-making process is realized

A study of the decision-making tools that potentially could be integrated to ease this process or involve all interested parties

A framework to integrate the process

The illustration of this framework through the current and past demonstrators of the ERPI Laboratory.

## **Organization of the thesis**

The thesis is organized as following schematic structure:



Section 1:  
Research context

- A state of the art on Smart Cities under Living Lab approach.
- A systematic literature review on application of decision-making methods in Smart City projects

Section 2:  
Model  
development

- The conceptual model
- The proposition of methodology: with automatic control system  
with human facilitator

Section 3:  
Model validation

- Case study and Experimentation
- A functional mock- up for a group decision making tool supporting argument and negotiation process.
- Model validation and Result analysis

Section 4:  
Conclusion

- Conclusions, limitation and perspectives

## General introduction

### Research context

**Chapter 1:** A state of the art on Smart Cities under Living Lab approach - How can improve the engagement of stakeholders? This chapter proposes an overview focusing on the Smart City concept under Living Lab approach. Besides, this chapter presents a state of the art on applying Living Lab and ICT – based solutions to engage stakeholders, especially citizens.

**Chapter 2: Application of decision-making methods in Smart City projects: A systematic literature review.** Presents a systematic literature review methodology on decision-making methods enabling communication between multi-stakeholders implication into various phases of Smart City projects.

### Conceptual framework

**Chapter 3: Group decision-making process and the conceptual model of group decision-making process under Living Lab approach.** The chapter illustrates the consensus reaching process in group decision- making as a generic scheme. This scheme continues to exploit and classify by to develop two types of conceptual framework with multi-stakeholders, a framework for a large scale group without a moderator and a framework guided by a human facilitator and support system tools.

### Model development

**Chapter 4: Proposition of an automatic control system based on multi-agent system to support Consensus Reaching Processes.** The proposition of a general

methodology is developed for an automatic reaching consensus in large scale groups of decision makers without a facilitator or direct interaction.

**Chapter 5: Proposition of multi-criteria and multi-stakeholders methodology supporting Consensus Reaching Processes with a human facilitator.** The proposition of a general methodology is designed for a consensus reaching process supervised by human facilitator and supported by an ICT- based tool.

#### **Case study application and results**

**Chapter 7: Case study and Experimentation.** The parameters to analyse the potential performances to design a Living Lab decision making for Smart City case studies.

**Chapter 6: A functional mock-up for a group decision-making tool supporting the argument and negotiation process.** Based on the needs of experimentation, this chapter developed online interfaces as decision-making tools for communication and negotiation of stakeholders in Living Lab environment. The first one developed in Excel Office, and the second is a web-based solution.

**Chapter 8: Model validation and Result analysis**

#### **Conclusion**





## **Extended Abstract**

### **Introduction**

Les villes sont par nature complexes et cette complexité exige une science et des connaissances nouvelles pour mieux comprendre les phénomènes et les gérer (Batty et al., 2012). Dans ce contexte, le concept de Smart City se développe à la frontière des nouvelles technologies, le management des méthodes et des connaissances. A l'ère actuelle, les projets de Smart City doivent faire face à de grands défis sociétaux, écologiques et technologiques tels que la numérisation, la pollution, les aspirations démocratiques, la nécessité d'être en sécurité, etc. L'implication accrue de multiples acteurs (citoyens, usagers, ingénieurs, chercheurs, élus, etc.) dans les différentes phases des projets, est une stratégie qui permet de prendre en compte des perspectives variées et de développer ainsi une vision partagée de la ville. Paradoxalement, la nature dynamique et multiple des intervenants semble être une source de complications et d'incertitude dans le processus décisionnel. Notre étude se concentre plus particulièrement sur la décision partagée entre parties prenantes au sein des projets Smart City

Les recherches sur les outils d'aide à la décision se situent à l'intersection de plusieurs disciplines telles que la psychologie, la sociologie, les sciences de gestion, l'économie, le droit, mais aussi les mathématiques ou les recherches appliquées. Bien que nous nous appuyions sur plusieurs des disciplines précédemment citées, notre approche se concentre plus particulièrement sur les sciences du management de l'innovation et des technologies.

Avec un rôle central d'infrastructure pour les villes intelligentes, la technologie devrait être au service des citoyens en les aidant à produire et à transférer des connaissances et à créer de la valeur au delà du marché économique. Les Technologies de l'Information et des Communications (TIC), dans le cadre de la ville intelligente, regroupent les dispositifs intelligents intégrés des téléphones intelligents aux capteurs, ou autres compteurs communicants et divers instruments qui soutiennent « l'intelligence » de la ville. Les données provenant de ces capteurs, ou réseaux intégrés, peuvent fournir aux citoyens des informations en temps réel. En outre, les données ouvertes issues des entités gouvernementales sont une ressource supplémentaire permettant de développer des services nouveaux à disposition des citoyens. Ces derniers peuvent les utiliser pour ajouter de la pertinence et de la valeur à l'information existante, voire créer des applications partagées au service du plus grand nombre.

Le rôle que jouent les TIC dans les villes est le même que celui que ces technologies ont dans les organisations et qui a été largement décrit dans la littérature sur les systèmes d'information et les organisations : améliorer la productivité par des processus de routine automatiques et en renforçant les gestionnaires dans la prise de décision, la planification et le contrôle des activités.

Les citoyens, en vivant dans un vaste écosystème de Smart City, peuvent être en interaction permanente avec leurs environnement. Par conséquent, ils sont non seulement activement engagés dans la problématique urbaine, mais ils ont la possibilité de voir la ville « comme

quelque chose qu'ils peuvent collectivement régler, de sorte qu'elle soit efficace, interactive, engageante, adaptative et flexible » (Cities, 2010). Dans un contexte complexe et multi-échelle de Smart City, les parties prenantes sont en revanche confrontées à un débordement d'informations. L'énorme quantité d'informations disponibles n'est pas seulement un avantage pour les parties prenantes, mais aussi un défi pour une gestion plus structurée pour les autorités. Plusieurs recherches en cours sur le concept de ville intelligente ont mis l'accent sur le niveau d'engagement des intervenants, en particulier des citoyens, dans la coproduction de services et le processus décisionnel. La prise de décisions en projet Smart City, dans ces conditions d'évolution rapide, exige une compréhension holistique et une capacité de pensée systémique. Cependant, les discussions sur le processus de prise de décision et la collaboration dans Smart City manquent encore d'une vision globale et d'une compréhension systémique (Eräranta & Staffans, 2015).

Depuis la fin des années 2000, Living Lab est devenu un concept populaire pour concevoir de nouvelles solutions grâce à l'intégration de communautés d'utilisateurs aux différentes phases des projets. Ces solutions sont ensuite co-conçues, testées et évaluées de manière ouverte dans l'environnement naturel des utilisateurs. Le concept Living Lab a été appliqué à différents domaines tels que le bien-être, l'éducation, des projets en zones rurales, etc. Mais, le domaine où ce concept a été le plus adopté et appliqué semble être celui de la smart city ou ville intelligente (Bakici et al., 2013; Cardone et al., 2014; Cosgrave et al., 2013; Dupont et al., 2014; Naphade et al., 2011; Pallot et al., 2010; Skiba, 2014).

Ainsi à Nancy, un projet de rénovation urbaine est en cours autour de la gare depuis 2005 (ZAC et EcoQuartier Nancy Grand Cœur). Le Lorraine Smart Cities Living Lab développé par le laboratoire ERPI a accompagné la Métropole du Grand Nancy (ex-CUGN) pour co-concevoir avec les usagers ce projet d'éco-quartier de 2010 à 2014.

De 2012 à 2014, les chercheurs ont conçu des ateliers opérationnels avec des citoyens et des techniciens pour travailler à la mise en place de stations de mobilité innovantes sur la place Charles III ou encore pour concevoir des espaces publics durables et innovants. Au final, sur l'ensemble du processus, environ 300 citoyens (c'est-à-dire l'ensemble des participants, professionnels ou non) ont été mobilisés dans 31 ateliers pendant 5 ans. Les publications scientifiques basées sur ce projet ont conclu que les auteurs ont réussi à partager les connaissances entre les intervenants et à identifier les attentes et les besoins des participants (Dupont et al., 2016). Cependant, si on ne prend que le cas de la place Charles III, les décisions finales concernant l'installation d'une station de mobilité sur cette place nancéenne n'ont pas associé l'ensemble des parties prenantes et la réalisation finale ne tient pas compte de l'ensemble des attentes et des besoins des participants. Les chercheurs ont analysé, renforcé et ajouté de la valeur à l'étape du diagnostic initial du projet urbain, en revanche il existe encore un écart entre le diagnostic partagé et l'action partagée (Dupont et al., 2015).

Dans le cadre d'une approche Living Lab qui puisse s'appliquer à toute les étapes du projet de Smart City (de sa co-conception à sa co-évaluation en passant par l'arbitrage des décisions et la mise en œuvre), il y a une demande pour une méthodologie soutenant le processus de décisions partagées entre les parties prenantes. Il s'agit d'une étape indispensable pour passer du diagnostic partagé à l'action partagée.

Plusieurs questions de recherche ont été soulevées, telles que :

- Combien d'étapes sont nécessaires dans le processus de co-création soutenu par un Living Lab pour la réalisation d'un projet Smart City ?



- Comment construire des processus de prise de décision en groupe impliquant des acteurs ayant des rôles, des compétences, des connaissances et des expertises différentes ?
- Quelle technique de modélisation est la plus pertinente pour représenter un système de Smart City et la diversité des points de vue ?
- Comment soutenir un environnement proche de la réalité tout en assurant un plus haut niveau d'engagement des parties prenantes lors de la phase de co-crédation du processus d'innovation soutenu par un Living Lab ?
- Comment maintenir le rôle clé des citoyens à chaque étape du processus de co-crédation soutenu par un Living Lab vers la réalisation d'une Smart City ?

## **Objectifs de la recherche**

Les objectifs principaux de l'étude sont : d'étudier la méthodologie de prise de décision qui implique les citoyens de manière active ; de proposer et de mettre en œuvre un cadre conceptuel permettant aux parties prenantes du projet de suivre le processus de décision dans le cadre d'un projet Living Lab. L'intuition forte est la suivante : plus les décideurs sont bien informés sur les points d'accord et de désaccord, plus il est facile de parvenir à un consensus.

Obtenir un consensus, i.e. légitimer un processus décisionnel de groupe, est souvent difficile à atteindre en raison des attentes, besoins et comportements différents entre les parties. La présente recherche pose comme hypothèse principale que l'alliance entre l'intervention humaine et les outils automatiques pourrait faciliter le processus de consensus en identifiant les points de conflit et en suivant leur évolution après plusieurs cycles de discussion.

Afin d'atteindre cet objectif principal, plusieurs objectifs secondaires ont été listés, comprenant:

Un état de l'art sur la manière dont les TIC et l'interopérabilité changent les engagements des citoyens et la gestion des villes

Une description de la façon dont un processus de prise de décision de groupe dans le cadre de l'approche Living Lab est réalisé.

Une étude des outils d'aide à la décision pouvant potentiellement être intégrés pour faciliter ce processus ou impliquer toutes les parties intéressées

Un cadre pour intégrer le processus

L'illustration de ce cadre à travers les démonstrateurs actuels et passés du laboratoire ERPI.

## **Organisation de la thèse**

Notre étude comporte quatre volets : le contexte de recherche, l'élaboration d'un modèle, une maquette fonctionnelle des outils d'aide à la décision et, enfin, l'application et le résultat des études de cas.

### *Contexte de la recherche*

Cette partie traite du concept de ville intelligente et de l'engagement des parties prenantes, en particulier des citoyens, suivi d'une introduction de l'approche Living Lab en tant que facilitateur possible de l'innovation ascendante (bottom-up). Ensuite, plusieurs études de cas de Smart City utilisant des solutions basées sur les TIC pour tenir compte ou changer l'engagement des parties prenantes ont été examinées.

Selon l'analyse documentaire, l'utilisation des TIC génère une ville plus intelligente, car elle améliore l'efficacité et l'efficacité des processus, activités et services d'innovation de la ville. En outre, les études mettent également l'accent sur l'engagement des citoyens sur leurs rôles et leur impact sur le développement des villes intelligentes. Un bon équilibre entre les processus ascendants (y compris le partage des décisions et la réalisation d'actions avec les citoyens) et l'usage des technologies est un moyen souhaitable pour la gestion des villes intelligentes.

Dans cette partie, notre recherche contribue d'abord en une revue systématique de la littérature sur la prise de décision dans la Smart City comme entrée de données brutes pour l'étude. Nous avons utilisé la base de données Scopus. À partir de 606 articles potentiels de 2005 à 2018 extraits de la base de données Scopus®, un processus bibliométrique a permis de sélectionner 76 de ces articles décrivant différents modes de décision. Ces 76 références significatives ont été triées par thématique des villes intelligentes. D'après les examens catégoriels (Chai et al., 2013), les méthodes de prise de décision sont classées en quatre groupes : prise de décision multicritères (MCDM), programmation mathématique (MP), intelligence artificielle (AI), et méthodes intégrées (IM). Dans cette étude, les méthodes de prise de décision ont été examinées sous trois aspects : (1) les niveaux de décision, (2) les phases de mise en œuvre et (3) la participation et la négociation des parties prenantes.

Une approche qualitative, sur l'ensemble des données bibliométriques à l'aide de VOS Viewer, montre que la question des méthodes de prise de décision est un problème de recherche récent, assez peu étudié par la communauté universitaire. Par conséquent. L'analyse passe ainsi en revue les recherches sur les méthodes de prise de décision permettant l'échange entre les multiples parties prenantes, en particulier l'implication des citoyens dans les différentes phases des projets « Smart City ».

Une cartographie générale des différentes méthodes de prise de décision est établie à différents niveaux de décision et à différentes phases de mise en œuvre. On constate que les méthodes de MCDM sont employées à tous les niveaux de décision et tout au long des étapes des projets Smart City alors que les méthodes informatisées sont largement utilisées pour prendre des décisions opérationnelles et tactiques sur des problèmes concrets. Par ailleurs, les résultats obtenus permettent de déduire que la MP et l'AI sont les méthodes les plus appliquées pour développer des outils de prise de décision aux niveaux opérationnel et tactique et principalement au début des phases de mise en œuvre des processus du projet. Sur le plan pratique, la plupart des outils et boîte à outils d'aide à la décision ont été élaborés et mis à l'essai par des scientifiques alors qu'ils n'impliquaient guère les parties prenantes. Dans les cas de participation, les parties prenantes ont rarement l'occasion de négocier pour parvenir à un niveau d'accord plus élevé.

### *Élaboration du modèle*

Le terme consensus peut être défini comme un état d'accord mutuel entre les membres d'un groupe, lorsque la décision prise les satisfait tous. Parvenir à un consensus implique



normalement que les participants changent leurs opinions initiales dans un processus de discussion, tendant à les rapprocher les unes des autres, vers une opinion collective finale qui satisfait l'ensemble du groupe. En cas d'impossibilité de parvenir à un consensus, une recommandation est envoyée en retour aux parties prenantes pour modifier leurs préférences afin d'accroître le niveau d'accord lors des cycles de négociation suivants.

Dans cette partie nous cherchons à développer une méthodologie favorisant l'atteinte d'un consensus dans un environnement Living Lab. Les méthodologies, incluant deux types de consensus, le premier via un facilitateur humain et le second via un système de supervision automatique qui remplace les actions du facilitateur, sont développées à partir de modèles conceptuels (Palomares et al, 2013).

Tout d'abord, une méthodologie basée sur un système multi-agents est développée pour parvenir automatiquement à un consensus au sein d'un grand groupe de décideurs, sans facilitateurs et sans interaction directe. Les composants clés de notre système de contrôle automatique sont : les mécanismes et protocoles de communication considérés pour permettre aux agents de communiquer entre eux et les algorithmes de la méthode multi-agent. La formalisation du modèle consiste en deux tâches : la création d'un modèle narratif et l'expression de ce récit en pseudo-code. En utilisant une méthode basée sur un système multi-agents pour la prise de décision de groupe dans le cadre d'un projet en mode « Living Lab ». Le modèle proposé s'adapte à la complexité et à la dynamique de la prise de décision au sein d'un grand groupe.

Ensuite, une deuxième méthodologie associant un facilitateur humain basée sur l'analyse multicritère et les systèmes multi-agents est proposée. Cette nouvelle méthodologie peut supporter le processus de prise de décision collective des projets urbains d'innovation et permettre une participation active de multiples parties prenantes. La méthodologie proposée est appliquée en plusieurs étapes permettant de structurer et formaliser les processus décisionnels d'une manière transparente et cohérente. Elle permet de comparer les différentes options décisionnelles en fonction d'un ensemble de critères d'évaluation auxquels différents coefficients de pondération, représentant le degré d'importance, peuvent être appliqués. Par ailleurs, une approche système multi-agents est proposée pour soutenir une supervision constante, en augmentant l'autonomie du système pendant le processus de recherche de consensus. L'approche du système multi-agents comprend deux parties, un système de contrôle automatique du niveau de consensus et une recommandation de rétroaction aux intervenants. Concrètement, il existe deux types de recommandations pour les parties prenantes : 1) un graphique visuel révélant la diversité des opinions des participants dans une prise de décision en groupe et 2) une rétroaction automatique basée sur l'approche système multi-agents. Pour les participants qui ont besoin de modifier leurs préférences lors du processus de recherche de consensus les recommandations automatiques de retour d'information ont été programmées sur le logiciel Matlab®.

#### *Une maquette fonctionnelle pour les outils d'aide à la décision*

Les systèmes informatisés avancés d'aide à la décision peuvent générer des recommandations basées sur des informations concernant le niveau de consensus d'un

groupe et les préférences des autres membres pour aider les décideurs dans leur processus décisionnel. En utilisant cet outil de soutien informatisé, le modèle intégrant le processus d'obtention d'un consensus dans la méthodologie de prise de décision multicritères devrait tirer parti à la fois des outils basés sur les TIC et du rôle d'un modérateur humain. Comparativement aux processus décisionnels de groupe uniquement accompagnés par des modérateurs, l'outil d'aide à la décision devrait raccourcir le temps de réponse pour la prise de décisions et réduire le nombre de participants qui ont dû réviser leurs évaluations à chaque tour de discussion.

Cette partie présente une maquette fonctionnelle basée sur la méthodologie proposée qui met l'accent sur la façon dont les citoyens peuvent participer à la prise de décision collective des services Smart City. Il existe deux types d'outils d'aide à la décision.

Le premier outil inclut deux composantes principales : un modèle Excel en ligne pour l'interface utilisateur et un algorithme de système multi-agents pour la formulation du processus de négociation et la formulation de recommandations en retour. L'interface utilisateur en ligne est créée à l'aide du modèle Excel Drive qui est accessible pour tous les intervenants ou participants impliqués dans des problèmes de décision de groupe. L'outil proposé permet aux participants d'avoir les informations sur toutes les préférences et les évaluations des autres décideurs au moyen de graphiques visuels. Les participants utilisent ces graphiques comme moyen de recommandation visuelle pour identifier la différence entre leurs préférences et celles des autres ainsi que l'alternative choisie par la plupart des membres du groupe.

La seconde est une maquette de logiciel basée sur le Web qui intègre à la fois l'interface utilisateur et l'algorithme de consensus pour créer des recommandations. Le site comprend une interface de bienvenue, une page de connexion et des pages de configuration et de recommandation. Après s'être réunis dans les salles de discussion, tous les participants peuvent accéder à la page d'évaluation pour pondérer les critères et les alternatives. Lorsque tous les membres d'un groupe ont terminé l'évaluation, un graphique visuel et une recommandation linguistique sont affichés dans l'onglet de recommandation.

En général, ces outils d'aide à la décision sont conçus comme interface utilisateur qui facilite la participation de nombreux groupes à un processus décisionnel transparent et actif. Nos premières expériences nous amènent à conclure que plus on fournit d'information aux participants sur le processus de décision, plus il est facile pour eux d'arriver à un consensus.

#### *Une application d'étude de cas et son résultat*

Afin de mettre en œuvre les modèles proposés dans les chapitres précédents, cette section vise à mettre en place un "banc d'essai" proposé en environnement réel simulé avec un groupe d'étudiants du cycle ingénieur de l'ENSGSI et des masters IUVTT et IDEAS. La stratégie expérimentale de notre étude comprend les étapes suivantes. Dans un premier temps, une étude de cas appropriée est sélectionnée pour l'exécution de modèles dans une configuration expérimentale. Dans cette étude de cas issue d'une étude réalisée sur la ville de Messine (Italie) (Cavallaro, 2011), plusieurs intervenants sont engagés dans la planification d'une solution d'énergie renouvelable pour leur ville dès les phases initiales des projets. Afin de prendre en compte les multiples critères exprimant les objectifs de toutes les parties



prenantes impliquées et affectées par la planification énergétique et la performance du système énergétique, la méthodologie coopérative supervisée multicritères et multipartite est appliquée pour soutenir la négociation et le processus décisionnel partagé.

Dans le processus de mise en œuvre, l'exécution comprend l'exécution d'un programme informatique basé sur des mesures consensuelles et l'enregistrement des données de sortie. Ensuite, les données sont analysées à partir des résultats des simulations, des graphiques qui ont été faits du processus décisionnel au fil du temps. Enfin, nous présentons une discussion et une conclusion.

Tout au long de l'utilisation des deux méthodes, nous pouvons comparer la différence entre le modèle théorique et un processus d'expérimentation d'outils d'aide à la décision dans la vie réelle. Les résultats de l'analyse des données issues de l'expérimentation fournissent des suggestions pour améliorer le processus de prise de décision des parties prenantes ayant des objectifs et des antécédents divers dans les projets Smart City. Les résultats montrent également qu'il existe plusieurs facteurs dans la prise de décision au sein du groupe qui contribuent de manière significative à améliorer le processus d'obtention d'un consensus.

## Conclusion et perspectives

La principale contribution de notre étude est une méthodologie soutenant le processus de décisions partagées pour les parties prenantes des projets *Smart City* sous l'approche *Living Lab*. Il s'agit d'une étape indispensable entre le diagnostic partagé et l'action partagée.

Cependant, certaines limites de la contribution doivent être soulignées, afin de les replacer dans une perspective plus large. Dans une mise en pratique de situations de prise de décision, le groupe de participants et l'ensemble des alternatives peuvent varier dans le temps. Pour répondre à ces situations, un nouveau modèle de consensus doit se préoccuper de ces propriétés dynamiques des communautés réelles et permettre de changer les alternatives des problèmes.

Par ailleurs, l'étude de cas et l'atelier sont conçus pour un projet *Smart City* à Messine (Italie) avec des étudiants français ou internationaux. En raison des différences de contexte, de culture et d'institution politique, les futurs ateliers avec de véritables parties prenantes dans différents pays devraient modifier la procédure pour s'assurer que les modèles et les maquettes fonctionnelles fonctionnent toujours de manière efficace et exacte. Dans la poursuite de cette thèse, il y aura plusieurs ateliers avec des étudiants et des professionnels en formation continue qui nous offrent l'opportunité d'améliorer et de valider des prototypes fonctionnels pour des outils soutenant le processus de consensus dans des conditions réelles.

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# **SECTION 1: RESEARCH CONTEXT**

## **: A state of the art on Smart Cities under Living Lab approach - How can improve the engagement of stakeholders?**

### **Introduction**

In the current era, Smart City projects have to deal with big social, ecological and technological challenges such as digitalization, pollution, democratic aspirations, need to feel safe, etc. The higher involvement of multi-stakeholders (such as citizens, users, engineers, researchers, elected representatives, etc.) into the different project's phases is one of the answers allowing considering the variety of points of view needed to get a shared vision of the city. Paradoxically, these dynamic and the multiple natures of stakeholders appear to be a source of complication and uncertainty in decision-making process.

This chapter will provide an overview of Smart City under Living Lab approach, in order to allow the readers to understand the background of this study. The literature review in this chapter proves that applying Living Lab approach and ICT based- solutions will improve the level of engagement of stakeholders and change the way of Smart City management.

Chapter 1 : A state of the art on Smart Cities under Living Lab approach - How can improve the engagement of stakeholders?.....	<b>Erreur ! Signet non défini.</b>
Introduction .....	<b>Erreur ! Signet non défini.</b>
1.1. An overview about Smart City concept.....	<b>Erreur ! Signet non défini.</b>
1.1.1. Definition of Smart Cities .....	<b>Erreur ! Signet non défini.</b>
1.1.2. Smart Cities and their characteristics.....	<b>Erreur ! Signet non défini.</b>
1.1.3. Stakeholders in Smart Cities .....	<b>Erreur ! Signet non défini.</b>
1.2. Living Lab Approach.....	<b>Erreur ! Signet non défini.</b>
1.2.1. Living Lab- a methodology for the collaborative innovation in urban projects .....	<b>Erreur ! Signet non défini.</b>
1.2.2. Phases of Living Lab.....	<b>Erreur ! Signet non défini.</b>
1.3. An overview on Smart City under Living Lab approach	<b>Erreur ! Signet non défini.</b>
1.3.1. The framework of Smart City under Living Lab approach ..	<b>Erreur ! Signet non défini.</b>
1.3.2. Phases of a Smart City process under Living Lab approach: From concept to model, experiment and evaluation .....	<b>Erreur ! Signet non défini.</b>
1.4. Some considerations on how Living Lab are changing the engagements of stakeholders in Smart City projects by ICT and interoperability .....	<b>Erreur ! Signet non défini.</b>
1.4.1 The influence of ICT in changing stakeholder engagement ..	<b>Erreur ! Signet non défini.</b>
1.4.2. Applying a Living Lab approach supporting stakeholder engagement in Smart City .....	<b>Erreur ! Signet non défini.</b>
1.5. Decision-making process in urban projects.....	<b>Erreur ! Signet non défini.</b>
1.5.1. Decision-making process on multi- scale environment	<b>Erreur ! Signet non défini.</b>
1.5.2. Decision-making process in multi-actors environment	<b>Erreur ! Signet non défini.</b>
Conclusion	<b>Erreur ! Signet non défini.</b>



## 1.1. An overview about Smart City concept

### 1.1.1. Definition of Smart Cities

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 exclusively by city authorities, merely with traditional top-down approaches, but also integrating active participation of users and other stakeholders. The definitions of Smart City are various as this notion is being known popularly all over the world with different names and in different circumstances.

First of all, we focus on understanding possible meanings of the term “smart” in the Smart City context (Nam and Pardo, 2011). Some studies suggest that “smart” contains the term “intelligent,” because the smartness is realized only when an intelligent system adapts to the needs of users. In urban planning field, smartness in smart growth is treated as a normative claim and ideological dimension. Smart Cities require strategic developments targeting sustainable development, economic growth, and better quality of life for citizens (Huntley et al., 2003) (Schaffers et al., 2011). Therefore, authorities at all levels have to well understand about the notion of "smart" to develop their new policies, strategies, and programs in a "smart" way.

The smartness in smart technologies embraces the rapid development of technology, integrates systems and computers or robots that have human intelligence. Applications of Artificial intelligence and thinking machines in technology create cities with characteristics of “self-configuration, self-healing, self-protection, and self-optimization” (Spangler et al., 2010)). Besides, smart buildings, smart airports, smart hospitals or smart university campuses require connected sensors and actuators, mobile terminals as well as embedded devices to use space more efficiently and support a more flexible work environment (Klein and Kaefer, 2008). Smart ecosystem is an extension of the larger community and improves the active engagement of stakeholders in the development of technology (Yovanof and Hazapis, 2009).

Besides, there are ranges of conceptual variants generated by replacing “smart” with other alternative adjectives. In this study, an initial search was conducted on 17<sup>th</sup> June 2019 to identify the distribution of research articles in Smart City classification areas from the Scopus database. The queries used keywords contained “Smart City” or relevant terms of Smart City classification areas (i.e., “digital city,” “ubiquitous city,” etc.) (Anthopoulos and Fitsilis, 2013). The table 1-1 shows the number of publications related to different classification of “Smart City” term. A search strategy used classification areas of Smart City as selected terms in title, abstract or keywords to collect articles and conference papers from the Scopus database. It could be noticed that the term “Smart City” is discussed most with 14452 works.

Table 0-1 Terms for search article results about the classification of Smart City

Term	SCOPUS
Smart City	14452
Digital city	705
Virtual city/information city	576

Knowledge based city	16
Wireless city/mobile city	95
Ubiquitous city	111
Eco-city	513

In further analysis from Scopus, we found that the topic Smart City related to many subject areas, such as computer science, engineering, social science, mathematics, energy, decision science and so on. The figure 1.1 shows the distribution of 14452 documents referenced in Scopus database by different subject areas.

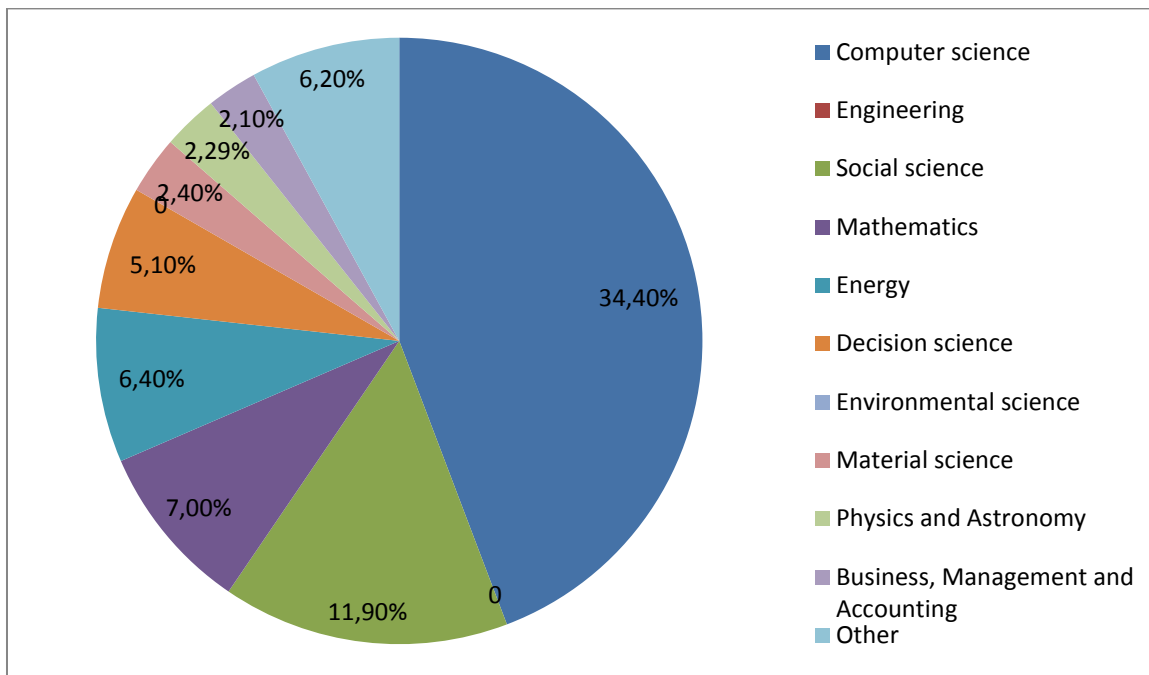


Figure 0-1 The percentage of different subject areas of “Smart City”- studies referenced in Scopus database on the period until 17<sup>th</sup> June 2019

When defining the term “Smart City”, some studies stress technologies. The study of Marinovici proposal of definition focuses on monitors and integrates conditions of critical infrastructures in Smart City (Marinovici et al., 2000). Besides, one of the core mechanisms in Smart City is a self-monitoring and self-response system.

Other definitions highlight different “soft” aspects of smart cities. For example, Rios’s approach is based on a definition of Smart City as a city that gives inspiration, shares culture, knowledge, and life, and motivates its inhabitants to create and flourish in their own lives (Rios, 2012). Partridge’s observation of Brisbane in Australia sheds light on social inclusion and equal participation as enhanced opportunities created by Smart City initiatives (Partridge, 2004). In the urban planning field, the term “Smart City” is often considered as a notion according to which being smarter entails strategic directions. Governments and public authorities at all levels use the concept of smartness to direct their policies and strategies a sustainable development way and improve the quality of life and create happiness for their citizens (Ballas, 2013).

In this study, we seek a definition that combining both “hard” and “soft” aspects of the city, including technology and social dimensions. By this way, Smart City is considered as a city



seeking to address public issues via Information and Communication Technology (ICT) - based solutions and the collaboration of multi stakeholders and municipally based partnership (Eskelinen et al., 2015).

### *1.1.2. Smart Cities and their characteristics*

Cities are increasingly growing to become larger and more complex than ever. As a consequence, dealing with issues such as mobility, pollution, health risks or new infrastructures, among others, can often no longer be treated exclusively by city authorities, merely with traditional top-down approaches, and so increasingly choose to integrate the active participation of end-users and other stakeholders. A several project management and urban studies have investigated citizens as users and stakeholders of urban projects (Lehmann et al., 2015).

Smart City is considered to be a well-performing and forward-looking city using the ‘smart’ combination of six main characteristics: economy, people, governance, mobility, environment and living (Giffinger, 2007). These characteristics form the framework for assessing the performance of smart cities. Smart economy focuses on economic factors related to competitiveness and integration of firms such as innovation, entrepreneurship, symbols, efficiency and flexibility of the labor market in both the national and international marketplace. The term “smart people” represents the quality of life, level of education of citizens and the ways in which they integrate and interact with others in open life. Smart mobility refers to the use of available and accessible ICTs in modes of transportation and transport systems. Attractive natural conditions (e.g. climate, green space) as well as managing and protecting natural resources are the important aspects of the smart environment. Smart living focuses on other aspects of life in a city, such as culture, health, security, housing, tourism, etc. Finally, smart governance comprises aspects of political participation and services for citizens which facilitate the involvement of citizens in transparent processes promoting collaboration, data exchange, service integration and communication. Some studies identify smart governance as the core in determining the success or failure of projects (Alawadhi et al., 2012) or one of the driving forces in Smart City framework that fosters innovation and sustainable economic development (Allam and Newman, 2018).

The roles of governance in Smart City not only focus on adopting new technologies but also on improving the transparency in sharing data and decision-making. The contribution of stakeholders, especially citizens for Smart City is based on their ideas for the future development policy. Therefore, smart governance is also considered as participatory governance or citizen-centric governance. In Smart City, ICT plays an important role for policymakers to collect data and govern cities in a better way with well-informed decisions and adequate policies (Allam and Dhunny, 2019). This leads to the data-led governance in Smart City that is affected by the Internet of things (IoT), sensor and big data. Smart City governance is inherently complex, with the multi-context and multi-level ecosystem of various stakeholders which are often driven by conflicting interests (Ruhlandt 2018). These dynamic and multiple natures appear to be a key source of complexity and uncertainty in decision-making processes (Chai et al., 2013).

This generates a need for effective decision-making tools for dealing with complex and sometimes conflicting issues in urban development projects (Dupont et al., 2015). In the following paragraphs, the types of decision-making methods, the levels of decision-making and the phase of implementation of the project are presented and described.

The table 1.2 explains all components of smart cities relating different aspects of urban life. The table is used as a reference framework to identify the field of articles regarding to aspects of Smart City.

Table 0-2 Aspects of a Smart City (Giffinger, 2007)

<b>Characteristics of a Smart City</b>	<b>Related aspect of urban life</b>
smart economy	Competitiveness
smart people	Social and Human Capital
smart governance	Democracy& Participation
smart mobility	logistics & infrastructures
smart environment	Natural resources
smart living	Quality of life

### 1.1.3. Stakeholders in Smart Cities

In the context of urban development projects, the term ‘Stakeholder’ refers to those who affect or could be affected by a proposed development initiative (World Bank, 1996). Urban development, in turn, is the main constituents of cities’ vision, particularly, a smart cities’ vision. It is worth noting that a Smart City concept is emerging as a new approach to make urban development more sustainable (Alawadhi et al., 2012). Thereby, the term stakeholder in Smart City projects could have the same meaning related to that used by urban development projects; meaning that “a Smart City’s stakeholder is any individual or group of individuals who can affect or is affected by a Smart City initiative”.

Stakeholders play a significant role in Smart City projects. They can offer many benefits to a Smart City transformation process and their influence on the results of a project can be high for the reasons that can summary in the table 1-3.

Table 0-3 Roles and influence of stakeholders in Smart City

	<b>Roles and influence of stakeholders in Smart City</b>	<b>References</b>
1	They provide a wide range of skills, experiences, and knowledge to a successfulness of a transformation process of Smart City project.	(Enrique et al., 2016)
2	They can improve the quality of the decision-making if they have a good understanding of a transformation process goals and objectives.	(Macharis et al., 2014)
3	Involvement of stakeholders boosts transparency and improves the quality of citizens, reducing oppositions and ensuring that opinions are for the Smart City transformation process.	(Veeckman and Graaf, 2015), (Kulju and Oksman, 2017)
4	Establishing good relationships with stakeholders and various groups of citizens ensure that complains and urgent modifications can be addressed at an early stage of a transformation process.	(Paskaleva et al., 2015)



5	They can facilitate the implementation of a Smart City transformation process activities and help in monitoring and evaluating its outcomes. Their feedbacks are crucial for the continuous improvements and sustainability of a transformation.	(Ibrahim et al., 2017)
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Stakeholders can take many forms; including persons, groups of people, citizens, institutions, public/private organizations, neighborhoods, societies, natural environment (Mitchell et al., 1997), government, local community organizations, advocates, media, consumers, unions, environmentalists, associations, political groups, employees, financial community, suppliers, education and research institutions, and others (Freeman, 2010).

Several project management researches and urban studies concern citizens as users and stakeholders of urban projects (Lehmann et al., 2015). In Smart City, citizens are active contributors within innovation and design communities. Various studies in the literature emphasized the necessity of the engagement of stakeholders in Smart City projects from an early stage and provides different conceptual models. The model of Cascetta and Pagliara was applied in a case study of the Regional Metro System project, Italy. Several tools supporting the engagement of stakeholders have discussed but the scope of studies only focus on transportation system (Cascetta and Pagliara, 2013). There is another model developed in more details for involving stakeholders in smart sustainable city (Ibrahim et al., 2017). However, this model did not execute any engagement tool. The model of Paskaleva et al, was designed as a concept of ‘Smart City stakeholder engagement’ and its application in the Living Lab to the co-production of Smart City services (Paskaleva et al., 2015). All these studies will be summarized in the table 1-4.

Table 0-4 Example models of engagement of stakeholders in Smart Cities

Reference	Context	Stages of model
(Cascetta and Pagliara, 2013)	Transportation system	5 stages, -Stakeholders identification, - Listening - Information giving, - Consultation - Participation.
(Ibrahim et al., 2017)	Smart sustainable city	8 stages: - Stakeholder Identification - Prioritizing stakeholders - Information Sharing with Stakeholders - Mapping Stakeholders - Create Partnerships - Managing Stakeholders, - Stakeholder Involvement - Monitoring and Evaluation
(Paskaleva et al., 2015)	Smart City, Living Lab approach	4 stage: - Stakeholder enlistment - Stakeholder enrolment

		- Stakeholder dialogue - Stakeholder innovation network
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Because collaboration and interaction among stakeholders, especially users, are considered as the core rationale for Smart City, a wide range of different tools are used across phases of stakeholder engagement models. In the study of Cascetta and Pagliara, several tools are classified to apply at different phases of stakeholder engagement process (Cascetta and Pagliara, 2013). Tools based on printed material such as letter, poster, brochure, newsletter or technical reports are mainly used to inform and consult stakeholders. Meanwhile, telephone and media may be of help during the listening and stakeholder's management levels as well as during the information communication and consulting levels. For the consulting and participation, levels of stakeholder engagement can be affected by the conferences, the referendum tools, while telephone and internet tools also play a significant role. The table 1-5 explores the application of different tools at phases of stakeholder engagement in the model of Cascetta of Pagliara (Cascetta and Pagliara, 2013).

Table 0-5 Stakeholder engagement tools

Stakeholder engagement tools	Stakeholder identification	Listening	Information giving	Consultation	Participation
<b>Printed material:</b>					
Letter			X		
Poster			X		
Brochure and Newsletter			X		
Technical reports			X		
<b>Telephone and media</b>					
Telephone		X	X		X
Radio and TV shows		X	X		
<b>Internet</b>					
Internet sites			X		X
Forum/chat	X	X	X	X	X
<b>Surveys</b>					
Questionnaire		X		X	
Direct surveys	X	X		X	
<b>Information events</b>					
Exhibition			X		
Public meetings	X	X	X		
<b>Stakeholder engagement group</b>					
Focus group		X		X	





Technical tables		X		X	X
Stakeholder conference		X	X	X	X
Citizens' jury					X
Referendum					

In term of Smart City under Living Lab approach, Dupont and his colleagues have compared some tools to support citizens' engagement in the co-creation stage of the urban design process relating parameters such as the level of collaboration between stakeholders, the way participants communicates with other entity and the degree of their engagement (Dupont et al., 2016a). With digital model and blueprints, stakeholders could discover and learn knowledge from engineers and companies. However, executing these physical models is not enough to support the interaction and collaboration between stakeholders. Meanwhile, the further developed models such as 3D scale models or mock-ups are used to generate ideas and creativity. Working with scale models is considered as a method of hand engagement that increasing group interaction in Living Lab environment. Through body-storming section, physically situated brainstorming needs role playing and improvisation in simulated environment. Body-storming is considered as a method of body engagement supporting group interaction to share knowledge and help stakeholders understand the point of view of others (Dupont et al., 2016a). It could be concluded that scale-model is more adapted to the ideation phase while body-storming fits better the co-creation phase.

## 1.2. Living Lab Approach

### 1.2.1. Living Lab- a methodology for the collaborative innovation in urban projects

The term Living Lab has been used in ICT research since early of 1991 to describe the use of co-operative partnerships in live field trials environment (Lasher et al., 1991). Since then, a variety of ICT based environments for innovation and development has been referred to as Living Labs (Følstad, 2008). The development of ICT allows collecting a huge amount of real-life data (Wi-Fi activity, cars traffic, money circulation, etc.) in short period of times on which it is possible to build the future development decisions.

In the literature, the term of Living Lab has been variously defined as:

An “experimentation environment” where stakeholders with public-private- people partner- ships (4Ps) collaborate to explore, experiment and evaluate new technologies, services or products in real-life contexts” (Følstad, 2008), (Leminen and Westerlund, 2014). This definition stresses on human connections in the experimentation process. One precondition in Living Lab experimentation activities is that they are situated in real-world contexts, not constructed laboratory settings.

A “methodology” or “innovation approach” where innovations, such as services, products or application enhancements, are created and validated in collaborative multi-contextual empirical real-world environments (Ballon et al., 2005), (Almirall et al., 2012).

A “innovation intermediary” for a mass of ideas, knowledge and experiences and substantially boosting the innovation capability (Eriksson et al., 2005). This definition

gives a slightly different with above. Here, the innovation is stressed and the connection to research is not included.

A “system” supporting users , including citizens and customers to take active roles as contributors and co- creators in the research and innovation process (ENoLL, 2007). In this definition, Living Lab is viewed from a system perspective, and it includes users as active co- creators, but here the real-life multi-contextual environment is excluded. The system perspective includes relation between the parts and the whole. Hence, the interrelation among people, products, research, and development process needs to be considered and taken care of.

Based on the above definitions, the starting point for any Living Lab is to, in close cooperation among involved stakeholders, develop products and services from the basis of what users really want and need, where the main role of the Living Lab is to engage and empower users to participate in the creation of valuable and viable assets. The interaction with users should be carried out in real-world contexts with active users aiming for innovation in close correlation with ongoing research and development processes.

In this study, from my perspective, Living Labs is both an environment and an approach. Firstly, Living Lab is considered as methods of user-centric design that involving communities of user in every stages of an innovation process. Secondly, Living Lab provides collective platforms for multi-stakeholders, especially users, working together and sharing knowledge and decisions. In aims of Living Lab methods is to support the innovation process by supporting the engagement of four main stakeholders: companies, users, public organizations and researchers that form a Public-private-people partnerships (4Ps) (Ståhlbröst, A., & Holst, 2012). These stakeholders can benefit from the Living Lab approach in many different ways, for instance companies can get new and innovative ideas, users can get the innovation they want, researchers can get study cases and public organizations can get increased return on investment on innovation research.

The above definition highlights key components of Living Labs, including:

“ICT & Infrastructure outlines the role that ICT technology can play to facilitate new ways of cooperating and co-creating new innovations among stakeholders.

Management represent the ownership, organization, and policy aspects, a Living Lab can be managed by e.g. consultants, companies or researchers.

Partners & Users bring their own specific wealth of knowledge and expertise to the collective, helping to achieve boundary spanning knowledge transfer.

Research symbolizes the collective learning and reflection that take place in the Living Lab. Technological research partners can also provide direct access to research that can benefit the outcome of a technological innovation.

Approach, represents the methods and techniques for practices which are necessary for professional and successful operations” (Ståhlbröst, A., & Holst, 2012)

The innovation activities are located at the centre of Living Lab model. They are different from testbeds, field trials, and other forms of innovation that take place in real-life environments. Collaboration and partnership between stakeholders are a vital characteristic of Living Labs, which are based on the principles of open innovation.

In Living Labs, users are considered as stakeholders of innovation (Winz et al., 2009), or as “experts” in his or her experience (Rahimi et al., 2016). Diverse competencies, priorities and



interests of participating stakeholders often make Living Lab projects complicated and volatile (Hakkarainen and Hyysalo, 2013).

In order to managing the levels of community interaction, especially users, and evaluate Living Lab projects, several frameworks have developed as a guidance tool for researchers and Living Lab managers. Veeckman and his colleagues have proposed an influential framework for Living Lab that measure the innovation outcomes through the triangulation relationship between environment, approach, and outcome in Living Labs (Veeckman et al., 2013). In Living Lab environment, they concerned a set of characteristics on the generic level refers to six criteria: technical infrastructure; the level of knowledge sharing; the degree of stakeholder engagement; values creating and sharing between stakeholders as well as the duration, the scale and the real-world context of the Living Lab. In the second pillar of the Living Lab triangle mentioned about approaches Living Lab related to different roles of users and different phase of innovation process from co- creation, context research and evaluation. Developed from this studies and others, a proposal framework developed as a maturity grid based assessment tool for evaluating Living Lab projects (Osorio et al., 2019). This updated framework consists of five pillars with several represented criteria. Each criterion is described by four level of maturity. The table 1-6 shows the detailed framework with pillars.

Table 0-6 A framework for maturity assessment Living Lab (Osorio et al., 2019)

<b>Pillars</b>	<b>Criteria</b>
Strategic intention	Strategic goals
	Ecosystem approach
	Real-world context
	User- centric innovation
	Culture and community
	Teamwork
	Lifespan
Process of creation	Intended innovation processes
	Intended creative activities
	Potential users and facilitators
	Available resources & constraints
	Intended events
Physical embodiment	Geographic location
	Experience Scale
	Real vs. virtual
	Flexibility
	Design values

	IT resources
	Data and information
	Prototyping & visualization
	Constraints
	Evolution
Process of use	Supporting innovation
	Supporting creativity
	Enabling teamwork
	Actual users & facilitators
	Actual events
Innovation outcomes	Achievement of strategic intention
	Tangible results
	Intangible results

### 1.2.2. Phases of Living Lab

Schuurman and his colleagues have identified three generic phases that are most common to many Living Labs including (Schuurman et al., 2016).

The exploration or concept stage focuses on exploring new idea or concept for innovation development. In this stage, collaborations are created to identify functionalities and restrictions products or validate conceptual prototypes.

The experimentation or prototype stage is a period of prototyping and technical development that focuses on implementation of prototypes by co-design and co-creation approaches in controlled environments.

Finally, the evaluation stage focuses on validation of prototypes by end users in real environments and supporting training and roll-out activities.

Ståhlbröst and Holst proposed that stages of a typical LL process are organized as loops or iteration cycle (Ståhlbröst, A., & Holst, 2012). For example, each stage is composed of main activities related to knowledge system (Lehmann et al., 2015) as describing in the figure 1.2

1. “Co-creation/ co-design activities allowing stakeholders to collectively create common grounds, understand contexts, ideate and create solutions together;
2. Exploration activities allowing users to deepen their understanding of the context, of the service itself, to document their ideas in the field, to identify new market opportunities, etc.;
3. Experimentation activities are set-up to test service provider solutions, at various level of maturity, to the reality of the field in user communities and in real conditions; and
4. Finally, evaluation activities designed to validate the potential of products and services in development from a collective perspective and to define orientations for the next iteration.”

A loop can be iterated until satisfaction on evaluation is reached. By essence, each iteration cycle or loop involves the contribution of all stakeholders of the Living Lab: investors, as well as designers, users, managers, specialists, consultants, researchers, etc.

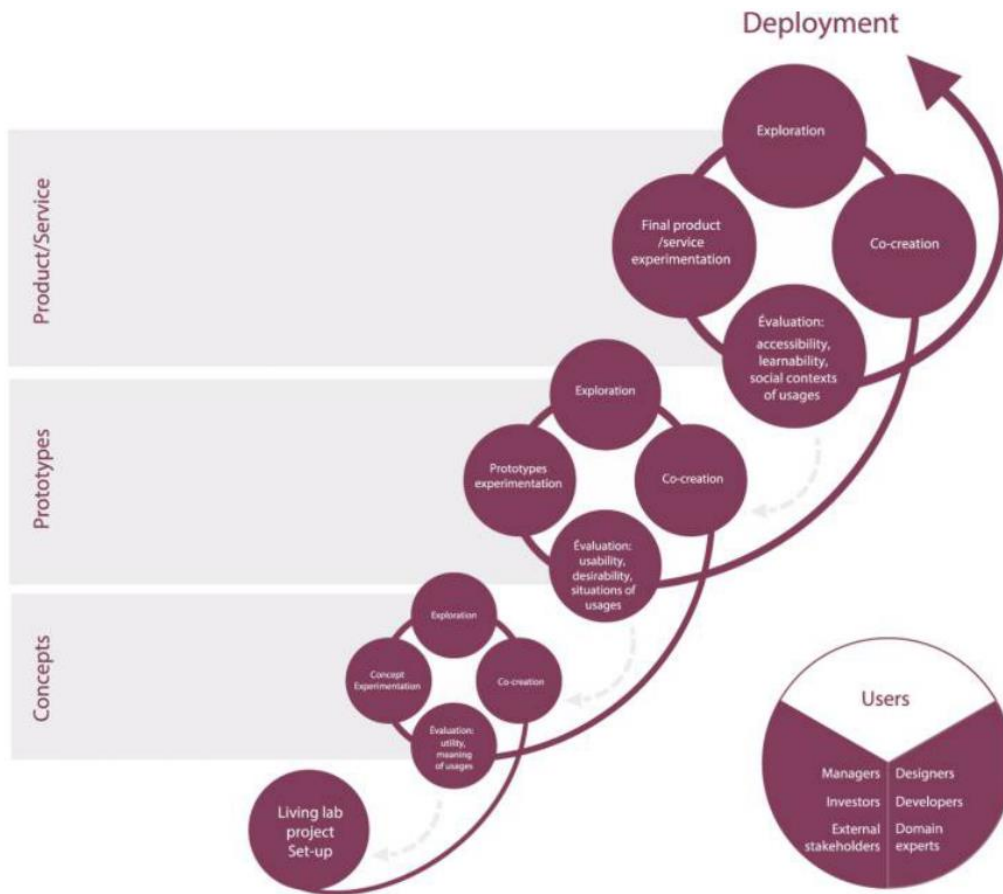


Figure 0-2 Iteration cycle within a Living Lab (Lehmann et al., 2015) which is inspired from (Ståhlbröst, A., & Holst, 2012)

In order to model the Smart City innovation flow supported by the Fab Living Lab platform, a generic process has describing with three stage (Dupont et al., 2016b)

The “co- creation and conceptualization” stage focuses on sharing knowledge, identifying context and giving a framework.

The “modeling and realizing” stage focuses on generating storyboards and multi-scenarios.

Finally, the “evaluation by use” stage focuses on usability, reliability, reversed use and contextual interaction.

### 1.3. An overview on Smart City under Living Lab approach

#### 1.3.1. The framework of Smart City under Living Lab approach

Since a decade, Living Lab is becoming a popular concept to design new solutions through the integration of communities of users in each stage of an innovation process. These solutions are

then, co-designed, tested and evaluated in an open manner within the natural environment of the users. 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 the Smart Cities (Dupont et al., 2014), (Lacroix et al., 2017). In Smart City projects, the Living Lab environment plays a central role as innovation intermediary in the ecosystem. It links citizens, developer community and other organizations with the government entities that facilitate the collaborative network and open access approach. By improving engagement and interaction, local authorities will become more aware of the citizens' needs and will ultimately reshape the citizen- government relationship (Torres et al., 2006).

A framework of Smart City Living Lab has introduced as an innovative public– people- private-partnership that strengthens the “use” point of view, as the principal path to an integrated solution in its ecosystem (Dupont et al., 2015). In this framework, citizens can have multiple roles, ranging from a mere informant, to tester as well as contributor and co-creator in the development processes. The emergence of this governance framework as a democratic process in which citizens and government engage in listening and talking to each other is fundamental for the implementation of urban projects on a citizen-driven, smart, all-inclusive and sustainable environment. By this methodology, urban projects under Living Lab method are considered as user-centric design or collaborative innovation process (Dupont et al., 2014)

Since the ERPI laboratory investigates 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 (Dupont et al., 2015). Each project has a specific added value and gives us characteristics to analyze Smart City:

“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) (Kaulio, 1998).

Solution's design process gives a level of collaborative process (Dupont, 2009): 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).

Level of integrated solution depends on its sustainability and viability, i.e. the number of dimensions considered by a solution. According to circles of sustainability (James, 2015), we reveal four dimensions for sustainable development (SD): Economics, Ecology, Politics, Culture. Furthermore, we add Governance as a dimension connecting the other four (CUGN, 2011).

Industrial-scale level is defined by demonstrator proximity with final form (marketable or completely adopted by users)

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.

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 Living Lab Project is a complex task and decisions along the project and after the project must be taken. The mechanisms, metrics and implications of types of



projects are not yet well-known as it implies several stakeholders and levels of decisions during its deployment. For example, in an Urban Living Lab, stakeholders have difficulties transforming “shared diagnosis” in “shared action” (Dupont et al., 2014; Dupont et al., 2015).

The emergence of a smart governance framework in which citizens and the authorities engage in listening and talking to others is fundamental for the implementation of the Smart City concept on a citizen-driven, smart, all-inclusive and sustainable environment. ICT is applied at a local level to capture user data to help to recreate and motivating collaborative communities to deliver bottom-up innovation and the voice of government and companies to represent the top-down view (Oliveira and Campolargo, 2015) (Veeckman and Graaf, 2014).

### *1.3.2. Phases of a Smart City process under Living Lab approach: From concept to model, experiment and evaluation*

The term “process” in various concepts of Smart City governance is defined by the way stakeholders interact to exchange information, communicate, collaborate or implement decisions (Ruhlandt, 2018). In the work of Pereira et al., implementation is described as the process of putting a decision or plan into execution (Pereira et al., 2017). The names of phases of implementing urban processes differ from nations, culture and scope of studies. For example, in the French system, an urban process includes six stages, starting from the emergence and formulation of problems, the technical formulation, the formulation and realization of solutions and finally, appropriation of solution (Lacroix et al., 2017). Meanwhile, three stages from concept, model to implementation, are used to assess urban ecosystem services (Haase et al., 2014). Nowadays, the Living Lab concept has been more adopted and applied in Smart City projects (Giang et al., 2017). Relating to the Living Lab approach, a process for innovation includes phases from co-creating, exploring, experimenting and evaluating scenarios that involved all stakeholders, especially users or citizens (Dupont et al., 2016b). As stakeholders involved have different information and knowledge of the problems, their complex decisions should be exposed to negotiation in various phases of the process.

In this study, we consider the process of implementing solutions has been composed of four phases, from concept to model, then experiment and finally, evaluation. This generic process is defined as a mature and development process in real-life final forms that marketable or completely adopted by users (Dupont et al., 2015). In an industrial setting, concepts are the first collaborative products at the early stages of design. Concepts allow the improved formulation of the meaning, planning and programs for a project (Dupont et al., 2012). Based on concepts, models are executed as a representation of a system using general rules. In the scientific method, an experiment is an empirical procedure that arbitrates models (Griffith and Brosing, 2012). Researchers use experimentation to execute existing models from trial to real-life conditions to support or disprove them. Finally, it is important to evaluate solutions by multi-stakeholders, especially citizens or users.

## **1.4. Some considerations on how Living Lab are changing the engagements of stakeholders in Smart City projects by ICT and interoperability**

### *1.4.1 The influence of ICT in changing stakeholder engagement*

A sustainable process of urban transformation into a Smart City requires co-operations between ICT infrastructure and soft approaches, and collaborations between multi-stakeholders in multi

contexts. In this regard, the city can be seen as an enabling platform, an environment where different stakeholders can work actively together. As discussed by Veeckman and Graaf, “Cities are becoming a Living Lab itself” where stakeholders have environments for innovation and transformation (Veeckman and Graaf, 2015).

The notion of Smart City is arising as an important strategy dealing with emerging problems relating to the urban population growth and rapid development. It is widely recognized that Information and Communications Technology (ICT) play a key role in addressing some of the urban societal challenges through intelligent solutions in efficient energy consumption, management of complex installations, or new business models. They provide the required infrastructure to connect various city systems to create a system-of-systems or network-of-networks that facilitate the interaction between different city levels. They act as a digital platform from which a network of information and knowledge could be created. Through this network, information and data can be aggregated for data analysis and to understand how a city is functioning concerning its services, consumption, and lifestyle. ICTs can also provide solutions and services that are environmentally friendly and viable. These solutions result in improving the quality of life of citizens in the society.

Besides, several integrated ICT platforms have been developed to support decision-making for policy-makers, citizens and other stakeholders. These innovation applications highlight the need for ICT driven policy making through the development of effective decision support systems to foster the development of Smart City. Such an approach can provide the citizen or other stakeholders the necessary information to understand, take into account and actively participate into decision-making processes. A better engagement of citizens in the policy-making process can produce better quality policies, build the trust and gain the acceptance of policy and share responsibility for policy-making processes. Table 1-7 provides a brief overview of existing ICT based- decision support systems to involve citizens in concrete Smart City case studies and also limitations of these ICT solutions.

Table 0-7 Case studies using ICT- based solution for changing stakeholder engagement

The case	Description	Limitation	Reference
DAREED project Funder: European Commission Duration: September 2013 - August 2016	The DAREED project (Decision Support Advisor For Innovative Business Models And User Engagement For Smart Energy Efficient Districts) consists of a multi-layer platform integrating a set of ICT tools that supports Decision Support Systems used for managing and optimize services oriented to foster Energy Efficiency and low carbon activities in neighborhoods and city level.	No recommendation systems. Limited predictive tools.	(Sivarajah et al., 2014)
BESOS project Funder: European Commission FP7 Duration: 01.10.2013 - 30.09.2016	The focus of BESOS (building energy decision support systems for smart cities) is on the development of integration technology to allow data sharing and communication between traditionally separated systems in an urban context (e.g.	No recommendation tools. Emphasis on integration and not on analysis,	(Anadiotis et al., 2015)





	lighting, heating). This integration layer enables the development of higher-level applications for monitoring and analysis tasks.	assessment, planning.	
The rehabilitation of the Charles III Square, Nancy, France  Funders: CUGN & UL-ERPI  Duration: 2012-2013	The implementing of Living Lab approach for the design of urban project and different tactics to connect participants to real-life situations by digital mock-up	Only focus on in the co-creation stage of the urban design process support citizens engagement	(Dupont et al., 2016a)
The SmartGov project  (shaped by four EU – countries Austria, Cyprus, Netherlands and Spain)	The SmartGov project uses digital technologies by integrating open and social media data in Fuzzy Cognitive Maps to model real life problems and simulate different scenarios leading to better decision making. Throughout the engagement of stakeholders, the project has been successful in creating a novel service for the town	Context is based on the garbage collection and the model did not integrated negotiation process	(Pereira et al., 2019)

1.4.2. Applying a Living Lab approach supporting stakeholder engagement in Smart City

Many studies on Smart City has emphasized on stakeholder engagement in the early stage of service development and considered this characteristic is one key element to setting up effective innovation networks. But once the environment is created and the collaboration is initiated, it is still difficult to start an innovation process. The reason is that many stakeholders may have different interests and different understandings of the problem domain and never worked together before (Fröbner et al., 2007). Supporting the generation of new ideas across a heterogeneous collaborative workspace, the Smart City under Living Lab approach, is a process that requires suitable methods and tools. Because of the complex of this process, using methods for seeking harmonization is essential (Mulder et al., 2008).

Though in the initiation stage, only limited number of people can be involved in setting-up a shared understanding of the project, a larger group of people, representative of the different organizations (and interest groups) concerned should be brought to the process, to start the decision- making process (Fröbner et al., 2007). As Levén and Holmström discerned, the co-creation and innovation in the Living Lab depends on establishing active processes from the very starting point (Levén and Holmström, 2008). This is needed to make sure that the open innovation co-production project is indeed the co-evolution of the network of stakeholders and affected by any individual stakeholder. The essence here is that good management makes the benefits to stakeholders. Nontechnical participation activities at the initial stage of Smart City

service co-design appearing are also critical for bringing stakeholders together (Bergvall-Kåreborn et al., 2010). Indeed, nontechnical participation activities, such as paper-based techniques or open debates, should take place rather than just producing technical prototypes. The process can involve various types of engagement, including focus groups, questionnaires, diaries, and picture-taking, to collect different types of data and also to allow for different formats for user contributions.

When establishing a Living Lab, the needs and desires of stakeholders have to be understood from the beginning. Moreover, it is also essential to build mutual trust that extends outside specific project activities. During the engagement process, mutual trust should increase, so unreasonable or false expectations have to be explicitly managed so that levels of commitment of stakeholders can grow. The study of Paskaleva et al proposed requirements for the engagement of stakeholders as well as about the degree of involvement required (Paskaleva et al., 2015):

Involving stakeholders early in the process, before projects are formulated.

Engaging users with diverse backgrounds, competencies and agendas and stress how, through their collaboration, they will complement and learn from each other.

Identifying and work upon what participants can gain from taking part. Active engagement rests upon how beneficial it proved to be for each partner

Assuring different levels of impact, both in terms of the direction of political decision-making and significance for other communities represented by influential participants.

Be sensitive to possible sources of conflict, not only internally within the network but also outside of the network with important others

Using both direct and indirect methods for recruiting

Using alignment to achieve match-making and accelerated buy-in

Ensuring co-production creates a unique project space with outcomes beyond what might have happened in any case.

Securing a good governance structure and mechanism in the Living Lab from the beginning. As the Living Lab grows larger and more complex, the need for formalization of its governance structure will become stronger and more evident.

The figure 1.3 compares stakeholder engagement in urban projects under the French context (the above part of the figure) and under Living Lab approach (the below part of figure). In the French urban process, there are six steps in the implementation of eco-neighborhoods and eco-cities (Lacroix et al., 2017). At each step, different stakeholders are mobilized to solve issues. The citizen consultation is compulsory at the time of the formulation of the project by project ownership and at the time of the design phase by the project manager (Zetlaoui-Léger, 2009). However, users or citizens only appear when it comes to the appropriation of the urban solution (Step 6). This process still lacks the integration of users' viewpoints and a careful user need analysis from the beginning phases. In Living Lab projects, collaborative workspace allows stakeholders, especially users, to work together and enrich the urban project's practices since the beginning of the process. In that sense, the decision-making process is driven by these stakeholders during steps under a Living Lab approach.

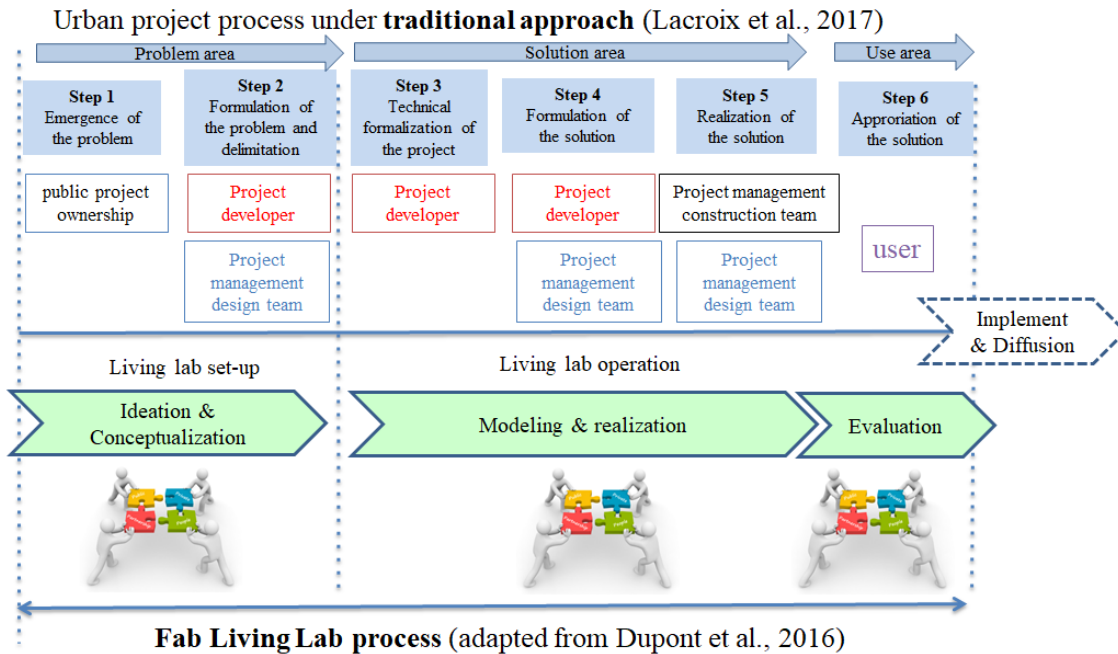


Figure 0-3 A comparison of engagement of stakeholders in urban projects under different approaches

## 1.5. Decision-making process in urban projects

### 1.5.1. Decision-making process on multi- scale environment

Smart City projects are considered as systems where various scales and subsystems have to be aligned for the envisioned development to take place. Therefore, cities can be understood as complex constructions created by the interaction of stakeholders in multiple networks.

Besides, in the information age, the rate of producing and accessing information has grown rapidly. There is a huge gap between the spread data being produced and the ability of people could find and process data (Endsley and Jones, 2016). This calls for digital methods of bringing together and visualizing various kinds of information during decision- making processes. Digital technologies enhance the scalability of collaboration, such as co-design tools, collaborative work environments, and crowdsourcing solutions and data interoperability over urban operational systems.

As de Bruijn states, a change in complex issues always has three characteristics: there are always multiple stakeholders involved in network settings, these stakeholders dependent on each other and negotiate, and the negotiation is a process that can take place at various levels (De Bruijn et al., 2010).

### 1.5.2. Decision-making process in multi-actors environment

Smart City planning, or expanded urban planning, has also become multi-actor with new stakeholders actively involving in urban development processes. Urban development entails perspectives from at least urban design, planning, transportation planning, traffic engineering, real estate theory, management and organization theory, economics, law, policy studies,

sociology etc. As stakeholders involved have different information and knowledge of the problems, complex decisions should be exposed to discussion and negotiation in various phases of the urban process (Eräranta and Staffans, 2015).

In order to support the discussion and understanding of the complex decisions, there is a need for developing collective tools and practical methods to bring various materials into the decision-making process.

Various working groups and round-table meetings of local participants are considered as examples of collaborative tools of decision-making process, where information is shared and discussed. Round-table meetings can create a platform for discussing the various objectives and development plans of the local participants, as well as their impacts on the objectives and plans of the other participants. These activities enable open discussion between various perspectives and arguments between stakeholders. Opposition and difference from stakeholders are important in creating new practices and innovations. The presence of diverse values can aid creativity and coordination (Gomez et al., 2017). A physical and digital platform could bring numerous types of information and facilitate discussions among stakeholders. There are several types of round-table meetings that influenced on the fluency of discussion and information sharing as shown in the figure 1.4 (Eräranta, 2013). Obviously, a smaller group of members, a more efficient discussion and negotiation are. In small groups, for example, working group or round-table group, participants have effective discussion forums. Besides, there is a research gap in enhancing the fluency of discussion and information sharing in a large group of decision-makers such as workshops or briefings. In this study, we will concern decision-making processes in both small and large groups of decision-makers.

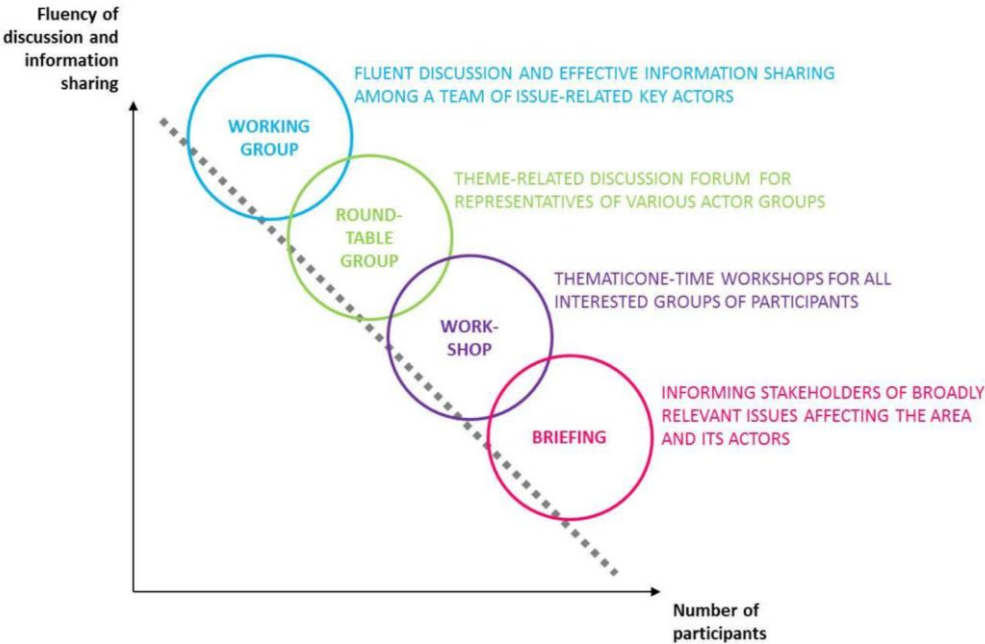


Figure 0-4 Classification of various types of round-table groups (Eräranta, 2013)

**Conclusion**

Since the 20th century, the idea that a city is becoming smart attracts the attention of academic communities. As presented in this chapter, Smart Cities is a concept not only in terms of the way ICT- based solutions solve complex problems to improve quality of life but also the bottom-up process that facilitates participation and collaboration among city stakeholders. A



lot of studies have focused on applying Living Lab approach to empower citizen involvement in the context of the urban public sector (Veeckman and Graaf, 2015) (Lacroix et al., 2017).

This chapter discusses the Smart City concept and the engagement of stakeholders, especially citizens, followed by an introduction of the Living Lab approach as a possible facilitator of bottom-up innovation. Next, several case studies of Smart City using ICT- based solutions for changing stakeholder engagement have been reviewed.

According to the literature review, the use of ICT makes a city smarter, because it improves the efficiency and effectiveness of the city innovation processes, activities, and services. Besides, the studies also highlight on engaging citizens about the role and impact. A good balance between bottom-up processes (i.e., including the sharing decision and action with citizens), and the technology push is a desirable way for Smart City management.

# **: Application of decision-making methods in Smart City projects: A systematic literature review**

## **Introduction:**

Cities are places where different interrelated components of ecosystems together live and interact. As a system, cities have become increasingly complex due to unpredictable behaviors and the existence of non-linear relationships between their constitutive elements (Kapelan and Walters, 2005). A sustainable process of urban transformation into a Smart City requires co-operations supported by ICT infrastructure but also the integration of other dimensions, such as sustainable development, green growth, and collaborations between multi-stakeholders in multiple levels (Dupont et al., 2015). Therefore, making decisions in the context of Smart Cities has become more complex than ever due to the available and huge information and the involvement of multi-stakeholders with often conflicting objectives and dynamic interactions at different phases of these projects. For this reason, it is important to study how urban projects became smarter by a wise management of natural resources and participatory governance with involvement of multi-stakeholders such as citizens, users, engineers, researchers, elected representative, etc. A large number of new ideas, techniques, and approaches have been contributing to the area of decision making in smart cities these last years (Kurniawan et al., 2017). However, there is not a general approach that supports stakeholders on the more suitable decision tool regarding to the level of decision, stage of the project, and particular context.

This paper aims then, to propose a systematic literature review of formalization tools for decision-making process in collaborative Smart City projects. Beginning with 606 potential papers from 2005 to 2018 extracted from Scopus® database, a bibliometric process led to the selection of 76 of these articles. These 76 significant references in terms of different decision-making methods were sorted by components of smart cities. Based on categorical reviews in (Chai et al., 2013), decision-making methods are classified into four groups: multi-criteria decision making (MCDM), mathematical programming (MP), artificial intelligence (AI), and integrated methods (IM). In this study, decision making methods have reviewed regarding to three aspects (1) levels of decision, (2) phases of implementation and (3) involvement and negotiation of stakeholders. Detailed analysis of these documents generated a general map for applying different decision-making methods at various levels of decision and implementation phases of Smart City projects. This review is necessary to increase the understanding of how decision-making methods are applied in Smart City projects and, as a subsequently, how researchers choose the correct approaches to formulate the decision-making process.

Obtained results show that MCDM becoming popular method at strategic level at all phase of urban projects, from concept to experiment and finally, evaluate solutions of decision-making tools in the real-life. Meanwhile, the obtained results allow to infer that MP and AI are the more applied methods to develop tools for making decisions at the operational and tactical levels and mainly at beginning phases of the implementing processes of the project. In terms of practical dimension, most of decision-making tools and toolkits were developed and tested by scientists while hardly involving stakeholders. In those cases of involving stakeholders still rarely have chance to negotiation for reaching higher level of agreement.

This chapter has been published as a review paper with title "Application of Decision-Making Methods in Smart City Projects: A Systematic Literature Review" in Smart Cities journal as part of the Special Issue Big Data Science for Cities Management:



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<https://doi.org/10.3390/smartcities2030027>

Chapter 2 : Application of decision-making methods in Smart City projects: A systematic literature review..... **Erreur ! Signet non défini.**

Introduction: ..... **Erreur ! Signet non défini.**

2.1.1. Categories of decision-making methods ..... **Erreur ! Signet non défini.**

2.1.2 Level of decision..... **Erreur ! Signet non défini.**

2.2. Methodology..... **Erreur ! Signet non défini.**

2.2.1. The first search strategy – the first filter ..... **Erreur ! Signet non défini.**

2.2.2. The second search strategy – the second filter..... **Erreur ! Signet non défini.**

2.2.3. The third filter ..... **Erreur ! Signet non défini.**

2.2.4. The fourth filter..... **Erreur ! Signet non défini.**

2.3. Results ..... **Erreur ! Signet non défini.**

2.3.1. The first data statistic by VOSviewer ..... **Erreur ! Signet non défini.**

2.3.2. The quantitative review: documents analysis ..... **Erreur ! Signet non défini.**

2.4. Discussion..... **Erreur ! Signet non défini.**

2.4.1. Trend of publications ..... **Erreur ! Signet non défini.**

2.4.2. Level of decision..... **Erreur ! Signet non défini.**

2.4.3. Phase of implementation: From concept to model, experiment and evaluation  
..... **Erreur ! Signet non défini.**

2.4.4. The involvement of citizens and other stakeholders in group decision making  
..... **Erreur ! Signet non défini.**

Conclusion **Erreur ! Signet non défini.**

2.1. Overview of decision-making methods in Smart City projects

2.1.1. Categories of decision-making methods

Based on categorical reviews proposed in (Chai et al., 2013), decision-making methods are classified into: Multi- criteria decision making, mathematical programming, artificial intelligence, and integrated methods.

Multi-criteria decision making (MCDM) is a multi-step process consisting of a set of methods to structure and formalize decision-making processes. They allow decision-makers to find a best compromise among a set of alternatives by evaluating these alternatives simultaneously on regards of multiple dimensions (criteria). However, MCDM are considered steady-state methods 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 (Langemeyer et al., 2016).

Mathematical programming (MP) methods optimize objectives by considering constraints and different issues; which allow stakeholders to make an effective decision. Several optimization methods such as goal programming, linear programming, stochastic programming and data envelopment analysis have been applied in this area. A significant problem with using mathematical programming methods is that most of them are too complex for practical use by non-expert stakeholders (Sanayei et al., 2010).

In order to overcome limitation in MP models relating to dynamic complexity and nonlinear properties, there are great advances in computer techniques—particularly the use of complex analysis and artificial intelligence (AI) methods such as cellular automata, multi agent system, swarm intelligent, genetic algorithm, simulated annealing, Bayesian network, reasoning system. These methods are based on computer-aided systems that perceive environment and take actions as a human (Wu and Silva, 2010). These methods are widely accepted to tackle complex and dynamic problems in urban studies by using Information and Communications Technology based solutions and high advanced computer programs.

In our view, the required methods and approaches for making collaborative decisions in sustainable urban projects have to adapt a number of characteristics as mentioned in the research of Mayer (Mayer et al., 2005).

Table 0-1 Characteristics of collaborative Decision making methods in sustainable urban projects

Characteristics of collaborative Decision making methods in sustainable urban projects		MCDM	MP	AI	
1	Integrative	consider different aspects decision making in a holistic and systematic way.	x	x	x
2	Dynamics:	show the 'performance' of various alternatives in relation to preferences and 'behavior' of stakeholders.	x	x	x
3	Interactive	support the negotiation process between stakeholders	no	x	x





Characteristics of collaborative Decision making methods in sustainable urban projects			MCDM	MP	AI
4	Transparent	produce results that are clear and understandable to all stakeholders	x	x	x
5	Flexible and Re-usable:	usable for, or adaptable to, a range of (similar) situations.	x	no, different conditions for programming	x
6	Fast and easy to use	the time required to apply them should be relatively short, and non-experts, for example, residents and politicians, should be able to use them	x	no, need programming skill	No, need advanced computer programs
7	Communicative and educational	able to convey meaning and insight to stakeholders about problem structure, alternatives, and different perspectives	x	no	no
8	Authoritative	meet analytical standards (of, for example, validity) and political standards (for example, safeguarding core values and timeliness) in order to increase the likelihood that the outcomes are used	x	x	x

It can be realized from the table that MCDM is better fit to characteristics of multi-actor and complex decision-making in urban systems. The only problem with MCDM is that this steady-state method is difficult to be integrated with time variable and therefore, unable to support the negotiation process between stakeholders. Meanwhile, mathematical programming or artificial intelligence without specific tools are not easy for non-expert stakeholders to use and educate because of requirements in programming skills or advanced computer programs. Different conditions also need dissimilar rules for programming that is unable to apply the same mathematical programming method into a wide range of similar situations. These reason lead to an overwhelming tendency of researches attempted to integrate MCDM method and the other decision model for dealing with different system complexity issues in urban development projects (Chai et al., 2013). For example, there are an integrated decision model into decision-support system for a sustainable design of neighborhoods or residential units (Hendriks, 2001) or the use of a decision-support tool combined with the simulation-gaming procedure in the field of sustainable urban renewal (Mayer et al., 2005) or a novel consensus support system based on the multi-agent system paradigm for group decision making problems (Palomares and Martinez, 2013).

### 2.1.2 Level of decision

In the context of Smart City and urban projects, decisions are made into three main levels, strategic, tactical and operational (Giang et al., 2017), (Kabisch, 2015). This multi-level governance is used as an analytical framework to analyze how Smart City authorities deal with complex issues and how stakeholders are connected (Kabisch, 2015).

Strategic decisions are the basis for tactical and operational decisions (Espinoza Pérez et al., 2017). The strategic level includes processes and activities of setting long-term goals, policy development, visions, or values for the overall development of the city as a whole.

Tactical level considers the medium term decisions on mid-level, in order to achieve results specified at the strategic level. This level refers to the development of concrete green space related agendas, all stakeholders that regularly deal with programs, funding, and establishment of networks and partnerships. These stakeholders include planers, universities, NGOs, etc.

Finally, the operational level corresponds to experiments and actions with short-term vision, which concern to the implementation of goals, assets and the execution of concrete projects (Salet et al., 2013). Operational decisions are mostly used to give operational solutions or to assess obtained results at low-level managers in smart cities (Loorbach, 2010).

## 2.2. Methodology

In this study, the approach is the systematic literature selection process using different filters to narrow the number of scientific publications relating to decision-making in Smart Cities. Figure 2.1 shows a flow diagram as a process including four filters with different search strategies and exclusion criteria. The large amount of articles collected after the first filter form the data for a qualitative data analysis carried out by VOSviewer® software. VOSviewer is freely available software at [www.vosviewer.com](http://www.vosviewer.com). This software tool provides bibliometric mapping based on a network of keywords. It implements the mapping technique, and co-occurrence data analysis following a similarity matrix (van Eck and Waltman, 2010). The VOS (visualization of similarities) mapping provides a high quality of visual representation to explore the maps in detail by offering zooming and scrolling option. Finally, publications selected after the fourth filter were retained and used for a quantitative review.

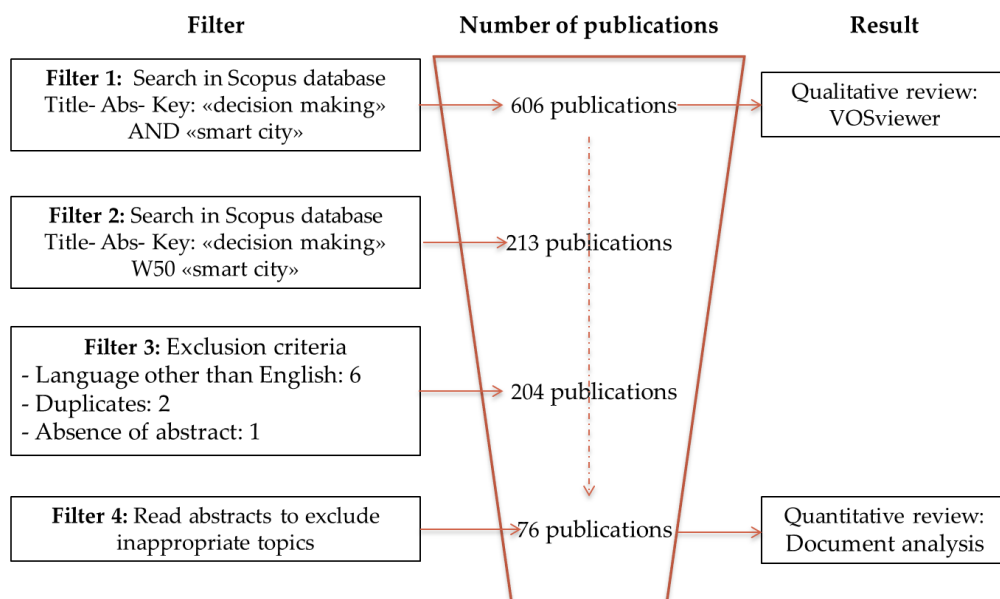


Figure 0-1 Flow diagram of the literature selection process.



### 2.2.1. The first search strategy – the first filter

This step consists in defining the first filter as a search equation, which is composed of keywords, period of time, database and type of documents to be analysed (Table 2-2). The keyword field was divided into two complementary parts. The first one regarding to “decision making”, and the second one focused on “Smart City”. These keywords were defined according to a preliminary literature review (Giang et al., 2017), whereas the period of time was selected from the year 2018 backwards. We focus only on articles and conference papers therefore unpublished articles, working papers and magazine articles were excluded during the data purification process.

Table 0-2 The first search strategy

Field	Option Introduced
Keywords	“decision making” AND (“Smart City” OR “smart cities”)
Search in	Title, abstract, keywords
Period explored	to 2018
Type of documents	Articles and conference papers
Database	Scopus®

After applying the first search strategy, there are 606 initial scientific publications were found in Scopus® database. The whole database of 606 papers relating to their title, keyword statistics, citation counts author names and affiliations are collected and exported from Scopus website into a CSV data file. Then, the data is uploaded to VOSviewer software. This large amount of data is the input for mapping bibliometric and conducting network of keywords and their relatedness by means of co- occurrence analysis. This result will be discussed in section 3.1.

### 2.2.2. The second search strategy – the second filter

In this search equation, we use the proximity operator “w50” between two parts of keywords: “decision making” and “Smart City”. This is a search tip from Scopus website to make sure all searching terms appearing in the title or the same paragraph. By using this tip, the number of selected publications is narrow and the topic of these studies is closer to our objectives. In this step, the period of search, database and type of documents are similar to the first search step. After applying this search strategy, we found 213 potential publications from Scopus database.

### 2.2.3. The third filter

The number of publications is subsequently selected or excluded through supporting tools in Scopus website. The three main reasons of ejecting are language other than English, duplicates and the absence of abstract. The 204 remaining scientific publications are used for the initial data statistic.

### 2.2.4. The fourth filter

There were several works unrelated to the Smart City topic in 204 scientific publications from the previous filter. Several reviews and theoretical studies did not perform a concrete method

to make a decision or lacked practical contribution in projects or case studies. In order to choose the most relevant papers, a filter was performed based on reading and analysing the abstracts of these 204 selected articles. From this, articles using different methods to formulate decision-making processes in concrete Smart City projects were retained and listed herein. These 76 selected papers were carefully reviewed and selected strictly according to the category of decision-making methods formulated above, levels of decision-making and phases of implementation of Smart City projects. The result of this quantitative analysis is discussed in Section 2.3.2.

## 2.3. Results

### 2.3.1. The first data statistic by VOSviewer

The 606 publications selected from the first search strategy were transferred as bibliographical data to the VOSviewer software. These bibliographical data were used to develop a network of keywords by co-occurrence links. The whole network of keywords and their links is mapped out in Figure 2.2. In this network, the circles are a representation of keywords and the diameter of circles represents for the frequency of occurrence of each keyword. The distance between two keywords indicates their relatedness in terms of co-occurrence links. These co-occurrence links were determined based on the number of documents in which keywords occur together. So, the closer two keywords are located to each other, the stronger their relatedness.

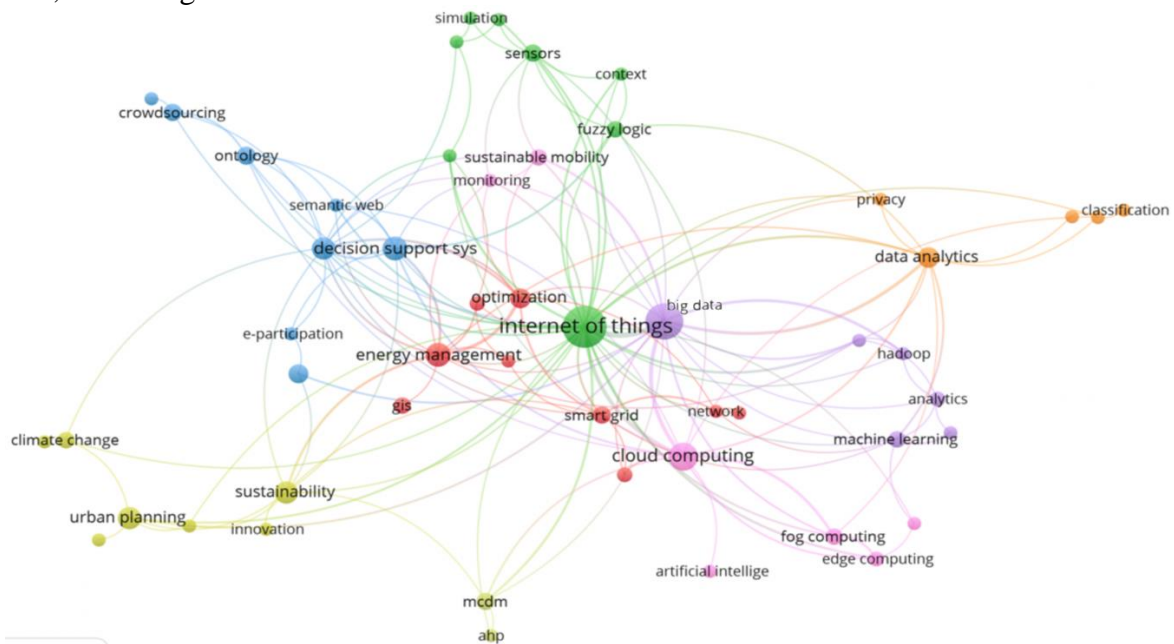


Figure 0-2 A network analysis of 606 publications by VOSviewer software mcdm = multi-criteria decision-making, ahp = Analytic Hierarchy Process

In the network, a collection of keywords having strong relationship creates clusters, tagged by different colour. Using all keywords in one cluster for search equation in Scopus database, we found a list of papers, represented for the research trend of each cluster. The seven main clusters of networks in VOSviewer are described in table 2.3, which including the colour, components of clusters, some example publications and current research mentioned in each cluster.

Table 0-3 Clusters analysis ICT = Information Communication and Technology; IOT = internet of things; GIS = geographic information system.



Cluster	Main keywords	Other keywords	Example Reference	Research trend
1 (green)	Internet of things	Fuzzy logic Smart home, Sensors, Waste management, Context, Carbon footprint, Sensors, Simulation	(Anagnostopoulos et al., 2018), (Simmhan et al., 2018), (Zyrianoff et al., 2018)	IOT based application for Smart City
2 (blue)	Decision support system, ICT	e-participation, smart governance, crowdsourcing, emergency response, ontology, semantic web	(Abu-Elkheir et al., 2016), (Bartolozzi et al., 2015), (Sivarajah et al., 2014)	Decision support system based on ICT for smart governance
3 (purple)	Big data	Deep learning, machine learning, healthcare, intelligent transportation system	(Khan et al., 2015), (Alam et al., 2016), (Fabbiani et al., 2017)	The application of big data analysis and data mining algorithms in Smart City
4 (red)	Optimization	Smart grid, energy management, GIS, network, security, visualization, game theory, demand response	(Olszewski and Turek, 2016), (Carli et al., 2017)	Optimization tools for networks in smart cities
5 (yellow)	Sustainability	Infrastructure, innovation, social network, urban planning, earth observation, climate change, Mcdm, ahp	(Ahvenniemi et al., 2017), (Mora et al., 2018), (Lugaric and Krajcar, 2016)	Assessment of Smart City on sustainable way
6 (pink)	Cloud computing	artificial intelligence, edge computing, fog computing	(Chen et al., 2016), (Khan and Kiani, 2012), (El-Sayed et al., 2018)	Decision based on cloud computing and artificial intelligence methods
7 (orange)	Data analytics	open data, wireless sensor networks, privacy, classification	(Mohamed et al., 2018), (Barns, 2016), (Saggi and Jain, 2018)	Data analytics, a paradigm and solution for decision making

After exploring cluster network, it is interesting to continue discover the distribution and the evolution in time of keywords in the network. Using the overlay and the density visualization of VOSviewer, the same network could display the total occurrence and the time in research of each keyword. In the figure 2.3, colours are defined by the average publication per year of each keyword, with yellow for the most recent and dark blue for the oldest. It can be noticed that our research issue is a recent topic with average time from 2016 to 2018. Clusters on the left are discussed mainly in 2016 while internet of things- based solutions and application of decision-making methods (such as MCDM, computing or artificial intelligence) still attract the interest of academic communities. The figure 2.4 also shows the low density at the issue of decision-making methods comparing to others topic. Therefore, it is necessary to focus more on application of decision-making methods in to formulize problems of Smart City projects.

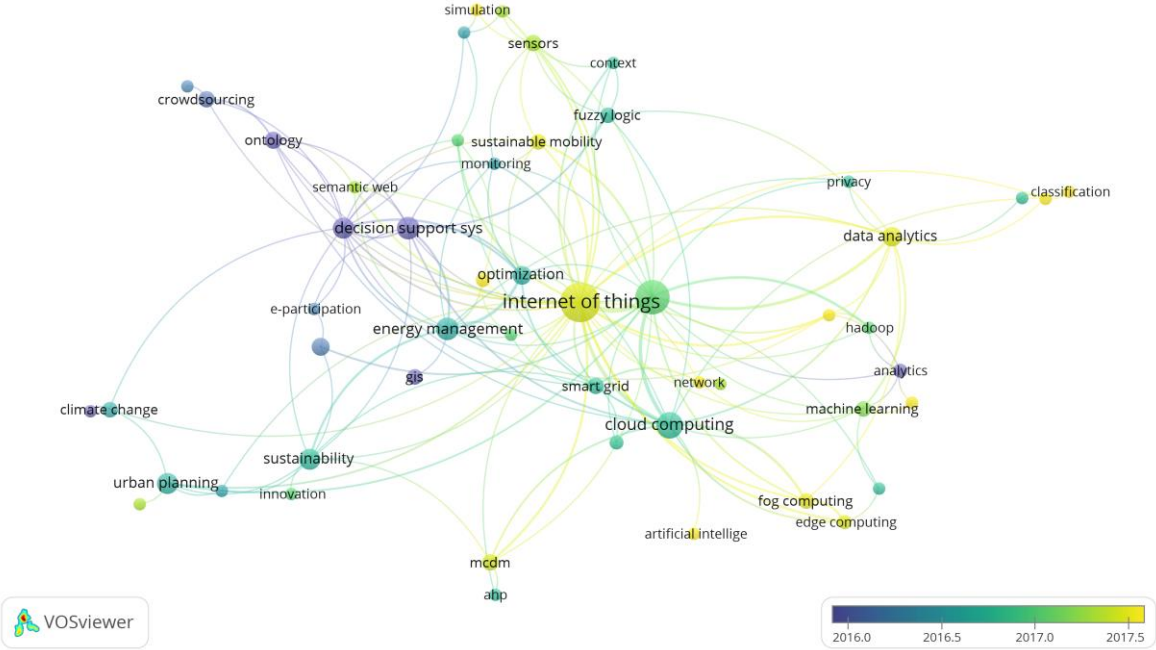


Figure 0-3 The evolution over time of keywords

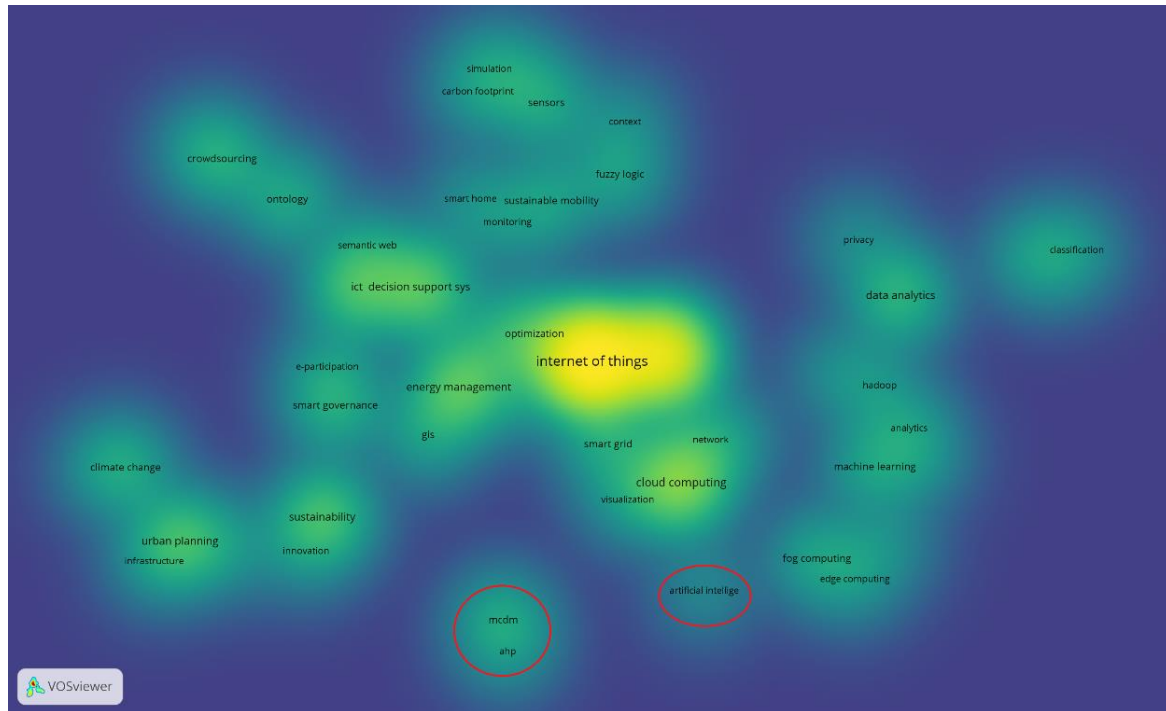


Figure 0-4 A visual diagram of density distribution of keywords

### 2.3.2. The quantitative review: documents analysis

A methodological analysis has been applied to sort the selected articles and then subsequently form the table 2-4. In below table, we provide an overall summary of 4 groups of decision-making methods discussed in the 76 selected journal articles. Firstly, the field of articles is sorted based on relating main components of Smart City. After that, the level of decision (strategic, tactical and operational level) is identified. In next columns relating to phases of implementation, we continue to determine which methods are used to formulate decision-making process at different phases of Smart City projects, from concept to model, experiment and finally, evaluate solutions. Finally, it is necessary to note the involvement multi-stakeholders into decision process and the way they keep communicating and negotiating in reaching consensus process.

Table 0-4 Publications summary

(MC- Main characteristic; O- Operational; T- Tactical; S- Strategic; C- Concept; M- Model; Ex- Experiment; Ev- Evaluate; MS- Multi-stakeholders involvement; I- Individual; G- Group; en- environment; pe- people; li- living; eco- economic; mo- mobility; go- government)

No	Ref	MC	Group of method	Method	Level of decision			Phase of Implementation				MS	Type	
					O	T	S	C	M	Ex	A		I	G
1	(Liu et al., 2018)	li	MCDM	DEMAT EL			x			x				x

No	Ref	MC	Group of method	Method	Level of decision			Phase of Implementation				M S	Type		
					O	T	S	C	M	Ex	A		I	G	
2	(Ju et al., 2018)	go	AI	Bayesian	x					x					x
3	(Bellini et al., 2018)	li	MP	LP	x				x					x	
4	(Mouchili et al., 2018)	mo	MP	Machine leaning	x				x					x	
5	(Fadda et al., 2018)	mo	MP	MP		x					x	x			x
6	(Stefanic et al., 2017)	li	IM	MCDM& AI	x				x						
7	(Pereira et al., 2019)	go	MP	Cognitive maps			x			x				x	
8	(Torabi Moghadam et al., 2018)	mo	IM	LP			x				x			x	
9	(E. Wang et al., 2018)	eco	AI	AI	x					x				x	
10	(Mohamed et al., 2018)	en	MP	MP	x				x					x	
11	(Alencar Bezerra et al., 2017)	mo	MP	DEA	x				x					x	
12	(Abastante et al., 2017)	mo	IM	IM & MCDM		x				x				x	
13	(Dowling et al., 2017)	en	MCDM	MAUT			x		x					x	
14	(Bhattacharya and Painho, 2017)	mo	MP	MP	x			x						x	
15	(Abdel-Basset and Mohamed, 2018)	li	MP	MOP	x					x				x	
16	(Khansari et al., 2017)	en	AI	ABM	x				x					x	
17	(Mihăiță et al., 2018)	mo	MP	MP	x					x				x	





No	Ref	MC	Group of method	Method	Level of decision			Phase of Implementation				M S	Type		
					O	T	S	C	M	Ex	A		I	G	
18	(Giacobbe et al., 2018)	go	MCDM	MCDM			x			x					x
19	(Gheibi et al., 2018)	go	MCDM	TOPSIS	x			x							x
20	(Abbasi et al., 2018)	li	AI	MAS	x					x				x	
21	(Kinawy et al., 2018)	li	MP	MP			x				x	x			x
22	(D'Aniello et al., 2018)	li	AI	Stream reason	x					x				x	
23	(Hou et al., 2018)	en	MP	Edge computing	x				x						x
24	(Vallejo et al., 2017)	mo	MCDM	MAUT			x				x	x			x
25	(Iqbal et al., 2018)	mo	AI	Artificial network	x				x					x	
26	(Mangele et al., 2017)	li	MP	MP	x				x					x	
27	(Ghaemi Rad et al., 2018)	li	MCDM	ANP & DEMATE			x			x				x	
28	(Zelentsov and Mailyan, 2017)	li	MP	MP	x				x						x
29	(Mosannenzadeh et al., 2017)	mo	MCDM	MAUT		x				x					x
30	(Rahman et al., 2017)	mo	AI	GA	x				x	x				x	
31	(Fedyanin and Vershinin, 2018)	mo	AI	MAS	x				x					x	
32	(Agugiario, 2016)	mo	MP	MP	x					x				x	

No	Ref	MC	Group of method	Method	Level of decision			Phase of Implementation				M S	Type	
					O	T	S	C	M	Ex	A		I	G
33	(Hendy et al., 2015)	li	MCDM	MAUT			x		x			x		x
34	(Yang et al., 2018)	mo	AI	AI	x			x					x	
35	(Ruiz et al., 2018)	mo	MP	MP	x					x			x	
36	(Eswaran et al., 2018)	en	MCDM	MCDM	x				x					x
37	(Oswald Beiler and Phillips, 2016)	mo	MCDM	MAUT		x				x				x
38	(Rondini et al., 2018)	li	MCDM	MCDM	x					x				x
39	(S. Wang et al., 2018)	en	MP	Game theoretic	x				x				x	
40	(De Maio et al., 2017)	li	MP	Non LP	x				x					x
41	(Abberley et al., 2017)	mo	MP	MP	x				x				x	
42	(Digiesi et al., 2015)	mo	MCDM	MAUT	x					x				x
43	(Saaty and De Paola, 2017)	en	MCDM	MCDM			x			x				x
44	(Orłowski, 2014)	eco	MP	MP		x			x				x	
45	(Sarkar et al., 2017)	en	MP	MP	x						x	x		x
46	(D'Asaro et al., 2017)	go	AI	AI			x							x
47	(Sivarajah et al., 2014)	go	AI	AI			x		x			x		x
48	(Ahvenniemi et al., 2017)	en	MCDM	MCDM			x		x				x	
49	(Kraemer et al., 2013)	en	AI	AI		x			x					x



No	Ref	MC	Group of method	Method	Level of decision			Phase of Implementation				M S	Type	
					O	T	S	C	M	Ex	A		I	G
50	(Latorre-Biel et al., 2017)	mo	MP	LP						x			x	
51	(Mokoena et al., 2017)	en	MCDM	AHP			x			x				x
52	(Lazaroiu and Roscia, 2012)	go	MCDM	MAUT			x		x					x
53	(Anthopoulos et al., 2011)	go	MCDM	MAUT	x				x					x
54	(Kulju and Oksman, 2017)	en	MP	MP	x		x			x				x
55	(Maktav et al., 2011)	en	IM	MCDM& AI			x		x				x	
56	(Raikov, 2017)	en	AI	GA			x			x		x		x
57	(Chowdhary and Kaur, 2017)	mo	AI	MAUT		x				x		x		x
58	(Rall and Haase, 2011)	en	MCDM	MAUT		x				x		x		x
59	(Moreno et al., 2017)	li	MP	MP	x					x			x	
60	(Hermans et al., 2007)	en	MCDM	MAUT			x		x			x		x
61	(dos Santos, 2016)	en	IM	DEA& MP			x		x					x
62	(Khandokar et al., 2016)	mo	MP	MP			x		x				x	
63	(Orłowski et al., 2018)	li	MP	MP			x		x				x	
64	(Carli et al., 2016)	en	MP	MP			x		x				x	
65	(Fahad et al., 2014)	li	AI	MAS		x				x		x		x

No	Ref	MC	Group of method	Method	Level of decision			Phase of Implementation				M S	Type	
					O	T	S	C	M	Ex	A		I	G
66	(Ligtenberg et al., 2009)	en	AI	MAS		x			x			x		x
67	(Ghosh et al., 2016)	en	MP	machine leaning	x				x				x	
68	(Rolim et al., 2015)	li	MP	MP	x				x				x	
69	(Kosmides et al., 2015)	li	MP	MP	x			x					x	
70	(Foucault and Moulier-Boutang, 2015)	mo	MCDM	MCDM	x					x				x
71	(Papastamatiou et al., 2014)	en	MCDM	MCDM	x				x					x
72	(Palomares and Martinez, 2013)	pe	IM	MCDM & MAS		x				x		x		x
73	(Meza et al., 2007)	mo	IM	AHP& LP	x				x					x
74	(Wey, 2013)	mo	IM	AHP& DEA			x		x					x
75	(Amini et al., 2017)	mo	IM	GA & Swarm	x				x				x	
76	(Khansari et al., 2014)	en	AI	Cognitive theories	x				x				x	

## 2.4. Discussion

### 2.4.1. Trend of publications

The figure 2.5 shows a notable increase in published studies regarding decision-making processes in Smart City projects over the past 10 years. The evolution of the 76 selected studies over the years is represented in column data. In order to compare this trend, the red line represents the total 213 articles collected from the Scopus database after the second filter of the selection process was applied and the yellow line represents normalized data. The normalization process starts from the actual number of publications per year that were published at <https://dblp.uni-trier.de/statistics/publicationsperyear>. After computing the increase rate for each year, we normalized the data from the Scopus database.

In general, the evolution begins with a handful of papers per year in the period of 2008 to 2011, then rises dramatically from 2012 and peaks in 2018. Around half of these studies address individual problems, while the remaining works were related to collaborative decisions. The detail analysis on group decision-making is presented in the next section.

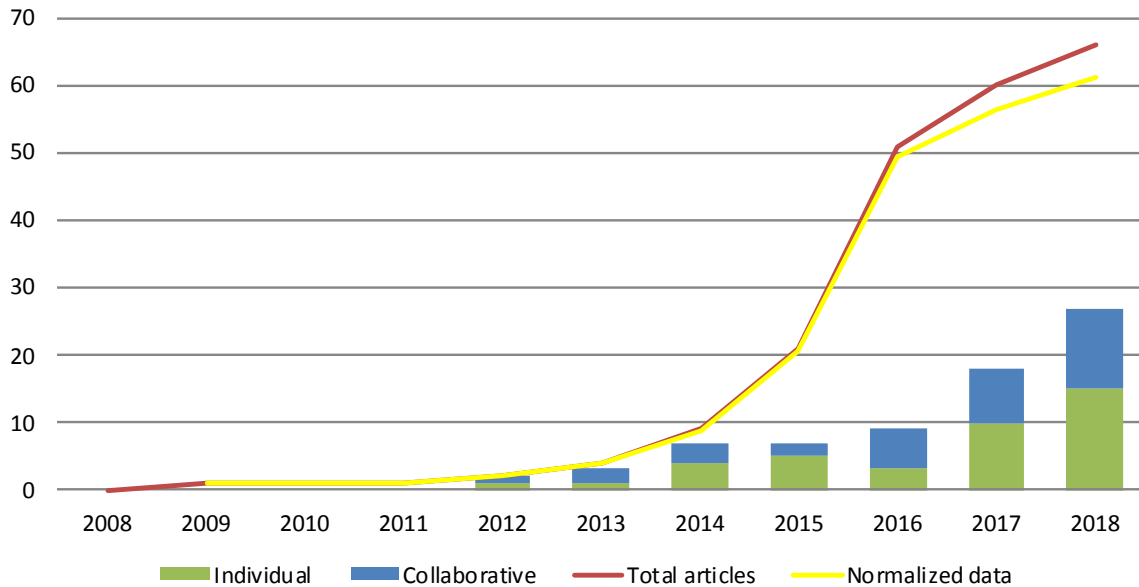


Figure 0-5 Distribution of publications from 2005 to 2018

Figure 2.6 (a) shows the percentage of publications according to their scope, based on the set of main characteristics of smart cities. It highlights the dominance of studies pertaining to smart mobility and smart environment, which amounted to 38% and 27% of the publications respectively. As mentioned in the literature, smart government plays an important role in Smart City projects (Alawadhi et al., 2012), however only 8% of the articles focus on this topic. To close this gap, it is necessary to increasingly pay attention to creating smart governance models in order to improve multi-stakeholder participation in decision-making processes.

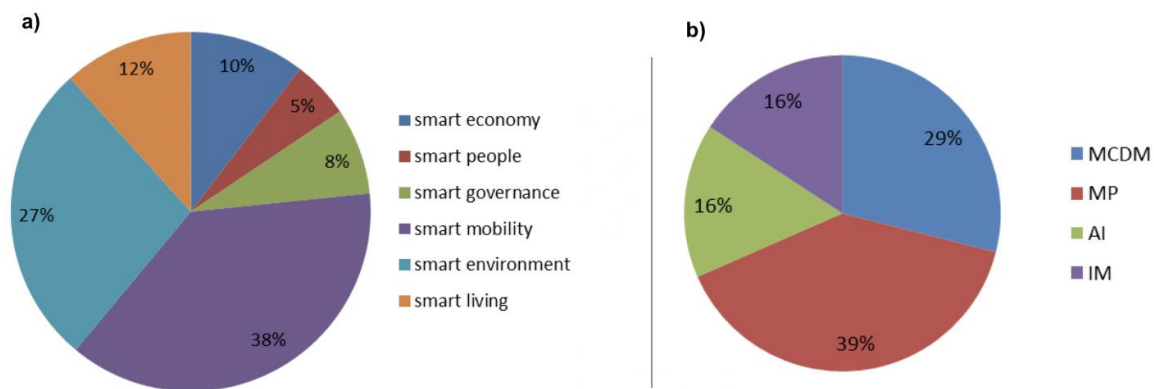


Figure 0-6 Distribution of 76 publications according to main characteristics (a), and decision-making methods (b) used in Smart City projects between 2008 and 2018

Figure 2-6 (b) illustrates how, between 2008 and 2018, a considerable number of articles used MCDM and MP for Smart City projects. On the other hand, applying AI methods in urban decisions was not yet a popular trend in this period, with only 17 related articles. AI methods are usually combined with ICT-based tools to quickly analyze operational data and improve urban decisions (E. Wang et al., 2018), (Kraemer et al., 2013). In terms of AI methods, there are only 4 works in total applying agent-based methods, such as a multi-agent system or agent-based model, to provide a decision support system in an automatic and robust way [33], (Fahad et al., 2014), [82]. In addition to this, it can be observed in the review that the majority of studies mentioning IM methods demonstrate a combination between MCDM and other methods to formulate urban decision-making processes. This trend also attests to the overwhelming majority of MCDM methods used in this research area.

#### *2.4.2. Level of decision*

Figure 2-7 shows that MCDM is a popular method at a strategic level. MCDM methods are widely used in strategic planning to analyze and interpret the multiple interactions underpinning complex urban environments (Torabi Moghadam et al., 2018), (Dowling et al., 2017) or to select the most suitable solution as a recommended strategy for public sectors (Vallejo et al., 2017), (Wey, 2013).

Meanwhile, MP and AI are mostly applied to develop ontologies and tools supporting operational and tactical decision-making with concrete objectives. For example, MP methods are applied to create data aggregation and service production for Smart City projects (Bellini et al., 2018), (Zelentsov and Mailyan, 2017). MP methods also contribute to assess and optimizing energy efficiency (Alencar Bezerra et al., 2017), (Agugiaro, 2016) or spatial data infrastructure projects (Bhattacharya and Painho, 2017), (F Terribile et al., 2015). Beyond this, AI methods provide the potential for solving high levels of complexity in the modeling process. For example, AI methods quickly analyze operational data to provide new insights and improve decision-making in the industrial system (E. Wang et al., 2018) or various social science theories of human behavior (Khansari et al., 2017).

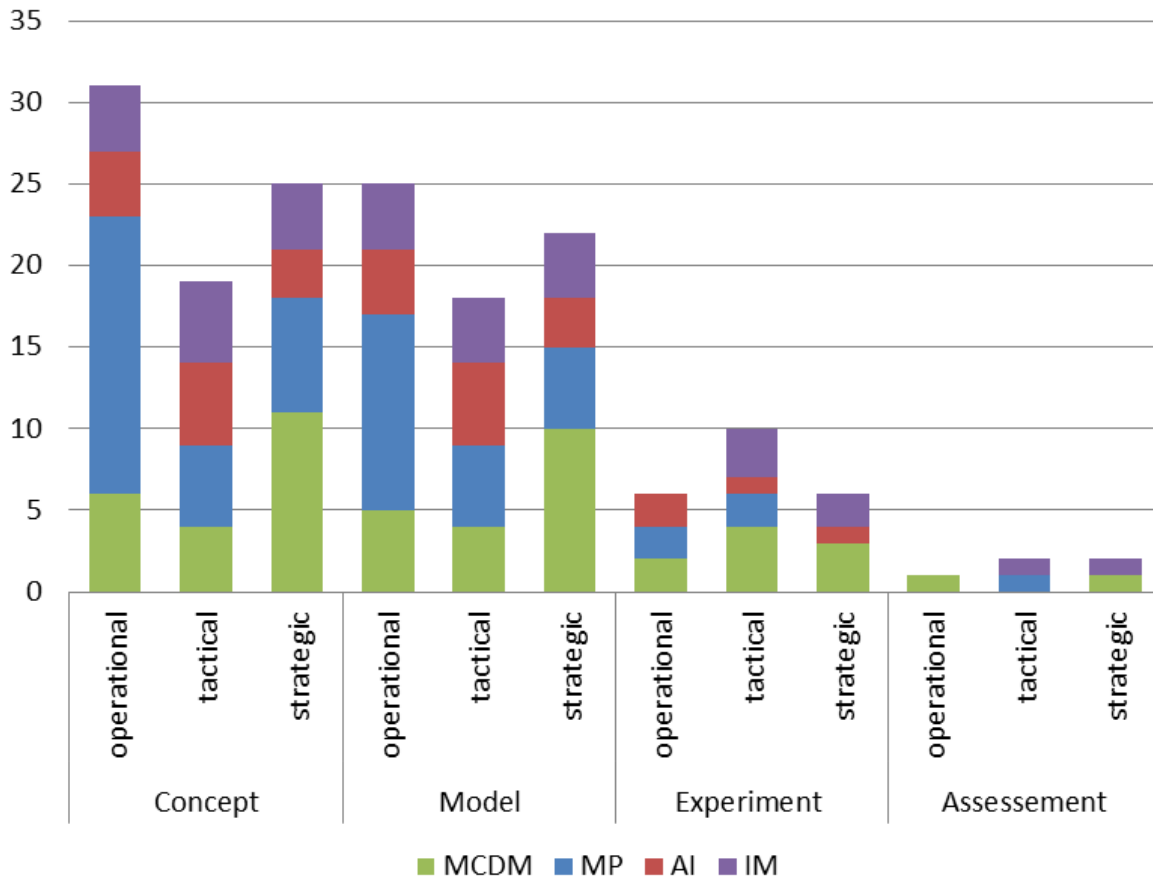


Figure 0-7 Distribution of 76 publications by level of decision-making and phases of implementation

#### 2.4.3. Phase of implementation: From concept to model, experiment and evaluation

Figure 2-7 also shows that MCDM and integrating MCDM with other methods are used in all phases of urban projects, from concept to experiment and finally, assessment of solutions of decision-making tools in real-life practices. This method is a holistic procedure for Smart City projects on multiple levels, providing and using a multi-criteria perspective. Decision-making tools are provided to support the diagnosis, selection and final assessment of measures and scenarios which enable the mass-market deployment of energy-efficient projects (Vallejo et al., 2017). In another example, the multi-actor multi-criteria analysis methodology is fully explained to assess urban freight solutions in order to appraise their chance of success [46]. Case studies in these articles are considered as references for the large demonstration cases in smart cities.

Meanwhile, MP and AI are mostly applied to developing tools at beginning phases of implementing processes. Several levels of models from conceptual to scale are designed and executed within smart cities. However, there is a gap between modeling the decision-making processes and experimenting with and assessing such models. MP and AI methods are usually used as a representation of a system to create a model and prototype in a real-life context which enables the visualization of internal relationships within collaborative platforms (Alencar Bezerra et al., 2017), (Bhattacharya and Painho, 2017).

Figure 2-7 also depicts the main publication journals related to the levels of decision-making and phases of Smart City projects between 2008 and 2018. As can be seen, most studies in this period developed a build concept and executed the model. Of the 76 studies examined in this review, only 16 studies were found to experiment with their decision-making tools in a real-life context. Of these 16 studies, 6 articles related to the assessment of decision-making tools made by multi-stakeholders or the author only. These results imply that decision-making tools are mainly executed at the beginning of the implementation process of urban projects. The involvement of multi-stakeholders in this assessment process is an extremely important aspect, as will be discussed in the next section. Moreover, from this review some supplementary aspects can also be underlined.

#### *2.4.4. The involvement of citizens and other stakeholders in group decision making*

A large number of new ideas, techniques, and approaches have been contributing to emphasize the involvement of stakeholders, in particular users and citizens, into making share decisions process of Smart City projects.

Even though around half of total studies regarding to group decision making, most of decision-making tools and toolkits were modeled and executed by experts or authors only. There is only 19 of total papers (make up 28%) mentioned about the involvement of multi-stakeholders. In case of involving, stakeholders still rarely have chance to negotiation for reaching higher level of agreement. Though, in some case, they just only debate or negotiate in several rounds [30] instead of compromising to reach consensus. Reaching consensus process is not a new concept in social science. However, from our literature review, the term “consensus” is only mentioned in a few articles. The decision making methods supporting reaching consensus process usually are MP or AI methods [31]. The reason is that programming and computer-aided systems are available to solve complex and dynamic problems in negotiation process when people conflict and also, compromise to share decisions.

## **Conclusion**

In many studies, urban and Smart City projects have been considered within complex contexts and over long-time scales which revealed multi-stakeholders and organizations with conflicting interests. Therefore, Smart City planning and decision-making are not only a data-driven multi-level scaling practices, but are also a collective learning procedure supported by advanced ICT-based technologies and visualizations of available data, constant processes, and local history and stories (Eräranta and Staffans, 2015). In order to increase the efficiency of discussions and negotiations, there is a need for situational awareness tools and approaches enabling collaborative decision-making processes which deal with the complex nature of Smart City projects.

In this study, a systematic literature review methodology with four filters is used to narrow the number of potential articles collected from Scopus database. Starting from a huge database of 606 papers, collaborative decision-making methods in Smart City projects was undertaken through the qualitative analysis of 76 selected research documents.

This literature study contributes a general mapping of different decision-making methods applied at the levels of decision-making and the phases of implementation. The main contributions of this study are the following:

Even though smart government with citizen participation is an important characteristic of a Smart City, few articles focus on this issue.





MCDM is a popular method at every level of decision-making and throughout all stages of Smart City projects. Meanwhile, MP and AI are widely used for making operational and tactical decisions.

Regarding the implementation process, several papers cover all phases, from concept to modeling and assessing decision-making tools. However, assessing solutions, the final phase, tends to lack efficient engagement of multi stakeholders, especially citizens.

The involvement of multi-stakeholders is not considered in most phases of Smart City projects. In cases where they are involved, there is lack of decision-making tools supporting the negotiation between stakeholders.

As evidenced in Figure 2-7, the research efforts in this field remain in conceptual ideas and models.

Hence, there is an opportunity for future works focus on smart government supporting the involvement of stakeholders, especially citizen, into decision-making process and the way they keep negotiating for reaching consensus. The combination between the wide applicability of MCDM methods and the capacity solving complex problems of mathematical or computer-based methods could be potential methodology for complex and dynamic decision-making process in Smart City projects.

In next chapter, I will explain how to make the design process more participatory. Moreover, it is necessary to find the consensus between stakeholders instead of their differences on values, goals and priorities.

## **SECTION 2:**

# **CONCEPTUAL FRAMEWORK**

### **: Group decision-making process and the conceptual model of group decision-making process under Living Lab approach**

#### **Introduction:**

The term of consensus is defined as a process creating a cooperative dynamic where everyone works together to bring their opinions closer (Herrera et al., 1995). Any ideas are raised and concerned, sometimes one by one, until all members in the group are heard. Finally, a shared decision or a solution can be created more cooperatively. The mechanisms determining to get consensus on decision-making problems under the framework of Smart City projects are still to be studied.

Moreover, it can be concluded from the second chapter that the involvement of multi-stakeholders is not considered in most of the phases of Smart City projects. In the case of involving, there is a lack of decision-making tools supporting the negotiation process between stakeholders.

Therefore, this chapter will focus on a general conceptual framework proposition for group decision-making processes supporting the negotiation between stakeholders. Firstly, fundamentals and a scheme of group decision-making process supporting reaching consensus in group decision-making will be described. This scheme continues to exploit and classify in Living Lab environment. The mechanisms enabling to reach consensus are used to develop a conceptual framework for reaching consensus with multi-stakeholders.



Chapter 3 : Group decision-making process and the conceptual model of group decision-making process under Living Lab approach ..... **Erreur ! Signet non défini.**

Introduction: ..... **Erreur ! Signet non défini.**

3.1. Overview of a group decision-making process ..... **Erreur ! Signet non défini.**

3.2. The role of situation awareness in a decision-making process.... **Erreur ! Signet non défini.**

3.3. Consensus reaching process in a group decision making **Erreur ! Signet non défini.**

    3.3.1. Preference relations..... **Erreur ! Signet non défini.**

    3.3.2. Measures of consistency and consensus ..... **Erreur ! Signet non défini.**

    3.3.3. Type of facilitator in the consensus reaching process**Erreur ! Signet non défini.**

3.4. Group decision making and consensus reaching process in a Living Lab environment ..... **Erreur ! Signet non défini.**

3.5. Conceptual models of group decision making in Living Lab environment ... **Erreur ! Signet non défini.**

    3.5.1. The group decision making with an automatic control system**Erreur ! Signet non défini.**

    3.5.2. The group decision making with a human facilitator for reaching consensus process ..... **Erreur ! Signet non défini.**

    3.5.3. Comparing three types of consensus process: collaborative, distributed automatic and distributed collaborative..... **Erreur ! Signet non défini.**

Conclusion ..... **Erreur ! Signet non défini.**

### 3.1. Overview of a group decision-making process

In decision-making problems with several alternatives or possible solutions, decision-makers or stakeholders try to find out a common solution (Butler and Rothstein, 2007). Therefore, managing large groups of decision-makers faces frequently the existence of strong disagreement positions between participants (Lu and Ruan, 2007).

Traditionally, group decision-making problems have been solved by applying a selection process to choose the best alternative, without taking into account the level of agreement amongst stakeholders (Herrera et al., 1995). This process can lead sometimes to solutions that are not well accepted by some stakeholders in the group, because they might think that their own opinions have not been considered proper to make a shared decision.

In order to prevent such situations, it is advisable that stakeholders carry out a consensus reaching process, a dynamic and iterative process where stakeholders express, discuss, and modify their preferences to achieve a high level of agreement before making a decision (Butler and Rothstein, 2007). An updated model of group decision making has presented in the study of (Mata et al., 2009) that includes the following characteristics:

Decision problems are formalized as a set of alternatives. They are the input data for group decision-making process

After exploring the problem context, stakeholders give their own preferences and then start to communicate and negotiate through the consensus process. In the consensus reaching process, stakeholders discuss and modify their preferences based on the advice of a moderator in order to reach a sufficient agreement.

The shared decision is created after the consensus process. This is also the input for a selection to identify solutions for problems.

The figure 3.1 (a) describes a traditional group decision-making process (Herrera et al., 1995) while the figure 3.1 (b) illustrates an updated version of group decision-making process that includes the consensus reaching process and the selecting process (Butler and Rothstein, 2007)

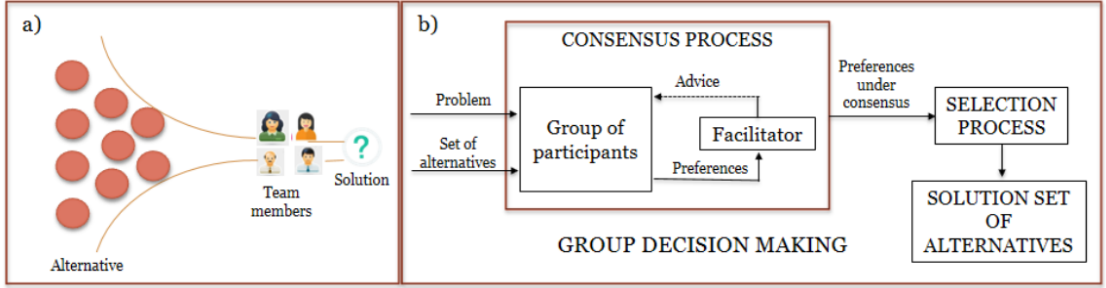


Figure 0-1 Group decision-making process in traditional way (a) (Herrera et al., 1995) and updated version (b) (Butler and Rothstein, 2007)

In a decision-making process of Smart City under Living Lab approach, stakeholders are considered as organizations or groups that have a common interest to participate as soon as in the decision-making process. The opinions of stakeholders are assumed to be a result of meetings with and consultations of other individuals. Moreover, participants in a decision-making process have their own goal to produce a solution or a selection that is supposed to be accepted by the majority involved participants. A shared decision is the result of a negotiation and communication process between participants with different and sometimes orthogonal views upon the possible alternatives or scenarios. The negotiation and communication end at least in a consensus, when all involved stakeholders accept the selection of some alternatives,

but not necessarily the selection of optimum ones. We consider group decision making as a process-oriented activity. It is aimed at satisficing rather than optimizing.

In this study, the decision-making process will be concerned in three scales including levels of decision, phases of implementing Smart City projects and types of decision, as shown in the figure 3.2. The strategic, tactical or operational level of decisions is a hierarchy based from short to medium and long- term time and vision of projects. The study starts at the top level, strategic level, as a tool supporting managers. In terms of implementation, we consider executing solutions as a process composing four phases, from concept to model, then experiment and finally, evaluation. Each phase involves different stakeholders with dissimilar objectives. Finally, the scope of our study is only focused on group decision-makers who need to share collaborative decisions.

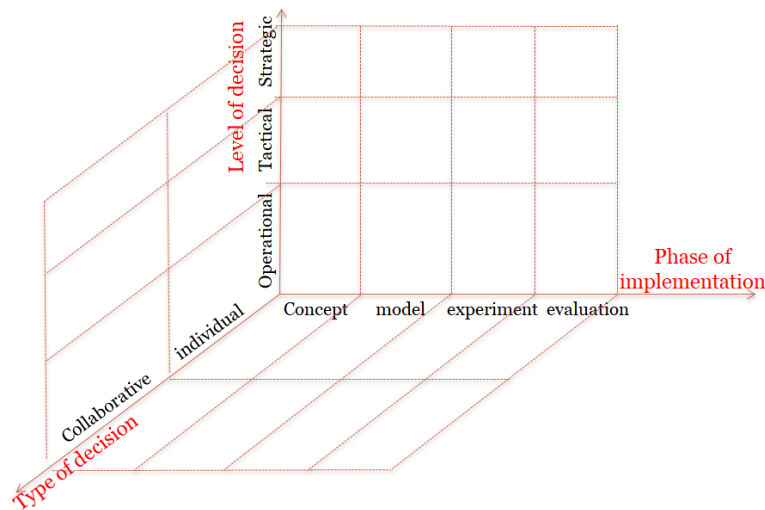


Figure 0-2 Dimensions of decisions under Living Lab approach

### 3.2. The role of situation awareness in a decision-making process

Situation awareness is described as an internal model of each people based on the way people aware of the state of the surrounding environment, decide what to do about the situation and carry out any necessary actions (Endsley, 1995). In groups of decision-makers, each team member has specific responsibilities and own situation awareness. In the case of conceiving the overall situation awareness, members of groups work together as a team to share actions or decisions. Thus, shared team situation awareness is dependent on the understanding of the status of all involved individuals (McNeese et al., 2001). The model of a shared situation awareness in a group can be described as the figure 3.3.

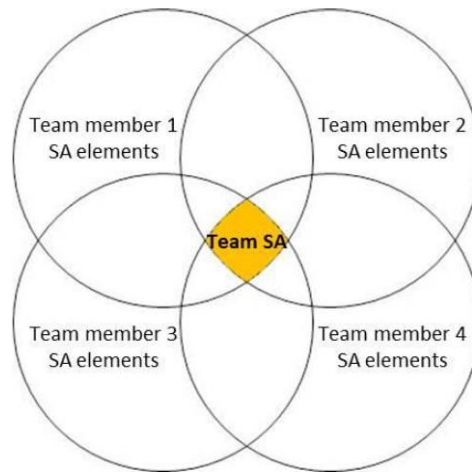


Figure 0-3. Team situation awareness (Endsley, 1995)

Figure 3.4 describes a group decision-making process based on the evolution of situation awareness. In the first phases of the decision process, a situation awareness is a personal aspect of each participating actor generated by the use of information, education, professional background, experiences, values, etc.. of each individual. When the negotiations and decision-making begin, relevant factors of situation awareness have to be exposed to the other participants for reaching a mutual decision. Finally, the main factors of the shared situation awareness are reported in the public decision documentation. Therefore, good situation awareness enhances the probability of shared decisions.

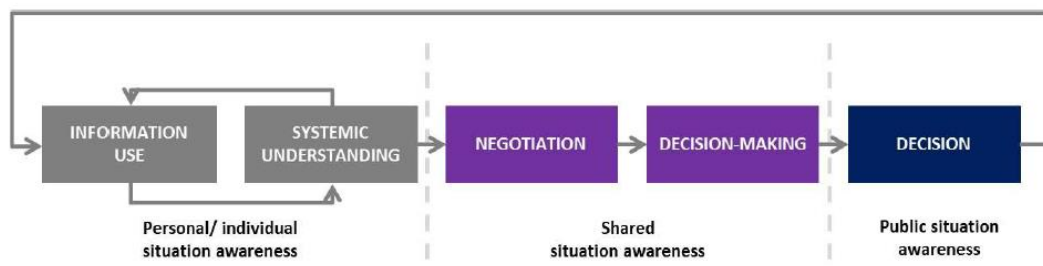


Figure 0-4 The evolution of situation awareness during a decision-making process (Eräranta, 2013)

One of the main obstacles of situation awareness in decision making is the use of information. The number of information sources varies and the way using information is dissimilar among participants. Long decision-making chains cause the information to be selected and filtered several times before reaching the final phase of decision-making process.

In order to enhance making a shared decision in a group of people, it is necessary to improve the share situation awareness throughout building a strong systematic understanding and sharing information between decision-makers.

### 3.3. Consensus reaching process in a group decision making

Consensus reaching processes normally consist of several rounds of discussion, coordinated by a facilitator, who helps the members of the group to make their opinions closer (Martinez and Montero, 2007). In this section, consensus reaching processes will be reviewed based on the classify of Wu & Xu: preference relations and measures (Wu and Xu, 2012). Beside, Palomares



& Martinez suggested one more criterion for this classify that is types of a moderator (Palomares and Martinez, 2013).

### 3.3.1. Preference relations

Because of the increasing complexity of the socio-economic environment, many decision-making processes in the real world take place in collaborative settings. Preference relations are popular and powerful techniques to model preferences of participant in group decision-making (Wu and Xu, 2012). The three commonly used preference relations are fuzzy preference relations, multiplicative preference relations (also known as pairwise comparison matrix in the Analytical Hierarchy Process), and linguistic preference relations (Herrera-viedma et al., 2014). In this section, based on (Herrera-viedma et al., 2014), we formalize preference relations as follows:

In a classical group decision making situation, there is a set of possible alternatives  $X = \{x_1, \dots, x_n\} (n \geq 2)$  and a group of participants,  $E = \{e_1, \dots, e_m\} (m \geq 2)$ , characterized by their background and knowledge, who express their opinions about  $X$  to achieve a common solution.

The preferences of participant  $l$  on  $X$  are described by means of a  $P^l = (p_{ij}^l)^{n \times n}$ ; where  $p_{ij}^l = \mu(x_i, x_j)$ ;  $\mu \rightarrow D$  can be interpreted as the preference degree or intensity of the alternative  $x_i$  over  $x_j$  expressed in the information representation domain  $D$ . Different types of preference relations can be used according to the domain used to evaluate the intensity of the preference:

- *Fuzzy preference relations*: If  $D = [0,1]$  every value  $p_{ij}^l$  in the matrix  $P^l$  represents the preference degree or intensity of preference of the alternative  $x_i$  over  $x_j$ ;  $p_{ij}^l = 1/2$  indicates indifference between  $x_i$  and  $x_j$ ;  $p_{ij}^l = 1$  indicates that  $x_i$  is absolutely preferred to  $x_j$ , and  $p_{ij}^l > 1/2$  indicates that  $x_i$  is absolutely preferred to  $x_j$ . It is usual to assume  $p_{ij}^l + p_{ji}^l = 1$ ;  $\forall i, j$

- *Multiplicative preference relations*: If  $D = [1/9,9]$  and then every value  $p_{ij}^l$  in the matrix  $P^l$  represents a ratio of the preference intensity of the alternative  $x_i$  to that of  $x_j$ ; i.e., it is interpreted as  $x_i$  is  $p_{ij}^l$  times good as  $x_j$ ;  $p_{ij}^l = 1$  indicates indifference between  $x_i$  and  $x_j$ ;  $p_{ij}^l = 9$  indicates that  $x_i$  is unanimously preferred to  $x_j$ , and  $p_{ij}^l \in \{2, 3, \dots, 8\}$  indicates intermediate evaluations. It is usual to assume  $p_{ij}^l \cdot p_{ji}^l = 1$ ;  $\forall i, j$

- *Linguistic preference relations*: If  $D = S$ , where  $S$  is a linguistic term set  $S = \{s_0, \dots, s_g\}$  with odd cardinality ( $g + 1$ ),  $s_{g/2}$  being a neutral label (meaning “equally preferred”) and the rest of labels distributed homogeneously around it, then every value  $p_{ij}^l$  in the matrix  $P^l$  represents the linguistic preference degree or linguistic intensity of preference of the alternative  $x_i$  over  $x_j$ .

### 3.3.2. Measures of consistency and consensus

The consistency and consensus measure is a vital basis of group decision making (Wu and Xu, 2012), (Zhang et al., 2014). When carrying out rational decision making, consistent information is more appropriate than information containing some contradictions. If we were to secure consensus and only thereafter consistency, we would destroy the consensus in favor of individual consistency and the final solution might not be acceptable to the decision-makers. Clearly, it is preferable that the set of decision-makers reach a high degree of individual consistency before reaching consensus and then, applying the selection process. In a rational group decision making process, both consensus and consistency should be pursued and sought after.

### 3.1.2.1. Consistency measures

Group decision-making usually focuses exclusively on several alternatives facilitates participants in expressing their preferences. However, providing preferences limits the global perception of participants about alternatives. As a consequence, the provided preference relations may lead to irrational or inconsistent conclusions.

The decision-maker makes a direct choice of one object over another when comparing two objects by expressing preferences through the use of pairwise comparisons. However, inconsistencies are not unexpected, as making value judgments can be difficult in some situations. Many authors have paid attention to the individual consistency problems of preference relations. For multiplicative preference relations, there are two well established methods to create a consistency index. One of these is the consistency ratio based on Saaty's eigenvector method. The other method proposed by Crawford and Williams is the geometric consistency index based on a row geometric mean prioritization.

Let  $P^l = (p_{ij}^l)^{n \times n}$  where  $p_{ij}^l > 0$ , is a judgment matrix provided by the decision-maker  $l$  on a set of possible alternatives  $X = \{x_1, \dots, x_n\} (n \geq 2)$ .

- The eigenvector method by Saaty (Saaty, 1990a)

Saaty defined the consistency index as  $CI_A = \frac{\lambda_{max} - n}{n-1}$ , where  $\lambda_{max}$  is the largest or principal eigenvalue of  $P^l$  and  $n$  is the number of criteria.

To measure the inconsistency of the matrix  $P^l$ , we use the consistency ratio  $CR_A = \frac{CI_A}{RI_n}$ , where  $RI_n$  is average random consistency index derived from randomly generated index. In general, if  $CRA$  is less than 0.10, we say that the matrix  $P^l$  is acceptably consistent

Table 0-1 The random consistency index

n	1	2	3	4	5	6	7	8	9	10
RI <sub>n</sub>	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

- The row geometric mean method by Crawford and Williams (Crawford and Williams, 1985):

Let  $W = (w_1, w_2, \dots, w_n)$  be the priority vector derived from matrix  $P^l$ ,

$$\text{where } w_i = \frac{\sqrt[n]{\prod_{j=1}^n p_{ij}}}{\sum_{i=1}^n (\sqrt[n]{\prod_{j=1}^n p_{ij}})}$$

The geometric consistency index (GCI) is given by

$$GCI = \frac{2}{(n-1)(n-2)} \sum_{i < j} (\log a_{ij} - \log w_i + \log w_j)^2$$

When  $GCI = 0$ , we consider  $P^l$  fully consistent.

The thresholds ( $\overline{GCI}$ ) for geometric consistency index  $GCI$  is selected from:  $\overline{GCI} = 0.31$  for  $n=3$ ;  $\overline{GCI} = 0.35$  for  $n=4$  and  $\overline{GCI} = 0.37$  for  $n > 4$ .

When  $GCI < \overline{GCI}$ , we consider that the matrix  $P^l$  is of acceptably individual consistency.



### 3.1.2.2. Consensus measure

The consensus measure is used to measure the difference among decision-makers and is a vital element of consensus models. A consensus process can be viewed as a dynamic and iterative group discussion process with several consensus rounds, in which the decision-makers agree to change their preferences following advice given by a facilitator. The facilitator knows the agreement at each moment of the consensus process by means of the computation of various consensus measures and is in charge of supervising and moving the consensus process towards success. Different models that guide the moderator and the decision-makers in achieving the consensus process have been developed for group decision making problems.

A concept of consensus refers to the final decision accepted by most of members of group after several rounds of negotiation (Tapia, 2018). Figure 3.5 describes a scheme of consensus reaching process as a dynamic process with iterative group discussion rounds (Palomares & Martinez, 2013), (Palomares, Quesada, & Martínez, 2014). In each round, the current consensus degree among stakeholders have been calculated based on their preferences. If the agreement level is lower than a minimum consensus threshold fixed a priori by the group, a set of recommendations is created for stakeholders to modify their preferences in order to make them closer during the subsequent discussion rounds. Otherwise, when the agreement is acceptable, the selection process it would apply in order to obtain the final solution for a group decision-making problem.

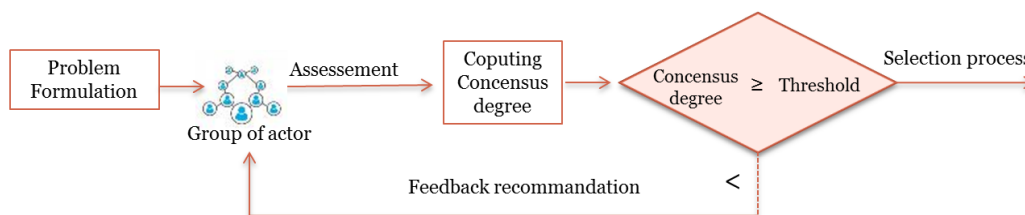


Figure 0-5 General consensus reaching process in group decision making (Palomares & Martinez, 2013)

### 3.3.3. Type of facilitator in the consensus reaching process

#### 3.3.3.1. Consensus reaching process with a human facilitator

Normally, the consensus process is guided by a human figure called a moderator or a facilitator who is a person that does not participate in the discussion but monitors the agreement in each moment of the consensus process. Moreover, he/she is in charge of supervising and addressing the consensus process toward success, i.e., to achieve the maximum possible agreement and to reduce the number of participants outside of the consensus in each new consensus round. However, the human moderator can face overload information in the process (Palomares and Martinez, 2013). To overcome this problem, making more effective and efficient decision-making processes, new consensus approaches have been proposed by substituting the moderator figure or providing a moderator and the group with better analysis tools.

#### 3.3.3.2. An automatic consensus reaching process

In large groups of decision-makers, the existence of subgroups with very different opinions is especially frequent. Due to this fact, stakeholders might need to dedicate a higher amount of

time to revise and modify their preferences during the consensus reaching process. For this reason, it is necessary to develop a model based on a highly scalable and distributed architecture, which is suitable to support computationally consensus reaching process in large-scale group decision-making problems, especially where it is difficult to organize physical meetings which all stakeholders can attend (Filip, 2007). In this consensus support system, a negotiation process is supervised automatically without using a human moderator. This system, called “automatic consensus reaching process” checks the consensus degree in each round of the group discussion process. Besides, a feedback mechanism based on rules is provided to generate the recommendations and help participants change their opinions in the group discussion process.

### **3.4. Group decision making and consensus reaching process in a Living Lab environment**

As defined in chapter 2, Living Lab is considered as an opened innovation ecosystem in which the practices of open-innovation are adopted to identify and co-design the urban problems (Lacroix et al., 2017). Dupont et al. have reviewed the main types of collective design processes dedicated to urban issues (Dupont et al., 2012). First, there is a *distributed design*, in which design team members are assigned clearly separated tasks and duties towards a mutual objective. Second, there is a *collaborative design*, in which members of a group are working within the same environment. Finally, a *distributed collaborative design* technology is proposed as a method that combines both *distributed* and *collaborative* strategies. In this section, we continue to further research about these three types of collective design process and the consensus reaching process designed for each process.

#### *Collaborative process*

In a collaborative process, stakeholders working with others to find solutions that are satisfactory to all concerned (Dupont et al., 2012). The collaborative process is a human-based, “interdisciplinary and socio-technical activity” that brings various stakeholders who have different backgrounds and objectives to work together in a physical environment (i.e. in the same place) or in virtual space and at the same time (Lu et al., 2000). After a series of interactions and multiple critical discussions between members of a group who negotiate for a shared understanding, sub-final decisions are taken before making a final decision. Many of the conflicts in this strategy are related to interactions because ‘roles often overlap’ that could be resolved by negotiations and face-to-face meetings (Gabriel and Maher, 2002).

The concept of consensus reaching process in collaborative decision making is described as a process of deciding sub-decisions after each round of face – to – face negotiation. The final decision has to satisfy all objectives of different stakeholders. In this process, the role of a facilitator is extremely important.

#### *Distributed process*

In the concept of distributed design, participants work in a distributed context, achieving separate activities in parallel towards a mutual objective (Dupont et al., 2012). These participants have various abilities to work simultaneously, but separately, involved in the same collective process (Kvan, 2000). It is thus possible to conclude that this method comprises an asynchronous working method. Operational synchronization is necessary in order to manage processes and to coordinate different participants. In order to synchronize this process, a virtual environment with a common language could play the role as an intermediate space for communication of stakeholders.



The reaching consensus process in this way could be considered as a system, where each participant separates at different times, different spaces but compromises and discusses with the same interface. Therefore, a model of reaching consensus in distributed process have to base on a highly scalable and dispersed architecture, which is facilitated to organize both physical and virtual meetings for a large number of stakeholders.

#### *Distributed collaborative process*

Dupont et al have illustrated a distributed collaborative process where the first level, where stakeholders work together or individually in accordance with the ‘moment’ (or stage) of the project in which they are involved. At this level, they listen to the opinions from others. At the second level, which is superior, participants work at the same time but individually to give their own decision (Dupont et al., 2012).

### **3.5. Conceptual models of group decision making in Living Lab environment**

The decision-making process under Living Lab approach includes a negotiation and consensus process. During this decision- making process, all 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.

In this section, we propose a conceptual model for group decision making covering all three aspects of a reaching consensus process. Firstly, this model has to be applicable with three types of preference relations, multiplicative, fuzzy and linguistic preference relations. Besides, this model also has to consider both consistency and consensus measures before making the selecting process. Finally, it is necessary to clarify two types of a moderator in reaching consensus process, automate and human facilitator.

#### *3.5.1. The group decision making with an automatic control system*

In the context of distributed or large group decision-making process, it has been considered much more promising to run the consensus reaching session with the help of a special agent, called an artificial moderator or facilitator. In such a way, the consensus reaching process could be guided automatically, without a moderator, avoiding the possible subjectivity that moderator could introduce in the consensus reaching process. This automatic control system uses consensus degrees to decide when the consensus process should finish and creates a feedback mechanism based on rules and algorithms to aid participants to change their preference automatically in the next consensus rounds.

The consensus process with automatic control system is described as figure 3.6 that including several steps:

1. Firstly, the problem has been previously structured in a set of criteria (see section 1.5) and presented to each member of the group, along with the different alternatives that they have to choose the best one.
2. Then, participants can discuss and share their knowledge about the problem and alternatives.
3. Participants provide their preferences about the alternatives in a particular preference relation, multiplicative, fuzzy or linguistic preference relations. At this step, an interface of supported tools is provided for participants to collect their preferences.

4. The automatic control system is used to compute some consensus measures that will allow identifying if enough consensus state has been reached or not. If the consensus state has reached a fixed threshold, the consensus process ends, and the selection process starts. Otherwise, the automatic control system gives recommendations for the representation of participants to change preferences and reach consensus.

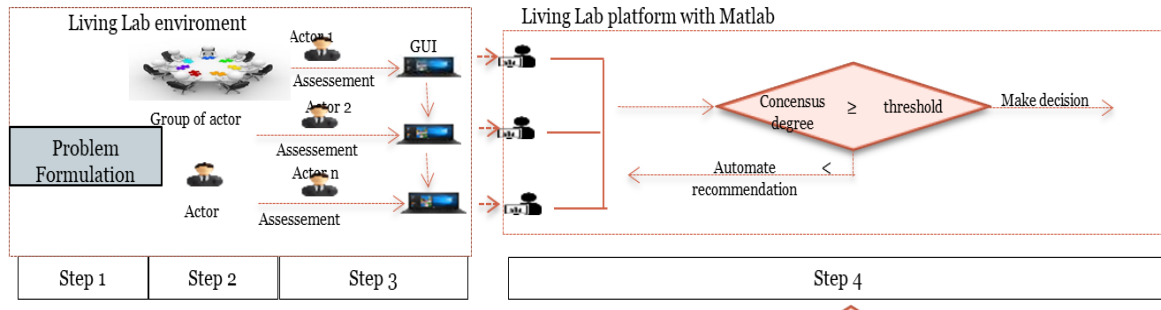


Figure 0-6 The consensus reaching process with automatic control system

### 3.5.2. The group decision making with a human facilitator for reaching consensus process

The reaching consensus process consists in obtaining the maximum degree of consensus or agreement between the set of participants on the solution set of alternatives. In this part, we focus on the consensus approaches in which there is a human moderator, whose task is to help the individuals involved while changing their testimonies towards consensus, by rational arguments and persuasion. Clearly, he or she should be supported by some information to be provided by tools and techniques.

A consensus process is considered as a negotiation process developed iteratively among the group members and composed by several consensus rounds, where the participants accept to change their preferences following the advice given by a moderator. In order to shorten the time of recommendation, the moderator uses a supported tool or technique to compute the agreement degree in each round of the consensus process and then give recommendations. The consensus process with human facilitator is described as figure 3.7 that including several steps:

1. Firstly, the problem is presented to each member of groups, along with the different alternatives that they have to choose the best one.
2. Then, participants can discuss and share their knowledge about the problem and alternatives.
3. Participants provide their preferences about the alternatives in a particular preference relation, multiplicative, fuzzy or linguistic preference relations. At this step, an interface of supported tools is provided for participants to collect their preferences.
4. The supported tool is used to computes some consensus measures that will allow identifying if enough consensus degree has been reached or not.
5. If the consensus level is higher than the fixed threshold, the consensus process stops, and the selection process begins. Otherwise, a recommendation process starts with suggests and feedback for participants to improve their agreement level.
6. The moderator and the supported tool give advice and recommendations for participants to more easily reach consensus. The first round of consensus is finished. Again, participants must discuss their opinions and preferences in order to approach their points of view (Step 2).

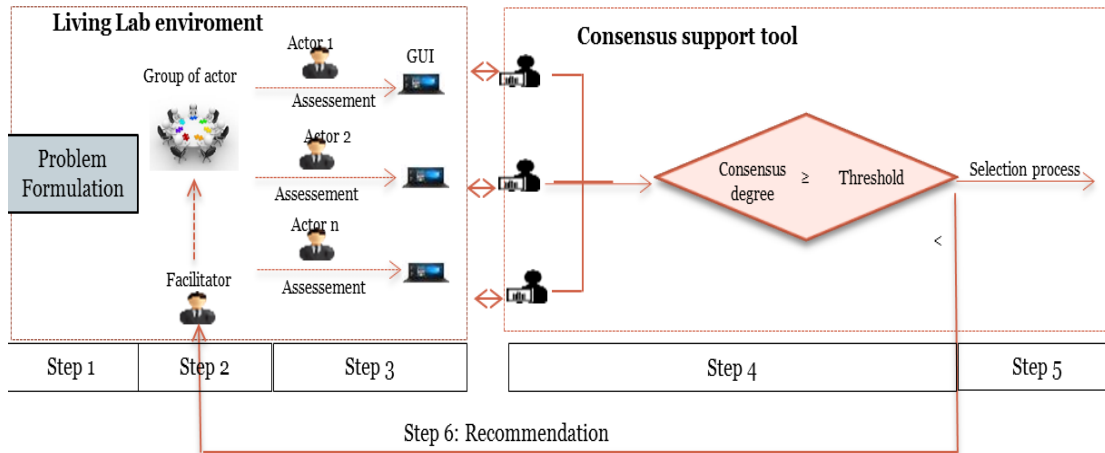


Figure 0-7 The consensus reaching process supervised by human facilitator

### 3.5.3. Comparing three types of consensus process: collaborative, distributed automatic and distributed collaborative.

Based on characteristics of three types of a collaborative process dedicated to urban issues (Dupont et al., 2012), I have developed three corresponding types of consensus reaching process collaborative, distributed automatic and, distributed collaborative. In this section, I will summarize and compare these consensus reaching processes regarding to the main characteristic in space of negotiation, their outcome and limit (table 3-2).

Table 0-2 Comparing three types of consensus process

	Collaborative consensus process	Distributed Automatic consensus process	Distributed collaborative consensus process
Space for negotiation	Stakeholders work together in physical environment (i.e. in the same place) or in virtual space and at the same time.	Stakeholders work simultaneously, but separately in a distributed context at different time, different space but communicate with the same artifact	At first level, stakeholders work together/collectively or individually/alone; a second level, where the participants work at the same time together and individually
Outcome	One sub- final decision of group is given after each round of face – to – face negotiation	After receiving a feedback recommendation, stakeholders automate to change their assessment based on a rule	After face – to – face negotiation, stakeholders give their assessment individually. They automate to change their assessment based on a rule.
Limiting aspects	- Conflicts because 'roles often overlap'	- In real situations, some stakeholders want to	A complex model that need a suitable algorithm.

	<ul style="list-style-type: none"> <li>- Take a lot of time in large groups</li> <li>- Difficult to organize physical meetings which all stakeholders can attend</li> <li>- Trust between stakeholders</li> </ul>	<ul style="list-style-type: none"> <li>revise and accept/reject the modifications by themselves</li> <li>- Some stakeholders want to keep their sovereignty and power in negotiation process</li> <li>- Trust in the AI (It is difficult to accept machine can better than human brain...)</li> </ul>	<ul style="list-style-type: none"> <li>Trust between stakeholders and confidence in its own abilities</li> </ul>
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## Conclusion

The term consensus can be defined as a state of mutual agreement among members of a group, where the decision made satisfies all of them. Reaching a consensus normally implies that participants change their initial opinions in a discussion process, tending to make them closer to each other, towards a final collective opinion which satisfies the whole group. In case it is unable to achieve a consensus, a feedback recommendation is sent to stakeholders to modify their preferences in order to increase the level of agreement in the following negotiation rounds.

In this chapter, after defining the most important terms and the mechanism enabling to reach consensus in different situation, we propose conceptual models for two kind of reaching consensus process: a process with human facilitator and an automatic control system that substitutes the facilitator's actions. In the next chapters, we will continue to explain about model formalization as well as a description of the consensus reaching algorithms.



## **SECTION 3: MODEL DEVELOPMENT**

### **: Proposition of an automatic control system based on Multi- Agent System to support Consensus Reaching Processes**

#### **Introduction**

The idea of using networked technology is already applied in China as a tool of government (Larson, 2018) or in American campaign that kicked off a technological revolution in electioneering (Knight, 2018). Advanced technology, including progress in data, AI and internet surveillance, has brought visions of authorities closer to real-life conditions. The question is whether ICT has become a factor of transparent democracy when citizens have a chance to gathering information and actively involvement in public decisions or just only a powerful governmental tool of authority.

According to the analysis shown in chapter 2, artificial intelligence-based methods have a strong potential for solving high levels of complexity in the modeling process of group decision making at the operational and tactical levels. However, there are a few studies that focus on using decision- making tools to support consensus reaching process in Smart City projects. Based on the classification given in chapter 3, there are two types of group decision-making process including the reaching consensus process, namely automatic control system and the process supervised by a human facilitator. In order to provide an artificial intelligent -based automatic consensus control system, some researchers have developed several consensus support systems focused on the implementation of different consensus models. Among artificial intelligent technique, the multi-agent system paradigm would be a convenient choice to develop a consensus support system that overcomes the above difficulties in large and distributed group decision-making, due to its scalability, distributed computing capabilities and the possibilities it offers to model different types of behavior by means of software agents. This chapter develops an attempt to presenting a methodological proposal for group decision-making processes supporting the consensus reaching processes between stakeholders.

Chapter 4 : Proposition of an automatic control system based on Multi- Agent System to support Consensus Reaching Processes ..... **Erreur ! Signet non défini.**

    Introduction ..... **Erreur ! Signet non défini.**

    4.1. Automatic control systems to support Consensus Reaching Processes**Erreur ! Signet non défini.**

    4.2. The multi-agent systems approach/ paradigm ..... **Erreur ! Signet non défini.**

        4.2.1. Concept of multi-agent system ..... **Erreur ! Signet non défini.**

        4.2.2. Definition of multi-agent system ..... **Erreur ! Signet non défini.**

        4.2.3. Applications of multi-agent systems in decision theory**Erreur ! Signet non défini.**

        4.2.4. Applications of multi-agent system in Living Lab ... **Erreur ! Signet non défini.**

    4.3. An automatic control system based on multi-agent system for group decision-making process under a Living Lab environment ..... **Erreur ! Signet non défini.**

        4.3.1. The model formalization..... **Erreur ! Signet non défini.**

        4.3.2. The software implementation..... **Erreur ! Signet non défini.**

    Conclusion ..... **Erreur ! Signet non défini.**





#### 4.1. Automatic control systems to support Consensus Reaching Processes

A consensus reaching process could be guided automatically, without a moderator, avoiding the possible subjectivity that a moderator could introduce in the consensus reaching process.

Herrera and his colleagues deal with the consensus problem by assuming that participants could use different linguistic domains to express their opinions (Herrera et al., 1995). The main novelty of this contribution is to present an automatic control system to guide the consensus process that substitutes the moderator's actions. This consensus model uses the consensus degrees to decide when the consensus process should finish and the proximity measures to define a recommendation system that recommends participants about the preferences that they should change in the next consensus rounds.

Another consensus contribution is proposed in (Alonso et al., 2007) to provide tools to support the consensus processes in the presence of incomplete information or missing values in group decision-making problems. In such a way, the authors define the first consensus model without a moderator which is controlled automatically by means of three kinds of measures: consensus measures, consistency measures and incompleteness measures.

Another study on a peer to peer dynamic adaptive consensus reaching model for the group AHP decision problems is proposed by Q. Dong and O. Cooper (Dong and Cooper, 2016). This automatic feedback mechanism of the consensus reaching model is developed to adapt the portion of judgments of decision-makers in a dynamic group consensus reaching process.

In terms of urban planning research, a paper presents a multi-agent system to simulate the multi-actors interactive spatial-planning process (Ligtenberg et al., 2004). This multi-agent system extends an existing approach with the principle of sharing knowledge between participating actors while trying to create a shared vision. In the simulation, actors are modeled as agents. They have desires and preferences regarding their individual views on what areas are eligible for change.

Most of these consensus models use only consensus measures to control and guide the consensus process in social contexts. There is a lack of types of negotiation model in complex and dynamic systems as Smart City projects. As mentioned in the 2<sup>nd</sup> chapter, the artificial intelligent paradigm, which is characterized by its scalability and distributed computing capabilities, can be a reasonable choice to develop a consensus support system that supports large groups effectively. Among artificial method, multi-agent system is one of the popular choices to model the group decision making method in a complex system.

#### 4.2. The multi-agent systems approach/ paradigm

Amongst the current challenges and difficulties of consensus reaching process stated in the chapter 3, it was pointed out the importance of selecting a tool of consensus support system suitable to deal with large-scale group decision-making problems efficiently, minimizes participants' supervision of preferences and their sovereignty is to some extent eliminated.

In this section, we briefly revise multi-agent system technologies and some related works on consensus models, consensus support systems and some existing multi-agent based proposals for group decision-making in the literature.

#### *4.2.1. Concept of multi-agent system*

The artificial intelligence is intelligence demonstrated by machines that widely used as a formal representation of the brain to allow behavior "smart" for the machines (Ferber et al., 1999). The artificial intelligence has laid the foundation for the development of systems based on agents. Similarly, since the 40s, the idea of modeling based on multi-agent, was designed as a simple concept of "The Von Neumann Machine" (Neumann and Morgenster, 1944) Then, with the development of distributed computing based on object-oriented programming, the power of computing and machine has been increased to solve more complex systems. The complex system will thus be the result of distributed artificial intelligence (Avouris and Gasser, 1992).

Multi-agent system is an area of knowledge of distributed artificial intelligence. This notion is also considered as a new methodological approach to the study and the characterization of the behavior of complex systems. In this way, this concept is a new way of model and simulate real systems, which allows for autonomous interaction between agents artificial and human (users), thus approaching the essence of the concept of artificial intelligence.

The concept of multi-agent systems is interdisciplinary because it is inspired from different domains such as economics, philosophy, logic, ecology and science (Wooldridge, 1999). It is therefore not surprising that there are different points of view, applications and various definitions of these agents. But this diversity makes it an approach interesting for solving the problems.

#### *4.2.2. Definition of multi-agent system*

In a multi-agent system (MAS) method, the term of agent refers to a software entity capable of achieving a goal in an autonomous and intelligent way, exchanging information with its environment or with other agents (Wooldridge, 1999).

From the point of view of Wooldridge, the agent has the following properties:

**Interaction:** the general ability of communication with the environment and with other agents in the environment. These interactions affect any type of agent: human, computer, legal systems or sources of information.

**Coordination:** the ability to execute shared activities with other agents. The activity is achieved through the coherence of action plans or the establishment of other management mechanisms.

**Cooperation and collaboration:** this time we are referring to achieve common objectives. The agents share a future vision of the environment and the role of each other.

**Competition:** it's the opposite of cooperation, so the success of an agent leads to the failure of others.

**Rationality:** is defined as the possibility of choosing an action according to its objectives own and /or knowledge.

**Adaptability:** this function is related to learning available to an agent and his ability to change its behavior based on this learning.

**Veracity:** in MAS, it is assumed that an agent cannot deliberately communicate false information.

**Benevolence:** in MAS, it is assumed that an agent is ready to help other agents sharing the same goals. It is this property of benevolence that makes possible the cooperation between agents.



An agent in a multi-agent system is independent and capable of making its own decisions. A multi-agent system can be defined as a system composed of a number of agents with different roles and responsibilities that operate in an organized and coordinated way to achieve an individual or collective goal (Van Dam et al., 2012).

Finally, the classification according to the criterion of interaction capacities of the agents (Wooldridge, 1999).

**Reactive agent:** This is a basic agent, because it has no symbolic models of its environment. Its only possibility is to respond to the stimuli of the environment (reaction action). It acts according to the current state of the environment. Reactive agents are not individually intelligent, but globally intelligent. Reactive systems are generally composed of a large number of agents. They cooperate and communicate to perform actions, but they do not have a knowledge base (memory of past actions) and they behave only in accordance with stimulations, changes or inputs received from the outside environment.

**Cognitive agent:** The cognitive agents are those who are capable of carrying out complex operations, they mobilize reasoning a knowledge base, they communicate with the other agents and reach an agreement on decisions with all or part of them. A cognitive system is made up of a small number of cognitive agents capable of negotiating their individual goals. They use an internal reasoning model that allows them to plan and make contact with other agents. In these systems, we accept the idea of sharing with agents common planning which determines the measures to reach their objectives. Thus, a cognitive agent (or with a deliberative architecture) is one that contains a model explicit symbolic of the world where decisions are made using reasoning mechanisms logic based on matching patterns and symbolic manipulation.

**Hybrid Agents:** It is possible to design heterogeneous systems whose behavior is derived from both types of agents and of which he possesses some of their characteristics. That is, it is possible to endow cognitive agents of event reaction capabilities. These agents can be called hybrid agents. A hybrid agent may be constructed on the basis of two subsystems: a deliberative with a model symbolic of the world and which generates plans to follow, and another reactive to the events in the environment and does not require complex reasoning mechanism.

#### *4.2.3. Applications of multi-agent systems in decision theory*

A number of approaches based on a multi-agent system to support group decisions have been proposed in the last few years. They are briefly revised, together with some related work in consensus reaching.

Regarding proposals based on a multi-agent system for group decisions, several authors have focused their research on multi-agent architectures applied to negotiation frameworks. A preliminary discussion on the use of a multi-agent system for supporting distributed negotiation processes can be found in (Weiss, 1999). A review of different group negotiation protocols (e.g. voting methods, bargaining, auctions, etc.) is given in this work, together with the basic guidelines to model such protocols by means of software agents. Hindriks et al. proposed an agent-based architecture for negotiation processes (Hindriks et al., 2008). The study proposed an architecture to conduct bilateral negotiations in different context of e-commerce. Each agent is represented by different buyer and seller tactics. More recently, Sanchez-Anguix et al.

presented an agent-based negotiation model for automating purchases in the e-market. In this model, the decision group harmonized by a mediator has to discuss with an opponent before proceeding to buy a product (Sanchez-Anguix et al., 2012). A thorough research on different team strategies and agreement technologies to be considered in such a model was later presented by the same authors (Sánchez-Anguix et al., 2013).

A multi-agent approach for large-scale group decisions was proposed by Okumura et al. (Okumura et al., 2013). They presented a multi-agent system for collaborative park-design support, characterized by gathering opinions from participants, estimating utility functions upon such preferences and applying an automated agent-based negotiation protocol to find optimal agreements. The negotiation process to find a consensus is carried out in a completely autonomous way. Therefore, participants provide their preferences to the system only at the beginning of the process.

The works revised above utilize the multi-agent system paradigm to support group decisions that require a high level of agreement by means of specific negotiation frameworks and protocols. The development of a multi-agent system -based consensus support system, would be particularly convenient when it comes to deal with large-scale group decision- making problems, due to the considerable computational cost and required scalability.

#### *4.2.4. Applications of multi-agent system in Living Lab*

PowerMatching City is the first Living Lab smart grid in Europe, located in Groningen, Northeast of the Netherlands (Bliek et al., 2010). In a successor project, appliances in 40 households are being coordinated within the smart grid. The distributed coordination technology, called PowerMatcher, is a multi-agent system using electronic exchange markets to match the electricity supply and demand. All appliances are represented by an agent that is entrusted with the optimization of the device's objective. Every agent defines a bid that represents the allocated power for a given PowerMatcher price range (Wijbenga et al., 2014).

Tokyo Virtual Living Lab project is an experimental space based on 3D Internet technology for conducting controlled driving and travel studies (Prendinger et al., 2013). This virtual lab supports the involvement of users into the same mutual space. This is a vital feature for analyzing collaboration in future smart cities. In this study, a multi-agent traffic simulator is developed based on the Navigation Network to support the integration of user-controlled vehicles.

In these studies, reactive agents are represented for technological aspects or devices of Living Lab environment. In the next section, we will use cognitive and reactive agents for modeling decision-making process throughout the model formalization and software implementation.

### **4.3. An automatic control system based on multi-agent system for group decision-making process under a Living Lab environment**

#### *4.3.1. The model formalization*

In this subsection, the key components of our automatic control system based on multiagent system for group decision-making process in Living Lab environment are described. Such components are, namely: the communication mechanisms and protocols considered to allow agents to communicate with each other and the algorithms of multi-agent based method. The model formalization consists of two tasks: creation of a model narrative and the expression of this narrative in pseudo-code.

#### 4.3.1.1. Model narrative

A narrative is a description of the generative theory of the system; leading to patterns we are interested in exploring. For an agent-based model, the behavior of each of the agents can be captured in a story which explains the actions and the communication mechanisms of agents.

##### a) Components of multi-agent system

In this section, each agent with a specific function has been designed and implemented with the purpose of supporting the consensus reaching process, as concluded in table 4-1. There are three types of agents, namely:

**Actor Agent:** An actor agent represents a participant in the group, acting autonomously. It represents the actor's preferences. Therefore, the actor agent is a cognitive agent in this multi-agent system. Actor agents implement the change profiles and rules defined by the automatic consensus support rule.

**Consensus Evaluation Agent:** This agent assumes the human moderator role, automating his/her responsibilities. This agent is in charge of computing consensus degree, as well as compare consensus degree and threshold.

**Feedback to change Agent:** Its responsibility is focused on carrying out the phase of generating recommendations based on computing parameters of changes.

Other essential components in the system architecture are:

The graphical user interface (GUI) for participants access and provide their preferences

The ontology to facilitate communication between agents.

A database to store data about previous consensus rounds in the group decision-making problem.

Table 0-1 The functions of Agents

<b>Agent</b>	<b>Type of Agent</b>	<b>Function</b>
Actor Agent	Cognitive agent	Gather preferences of actor by GUI Change preference according to recommendation of "Agent feedback to change"
Consensus Evaluation Agent	Reactive agent	Computing consensus degree Compare consensus degree and threshold
Feedback to change Agent	Reactive agent	Compute parameters of change

Figure 4.1 represents the different types of agents (human, cognitive and reactive) on different "platforms" with relationships within and between levels. The overall representation of the multi-agent system in Figure 4.1 illustrates the interactions between the agents. In multi-agent system organization, actor agent represents for human actors in a collaborative process. Meanwhile, other agents communicate directly with the Actor Agent by sending messages.

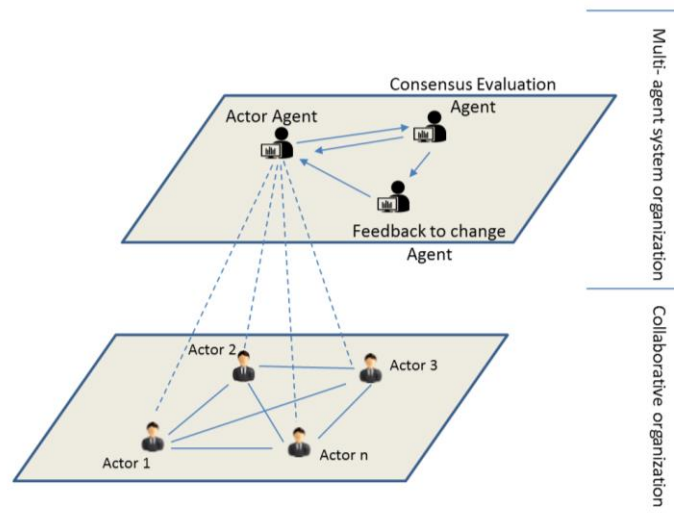


Figure 0-1 The global representation of the multi-agent system for collaboration

In order to have a detailed vision about the structure of this multi-agent based consensus support system, we describe in further detail communication flows between agents as figure 4.2.

**Actor Agent:** Its goal is to automate the tasks carried out by participants in real consensus reaching process. Each member of the group has associated an actor agent during a group decision-making problem in which he participates. In the first discussion round, Actor agent collects the preference relation of a human actor and then provides to the Consensus Evaluation Agent. Then, when a change recommendation on preferences is received, the actor agent checks it before giving preferences back to Consensus Evaluation Agent.

**Consensus Evaluation Agent:** this agent is responsible for replacing the human moderator. Therefore, it is a core element of the system. As occurs in real consensus reaching process, the communication of this agent with others is described below:

- Request Preferences: At the beginning of each round, the moderator agent requests Actor agents their preferences. If one or more discussion rounds have already taken place, the request includes the set of recommendations from Feedback to change Agent to the selected Actor Agent.
- Consensus Control: If the consensus degree is enough, the moderator agent informs actor agents about it. Otherwise, it requests a change detector agent to compute change recommendations.
- Feedback to change Agent: This agent is invoked by the Consensus Evaluation agent when a consensus degree is not enough, to identify furthest preferences from the agreement and determine which Actor agents must be given recommendations to modify such preferences.

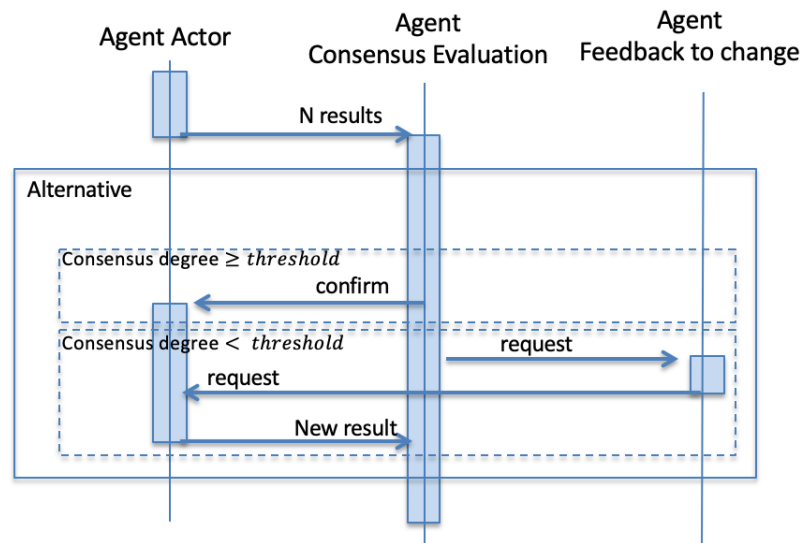


Figure 0-2 The communication model of agents in multi-agent system

#### b) Feedback recommendation

In the following, the main components of the proposed feedback recommendation in a automated way are based on change profiles and rules of change.

#### Profile of agents

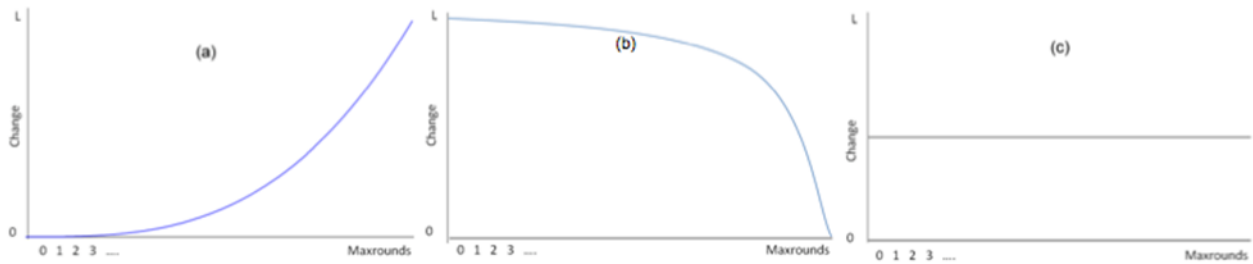
In consensus reaching process (CRP), actors usually adopt different strategies to modify preferences. In order to emulate such proposed strategies, three types of profiles that change functions of agents in the system are represented in the figure 4.3 (Palomares and Martinez, 2013):

**Sure profile:** It represents participants who are sure about their initial opinions. They apply minor changes at the beginning of the consensus reaching process although such changes become greater as the number of discussion rounds increases.

**Unsure profile:** It represents participants who are rather unsure about their initial opinions. They apply major changes at the beginning of the CRP, but these changes become smaller as the process goes on.

**Neutral profile:** It represents participants who are moderately sure about their initial opinions and prefer to apply uniform changes to them during the CRP.

In the automatic control system for group decision-making process, each participant previously chooses the profile that better reflects his/her behavior in order to determine the degree of increase/decrease on an assessment, according to the current consensus round.



(a) “sure” profile, (b) unsure profile, (c) neutral profile

Figure 0-3 Examples of change functions

#### c) Rule of change

First of all, the farthest values of decision criteria from the preferences of all participants that are considered by a participant from the current consensus level at each round is identified. After that, a recommendation gives for this participant to modify (either increase or decrease) such assessments, in order to increase the consensus degree in the next round. Based on this rule, participants should increase the assessment if their preference is lower than the average preference and otherwise, the assessment should decrease if their preference is higher than the average value.

As proposed by I Palomares & Martinez, the value of change ( $\Delta_i(r)$ ) at round  $r$  is formally defined upon an upper limit of change set as  $L$ , Max rounds and the current discussion round  $r$ , as follows (Palomares and Martinez, 2013):  $\Delta_i = (0, \dots, L)$

- for Neutral Profile  $\Delta_i(r) = \frac{L}{2}$

- for Sure Profile  $\Delta_i(r) = L \left( \frac{r}{Maxround} \right)^3$

- for Unsure Profile  $\Delta_i(r) = L \left( 1 - \left( \frac{r}{Maxround} \right)^3 \right)$ ,

where  $r = (1, \dots, Maxround)$  is the round of negotiation.

#### 4.3.1.2. Pseudo- code

- Problem definition

Formally, the problem is defined as a function of the hierarchical structure of the AHP method to identify the global decision to be made.

- Participant analysis and engagement

A set  $E$  of participants has been invited to participate in the decision-making process and express their judgments:

$$E = (e_1, \dots, e_m) (m \geq 2)$$

- Definition of alternatives

A set  $Y$  of two or more alternatives:  $Y = (y_1, \dots, y_s) (s \geq 2)$

These alternatives will be evaluated under the following set of criteria

- Definition of criteria

A set  $X$  of two or more criteria:  $X = (x_1, \dots, x_n) (n \geq 2)$

- Weighting of criteria





Each participant  $e_i$  provides his/her opinion for every pair of criteria which reflect the degree of preference of the first criteria over the second one.

The concept of the pairwise comparison matrix is given below

A pairwise comparison matrix on a set of criteria X associated to participant  $e_i$  is represented

$$\text{by a square matrix } A_i = (a_i^{lk})^{n \times n} = \begin{pmatrix} a_i^{11} & \dots & a_i^{1n} \\ \vdots & \ddots & \vdots \\ a_i^{n1} & \dots & a_i^{nn} \end{pmatrix}$$

where each assessment  $a_i^{lk}$  belonged precisely to the Saaty 1–9 scale and is indicates a ratio of preference intensity of criteria  $x^l$  respect to  $x^k$  by participant  $e^i$ . So that  $a_i^{lk} = \frac{1}{a_i^{kl}}$ ,  $\forall i, j \in N$ .

*Remark:* Assessment  $a_i^{ll} = 1$ ,  $\forall l \in \{1, \dots, n\}$ , situated in the diagonal of the matrix, since criteria  $x^l$  is not assessed to itself.

Based on the assessment of each participant, the weight of criteria is calculated. This means each participant has different prioritization order for set X of criteria.

- Prioritization of alternatives

The set of alternatives have evaluated by using suitable measure scales. In this case, the measure scale and the evaluation of alternatives are decided and fixed by participants.

Base on the weight of criteria and the evaluation of alternatives, each participant has different ranking for alternatives

- Consensus process for group decision making process

Before the process begins, the initial problem parameters are fixed, including a consensus threshold,  $\mu \in [0, 1]$ , and the maximum number of rounds for negotiation, (*Maxrounds*).

The level of agreement between participants is computed by the following steps:

#### 1) Normalization

The pairwise comparison matrix of participant  $e^i$ :  $A_i = (a_i^{lk})^{n \times n}$  is converted into a fuzzy preference relation matrix  $P_i = (p_i^{lk})^{n \times n}$  by means of adequate transformation functions proposed in (Chiclana and Herrera, 2001).

$$P_i = (p_i^{lk})^{n \times n} = \begin{pmatrix} p_i^{11} & \dots & p_i^{1n} \\ \vdots & \ddots & \vdots \\ p_i^{n1} & \dots & p_i^{nn} \end{pmatrix}; \text{ where } p_i^{lk} = f(a_i^{lk}) = \frac{1}{2} (1 + \log_9 a_i^{lk})$$

#### 2) Compute Consensus Degree:

For each pair of participants:  $e^i$  and  $e^j$ , the similarity degree between them in their assessments is defined by a similarity matrix  $SM_{ij}$

$$SM_{ij} = (sm_{ij}^{lk})^{n \times n} = \begin{pmatrix} sm_{ij}^{11} & \dots & sm_{ij}^{1n} \\ \vdots & \ddots & \vdots \\ sm_{ij}^{n1} & \dots & sm_{ij}^{nn} \end{pmatrix}; \text{ where } sm_{ij}^{lk} = 1 - |p_i^{lk} - p_j^{lk}|$$

With m participants, there are  $m(m-1)$  similarity matrices.

A consensus matrix is computed by average aggregation of similarity matrices

$$CM = (cm^{lk})^{n \times n} = \begin{pmatrix} cm^{11} & \dots & cm^{1n} \\ \vdots & \ddots & \vdots \\ cm^{n1} & \dots & cm^{nn} \end{pmatrix}; \text{ where } cm^{lk} = \frac{\sum sm_{ij}^{lk}}{m(m-1)}; \forall i, j \in \{1, \dots, m\}$$

Consensus degree regarding to criteria  $xk$ , ( $\forall xk \in X$ ) is computed:

$$cp^k = \frac{(cm^{k1} + cm^{k1} + \dots + cm^{kn} - cm^{kk}) + (cm^{1k} + cm^{2k} + \dots + cm^{nk} - cm^{kk})}{2(n-1)}; \forall k \in \{1, \dots, n\}$$

Remark: The value  $cm^{kk}$  is not taken into account since criteria  $k$  is not used to assess itself.

Consensus degree of the whole process is computed  $cr = \frac{\sum_{k=1}^n cp^k}{n}$

### 3) Consensus control

The consensus threshold  $\mu$  is defined and fixed by the moderator of groups before starting negotiation,  $\mu \in [0, 1]$ , based on the complex of problems and the characteristics of groups of decision-makers. In order to reach consensus easily, the moderators will set up a lower value for threshold in large groups with heterogeneous members facing highly complex issues.

The consensus degree  $cr$  is compared with a consensus threshold  $\mu$ . If  $cr \geq \mu$ , then, the consensus process ends successfully and the group moves on to the selection process; otherwise, the consensus reaching process requires further discussion (so decision round). *Maxrounds* index controls the maximum number of discussion rounds allowed. *Maxrounds* index, therefore, controls the limited time for discussion and negotiation.

### 4) Feedback recommendation

The assessment of participant  $ei$  on a set of criteria is represented by a matrix

$$Ai = (a_i^{lk})^{n \times n} = \begin{pmatrix} a_i^{11} & \dots & a_i^{1n} \\ \vdots & \ddots & \vdots \\ a_i^{n1} & \dots & a_i^{nn} \end{pmatrix}$$

If the consensus degree of group of participants  $cr$  is lower than the consensus threshold  $\mu$  ( $cr < \mu$ ), participants are advised to modify their preferences in order to improve the level of consensus in the following rounds. Steps for giving recommendation are considered:

- Computing the average collective preference of groups of participants:

$$Ac = (Ac^{lk})^{n \times n} = \begin{pmatrix} Ac^{11} & \dots & Ac^{1n} \\ \vdots & \ddots & \vdots \\ Ac^{n1} & \dots & Ac^{nn} \end{pmatrix}; \text{ where } Ac^{lk} = \frac{\sum_{i=1}^m a_i^{lk}}{m}$$

- Computing proximity values between the preference of each participant and the average collective preference. The proximity matrix for participant  $e_i$  is defined:

$$A_{pi} = (ap_i^{lk})^{n \times n} = \begin{pmatrix} ap_i^{11} & \dots & ap_i^{1n} \\ \vdots & \ddots & \vdots \\ ap_i^{n1} & \dots & ap_i^{nn} \end{pmatrix}; \text{ where } ap_i^{lk} = 1 - |a_i^{lk} - Ac^{lk}|$$

Proximity values are used to identify the furthest preferences from the collective opinion and, therefore, those preferences need to be changed.

### Making share- decision

After several rounds of negotiation, participants could change their minds thanks to discussions with others and receiving recommendations from the facilitator. When the consensus degree of



the group reaches the given consensus threshold, the consensus process ends successfully, and the group could make a shared-decision.

#### *4.3.2. The software implementation*

MATLAB<sup>®</sup> (matrix laboratory) is a programming language developed by MathWorks for the multi-paradigm numerical computing environment. MATLAB<sup>®</sup> is used to compute matrix operations, execute algorithms, a plot of functions and data and design of user interfaces. This programming software also interfaces with programs written in other languages, including C, C++, C#, Java, Fortran and Python. Because of its function on matrix manipulations and user interface, this software is suitable for algorithms of consensus support system tools.

The Matlab<sup>®</sup> software is used to program the automatic control system based on multiagent system for group decision-making process supporting reaching consensus. Algorithms are described in Appendix A. Besides, the part of algorithms for the automatic consensus reaching process will be used in the supervised decision-making processes of the next chapter.

## **Conclusion**

In terms of group decision making, there are two ways of reaching consensus including an automatic control system without a human facilitator and a supervised consensus reaching process guided by a moderator. In this chapter, the first model has been developed as a potential methodology for large and distributed group decision-making with a huge number of participants and where the physical environment for meeting is unnecessary. By using multi-agent system method, the proposed model adapted to the complex and dynamic of large group decision making. This is a strong hypothesis: the more the decision-makers are well informed about the agreement and conflicting points, the easiest it is to reach a consensus.

In order to justify this hypothesis, in the next chapter, the model of consensus reaching process will be illustrated as a combination of human facilitator and ICT –based supporting tool. To improve the decision-maker interaction, two types of recommendations, linguistic and graphical recommendation will be included. These graphics provide more information about the consensus level of groups and help participants to recognize how different between them and the others in assessment.

# **: Proposition of multi-criteria and multi-stakeholders methodology supporting Consensus Reaching Processes with a human facilitator**

## **Introduction**

In the current era, sustainable urban projects become larger and more complex than ever due to the involvement of multi-stakeholders in their different phases and the application of multi-criteria for assessment processes. These dynamic and multiple nature appears to be a key source of complexity and uncertainty in decision-making process (Kapelan and Walters, 2005). A large number of new ideas, techniques, and approaches have been contributing to this promising area. A multi-criteria assessment and decision support system becoming a popular method at the strategic level of implementation to evaluate the sustainability and resource efficiency of urban ecosystem services (Haase et al., 2014). However, multi-criteria decision making is only considered a steady-state method based on historical data without providing projections, trends in the future or taking into account the interactions of different metrics, outputs and parameters over time (Ligtenberg et al., 2004). In order to help stakeholders to be more confident in group decision-making process, we need to model the dynamic interrelationships of these variables over time. This is also a current study trend since there is an overwhelming majority of articles attempted to integrate multiple methods into an effective decision model for dealing with different system complexity issues in urban development projects (Chai et al., 2013).

Moreover, in order to address public issues via ICT-based solutions for Smart Cities at different levels of decision, this chapter proposes a new approach based on a combined application of two methods, a multi-criteria decision making and an agent-based modeling methods, as a new methodology that can support group decision-making process of innovation urban projects and enable multi-stakeholders in an active participation. The approach relies on a hypothesis that an integrated and collaborative approach for making decisions is necessary to deal with urban projects in a smoother way.



Chapter 5 : Proposition of multi-criteria and multi-stakeholders methodology supporting Consensus Reaching Processes with a human facilitator ..... **Erreur ! Signet non défini.**

Introduction ..... **Erreur ! Signet non défini.**

5.1. The group decision-making and Consensus Reaching Processes with a human facilitator..... **Erreur ! Signet non défini.**

    5.1.1. Group decision-making and the role of a human facilitator . **Erreur ! Signet non défini.**

    5.1.2. ICT- a key role in linking smart government and collaborative process . **Erreur ! Signet non défini.**

5.2. Multi-Criteria Decision Making (MCDM) methodology **Erreur ! Signet non défini.**

    - Step 1: Problem definition (scale and scope) ..... **Erreur ! Signet non défini.**

    - Step 2: Stakeholder analysis and engagement ..... **Erreur ! Signet non défini.**

    - Step 3: Definition of alternatives ..... **Erreur ! Signet non défini.**

    - Step 4: Definition of criteria ..... **Erreur ! Signet non défini.**

    - Step 5: Selection and weighting of criteria ..... **Erreur ! Signet non défini.**

    - Step 6: Prioritization of alternatives ..... **Erreur ! Signet non défini.**

5.3. A proposal of methodology for group decision-making process under a Living Lab environment for Smart City projects ..... **Erreur ! Signet non défini.**

    - Step 1: Problem definition - “share diagnosis” ..... **Erreur ! Signet non défini.**

    - Step 2: Stakeholder analysis and engagement ..... **Erreur ! Signet non défini.**

    Practical example based on an ERPI case study: “VéloOstan connectés” **Erreur ! Signet non défini.**

    - Step 3: Definition of alternatives ..... **Erreur ! Signet non défini.**

    - Step 4: Definition of criteria ..... **Erreur ! Signet non défini.**

    - Step 5: Selection and weighting of criteria ..... **Erreur ! Signet non défini.**

    - Step 6: Consensus reaching process ..... **Erreur ! Signet non défini.**

    - Step 7: Prioritization of alternatives ..... **Erreur ! Signet non défini.**

Conclusion ..... **Erreur ! Signet non défini.**

## **5.1. The group decision-making and Consensus Reaching Processes with a human facilitator**

### *5.1.1. Group decision-making and the role of a human facilitator*

Group decision-making problems arise from many real-world situations. To solve these problems, participants apply two processes before obtaining a final solution: consensus process and selection process. The consensus reaching process aims to achieve the maximum level of agreement between the members of a group on a set of alternatives or solutions. However, a group of participants firstly may have very different opinions due to the different backgrounds, knowledge, and experience of participants. Therefore, it is necessary to develop a consensus reaching process to help participants achieve an agreement. Normally, the consensus process is guided by a human figure called moderator who does not participate in the discussion but identifies the agreement in each moment of the consensus process and is in charge of supervising and addressing the consensus process toward success, i.e., to achieve the maximum possible agreement and to reduce the number of participants outside the consensus in each new consensus round.

At the beginning of every group decision-making problem, the set of participants has diverging opinions, then the consensus process is applied and, in each step, the degree of existing consensus among participants' opinions is measured. If the consensus degree is lower than a specified threshold, the moderator would urge participants to discuss their opinions further in an effort to bring them closer. Otherwise, the moderator would apply the selection process in order to obtain the final consensus solution to the group decision-making problem.

The constant human supervision required by decision-makers to revise and modify their preferences throughout the consensus reaching processes (CRP) can lead to several problems, including the excessively high amount of time invested, and the possibility that some participants might abandon the CRP, because of their lack of interest and motivation to continue with the tedious supervision process. Therefore, the most important novelty in our system is the inclusion of a multi-agent system approach aimed to support such constant supervision,

### *5.1.2. ICT- a key role in linking smart government and collaborative process*

As stated by Giffinger, smart governance is a key component of a Smart City (Giffinger, 2007). Governance is the process of interaction and decision-making among the stakeholders involved in a collective issue. In recent years, with the development of ICT, the internet and social media, new forms of collaborative process have emerged. Rather than face-to-face meetings, online communication and interaction between different online participants (e.g. civic organizations and citizens) become crucial for consensus building (Cheng 2013; Deng et al. 2014). As decision-making process is getting more and more complex, it can benefit from the rapid development of ICT.

Batty et al. argue that new technological developments are providing new ways of public participation and collaboration in the decision-making processes (Batty et al., 2012). This study identifies the concept of smart governance with four modes in which ICT supports interactive collaboration and participation. First, portals and other access points support useful information about any aspect of routine living and working in cities. Secondly, the ways in which citizens can interact with software could enable them to learn more about the city. Besides, the engagement of citizens with crowd-sourced systems is a good way to respond to queries and upload information. Finally, fully fledged decision support systems enable citizens to engage in actual design and planning itself in terms of the future city (Batty et al., 2012). In terms of public debate, technical resources and socio-digital networks have significant influences on the



way citizens debate, the logic of circulating opinions and making collective decisions. Thanks to ICT, access to the public space has become more flexible for citizens to engage in conversation (Badouard et al., 2016).

Regarding the terms of "civic tech" or "civic technologies", a set of digital tools renew and facilitate the participation of citizens throughout the development of debates and the sharing of ideas, the setting up of social networks citizens citizen consultations mobile and web. Indeed, the new technologies offer several new opportunities for citizen action in the era of a democracy that is more participative and transparent.

INRIA (Institut National de Recherche en Informatique et en Automatique) and Public Missions have proposed a MOOC titled "Participation citoyenne: méthodes et civic tech" in October 2019 to enhance the participation of citizens by training in the various skills of civic technologies. The location of the face-to-face workshop is at INRIA, 75012 Paris. Through this MOOC training course, citizens could understand the added values of a participative approach, establish the best conditions for a participative process, and in the end, be able to propose innovative consultations or imagine for their own collective approach. This information is available on the website <https://www.fun-mooc.fr/news/democratie-2-0>.

It can be seen that ICT can play a key role in linking collaborative planning and smart governance. According to Epp (2012), ICT, including decision support system (DSS), can play an important role in supporting higher levels of public participation. For instance, web-based DSS can allow citizens, as either individuals or members of civil society organizations, to participate in public debates, to express their opinions and to hear about or develop new solutions to urban problems (Poplin et al. 2013). The application of DSS in collaborative planning can be seen to assist stakeholder participation and can be considered an alternative method of dealing with the wicked problems of planning practice (Goodspeed 2015). This coincides with the reflections by Klosterman (1997) in which he considers the increasing application of Public Support Systems in practice as continuing the planning trends from applied science to communication and collaboration, including broader concerns with intelligence and collective design. In fact, Public Support Systems are going more and more online. Online Public Support Systems can be used by citizens in social media on their smartphones and make its wider application possible.

A big challenge in collaboration is identified by Rydin, who acknowledges the validity of different knowledge claims posed by different stakeholders in the planning process (Rydin 2007). Conflicts are not automatically solved simply by bringing all stakeholders to a roundtable and expecting them to discuss the problem until it is resolved (Billé 2008; Davy 1997). The development of ICT can make the collaborative process become a form of smart governance. In particular, ICT methods can provide fundamental support for communication needs in group decision-making processes, increasing data access and levels of information, thereby enhancing knowledge levels of the specific issues.

## **5.2. Multi-Criteria Decision Making (MCDM) methodology**

Multi-Criteria Decision Analysis (MCDA), or Multi-Criteria Decision Making (MCDM), is a method supporting solving conflicting evaluations that decision-makers faced. MCDM is a multi-step process consisting of a set of methods to structure and formalize decision-making processes in a transparent and consistent manner. It allows for comparison among decision

alternatives based on a set of evaluation criteria to which different weights, representing the degree of importance, may be applied.

MCDM can be described in six major steps (Langemeyer et al., 2016), (Mika Marttunen, 2010): (i) Problem definition (including scale and scope), (ii) stakeholder analysis and engagement, (iii) definition of policy/planning alternatives, (iv) definition and assessment of criteria and corresponding indicators, (v) selection and weighting of criteria, and (vi) prioritization of alternatives (Figure 5.1). Below, we explain in detail each of these steps.

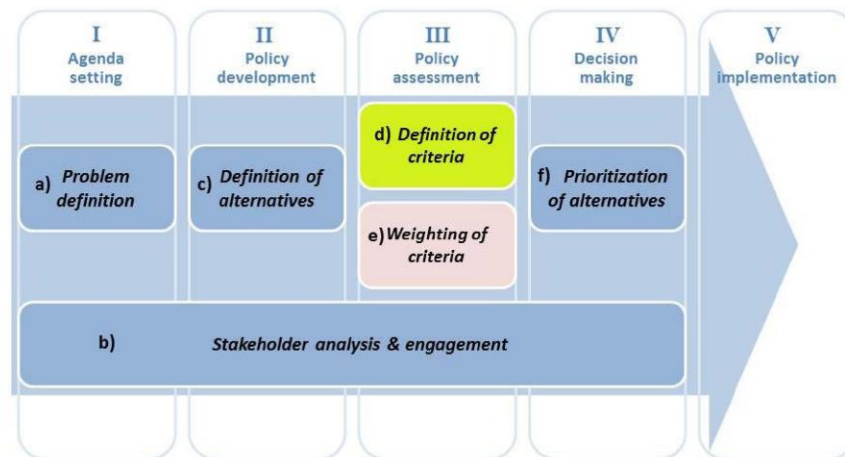


Figure 0-1 The MCDM methodology (Langemeyer et al., 2016)

*- Step 1: Problem definition (scale and scope)*

Typically, a decision problem is a situation where an individual has alternative courses of action available and has to select one of them, without a priori knowledge of which one is the best. The first step of the methodology includes the identification of problems in its scope and scale. Problem identification and structuring consists of identification of the purpose of the decision, recognition of the problem to be solved, diagnosis of the cause-effect relationships for the decision situation. Besides, this step aims to identify the main goal and the type of decision to be made.

*- Step 2: Stakeholder analysis and engagement*

A stakeholder can be defined as the range of people who are likely to use a system or be influenced either directly or indirectly by its use (MacHaris et al., 2012). In other words, stakeholders are people who have an interest, financial or otherwise, in the consequences of any decisions taken. An in-depth understanding of each stakeholder group's objectives is critical in order to appropriately assess the different alternatives. Stakeholder analysis should be viewed as an aid to properly identify the range of stakeholders that needs to be consulted and whose views should be considered in the evaluation process. In scientific literature, there are some methods described in order to come to an appropriate list of stakeholders. Munda claims that by an analysis of historical, legislative and administrative documents, complemented with in-depth interviews with locals and other interested parties, a map can be made of the most important social participants (Munda, 2004). Besides, there are other formal methods to identify stakeholders: the 7 procedures of Mason and Mitroff (Mason and Mitroff, 1981), the distinction between external stakeholders, corporate and organizational stakeholders (Blair, 1991).

Next, one should clearly elicit the weight of stakeholders. In all the MCDM applications so far, an approach is followed, and all stakeholders were given equal weight in order to express that we respect each point of view on an equal basis. When the government is one of the





stakeholders, one could say that this stakeholder represents society's point of view and therefore this should be the one to follow (MacHaris et al., 2012). Analyzing viewpoints of the other stakeholders, such as users, local people, producers, will indicate if a certain measure will probably be accepted or rejected by these groups.

*- Step 3: Definition of alternatives*

The identification of the set of alternatives is a crucial task. In MCDM theory, there are two categories including multi-attribute decision making in which the set of alternatives defined explicitly by a determinate list of attribute of stakeholders, and multi-objective optimization theory in which the set of alternatives is defined implicitly by a mathematical programming structure (Pavan and Todeschini, 2009).

This step aims to classify possible alternatives submitted for evaluation. Alternatives could have different forms based on the problem sets. They can be different technological solutions, possible future scenarios, different policy measures, long term strategic options or various needs of stakeholders. In order to be applied, there should be a minimum of two non-dominated alternatives to be compared.

*- Step 4: Definition of criteria*

The choice and definition of evaluation criteria are primarily based on the identified objectives of stakeholders and the purposes of the alternatives considered. A hierarchical criteria tree can be set up. Most of the time, this definition is pursued by an interactive discussion with the stakeholders in order to come to a particular set of criteria for those stakeholders. Generally, for each stakeholder group, we first track a preliminary criteria list based on the literature and knowledge of the problem at stake. Next, during interactive discussions with stakeholders (e.g., by telephone, workshops, etc.), each stakeholder group gets the opportunity to evaluate and validate the pre-defined criteria. Here, it is important to come to an agreement on the exact meaning or definition of the criteria that are withheld in order to enhance the common understanding of the criteria tree.

*- Step 5: Selection and weighting of criteria*

This step aims to develop a process of selecting and weighting the evaluation criteria. Studies like that by (Cork and Proctor, 2005) involve multiple stakeholders in the selection of evaluation criteria, while other studies rely on the judgment of participants (Schwenk et al., 2012).

Even though the use of weights is not necessary in MCDM, and some studies neither apply weights nor consider values (e.g. Mitsova et al., 2011; Shang et al., 2012). However, the attachment of weights to the evaluation criteria can be an intuitive way to integrate values into policy processes. Some studies propose techniques, including Likert- scale- rankings (Sell et al., 2006), holistic choice approaches (Sell et al., 2007), and trade-off valuation (Locatelli et al., 2008), often embedded in deliberative group exercises (Cork and Proctor, 2005) or MECE (Mutually Exclusive Collectively Exhaustive) principle (Lee and Chen, 2018).

The selection of evaluation criteria can conceptually be interpreted as the definition of the benefits humans derive under a given governance choice. Yet, the focus on citizen benefits and values can also be an inherent limitation in participatory decision-making (e.g. through a referendum). Karjalainen et al. (2013) compare participant and citizen-based approaches to criteria selection and resume that citizens tend to focus on short term benefits, whereas

participants account more strongly as future assets and “insurance values”. Thus, indicating a need for citizens to be well informed about potential long-term, environmental impacts of given decisions.

#### *- Step 6: Prioritization of alternatives*

In this step, every alternative (from step 3) is evaluated on the different criteria throughout the use of measurement methods and this for each stakeholder (step 2).

The comparison and prioritization of alternatives in the reviewed studies followed three different approaches (Langemeyer et al., 2016). First, the Analytical Hierarchy Process (AHP) (Sell et al., 2007, 2006), (Srdjevic et al., 2013) is used to structure decision-making processes, rank objectives, criteria and values and to prioritize one alternative. Second, pair-wise comparison (Fontana et al., 2013), (Oikonomou et al., 2011), evaluates always two alternatives ‘side-by-side’ for each of the criteria until a full ranking of all alternatives is provided. Finally, value-function based aggregation rules are used in most of the studies, in particular, those conducting spatial explicit assessments (Jackson et al., 2013), (Schwenk et al., 2012). Value-function approaches are based on the epistemological assumption that a single optimal alternative can be found; and alternatives are either compared by linear aggregation, i.e. the sum of all normalized urban values (Corsair et al., 2009), (Koschke et al., 2012), or by ideal point approaches, which use the sum of normalized differences between the actual and an ideal criteria performance (Jannoyer et al., 2011), (Mitsova et al., 2011), (Sanon et al., 2012).

There are several Multi-criteria Analysis methods that support preferences modeling such as AHP (Analytic Hierarchy Process), PROMETHEE or ordered weighted averaging (OWA) operator among others.

In AHP, the relation priorities of each component in the hierarchy are determined by comparing all the elements of the lower level against the criteria with which a causal relationship exists. For this purpose, decision-making software packages such as Total Decision based on Saaty's AHP can be used. Besides Total Decision, other decision support software packages like ERGO, 1000Minds or Expert Decision can also be used to perform pairwise comparisons.

Besides AHP, other MCA techniques are also suited to perform the MCDM. However, in cases where PROMETHEE is used, no specific guidelines yet exist to determine the weights. PROMETHEE only adopts that the decision-maker is capable to weigh the criteria correctly, at least when there are a large number of criteria.

Because of the complex and multi-scale of the context in Smart City, the AHP method is suitable to describe problems into smaller components by creating hierarchical Structuring of decision problems.

### **5.3. A proposal of methodology for group decision-making process under a Living Lab environment for Smart City projects**

In order to deal with the dynamic nature of group decision-making process, this part will propose a methodology so-called a supervised cooperative multi-criteria and multi-stakeholders that integrates consensus reaching process into multi-criteria decision-making methodology. In this methodology, the AHP method is used to build the hierarchical construction of the problem and determine the set of criteria weights. The overall methodology is shown in figure 5.2. The various steps are discussed in more detail below.

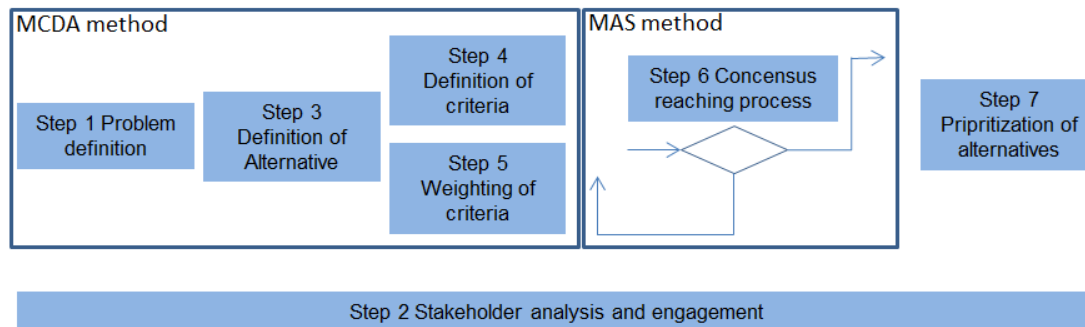


Figure 0-2 The proposal multi-criteria and multi-stakeholders methodology under a Living Lab environment

*- Step 1: Problem definition - “share diagnosis”*

The first step of the methodology consists of identifying problems and classifying the possible alternatives submitted for evaluation. Based on reviewed studies using MCDM methods in chapter 2, we found that research problems were defined at different scopes from six aspects of Smart City: economy, people, governance, mobility environment and living and at different scales, from operational, tactical to strategic levels.

The problem formulation has followed to identify input data for the group decision- making process of stakeholders. Based on the objectives of this process, suitable methods would be chosen for formulating problems.

*- Step 2: Stakeholder analysis and engagement*

This step consists of three sub-steps including, identifying stakeholders, indicating their relationship and the important weight of each of them.

First of all, all stakeholders that can affect or being affected, directly or indirectly, by a Smart City process should be identified. According to the expected roles in a Smart City process, the identified stakeholders could be divided into groups of key or secondary stakeholders (Ibrahim et al., 2017).

**Primary Stakeholders:** include all stakeholders groups that are capital that is without their support a Smart City project may cease to exist. They are also known as ‘Key Stakeholders’.

**Secondary Stakeholders:** include all stakeholders groups who can affect or being affected by a Smart City project outputs.

The more popular classifications for stakeholders in Smart City under Living Lab approach are based on Public-Private-People Partnership concept (Dupont et al., 2015). In this context, the contributions from different groups of stakeholders could be understood as enablers, utilizers, providers and users (Juujärvi and Pessoa, 2013):

The groups of local authorities, elected representatives and territorial engineers are representatives as enablers. They create the vision and allocating resources, provide strategic leadership and promote networking.

The groups of firms and local service providers are representatives as utilizers who producing place-based knowledge, setting small-scale objectives and creating suitable products and services

The group of educational institutions is representatives as providers who engaging students as innovators, providing innovative R&D methods and augmenting knowledge systematically

The groups of residents are representatives as users who producing place-based user experience, participating in experiments and empowering citizens through co-creation.

Next, the second sub-step tries to identify the links between stakeholders through a matrix of relationships.

Finally, it is necessary to evaluate the weight of each stakeholder. This stage aims at ranking the degree of importance of stakeholders based on their potential impact (i.e. influence) on the success of a Smart City project (Toledo Rojas, 2014). All stakeholders are important to a project; however; they should be prioritized according to their characteristics and the needs of a Smart City project. The prioritization task should consider those who have the power for decision-making; who can economically, socially, environmentally, and politically contribute to a Smart City project; and who are not directly linked to projects, but they are interested in its outputs. There are several methods to assess the weight of stakeholders.

The first method is based on the way stakeholders are involved in different activities of smart cities. For instance, the “Stakeholders/Activities Prioritization Matrix” could allow a Smart City project team to determine the degree of importance of each stakeholder in achieving each identified transformation activity (Ibrahim et al., 2017). Table 5.1 provides a hypothesis example of this matrix. In this table, the degree of importance of each stakeholder is selected from the set of values {1,2,3,4,5}, which is a ranking scale used to represent “Not Important”, “Slightly Important”, “Moderately Important”, “Important”, and “Critically Important” respectively. The set of abbreviation values {“Activity A”, “Activity B”, “Activity C”, ..., “Activity X”} is used to represent different types of transformation activities.

Table 0-1 Smart City Stakeholders/Activities Prioritization Matrix

<b>Stakeholders</b>	<b>Activity A</b>	<b>Activity B</b>	<b>....</b>	<b>Activity X</b>
Actor 1	(1 to 5) or (NA)			
Actor 2				
Actor 3				
...				
Actor n				

1 Not important to achieve activity success

3 Moderately important to achieve activity success

5 Critically important to achieve activity success

NA = not a stakeholder in this activity scale

Secondly, Saaty proposed a hierarchy of criteria such as, for example, expertise, experience, previous performance, persuasive abilities, effort on the problem to determine the weight vector of the decision-makers (Saaty, 1990a), as shown in Figure 5.3. This is a natural way to

determine the individual weight in a group by using prior information about the decision-makers.

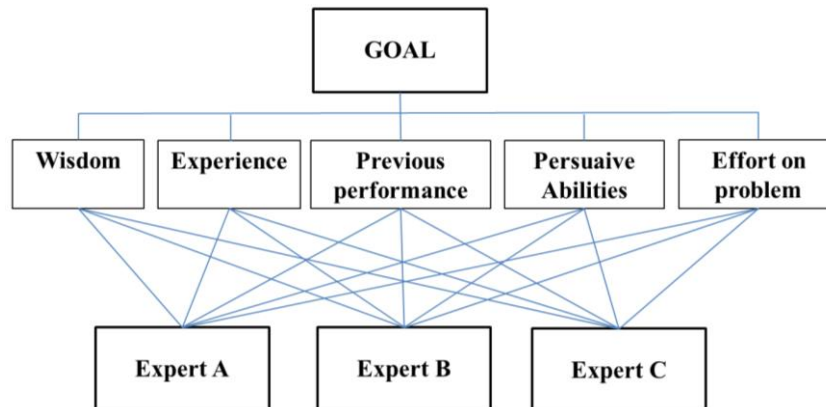


Figure 0-3 Hierarchy for judging weight of stakeholders (Saaty, 1990a)

Besides, in certain circumstances, some participants might be more familiar with the group decision-making problem than others because of different degrees of knowledge or different roles in the group. Generally, the moderator assigns them different importance weights assigned to participants (Palomares and Martinez, 2013). However, these methods suffer drawbacks. In some cases, it is difficult to find a knowledgeable person to provide subjective judgments. In practice, this potential for bias is a significant obstacle to overcome.

*Practical example based on an ERPI case study: “VélOstan connectés”*

Following the initiative of the Greater Nancy Metropolis, the Maison du Vélo, the Université de Lorraine (Lorraine Fab Living Lab – LF2L; schools of engineers) and the Greenberry startup company developed a project of connected and smart bicycle, so-called “VélOstan connectés” project. Bicycles offered for rent equipped with new technologies and features such as geo-location, GPS guidance, measurement performance, route optimization, smartphone charger, chip RFID, environmental data sensor... The objectives of the project are promoting the user experience as well as improving the managing process of the rental of bicycles by the community through identification and tracking each bike. In this project, started at the end of 2015, stakeholders tried to reach different objectives. The Greater Nancy Metropolis wanted to promote active mobility and Smart City; Maison du Vélo wanted to develop new services; GreenBerry imagined generating a new business model based on the “physical” concept and adapted to urban mobility; Université de Lorraine (LF2L) had to demonstrate how LF2L process is efficient. This experimental project has been awarded in 2016 by the national network of French cities involved in digital transition “Les interconnectés” (*13e Fourn- Les Interconnectes- Le réseau des territoires innovants*, 2016). Several scenarios have emerged from the Fab Living Lab approach (Dupont et al., 2015). The figure 5.4 shows a citizen workshops with 21 participants in March 2016 (on the step of the process based on innovation by use).



Figure 0-4 “VélOstan Connecté” workshop at LF2L Platform, 16/03/2016 (Picture from UL-ERPI-LF2L)

Outcomes are described in technical reports (Dupont and Arbelaez, 2017), (Dupont et al., 2017). Nevertheless, the stakeholders have not been able to scale up the prototype. Thus, I was asked to analyze this project and give a new theoretical point of view based on the “shared” diagnosis given to the Greater Nancy Metropolis. Indeed, this LF2L project underlined that technical, political, environmental, societal (usage) dimensions are linked together (Dupont and Arbelaez, 2017) and stakeholders could continue to work together to make a decision for action.

So, this case study is used as a practical example for steps of the stakeholder analysis process. In order to illustrate this aspect let’s describe the hierarchical process that was realized within the framework of a Living Lab project and the Lorraine Fab Living Lab (LF2L) platform.

In the table 5-2, the number 1 is represented for a strong relatedness and the number 0 is represented for the lack of relationship between two stakeholders.

Table 0-2 The relationships between stakeholders (example from VélOstan project, Grand Nancy Métropolis)

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
A1	–	1	1	0	1	1	0	1	0	1
A2	1	–	?	0	1	1	1	1	1	1
A3	1	0	–	0	0	?	0	0	0	0

A4	0	0	0	–	1	0	1	1	1	0
A5	1	1	0	1	–	1	1	1	1	0
A6	1	1	?	0	1	–	0	1	1	1
A7	0	1	0	1	1	0	–	1	1	0
A8	1	1	0	1	1	1	1	–	1	1
A9	0	1	0	1	1	1	1	1	–	0
A10	1	1	0	0	0	1	0	1	0	–

*A1 is represented for Mobility department (Soft mobility: walk, public spaces, bicycle)*

*A2 is represented for Maison du Vélo du Grand Nancy (Mdv)*

*A3 is represented for Infrastructure Department*

*A4 is represented for University partnership Department*

*A5 is represented for Economic Development & New technology (Digital) Department*

*A6 is represented for politician (vice president) in charge of Mobility*

*A7 is represented for politician (vice president) in charge of Research, Education & Digital Development*

*A8 is represented for Lorraine Fab Living Lab (LF2L)*

*A9 is represented for Green Berry*

*A10 is represented for Users (Subscribers and Non-Subscribers)*

The result of this sub-step is a map of all stakeholders visualizing their relationships and importance weights. The figure 5.5 is an example of a map of stakeholders at the VeloStan project. The figure shows hieratical and cooperative relationships between stakeholders. The blue color represented for departments in Grand Nancy, while the purple color is designed for politicians. The other stakeholders are an educational institute (LF2L) and a startup company (Green Berry).

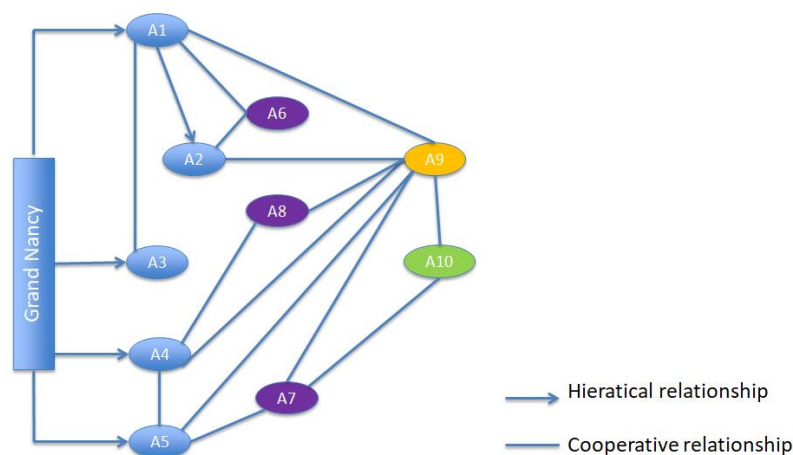


Figure 0-5 The map of stakeholders (example from VeloStan project, Grand Nancy)

- Step 3: Definition of alternatives

Multi-criteria decision making (MCDM) is a discipline in its own right, which deals with decisions involving the choice of the best alternative from several potential candidates in a decision, subject to several criteria or attribute that may be concrete or vague. The proposal alternatives can take various forms according to the problem situation. They can differ at phases of Smart City process from the concept, model, and implement to evaluation phase.

- Step 4: Definition of criteria

Decision making requires comparing different kinds of alternatives by decomposing the preferences into the many properties that the alternatives have, determining their importance, comparing and obtaining the relative preference of alternatives with respect to each property, and synthesizing the results to get the overall preference. Therefore, the strategy consists of describing a complex problem into its smaller components and establishing importance or priority to rank the alternatives in a comprehensive and general way to look at the problem.

As mentioned before, in this study, we decide to choose the AHP method, a relatively simple and systematic approach that can be used by decision-makers, firstly introduced by Saaty (1980). AHP method could be used to build a hierarchy construction. The hierarchy construction step consists of decomposing the problem into hierarchical structures with distinctive levels which are, generally, the goal level, criteria, and decision alternatives. The decomposition can be obtained using a graphical representation, as shown in Figure 5.6.

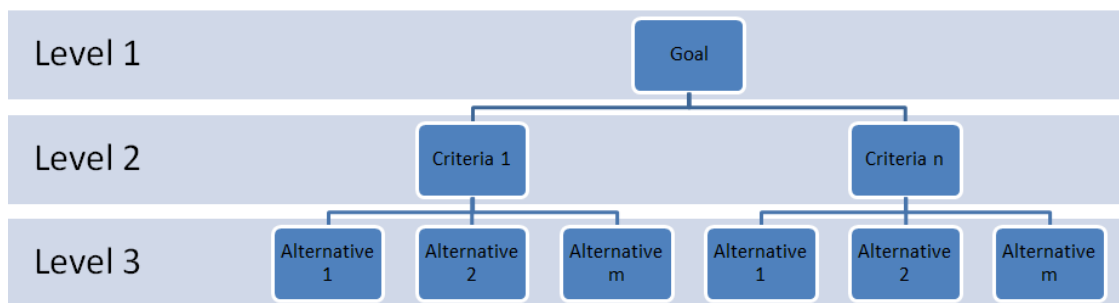


Figure 0-6 AHP graphical representation

- Step 5: Selection and weighting of criteria

In this step, clear criteria must be defined to evaluate the adequacy of the different alternatives.

In this study, pairwise comparisons are based on Saaty's AHP method, it involves establishing priorities at each level by comparing pairwise each criterion and alternatives. Stakeholders express the relative importance of one criterion versus another regarding the fixed objective.

Stakeholders' judgments are based on the scale of relative importance that assumes values between 0 and 9 (Kim et al. (1999), Saaty (1980)) as presented in Table 5-3. A Basic assumption is that if attribute A is absolutely more important than attribute B and is rated at 9, then B must be absolutely less important than A and is valued at 1/9.

Table 0-3 Saaty scale used for pairwise comparisons.

	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective





3	Weak	Between equal and moderate
3	Moderate importance	Experience and judgement slightly favor one activity over another
4	Moderate plus	Between moderate and strong
5	Strong importance	Experience and judgement strongly favor one activity over another
6	Strong plus	Between strong and very strong
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	Between very strong and extreme
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

- Step 6: Consensus reaching process

Traditionally, the weight of criteria have been rating, without taking into account the level of agreement amongst stakeholders (Herrera et al., 1995). This process can lead sometimes to solutions that are not well accepted by some stakeholders in the group, because they might think that their own opinions have not been considered proper to make the decision. In order to prevent such situations, it is advisable that stakeholders carry out a Consensus Reaching Process (CRP), a dynamic and iterative process composed where the stakeholders express, discuss, and modify their preferences to achieve a high level of agreement before making a decision (Butler and Rothstein, 2007). CRPs normally consist of several rounds of discussion (Martinez and Montero, 2007). 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. The term consensus can be defined as a state of mutual agreement among members of a group, where the decision made satisfies all of them. Reaching a consensus normally implies that participants change their initial opinions in a discussion process, tending to make them closer to each other, towards a final collective opinion which satisfies the whole group. In case it is unable to achieve a consensus, a feedback recommendation is sent to stakeholders to modify their preferences in order to increase the level of agreement in the following negotiation rounds.

In our proposed methodology a multi-agent system approach is proposed to support constant supervision, by increasing the system's autonomy during the overall consensus reaching process. Our system's underlying consensus model is managed by agents that operate cooperatively to reach an agreement. Such agents should be as autonomous as possible, therefore they implement a semi-supervised approach that allows participants to modify and provide their opinions in a semi-supervised way, by delegating these tasks to agents, in order to exclude the dependence on human supervision during the process. It is worth to say that that the semi-supervised approach presented here is not necessarily dependent on the theoretical consensus model proposed in the previous subsection, but it can be rather viewed as an

additional module of our CRP which might be adapted and applied in combination with any other consensus models.

The multi-agent system approach includes two parts, an automatic control system of consensus level and a feedback recommendation to stakeholders. The first part is similar to the automatic consensus control system presented in the chapter 4. In the second part, a mechanism of feedback recommendation is proposed as a supporting tool for a human facilitator in consensus reaching process. Basically, there are two types of recommendations for stakeholders including a visual graph showing how different opinions of all participants in group decision making and automatic feedback based on MAS approach. An excel interface will be created for the visual recommendation that will be discussed in chapter 6. Meanwhile, all automatic feedback recommendation programmed by Matlab<sup>®</sup> software to participants who need to modify their preference in consensus reaching process

Algorithms are written in Matlab<sup>®</sup> software and explained in the figure 5.7

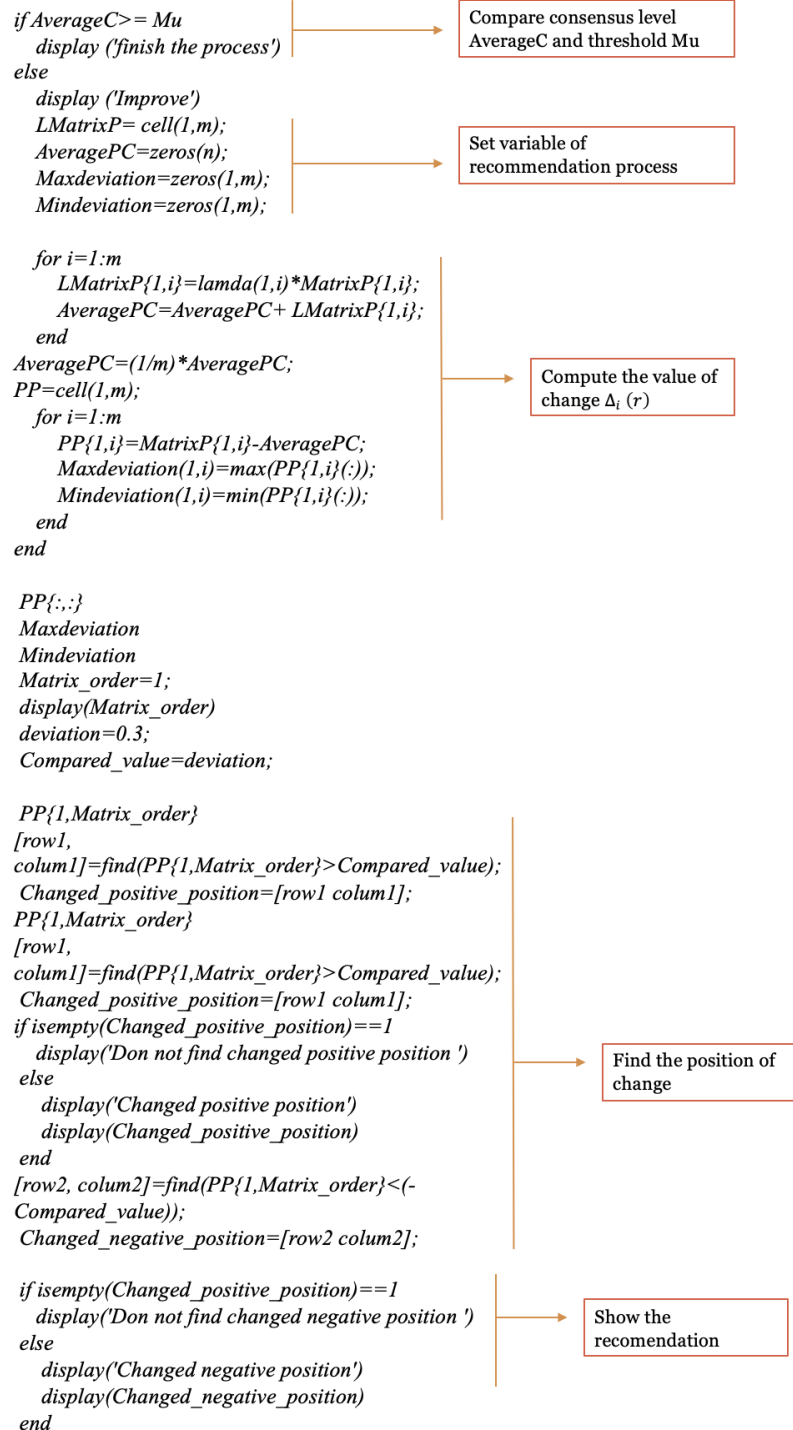


Figure 0-7 The scheme of code and explanation

- Step 7: Prioritization of alternatives

This step is the so-called model development and use, which includes the development of formal models of decision-making preferences, values, trade-offs, goals to compare the alternatives or actions under consideration with each other in a systematic and transparent way.

This step represents the final aggregation of the obtained weight and the evaluation of the alternatives on each single criterion.

There are three basic methods to evaluate alternatives: Pair- wised, direct rating or linear approach.

- The pairwise method compares each criteria or alternatives with others. Participants express the relative importance of one alternative versus another regarding each criterion. Since participants' judgments are used as a scale, the alternative ratios reflect the relative importance of the criteria in achieving the goal. The scale of relative importance between 0 and 9 is presented in above Table 5.3.

- The direct rating approach is another method that can be used for the formation of a value scale. It requires only the definition of the reference points of the scale. Both local and global scales can be used. In the case of a local scale, the best alternative is given the highest rate (usually 100, 10, or 1) and the worst alternative is given a score of 0. All the other alternatives are then located directly on the scale reflecting their performance with respect to the two reference points. The main disadvantage in using local scales is that if new alternatives are subsequently introduced into the decision problem, then the scales have to be redefined, and consequentially the weighting criteria.

- Linear Numeric Scale: In this scale, decision-makers offer some numeric answers to a question or statement. This comprises objects like satisfaction, ease, brand favorability, feature importance, or likelihood to recommend. The Single Ease Question (SEQ) and the likelihood to recommend items are examples of linear numeric scales. This scale normally has at least the endpoints identified.

Any MCDA method can be used to assess the different alternatives. These methods give each stakeholder the liberty of having their own criteria, weights and preference structure. In this step, the evaluation of the different alternatives should be inserted in the evaluation table that leads to a classification of the proposed alternatives. Only at the end of the consensus reaching process, the different points of view get a compromise and the shared decision is made.

## **Conclusion**

Decision making in Smart City projects frequently leads to much discussion, controversy and disagreement. In the absence of methodologies that cope with different points of view of stakeholders, projects are often not implemented or lead to unacceptable delays.

In this chapter, we propose to use a new approach based on a combined application of two methods, a multi-criteria decision making and an agent- based modeling methods, for the evaluation of Smart City projects. In this methodology, which can be seen as an extension of the traditional MCDM, the stakeholders are explicitly taken into account. In the next chapters, both this methodology and the methodology proposed in the 4<sup>th</sup> chapter will be validated by a concrete case study. The case study is used to illustrate, analyze and expose our scientific findings for the urban projects



## **SECTION 4:**

# **CASE STUDY APPLICATION AND RESULTS**

## **: Case study and Experimentation**

### **Introduction**

In previous chapters, we had distinguished two types of a group decision-making process that are the reaching consensus process, namely automatic control system and the process supervised by a human facilitator. The automatic control system based on multi-agent system approach and the supervised cooperative multi-criteria and multi-stakeholders methodology integrate both MCDM and MAS methods.

Once presented and described the operation and main features of the proposed supervised MAS to support a large-scale consensus reaching process, this section shows a case study in which the system is used to solve a real-life large-scale group decision-making problem. Such a problem is solved twice, by using the semi-supervised consensus support system proposed in this paper and another version of the system that includes a full-supervised approach of participants' preferences, with the aim of providing a comparison between results and findings obtained from the two above described types of group decision-making process methodologies.

In order to implement models that were proposed in previous chapters, this section aims to set up a proposed "testbed" in real-life simulated environment. The experimental strategy in our study includes the following steps. In the first step, a suitable case study is selected for execute models in an experimental setup. In the implementation process, the execution comprises running a computer program based on consensus metrics and recording the output data. Next, the data is analyzed results from the simulations, graphs that were made of decision-making process over time. Finally, we provide a discussion and a conclusion.

Chapter 6 : Case study and Experimentation .....	<b>Erreur ! Signet non défini.</b>
Introduction .....	<b>Erreur ! Signet non défini.</b>
6.1. Living Lab concept on urban energy planning .....	<b>Erreur ! Signet non défini.</b>
6.2. Case study description .....	<b>Erreur ! Signet non défini.</b>
6.2. Experimentation process.....	<b>Erreur ! Signet non défini.</b>
6.2.1. Phase 1: Group work with the same role .....	<b>Erreur ! Signet non défini.</b>
6.2.2. Phase 2: Group work with different role.....	<b>Erreur ! Signet non défini.</b>
Conclusion .....	<b>Erreur ! Signet non défini.</b>



## 6.1. Living Lab concept on urban energy planning

The global demand for energy is predicted to increase in the coming decades. Developed countries continue to consume huge amounts of energy while demand is increasing in developing countries (Pleßmann et al., 2014). Several research efforts have been contributed to integrate sustainable energy management into territory planning. New sources of renewable energy not only reshape the urban form and their energy infrastructure but also change the behavior in consumption and awareness of people.

It is obvious that innovations occur at every territory of Smart City, where local citizens, municipalities and businesses are initiating sustainable energy initiatives and creating vast challenges (Walker et al., 2010). Urban energy system planning is a topic of growing concern for cities in deregulated energy markets, which plan to decrease energy demand, reduce their dependence on fossil fuels, and increase the share of renewable energy sources (Cajot et al., 2017). Therefore, urban energy planning is not merely a matter of spatial design but also of governmental design as it involves multi-stakeholders with multidisciplinary skills, diverse and sometimes conflicting objectives that must come to a consensus. Living Lab concept is both an environment and an approach, where innovation process is supported for all involved stakeholders in real-world contexts, it seems like a very promising approach to realize sustainable energy challenges in Smart City (Giannouli et al., 2018).

In this research, the case of urban energy planning under Living Lab approach is used for executing and verifying the proposed models. So, a dedicated case study was developed with a twofold objective: First, from the pedagogical perspective, the goal is to put learners in “real situation conditions” to be aware of the multidimensional nature of decision making of urban projects. Then, from the research point of view, conduct the consensus process and validate the relevance of the proposed approaches<sup>1</sup>.

In this case study, several stakeholders are engaged in planning a renewable energy resource solution for their city since the beginning phases of projects. In order to consider multiple criteria expressing objectives of all stakeholders involved in and affected by energy planning and the performance of the energy system, the supervised cooperative multi-criteria and multi-stakeholders methodology is applied for supporting negotiation and shared decision process.

## 6.2. Case study description

This case study considers a group decision-making problem in a real-life environment, in which participants who are highly motivated and interested in such a problem take part. This study is inspired by a study by Cavallaro (Cavallaro, 2011). The problem is formulated as follows:

The city of Messina in Sicily (Italy) is currently involved in a project of energy transition. This is an ambitious project to reshape the city's energy production system, integrating a significant proportion of renewable energy. This project is part of a general ambition of the city hall aimed at developing a strong ecological awareness in the local area.

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<sup>1</sup> The case study was initially developed by M. Enjolras and M. Camargo and adapted in its current version by G. Tran.

In view of the project's ambition and its potential impact, the city wants to consult the various stakeholders before launching the design of the final solution. This project involves the following stakeholders:

- **The City Hall:** It is the project owner; its ambition is to offer the best possible system to the community, while limiting the associated costs.
- **The Citizens of Messina:** The set of people who benefit (or suffer) directly from such a change in the city.
- **The city's Technical Department:** This stakeholder must ensure that the project and its implementation remain realistic and appropriate in terms of maintenance, safety and efficiency. They will be in charge of running the future system and ensuring its long-term operability.

Four different alternatives of renewable energy installations are considered:

- **Photovoltaic (PV):** installation of 200 PV units each with a power of 3 kW, linked to the grid and suitable for household use;
- **Wind power:** installation of 4 wind turbines of 600 kW each, in sites with annual average wind speed of around 4.7 m/s;
- **Biomass:** 5MW steam boiler fueled by energy crops especially “*Mischantus Sinensis*”. The adoption of a fluidized bed combustion system was favored over a traditional combustion furnace because, in spite of its higher cost, it does ensure superior performance in environmental terms;
- **Hydro-Turbine (Kobold):** this considers the possibility of using a Kobold1 turbine, namely a vertical axis Hydro-turbine, to convert the kinetic energy contained in marine currents (tidal streams) into mechanical energy. A prototype for demonstrative purposes is already installed in the Strait of Messina, although it is not yet in production. The introduction of 5 new turbines producing 150MWh each per annum is envisaged.

Finally, a working group was set up to select the most suitable project. The people involved in this group identified 6 criteria to be taken into account for the final decision:

- **Costs:** This criterion evaluates all the economic consequences of the implementation of the project, (equipment, payment of workers associated with the project...) as well as the operating costs on the system once implemented. This criterion is measured in Euros;
- **Primary energy saving.** This refers to the amount of fossil fuel currently used by power plants to produce electricity that could be saved. It is measured in Kg/year;
- **Maturity of the technology.** Measures the degree of reliability of the technology adopted as well as how widespread the technology is at both the national and European levels. This is appraised using a qualitative judgment transformed into the following four-point scale (Beccali et al., 2003):

Technologies tested in laboratory = 1

Only performed in pilot plants = 2

Requiring further improvements to increase their efficiency levels = 3;

Commercial mature technologies with a solid market position = 4;

- **Impacts on the city:** This criterion takes into account the impacts on the city: the visual nuisance that may be created, any noise disturbance and odors arising from productive activity of plants, the potential risk to ecosystems caused by the production





operations of the various projects included in the strategies and the social acceptability. This is also measured qualitatively and translated into the following five-point scale (Beccali et al., 2003):

Extremely high impact = 1

High impact = 2

Moderate impact = 3

Slight impact = 4

No impact = 5.

- **Contribution to local development:** This criterion estimates the global social and economic effects that may be felt in the areas affected by the initiatives. The potential effects are the creation of new jobs, new supply chain businesses, emerging energy sector businesses, industrial districts etc. The following rating scale was applied (Beccali et al., 2003):

o Impact on local economy rated weak =1

o Impact on local economy rated moderate (some permanent jobs) = 2

o Impact on local economy rated medium-high (jobs + supply chain businesses) = 3

o Impact on local economy rated high (strong impetus to local development, creation of small industrial districts) = 4

- **Realization time:** This criterion measures the time to realize and put into operation the plants designed. It is expressed in number of months.

Thus the 4 possible alternatives are evaluated according to the following Table 6-1:

Table 0-1 Alternatives and evaluation scale by criteria

	Costs (M€)	Primary Energy Saving (T/year)	Maturity of technology (1-4)	Impacts (1-5)	Local Development (1-4)	Realization Time (months)
Photovoltaic	2	1000	3	4	3	12
Wind Power	3	1800	4	3	2	18
Biomass	9.5	4000	3	3	3	24
Hydro-Turbine	0.75	375	2	5	1	12

In order to experiment with the methodology, we conduct several workshops with engineering Bachelor and master students who play the role of three above stakeholders. In charge of members of discussion, they need to achieve and shared decision before deciding the suitable renewable energy installations for the city. All students' preferences are regarded as equally important. The students have to reach a high level of agreement ( $\mu = 0.85$ ) (threshold of

consensus), before making the decision. The maximum number of discussion rounds allowed was 10 rounds.

From 17/8/2018, we organized 4 different workshops for students from dissimilar backgrounds, disciplines and origins. One workshop includes student meeting for the first time while in other cases, they have months or years of acquaintance.

The Table 6-2 will describe basic information of workshops including time, the background of participants and the type of recommendations giving for them.

Table 0-2 Workshop information

<b>Date</b>	<b>27/08/2018</b>	<b>26/09/2018</b>	<b>17/10/2018</b>	<b>22/11/2018</b>
<b>Title of participants</b>	PhD Students	Master Students	Master Students	Bachelor Students
<b>Number of participants</b>	6	24	23	60
<b>The date starting community</b>	> 1 year	Beginning contact	1,5 months	1 year
<b>Origin by nationality</b>	International student	International students	International students	French students
<b>Origin by training program</b>	ERPI (Research team on innovation process)	IDEAS (Master innovation et design évalués par les usages)	IUVTT (Innovation urbaine pour des villes et territoires en transformation)	Industrial engineering / Innovation management
<b>Time</b>	2 hours	3 hours	1 day	3 hours
<b>Recommendation</b>	No	Linguistic and graphical recommendation, questions for discussion		

Figure 6.1 illustrates how students work in groups where each members of the group play roles as stakeholders of energy planning projects in Messina in Sicily (Italy). This workshop takes place on 17/10/2018 for master students from “Innovation Urbaine pour des Villes et Territoires en Transformation” (IUVTT) training program.



Figure 0-1 The photo of workshop of IUVTT students on 17/10/2018 (Picture from UL-ERPI)

The main goal for each workshop was to compare results of consensus under simulated “real conditions” and these using the automatic consensus reaching system.

## 6.2. Experimentation process

In this section, we present the process of workshops. Each workshop gives a chance for participants working individually and in groups. We create both groups of homogeneous and heterogeneous roles as the following figure.

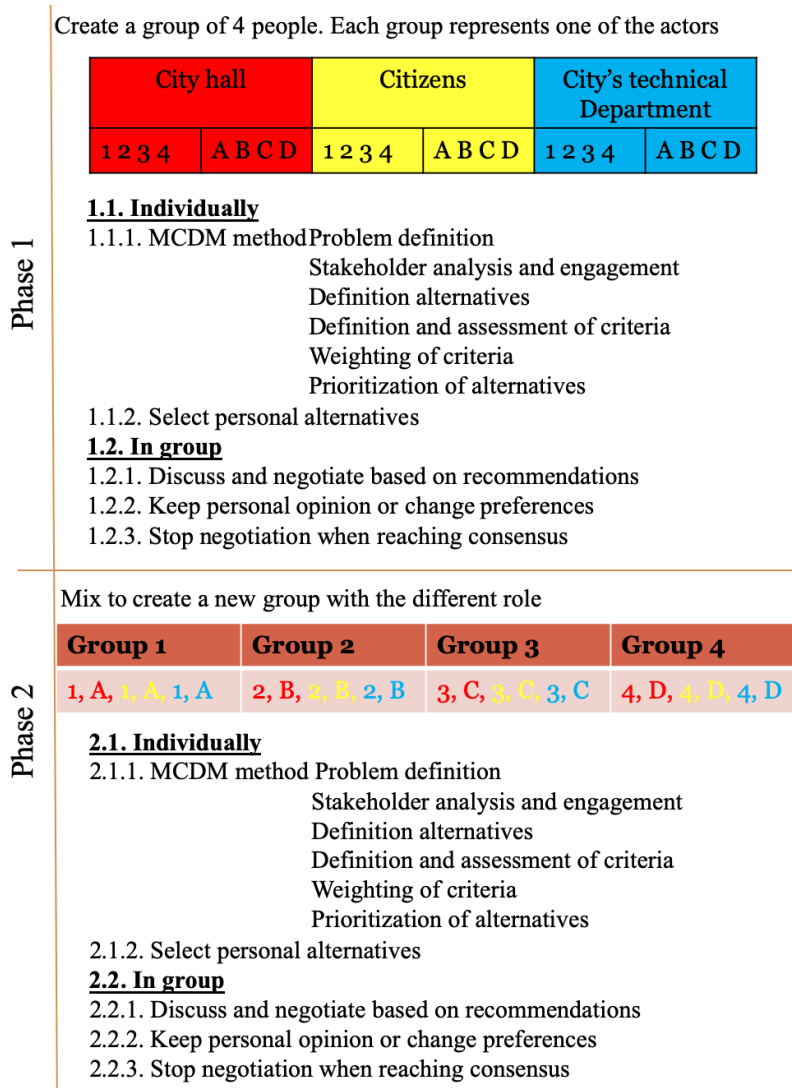


Figure 0-2 The schedule of workshops

### 6.2.1. Phase 1: Group work with the same role

First of all, we created several groups, each group having a concrete number of members (for example 4 or 6). Each group represents one of the 3 stakeholders presented above (a color and a number will be assigned to each member of a group). Each participant must agree, within the group on the decision to be taken.

#### 6.2.1.1. Phase 1 - Step 1: Individually

Then, each participant has to follow seven actions below, including:

1. Install the TotalDecision software ([https://vilenio.com/td\\_download.html](https://vilenio.com/td_download.html))
2. Import the data of the decision problem (Criteria and Alternatives)
3. Perform a pairwise comparison of the criteria in order to obtain their weights (Weighting criteria)
4. Check the consistency of judgments, if  $CI > 15\%$ , modify the values of the pairwise comparisons to lower this consistency indicator.
5. Perform the evaluation of the alternatives from the table above (Weighting alternatives – Direct method)



6. View the ranking of alternatives (Results / Graphs)

7. Open the Excel Template and enter individually the values you have chosen for the evaluation of the criteria in the first sheet.

#### 6.2.1.1. Phase 1 - Step 2: In group

Once all the group members have filled in the template file, several graphs appear (as an example in the Figure 7.2 “Graph of preference of all decision-makers in-group” of the chapter 7<sup>th</sup>). From these graphs and the questions below, each participant presents his or her arguments to the group and try to find a compromise among all the members of the group.

Some suggestions for discussion:

- What are the most important criteria for me, why?
- Do the other members of the group agree with this?
- Which alternative is the best from my point of view? Why?
- On what criteria am I ready to negotiate?

During the discussions, each participant potentially changed his or her mind about the weight of the criteria.

#### 6.2.2. Phase 2: Group work with different role

We mix the groups to create a new group. In the new group, we have different members represented by different roles: the City Hall, the Citizens of Messina or the city's Technical Department.

At the beginning of phase 2, each member of the new group works individually. He or she has to open the excel template and copy/paste her or his lasted data from phase 1 to a new template.

Once all the group members have filled in the template file, several graphs appear. From these graphs and the questions below, participants have to present his or her arguments and try to find a compromise among all the members of the group.

Some suggestions for discussion:

- What are the most important criteria for me, why?
- Do the other members of the group agree with this?
- Which alternative is the best from my point of view? Why?
- On what criteria am I ready to negotiate?

Next, during the discussions, participants potentially changed his or her mind or agreed to compromise on the weight of the criteria. We repeat this operation: discussion and fill data ... until each group agrees on the solution to be used.

## Conclusion

Living Lab is considered as a method engaging all stakeholders, especially users from the beginning phase of the innovation process. Under Living Lab approach, stakeholders actively work and collaborate in real-life conditions to share decisions about solution alternatives.

In this chapter, four workshops with a case study related to sustainable energy planning in a Smart City of Italy are designed to experiment models proposed in the previous chapters. The schedule of workshops instructs participants individually and collaboratively work under Living Lab approach to find compromise and share decisions. Each participant plays different roles of real stakeholders in Smart City projects, who have dissimilar knowledge, backgrounds and objectives. In order to support the share decision process of participants in this experimentation process, we will develop a functional mock-up for group decision making tools in the next chapter.



## : A functional mock- up for a group decision-making tool supporting argument and negotiation process

### Introduction

Due to a large number of elements including variables, functions, and parameters involved in many decisions, computerized decision support has become a basic requirement to assist decision-makers in considering and conducting the implications of various courses of decision making. In the meantime, the impact of computer technology, particularly the Internet in recent years, on decision management is increasing.

This chapter particularly emphasis on how an ICT- based decision support system tool can be used to facilitate the negotiation of stakeholders. The first section will present an overview of computerised support system tools for a decision problem. Next, a functional mock-up of using on-line interaction is developed with a specific focus on how citizens can participate in the group decision making of Smart City services. There are two types of decision support system tool that will be created, spread sheet and web technologies

Chapter 7 : A functional mock- up for a group decision-making tool supporting argument and negotiation process ..... **Erreur ! Signet non défini.**

    Introduction ..... **Erreur ! Signet non défini.**

    7.1. An overview of computerized group decision making tools**Erreur ! Signet non défini.**

        7.1.1. A spread-sheet package..... **Erreur ! Signet non défini.**

        7.1.2. Web-based DSS ..... **Erreur ! Signet non défini.**

        7.1.3. Group Decision Support Systems Software..... **Erreur ! Signet non défini.**

    7.2. A proposal of group Decision Support Systems tool supporting argument and negotiation process ..... **Erreur ! Signet non défini.**

        7.2.1. An online interface for group decision-making ..... **Erreur ! Signet non défini.**

        7.2.2. A web- based consensus support system ..... **Erreur ! Signet non défini.**

    Conclusion ..... **Erreur ! Signet non défini.**





## 7.1. An overview of computerized group decision making tools

The terms Decision Support Tools or Decision Support Systems (DSS) refer to a wide range of computer-based tools (simulation models, and/or techniques and methods) developed to support decision analysis and participatory processes. A DSS consists of a database provided with a dedicated interface in order to be directly and more easily accessible by non-specialists (e.g. policy and decision-makers). Principally, DSS can facilitate dialogue and exchange of information thus providing insights to non-experts and support them in the exploration of policy options.

Interaction and cooperation between users and computers are rapidly growing to cover more and more aspects of decision activities. Internet or Intranet-based computerized information systems have now become vital to all kinds of organizations, including businesses and governments. Therefore, computer applications are moving from transaction processing and monitoring activities to problem analysis and solution finding. Web-based services are changing from online information presentation and data access to intelligent and personalized information delivery and product customization and recommendation (Lu and Ruan, 2007). Internet or intranet-based online analytical processing and real-time decision support are becoming the cornerstones of modern management within the development of e-commerce, e-business and e-government. There is a trend toward providing managers with information systems that can assist them directly in making decisions. Computerized decision support technologies can help decision making in several aspects.

First, computerized system allows decision-makers to perform large numbers of computations, such as complex optimization models, very quickly. It, therefore, makes many complex models be used in real decision problem solving, including some emergency situations, which need to be responded in a very short time.

Second, many decision problems involve data, which is stored in different databases, data warehouses, and websites possibly outside the organization. Also, data may have different types, such as sound and graphics, and complex relationships. Computerized technology can search, store, and transmit needed data quickly and economically for helping decision making.

Third, computerized technology can help reduce the risk of human errors and improve decision results' reliability.

Fourth, computerized support techniques can improve the quality of the decisions made. Using computerized support, decision-makers can understand the nature of the problem better, can perform complex simulations, check many possible alternatives, and assess diverse impacts. For example, for a complex multi-objective programming problem, more alternatives can be obtained and evaluated, more uncertain data can be dealt with, more times of complex situations can be analyzed, and knowledge can be applied through linking with systems. All these capabilities lead to better decisions.

Finally, computerized support can reduce decision costs. A good example is with the support of web-based systems, group members can be at different locations to have decision meetings.

The important issue is that with computerized technology, many complex decision-making tasks can be handled effectively now. Many computerized tools have been developed to provide

group decision support systems to support the work of group throughout every work activity such as idea generation, consensus building, anonymous ranking, voting. The development of computerized decision support system tools related to spread-sheet, web technologies and group DSS software (Power and Sharda, 2007).

#### *7.1.1. A spread-sheet package*

In order to deploy model-driven for a decision support system, a spread-sheet is one of the major enabling technologies. (Power and Sharda, 2007). Related to accounting, a spreadsheet includes single sheets and an assembly of cells where data is shown on a screen of computers for users. In a decision-making process, users could change cell values, repeat evaluation of all cell values and finally, implement analysis and observe the results of those adjustments. Spread-sheet packages are considered as a computer software package that offers tools supporting a developer to build a specific decision support system quickly and easily.

Spread-sheets seem especially suitable for developing a Decision Support System with small models (Power and Sharda, 2007). To support a decision-maker in data analysis, a developer implements the model and then adds buttons, spinners and other tools and representations. Spread-sheet-based Decision Support System can be created in an end-user development environment or in a multi-user environment. One of the most popular spread-sheet application development environments is Microsoft Excel. Besides, there are some other examples of spread-sheet-based DSS tools. For example, a powerful program example using spread-sheet models as a user guide is Crystal Ball (<http://www.crystalball.com>). It is a set of optimizations, risk analysis and forecasting tools based on Microsoft Excel to develop several particular applications. Decision ToolPak (<http://www.decisiontoolpak.com>) is a product consisting of three simulation add-ins for Microsoft Excel. Simtools.xla improves Monte Carlo simulation and risk analysis throughout procedures and statistical function in spread-sheets (<http://home.uchicago.edu/~rmyerson/addins.htm>).

#### *7.1.2. Web-based DSS*

A Web-based DSS is considered as a computerized system based on Web browser to support decision support information or decision support tools. Web technologies including a Web server, HTML, CGI, PHP, and probably a database product like Oracle 10g or MySQL are used for implementing Web-based DSS (Power and Sharda, 2007). Web technologies can be used to realize any type of DSS such as communications-driven, data-driven, document-driven, knowledge-driven or model-driven DSS.

Most systems related to Web-based DSS were connected to a data warehouse. A model-driven decision support simulation settled in Java can be delivered via the Web. With a Web-based DSS, there is no need for any particular decision support software. In this case, an Internet connection and a Web browser provide the users decision support functionalities. Several findings have motivated on reviewed web-based simulation research and developments (Kuljis and Paul, 2001), (Miller et al., 2001). A new innovation of Web-based model-driven DSS is starting to be developed based on the web services concept. A single issue in DSS could be solved using multiple modeling or solution paradigms developed by different sources as separate web services. So, the results are then presented to the user in an aggregated or summarized form (Fabio Terribile et al., 2015). In the future, researches about innovative web-based DSS are likely to be developed.

#### *7.1.3. Group Decision Support Systems Software*

The studies on Group Decision Support Systems have extensively paid attention in the literature and that research stream remains very potential. DeSanctis et al. provide an overview of



research issues in group DSS (DeSanctis and Gallupe, 1987). The primary focus of this research is about improving the process of group decision-making. For example, Group Systems Company has proposed technologies and process support to group decision-making as a term of decision conferencing. Catalyze also offers a combination of delivery services process and the use of DSS based on multi-criteria decision analysis encourages the use of group DSS. Based on the Analytical Hierarchy Process (AHP), The Team Expert Choice from Expert Choice Company is introduced as a generator for building specific group DSS.

There are other GDSS software developed for supporting decision-making process such as the analytic hierarchy process (AHP) – Total Decision; analytic network process (ANP) – Super Decisions, linear optimization – Excel’s Solver, LINGO, LINDO API, CPLEX, etc. However, there is a lack of tools or software supporting consensus reaching process in group decision making.

## **7.2. A proposal of group Decision Support Systems tool supporting argument and negotiation process**

### *7.2.1. An online interface for group decision-making*

The proposal group decision support system tool includes two main components: an online Excel template for user interface and, a multi-agent system algorithm for formulating negotiation process and giving feedback recommendations

The online user interface is created by the Excel Drive template as an example in figure 7.1. It is available to access for all stakeholders or participants involving in group decision problems. In this example, there are 4 students represented for 4 stakeholders of group decision-makers. Each participant has his or her own comparison table to access 5 criteria based on comparing pairwise method. After all values of decision criteria are filled, the consistency index CR is computed to make sure all the consistency of provided preference relations base on the method of Saaty (Saaty, 1990b).

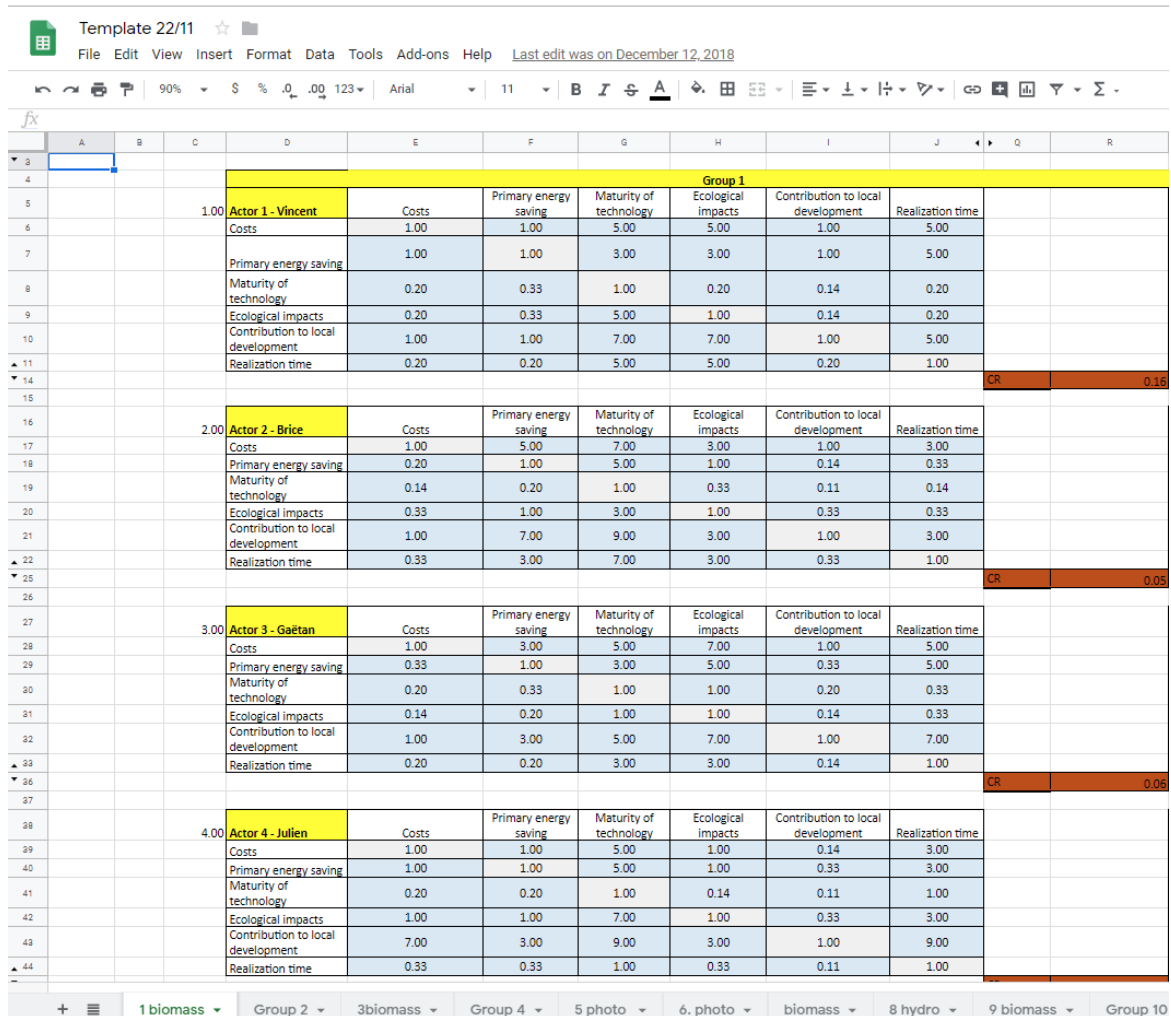


Figure 0-1 An example of user interface for group decision making

Following AHP method, each stakeholder has her or his own decision about the best alternative. However, in a group of participants, this decision could differ from the preferences of others. As a consequence, participants need to negotiate, discuss and convince others in a consensus reaching process.

In order to support this process, the proposed tool allows participants to access information about all preferences and assessments of other decision-makers through visual graphs. The figure 7.2 illustrates the map of preference of 4 members in a group relating to the weight of criteria and rank of alternatives. Each preference of members in a group is represented by a different colour. The first graph in figure 7.2 described differences in assessing the weight of 6 criteria: costs, primary energy saving, the maturity of technology, ecological impacts, contribution to local development and realization time. Meanwhile, the below graph showed the order of alternative by each participant. 4 alternatives, including photovoltaic, wind power, biomass and hydro- turbine, have specific colour respectively blue, orange, gray and yellow. Participants use these graphs as a visual recommendation to identify how different between her or his preference with others and which alternative is the choice of most of members in the group. As could be shown in the figure 7.2 participants got consensus about the criteria “primary energy-saving” and “ecological impacts” while the other criteria still continue to negotiate. The most different criteria that need to discuss in the next round of negotiation process is “maturity of technology”. Regarding alternatives, three participants in the group of

four chose photovoltaic (the blue column) as her/ his selection. Only the third member of the group selected hydro- turbine (the yellow column).

Based on these graphical visualizations, participants could decide to keep their own decision or follow the most popular results of the group or listen to the viewpoint of others to modify her/ his previous decision.

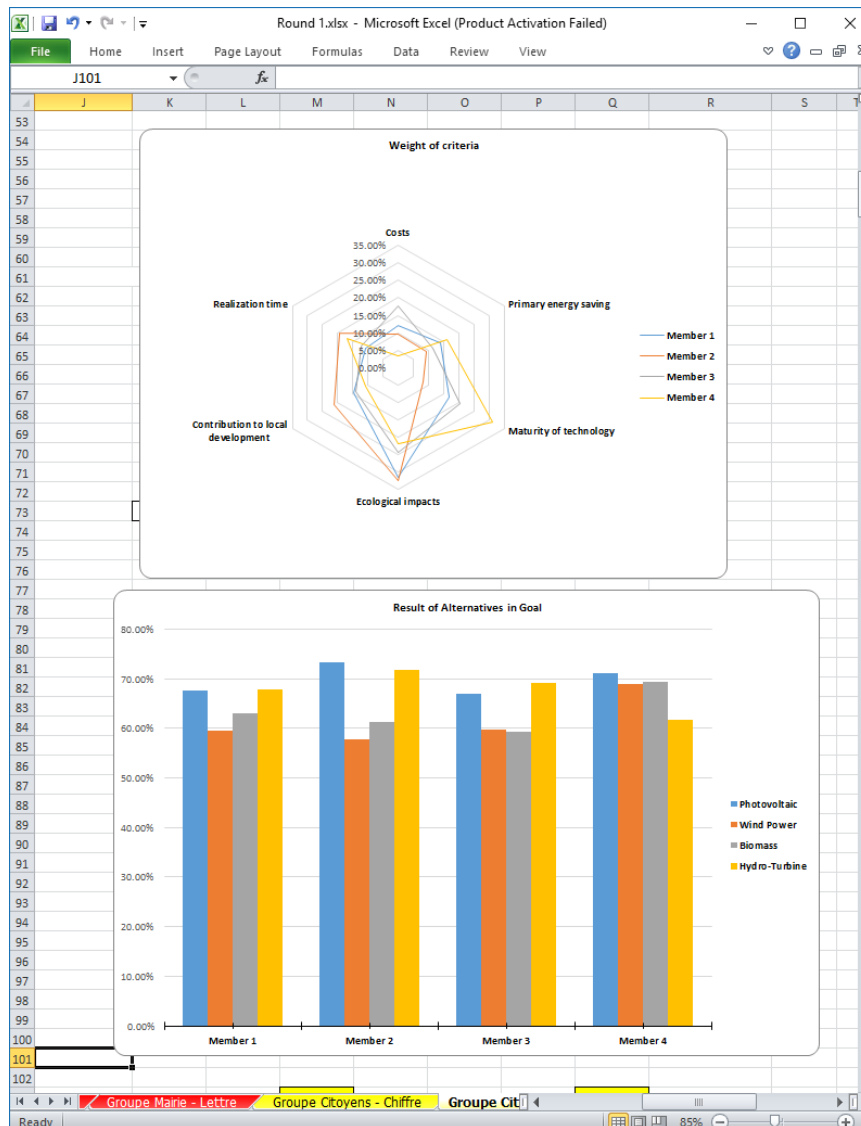


Figure 0-2 Graph of preference of all decision-makers in group

Besides, algorithms programed in Matlab® software identifies the level of consensus and also provides recommendations for participants about which value in his or her preference matrix furthest from the average value of group (Figure 7.3).

As showing in the figure 7.3, the outcome from the programming by Matlab® software is linguistic recommendations for each member of the group decision-makers to improve the consensus level of their group. These recommendations pointed out which participant should keep their assessment and which participant should increase or decrease their value of previous decision to a suggested value. For example, the member 1 should decrease his/her preference

on the criteria at row 2 and column 3 of the previous evaluation matrix “from 3 to a value closer 1.125”.

The detailed algorithms have been presented in section 5.3 of chapter 5. Using recommendations from Matlab® software, and depending on the collective discussions and arguments, participants could decide to change their own preferences or keep the original opinion.

Changes of a participant will modify the level of consensus. If the consensus degree still lower than the fixed threshold, participants continue to discuss and negotiate in the next rounds of consensus reaching process. When all participants in a group have the same chosen alternative, the shared decision is determined and the consensus reaching process stops.

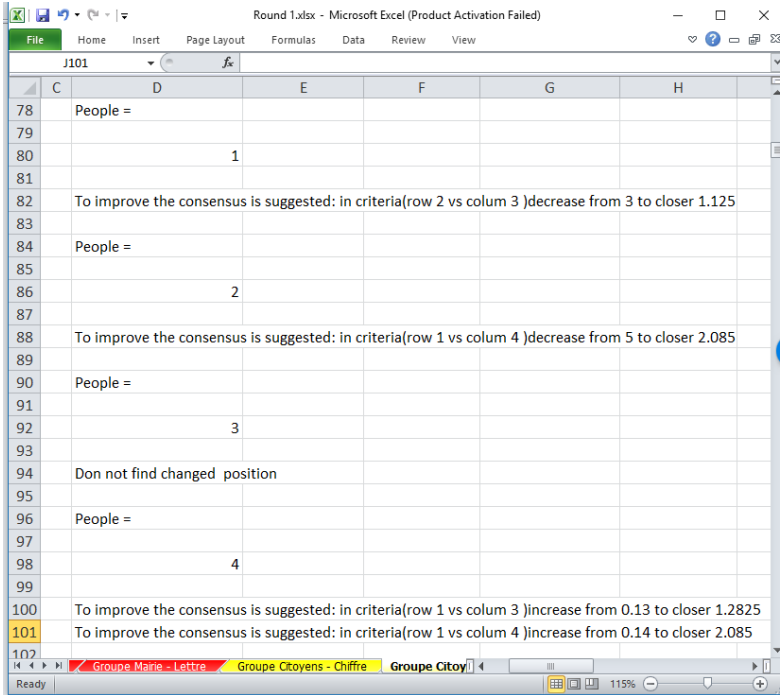


Figure 0-3 An example of recommendation from algorithms in Matlab® software

7.2.2. A web- based consensus support system

One of the advantages of the above online spread-sheet package is easily accessible through the available characteristics of the Google Driver interface. However, this spread-sheet package working independently with algorithms of Matlab® software. This leads to a demand for tools integrating both user interface and consensus algorithm creating recommendations.

This section is a product of cooperation between me and two students from Nancy Telecom University, Mr. Benjamin Cousin and Mr. Colin Flory under the supervision of Dr. L. Dupont and myself. Starting from the same objective with the DSS tool developed in the above section, we selected the web application because of its convenient for non- expert users. The link of web-based tool is available at <https://pidr-cousin-flory.firebaseio.com/>.

The framework React JS based on JavaScript language is chosen for this website. The database in Firebase is selected because it is easy to use with React and it is free. Furthermore, this solution allows you to host the website conveniently.

The website includes a welcome interface (figure 7.4), login page (figure 7.5) and pages for setting up (figure 7.6) and recommendation page (figure 7.7). First of all, the welcome interface

is designed to brief an introduction about our project. All participants have to create their accounts by email address and use it for sign in.



Figure 0-4 The welcome interface

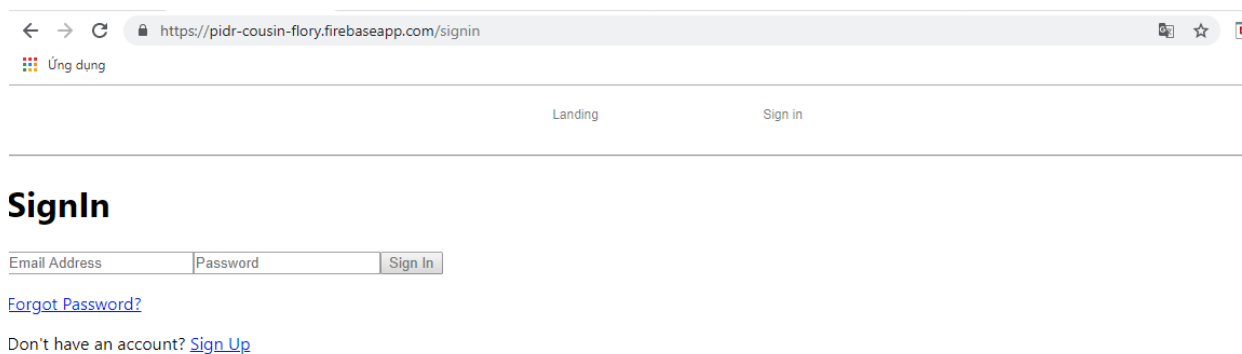


Figure 0-5 The log-in page

Next, the host or moderator has to set up all information about the room of discussing, goal, criteria and alternative in the setting up tab. The website will be tested with requirements of a case study in the 6<sup>th</sup> chapter. As described before, the goal of the case study is to reshape the city's energy production system by integrating a significant proportion of renewable energy. This project involves the following stakeholders: the city hall, the citizens of Messina and the city's technical department. Four different alternatives of renewable energy installations are considered: Photovoltaic (PV), Wind power, Biomass, and Hydro-Turbine. 6 criteria will be taken into account for the final decision: costs, primary energy saving, maturity of technology, Ecological impacts, Contribution to local development and realization time.

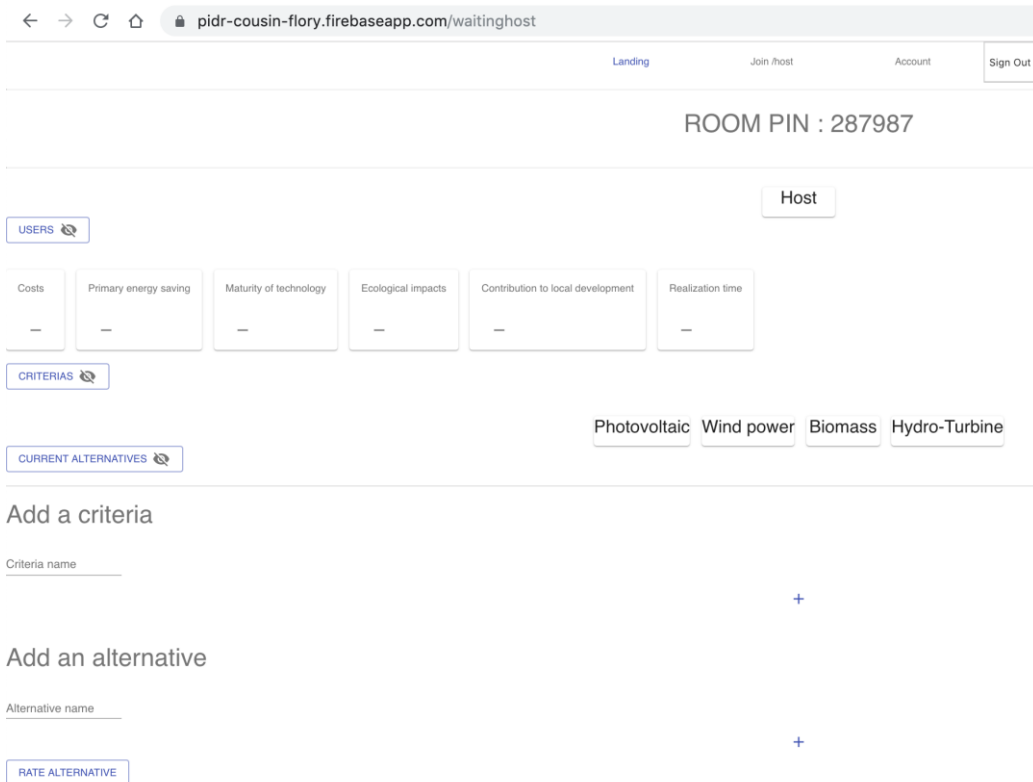


Figure 0-6 The setting up page

After joining into discuss rooms, all participants can access the evaluation page (figure 7.7) to weight criteria and alternatives. After all members of a group finish evaluation, visual graph and linguistic recommendation is shown in the recommendation tab. This information is the input for the consensus reaching process of each group.

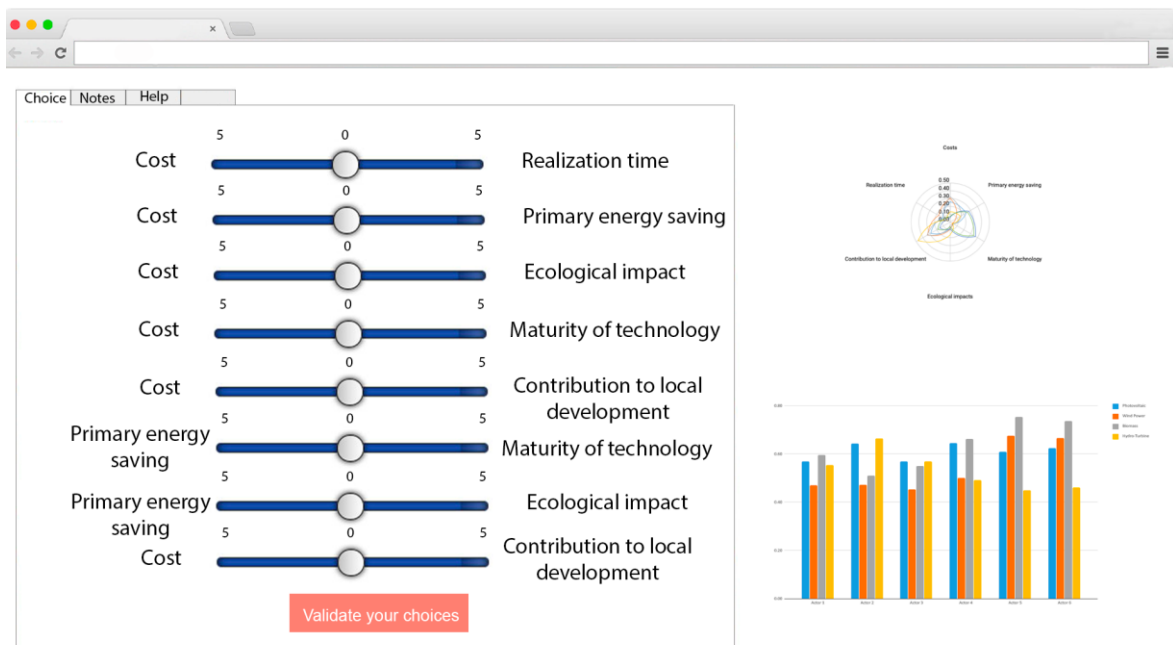


Figure 0-7 The evaluation page

Regarding the Firebase database, it is separated into three main parts: rooms, savedRooms and users as shown in the figure 7.8. The “rooms” matches the real currently being used by members



of a group of decision-makers. “SavedRooms” correspond to rooms that have been saved. Users correspond to the account created in the application.

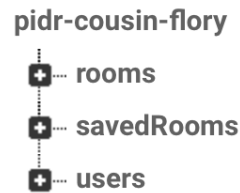


Figure 0-8 Firebase database

Each room is saved in the database like in the figure 7.9. When there is a plus it means that you can open the object to see it, like a list for example. So alternative, criteria, notation A, notes and users are lists of elements.

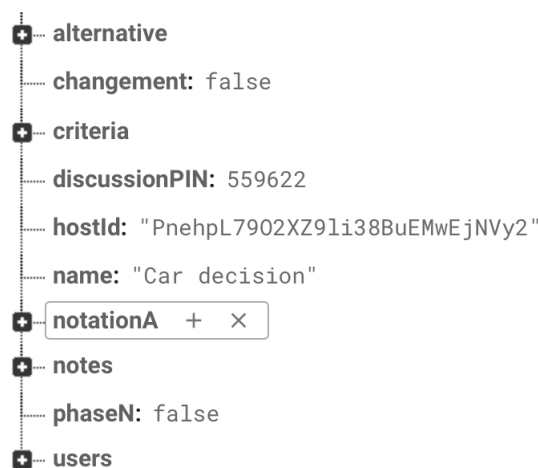


Figure 0-9 Firebase Database Room Example

The weighted grades that the participants gave to each criterion are saved in the notes part of the database. These grades are saved after each grading round. They are saved under each username, notes keep in memory the last round and then every “notes round n” matches the grades of the next round. The data is stored online in the Firebase Database and you can access it whenever you want.

## Conclusion

It could be concluded that advanced computerized decision support systems generate recommendations based on information about the consensus level of a group and preferences of other members to assist decision-makers in their decision-making process.

Developed from the proposed methodology in chapter 5, two types of computerised support system tools supporting the consensus reaching process have designed. However, due to the limited time and the real condition of students in the University of Lorraine, there is only the

first tool implemented by a concrete case study. This tool consists of a user interface by Excel Drive and a mechanism giving feedback recommendations based on programming algorithms.

Using this computerised support system tool, the model integrating consensus reaching process into multi-criteria decision-making methodology is expected to take advantage of both ICT-based tools and the role of a human moderator. Comparing to group decision making processes supporting only by moderators, the decision support system tool is expected to shorten response time of making decisions and reduce the number of participants who had to revise their assessments at each discussion round. As a result of this, the cost and time invested in conducting the whole CRP were significantly reduced. The result analysis from executing the proposed model and validation will be discussed in the next chapter.



## : Model validation and Result analysis

### Introduction

In order to meet the demands of the experimentation process in the 6<sup>th</sup> chapter, the study designed functional mock-ups based on the proposed methodologies for the automatic control decision-making process and the process supervised by a human facilitator. The models of these decision-making support tools have been executed in several workshops with a case study to reshape the city's energy production system in Messina (Italy).

This chapter will analysis results from experimentation and then, use these results to discuss about validating the proposed models. The results include both the model for large scale group without moderator and the model guided by human facilitator and support system tools.

Chapter 8 : Model validation and Result analysis .....	<b>Erreur ! Signet non défini.</b>
Introduction .....	<b>Erreur ! Signet non défini.</b>
8.1. Results analysis.....	<b>Erreur ! Signet non défini.</b>
8.1.1. The group decision making with human facilitator and ICT based consensus support system .....	<b>Erreur ! Signet non défini.</b>
8.1.2. The group decision-making process with an automatic control system ..	<b>Erreur ! Signet non défini.</b>
8.2. Model validation.....	<b>Erreur ! Signet non défini.</b>
8.3. Discussion.....	<b>Erreur ! Signet non défini.</b>

## 8.1. Results analysis

For each workshop, the data from the way participants make their first own decision and then, negotiate to modify and make a shared decision were systematically collected. This is the input for the result analysis of two types of group decision-making process, the process guided by human facilitator and ICT based consensus support system and the process with an automatic control system.

### 8.1.1. The group decision making with human facilitator and ICT based consensus support system

#### 8.1.1.1. Tracking behaviors of participants and classifying their profile

Through the visualization of changes after rounds of negotiation, we could track behaviors of participants and classify their profiles. The results correspond to the experimentation on 17/10/2018 with IUVTT master students. After the negotiation process, participants decided to change their preferences or not and how much should be changed. The data from these modifications have been collected according to different roles in group decision making as described in figure 8.1. Four colors: blue, orange, black and yellow represent different rounds of the negotiation process, from the first to the final round. In order to identify the profile of this participant, it is important to track his/ her assessment and modifications at different rounds.

As defined in Chapter 4, there are 3 different types of profile are defined, including sure profile, unsure profile and neutral profile. In the case of City hall C, this participant kept his/ her opinion in most of the negotiation process. The most obvious change appears in the last round when finally; all participants have to make a shared decision. Therefore, it could be concluded that City hall C has “sure” profile. Meanwhile, the participant in the role of City hall A significantly changed opinions after the first discussion with others. We could classify him/ her belong to “unsure” profile. Finally, the person represented for citizen 2 changed decisions neutrally after rounds of negotiation process. He/ she is identified as “neutral” profile.

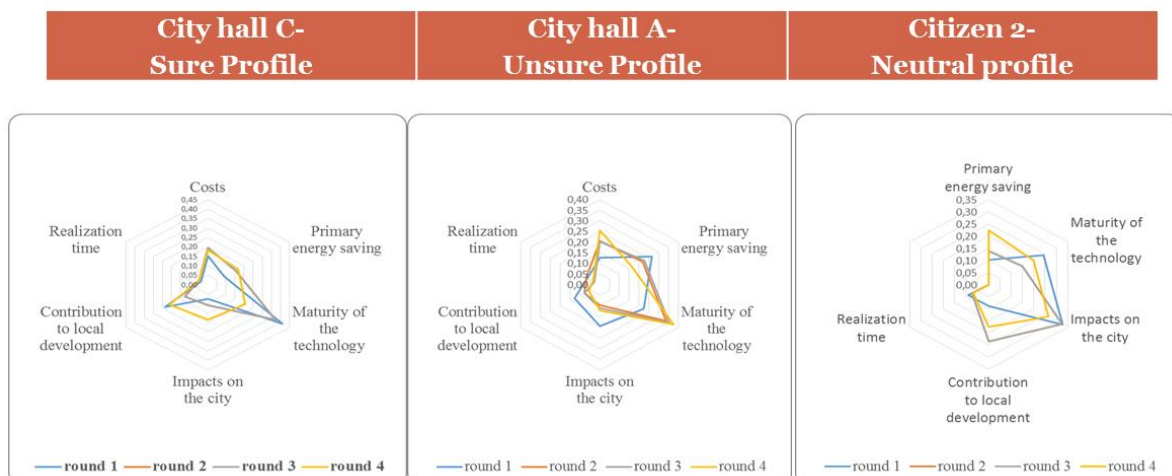


Figure 0-1 Changes in preferences of participants in charge of different roles

### 8.1.1.2. Factors impact on changes in direction of consensus reaching process

In this section, factors, impact on changes in the direction of consensus reaching process will be analyzed.

- The last round of the negotiation process:

This is the last chance for discussion before making the final decision. Participants become more concerned about achieving an agreement and therefore, have to apply a significant change in their preferences to improve the consensus degree of the group. It is important to fix the maximum round of negotiation before starting the process.

As be shown in the figure 8.1, the most significant modification is in the yellow line that presented for decisions of participants at the final round of discussion.

- Diversity of roles of participants in groups:

In the table 8-1, we present the result about whether the final shared decision of group decision-making process is made or not after stopping negotiation.

Table 0-1 The basic result of workshop.

<b>Workshop</b>	<b>Result in groups with the same role</b>	<b>Result in groups with different roles</b>
27/08/2018 (ERPI PhD Students)	3 groups: shared- decision	Increase consensus level but no shared- decision
26/09/2018 (IDEAS Master students)	5 groups: share- decision and 1 group: no shared- decision	1 group: share- decision and 3 groups: no share- decision
17/10/2018 (IUVTT Master students)	4 groups: share- decision and 2 group: no shared- decision	3 groups: share- decision and 1 group: no shared- decision
22/11/2018 (Industrial engineering / Innovation management students)	*	all groups: share- decision

\* In this workshop, participants only worked in group with different roles

The results from workshops proved that most of groups of homogeneous make a shared decision after the negotiation process. However, groups with heterogeneous roles face difficulties in reaching consensus. The reason is that, in groups where participants have the same role, it is easy to share preferences and objectives.

- Profiles of participants

From the data of workshops, we could track behaviors of participants and classify their profile belong to sure, unsure or neutral profile. It could be noticed that the more “sure profile” participants are in the group, the more difficulties the group face to reach consensus and make the final shared- decision.

The data from the workshop on 17/10/2018 (table 8-2) showed that, after 3 hours of discussion, the fourth Group with 6 “sure profile” participants did not give any final decision. Most of members in this group have “strong” opinion too be convinced by others in the negotiation process.

Table 0-2 The result from workshop on 17/10/2018 about relation between profile and consensus

	Group 1	Group 2	Group 3	Group 4
Profile of participants	5 sure + 1 unsure	5 sure + 1 neutral	5 sure + 1 neutral	6 sure
Final decision	Photovoltaic	Biomass	Biomass	No decision

- Phases of negotiation process:

In the workshop on 27/8/2018, participants used 3 rounds of discussion to make a shared decision. In figure 8.2, the way consensus degree changing is showed in the orange line while the blue line follows the consensus trajectory suggested by the agent based automated consensus reaching process.

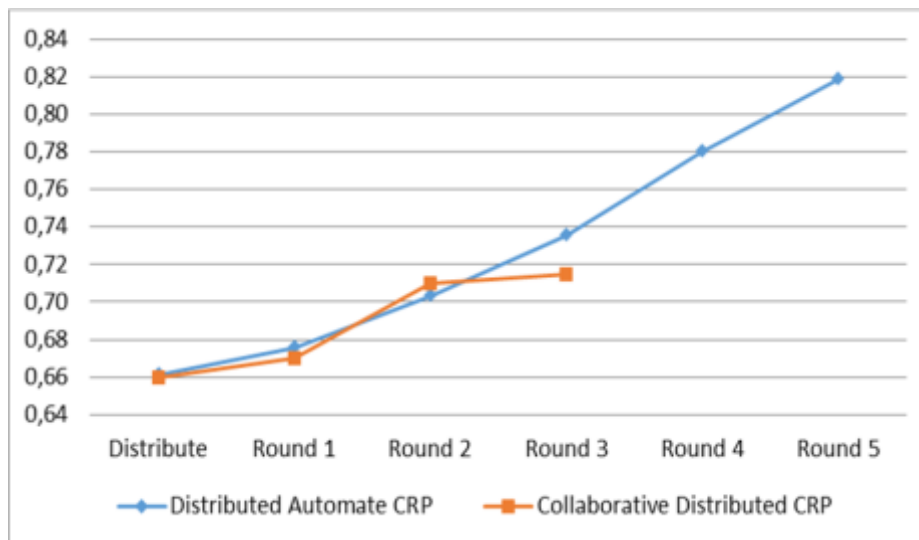


Figure 0-2 Changes in consensus degree after rounds of negotiation

It could be concluded that in the early stages of the negotiation process, participants have more information about the context and easily change their minds to find a suitable decision. Therefore, the level of consensus could be low at the starting point but after that, it would increase rapidly. However, in the next rounds, participants could be tired and lost concentration when the negotiation process lasts too long.

#### 8.1.1.3. Role of facilitators and tools supporting decision- making:

The workshop on 27/8/2019 is the first time we execute the proposed model in the simulated real-life conditions. At this workshop, we let students free to discuss and negotiate without giving any recommendations. Even though these Ph.D. students have the same discipline and they know each other for a long time, they did not have an efficient discussion to share decisions. At a few moments of the process, some groups faced more differences, especially groups with heterogeneous role did not reach consensus.

The figure 8.3 compares changes in a consensus degree of different groups after rounds of negotiation. The data collected from the behavior of group “city hall” in the workshop on 27/08/2018 noticed that without any recommendations, consensus degree could fluctuate, and it is difficult to reach consensus.

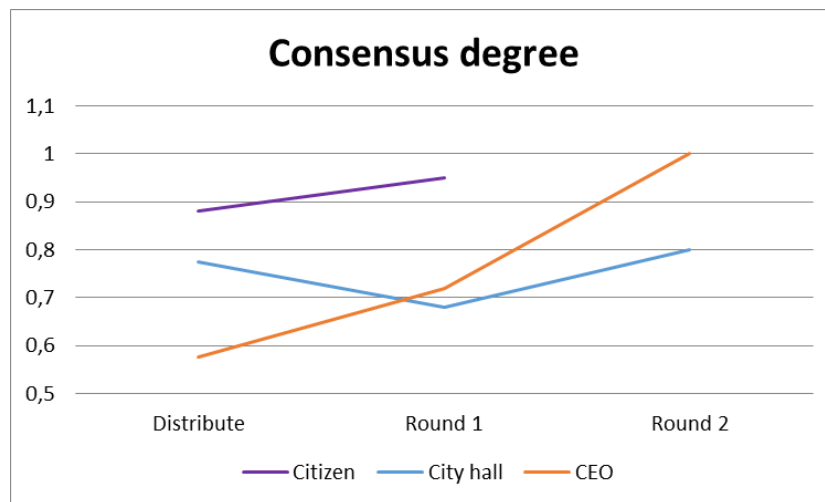


Figure 0-3 Changes in consensus degree of stakeholders

### 8.1.2. The group decision-making process with an automatic control system

In this section, we present the results collected from the automatic control system based on multi-agent system to support Consensus Reaching Processes. This process is executed in a parallel way with workshops to compare two types of group decision-making process, the process guided by a human facilitator and ICT based consensus support system in workshops and the process with a software control system.

In the previous figure 8.2, the blue line presented for the process with an automatic control system and the orange line showed the result from the process guided by a human facilitator and supervised by ICT based consensus support system in the workshop on 27/8/2018. In this workshop, students have to reach a high level of agreement ( $\mu = 0.85$ ) before making the decision. The maximum number of discussion rounds allowed 10 rounds. Because of limited time, the students did not reach the consensus threshold to make a final decision. However, with the results predicted from the blue line, the discussion could finish with two more rounds of negotiation. This is a valuable tool to predict the final decision in case discussion faces a lot of conflicts.

## 8.2. Model validation

The experimentation in the 6<sup>th</sup> chapter with decision support tools proposed in the 7<sup>th</sup> chapter allows me to explain our initial hypothesis and validate the developed model. Model validation methods are developed for judging the accuracy of the model in making relevant predictions (Winston and Goldberg, 2004). Validation for agent-based models focus on whether the model is useful and convincing in its explanation of how a system possible operation or potential states of the system. The outcome of these models can be validated through several different methods, including historic replay, face validation through expert consultation, literature validation and model replication (Van Dam et al., 2012).

**Historic Replay:** For models that can be executed in a real-world situation, a historic replay consists of a scenario and computational experiments. The scenario is a description of the path from some past point to the state of the world today through the system's observed parameter space. The people, actions and situations from the scenario are parameterised and translated to the model, then experiments explore whether the





emergent patterns from the observed scenario are present in the simulations and if the outcomes and end states of the model resemble the current state in the real system.

Expert Validation: Expert validation is the most commonly used validation approach in agent-based modeling (Van Dam et al., 2012). Experts and problem owners can discuss the behaviour of agents, the patterns of behaviour of the system and also the application of model for its designed purposes. Performing an expert validation usually includes structured interviews with individuals or workshops with larger groups of experts, systematically going through the model assumptions, mechanisms and outcomes.

Validation by Literature Comparison: Further validation can be performed by studying the academic literature. Similar conclusions reached through both theoretical research and non-agent-based models increase the confidence in the model outcomes. Further validation is possible if other, non-agent-based, models of the same or similar systems problems exist, even if they have been used to answer a different question (Xu et al., 2003). Furthermore, it may be possible to gain further validity by performing new experiments that better align the assumptions, inputs and scenarios between the models as described in the literature and those that seek validation. When performing such comparison experiments, we should not focus on replicating the exact outputs, but instead on the general outcomes and recommendations.

Validation by Model Replication: Finally, a strong - but labour intensive - form of model validation is model replication. Creating a second agent-based model with different system decomposition or a model using a different modeling technique (e.g. system dynamics) and comparing the outcomes can be a rich source of validation, and a good choice if the previously discussed options are unavailable. In an ideal situation, a different research team will build these models, to remove any bias.

In this section, the expert validation method is used and discussed in table 8-3 related to four features including model structure, data sources, problem formulation and results. In this case, experts are stakeholders who used this model for decision making in Smart City projects. The engagement of stakeholders in developing this model starts from beginning steps of the process to the final phase, from user need analysis to user validation.

Table 0-3 : Expert validation for the proposed model

Features	Requirements	Justification in this study
Model structure	Whether the model includes all aspects of reality considered important by participants.	The model is developed for formulating the complex and dynamic decision-making process in Smart City projects. Besides, this model considered every phase of projects and every level of decisions. Therefore, important aspects of reality are included in the proposed model.
Data sources	whether the best available data sources were used	Experimentation has used real data available from assessment of participants in case study. All databases of individual decisions and modification have collected.

Problem formulation	whether the setting, population, interventions, outcomes, assumptions, and time horizons correspond to those of interest	Problems in Smart City are always complex and dynamic. By solving systematic issues in a hierarchical way, the model covers problems efficiently.
Results	whether they match participants' expectations and, if not, whether the model can plausibly explain them	The result analysis in this chapter is consistent and reliable when comparing both automatic and supervised decision process. These results also adapt our expectations and objectives.

The experimentation with real stakeholders will convince the application of the model and point out limitations throughout their feedbacks. In fact, we only worked with students who are playing the role as real stakeholders in this study. This situation to some extent limits the convincement of model validation. However, it is noticed that students have a basic background related to urban management skills and they will be the real stakeholders in urban projects in the future. Experimentations with students are the basic and necessary preparation for the future workshop with real experts in urban projects.

After each workshop with students, we always receive their feedbacks. For example, students from IDEAS (Master innovation et design évalués par les usages) program give positive feedback about the workshops and the proposed decision support tools. They thought that the most helpful tool in the discussion is the visual graph showing differences in preferences of all members in a group about the weight of criteria and ranking of alternatives. Information about the preferences of other members in the group and their viewpoints contribute to improve the negotiation process and support shared decision making. Some students believed that the main goal of workshops achieved and playing roles as stakeholders help students understand the real-life situation of Smart City projects.

### 8.3. Discussion

In this chapter, both Living Lab decision-making models, the automatic and the supervised process, were validated in concrete case studies. Throughout using both methods, we can compare how different between the theoretical model and a process experimented in real-life.

The result from experimentations proved that

- There are some factors impact on changes in direction of consensus reaching process including diversity of roles of participants in groups, profiles of participants, phases of the negotiation process, especially the last round.
- Throughout tracking behaviors of participants, a moderator could classify profiles of participants and then create new groups with a balance component of profiles.
- Moderators and supporting decision tools play important roles in decision-making process.

Based on results obtained, we could summary differences, advantages and disadvantages of both proposed models, the supervised and the fully automatic consensus reaching process. It could be interesting to discuss more conditions for the success of experimentation executing the proposed models in the below table.



Table 0-4 The summary discussion about proposed models

Model	Supervised consensus reaching process	Fully automatic consensus reaching process
Description	The model guided by human facilitator and ICT based support system tool.	The model operating automatically without human facilitator
Conditions for application	Small and medium scale group of decision-makers.	Large scale group of decision-makers.
Advantage	The model takes advantages from ICT based solutions while still keeps the autonomy of decision-makers.	The model automatically operates the negotiation process. The results of automatic process could use to predict tendency of the process in real life conditions.
Disadvantage	The process takes a lot of time for negotiation in large scale group of decision-makers.	Behavior and psychology of human is a complex domain that is difficult to exactly formulate by artificial algorithm. The model did not be developed for groups having fluctuating numbers of member.

When managing workshops, we recognized there are both advantages and disadvantages for working with students. Students have the basic knowledge to executing the model in a case study. However, students do not have practical experiments as real stakeholders in Smart City project. Therefore, the final results in real life could differ from a case study when participants playing the role as real stakeholders. Besides, the motivation of each student is dissimilar to others. Most students follow the instruction of workshop managers; however, there are some of them did not actively engage in the negotiation process.

# Conclusions, limitation and perspectives

## Conclusion

In this decade, several researchers have studied the application of Living Lab method on urban project management. These contributions have based the influence of multi-disciplines of engineer sciences (for instant, industrial engineering) and human and social sciences (for an instant, sociology and political sciences). Many stakeholders of Smart City projects have been connected and involved into the eco-neighborhood project.

In Nancy (Nancy Grand Coeur) an urban project has been designed around the train station since 2005 as a renewed project of the city center. The Lorraine Smart Cities Living Lab developed by ERPI laboratory supported the local authorities (Greater Nancy Metropolis) to co-design this eco-neighborhood project from 2010 to 2014. During the first stage from 2010 to 2011, 180 diversified participants (organized and not organized inhabitants, technicians of local authorities, elected representatives, experts from companies, state services, etc.) engaged with 19 workshops (Dupont et al., 2014). One of the findings from this project is the model of “citizens panels” where a group of users has a chance to simulate solutions and express their experience, desires, wishes, disagreements and discontents. Several technical reports, submitted to the metropolis, present these data and results. From 2012 and 2014, researchers designed operational workshops with citizens and technicians to implement innovative mobility station on Charles III Square and innovative and sustainable public spaces. Finally, about 300 citizens (i.e. all participants, professional or not) were mobilized in 31 workshops for 5 years. Scientific publications based on this project concluded that the authors are succeeded to share knowledge between stakeholders and identify the expectations and needs of participants (Dupont et al., 2016a). However, in the end, the final decisions about setting up a mobility station at Charles III Square, Nancy have been chosen without taking into account the expectations and needs of participants. Researchers analyzed, strengthened and added value to the initial diagnosis stage of the urban project while there is still a gap between shared diagnosis and shared action (Dupont et al., 2015).

The main contribution of our study is a methodology supporting the process of shared decisions for stakeholders in Smart City projects under Living Lab approach. This is an important intermediate between shared diagnosis and shared action.

## Contribution

Our study includes four parts: research context, conceptual framework, model development and finally, case study application and result.

In the first part, this research firstly contributes a systematic literature review methodology to search and use the Scopus database related to decision making in Smart City as a raw data input for the study. Throughout a qualitative method as an original “big” data analysis with VOSviewer, the initial result shows the issue of decision-making methods is a recent research problem that inadequately attracts attention in the academic community. Therefore, the study continues to review researches on decision-making methods enabling communication between multi-stakeholders, especially citizens implication into various phases of Smart City projects. A general mapping of applying different decision-making methods is created at different levels of decision and phase of implementation. It is noticed that MCDM is a potential method at every level of decision and during the whole stages of the Smart City projects while



computerized methods are widely used to make operational and tactical decisions for concrete problems. The literature review also found a lack of decision-making tools supporting the negotiation between stakeholders in Smart City projects.

Secondly, we created the main contribution in the second and third part. This relates to a methodology supporting consensus reaching process in Living Lab environment has been presented. The methodologies, including two kinds of reaching consensus: a process with human facilitator and an automatic control system that substitutes the facilitator's actions, are developed from conceptual models. Then, multi-agent system algorithm is designed for the negotiation in consensus reaching process and the multi-actor multi-criteria method is applied for engagement stakeholders into multi-context assessment.

Thirdly, I developed a functional mock-up based on the proposed methodology focus on how citizens can participate in the group decision making of Smart City services. There are two types of decision support system tool. The first one developed in Excel Office and the second is a web-based solution. In general, these decision-making tools are designed as a user-interface that facilitates for engagement of many groups of urban stakeholders into a transparent and active decision-making process. It could be concluded, from our experiments that the more information provided to participants (i.e. the more they share a diagnosis), the easier for them is to reach consensus.

After the proposed methodology and decision support system tools, I then validate the model by concrete case studies. The results show that there are several factors in group decision making significantly contributing to improve consensus reaching process

### **Limits and perspectives of this research**

It is well known that in a thesis project, it is difficult to deepen in each field that has been considered. Consequently, some limitations of the contribution are highlighted, in order to put them into a larger perspective.

In this study, a group of decision-makers is created to fix participants over time. All of them are involved in the decision-making process from the beginning until the final round of negotiation. However, we can also find that in practical decision-making situations the group of participants could vary over time. For example, we could find new and important participants to solve the decision process or we could identify participants unsuitable for the decision process or we could require simplifying a subgroup of participants in order to facilitate the achievement of the solution. This happens more frequently in decision processes developed in the online community with a large number of participants. In such decision contexts, it is difficult to achieve acceptable consensus among the remaining participants. To address these situations, a new consensus model has to concern about these dynamic properties of real communities.

Besides, in the real decision process, we could find that the set of alternatives could be dynamic, i.e., that some alternatives negotiation is might disappear and new ones appear through the decision-making time. This could happen because of the availability of some of alternatives changes while participants are discussing and making the decision, or participants evaluate the alternatives poorly or we find better alternatives to solve our decision problem. To solve these situations, new consensus approaches have been proposed as a tool to deal with dynamic

decision frameworks by allowing to change the alternatives that compose the set of solution alternatives.

Finally, the case study and the workshop are designed for a Smart City project in Messina City (Italy) with French or international students. Because of differences in context, culture and political institution, future workshops with real stakeholders in different countries should be modified the procedure to make sure that the models and functional mock-ups still work efficiently and exactly.

In order to overcome the above drawbacks, several improvements for proposed methodologies could be implemented in the further future such as:

- In order to deal with dynamic decisions, a further study focuses on developing algorithms considering the variable time in decision-making process that allows changing the set of solution alternatives or numbers of participants.
- In artificial intelligence, another computer application to solve complex decision-making problems is an expert system (Harmon et al., 1988). An expert system is a computer system that emulates the decision-making ability of a human or an organization that has expert knowledge and experience in a particular field. For solving multi-objective decision making (MODM) problems, the architecture of a fuzzy expert system has been developed for determining the priorities and aspiration levels of decision-makers as well as to the analysis of conflict among the goals (Rasmy et al., 2002).
- In the next months, there will be several workshops with students and professionals (long-life training). These are opportunities to improve and validate functional mock-up for tools supporting consensus reaching process under real conditions. Besides, we intend to work with experts or real stakeholders of Smart City projects to implement and diffuse proposed methodologies in real-life situations. However, there are still several challenges in managing workshops with real stakeholders such as a large number of decision-makers, the long-time of the negotiation process, the conflict objectives or the difficulty in determining the weights of stakeholders. In several Smart City projects, there are stakeholders, for example, local government, having autonomy or strong power in the making-decision process. This autonomy could reduce fairness, justice and transparency in finding urban solutions.



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## Appendix A

```
if AverageC >= Mu
    display ('finish the process')
else
    display ('Improve')
    LMatrixP = cell(1,m);
    AveragePC = zeros(n);
    Maxdeviation = zeros(1,m);
    Mindeviation = zeros(1,m);
    for i = 1:m
        LMatrixP{1,i} = lamda(1,i)*MatrixP{1,i};
        AveragePC = AveragePC + LMatrixP{1,i};
    end
    AveragePC = (1/m)*AveragePC;
    LInputMatrix = cell(1,m);
    AverageInputMatrix = zeros(n);
    for i = 1:m
        LInputMatrix{1,i} = lamda(1,i)*InputMatrix{1,i};
        AverageInputMatrix = AverageInputMatrix + LInputMatrix{1,i};
    end
    AverageInputMatrix = (1/m)*AverageInputMatrix;

    PP = cell(1,m);
    for i = 1:m
        PP{1,i} = MatrixP{1,i} - AveragePC;
        Maxdeviation(1,i) = max(PP{1,i}(:));
        Mindeviation(1,i) = min(PP{1,i}(:));
    end
end
PP{:, :};
Maxdeviation
Mindeviation
```



```
deviation=0.24;  
Compared_value= deviation;  
Matrix_changed_people=[];  
for i=1:m  
    People=i;  
    display(People);  
    MatrixInput=PP{1,i};  
    MatrixPi=InputMatrix{1,i};  
    [Changed_positive_position,Changed_negative_position,changed_people]=Position(  
    AverageInputMatrix,MatrixPi,MatrixInput,Compared_value,People);  
    Matrix_changed_people=[Matrix_changed_people changed_people];  
end
```

## Appendix B

```
if AverageC >= Mu
    display('finish the process')
else
    display('Improve')
    LMatrixP = cell(1,m);
    AveragePC = zeros(n);
    Maxdeviation = zeros(1,m);
    Mindeviation = zeros(1,m);

    for i=1:m
        LMatrixP{1,i} = lamda(1,i)*MatrixP{1,i};
        AveragePC = AveragePC + LMatrixP{1,i};
    end
    AveragePC = (1/m)*AveragePC;
    PP = cell(1,m);
    for i=1:m
        PP{1,i} = MatrixP{1,i} - AveragePC;
        Maxdeviation(1,i) = max(PP{1,i}(:));
        Mindeviation(1,i) = min(PP{1,i}(:));
    end
end

PP{:, :}
Maxdeviation
Mindeviation
Matrix_order = 1;
display(Matrix_order)
deviation = 0.3;
Compared_value = deviation;

PP{1, Matrix_order}
```



```
[row1, colum1]=find(PP{1,Matrix_order}>Compared_value);  
  Changed_positive_position=[row1 colum1];  
PP{1,Matrix_order}  
[row1, colum1]=find(PP{1,Matrix_order}>Compared_value);  
  Changed_positive_position=[row1 colum1];  
if isempty(Changed_positive_position)==1  
  display('Don not find changed positive position ')  
else  
  display('Changed positive position')  
  display(Changed_positive_position)  
end  
[row2, colum2]=find(PP{1,Matrix_order}<(-Compared_value));  
  Changed_negative_position=[row2 colum2];  
  
if isempty(Changed_positive_position)==1  
  display('Don not find changed negative position ')  
else  
  display('Changed negative position')  
  display(Changed_negative_position)  
end
```

# **From “shared diagnosis” to “shared action”: how Living Lab process can support decision-making process involving citizen for Smart City**

## **Abstract**

In the current era, Smart City projects have to deal with big social, ecological and technological challenges such as digitalization, pollution, democratic aspirations, need to be safe, etc. The higher involvement of multi-stakeholders (such as citizens, users, engineers, researchers, elected representatives, etc.) in the different phases of the projects, is one strategy enabling a variety of perspectives to be considered and thus develop a shared vision of the city. Paradoxically, the dynamic and multiple nature of stakeholders appears to be a source of complications and uncertainty in the decision-making process.

Getting a consensus, which means legitimizing a group decision-making process, is often difficult to reach because the different expectations, needs and behaviours. The main hypothesis of the present research is that the consensus process could be facilitated by human and automatic tools through identifying conflicting points and following their evolution after several rounds of discussion.

This study will propose a general methodology for two kinds of decision-making process supporting the negotiation between stakeholders within a Living Lab environment, an automatic control system that substitutes the facilitator’s actions and a process supervised by human facilitator. First, a methodology based on a multi-agent system is developed for automatic reaching consensus in large scale group of making decisions without facilitators and direct interaction. Then, a second methodology combining a human facilitator and ICT-based supporting tool. A proposition of multi-criteria and multi-stakeholders methodology supporting consensus reaching processes is used as decision support system tool in Smart City projects under Living Lab environment.

Both Living Lab decision-making methodologies, the automatic and the supervised process, were developed, executed and validated in concrete case studies. Throughout using both methods, we can compare how different between the theoretical model and a process of experimenting decision-making tools in the real-life. The results of data analysis from experimentation provide suggestions to improve decision-making process of stakeholders with diverse objective and background in Smart City projects.

**Keywords:** Smart City, Living Lab, decision-making



# **D'un "diagnostic partagé" à "l'action partagée" : comment le mode projet Living Lab peut alimenter le processus d'aide à la décision du « faire la ville » en intégrant les citoyens pour une ville intelligente**

## **Résumé**

A l'ère actuelle, les projets de Smart City doivent faire face à de grands défis sociétaux, écologiques et technologiques tels que la numérisation, la pollution, les aspirations démocratiques, la nécessité d'être en sécurité, etc. L'implication accrue de multiples acteurs (citoyens, usagers, ingénieurs, chercheurs, élus, etc.) dans les différentes phases des projets, est une stratégie qui permet de prendre en compte des perspectives variées et de développer ainsi une vision partagée de la ville. Paradoxalement, la nature dynamique et multiple des intervenants semble être une source de complications et d'incertitude dans le processus décisionnel.

Obtenir un consensus, entendu comme légitimer un processus décisionnel de groupe, est souvent difficile à atteindre en raison des attentes, des besoins et des comportements différents. La présente recherche pose comme hypothèse principale propose que des outils humains et automatiques pourrait faciliter le processus de consensus en identifiant les points de conflit et en suivant leur évolution après plusieurs cycles de discussion.

Cette étude propose une méthodologie générale pour deux types de processus prenant en charge la négociation entre les parties prenantes dans le cadre d'un Living Lab, un système de contrôle automatique qui remplace les actions du facilitateur et un processus supervisé par un facilitateur humain. Tout d'abord, une méthodologie basée sur un système multi-agents est développée pour parvenir automatiquement à un consensus au sein d'un groupe à grande échelle de prise de décisions sans facilitateur et interaction directe. Ensuite, une deuxième méthodologie est développée en associant l'action d'un facilitateur humain et d'un outil d'appui basé sur les TIC. Enfin, une proposition de méthodologie multicritères et multi-acteurs soutenant les processus de recherche de consensus est utilisée comme outil d'aide à la décision dans les projets Smart City en mode Living Lab.

Deux méthodologies de prise de décision en mode Living Lab, le processus automatique et le processus supervisé, ont été développés, exécutés et validés via des études de cas. Tout au long de l'utilisation des deux méthodes, nous pouvons comparer la différence entre le modèle théorique et un processus d'expérimentation d'outils d'aide à la décision dans la vie réelle. Les résultats de l'analyse des données issues de l'expérimentation fournissent des suggestions pour améliorer le processus de prise de décision des parties prenantes ayant des objectifs et des antécédents divers dans les projets Smart City.

**Mots-clés:** Smart City, Living Lab, prise de décision