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Benjamin Delhomme

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THÈSE PRÉSENTÉE

POUR OBTENIR LE GRADE DE

DOCTEUR
DE L'UNIVERSITÉ DE BORDEAUX

ÉCOLE DOCTORALE DES SCIENCES PHYSIQUES DE L'INGENIEUR

SPÉCIALITÉ MÉCANIQUE

Par **Benjamin DELHOMME**

Une application web basée sur des systèmes d'argumentation et des méthodes d'aide à la décision multicritère pour la prise de décision en temps réel - application à la réhabilitation de parcs de bâtiments

Sous la direction de : **Laurent MORA**
Co-directeur : **Franck TAILLANDIER**

Soutenue le 11 février 2022

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Résumé

Une application web basée sur des systèmes d'argumentation et des méthodes d'aide à la décision multicritère pour la prise de décision en temps réel - application à la réhabilitation de parcs de bâtiments

Les décisions collectives, qui nécessitent souvent l'adhésion des différentes parties concernées, constituent un problème complexe. Avec des dimensions variées, telles que l'économie, le social, le culturel, le politique et l'environnemental, atteindre un consensus sur un sujet sérieux entre des parties prenantes implique d'avoir une bonne compréhension globale et une bonne capacité d'argumentation. Si de nombreuses méthodes ou outils tentent d'aider dans ce sens, aucun outil à notre connaissance ne permet de débattre en temps réel de milliers de solutions optimisées en permettant aux participants de visualiser les arguments et d'identifier les points de vue opposés pour résoudre les conflits. Dans cette thèse, nous avons introduit une méthode innovante (AMHORE) combinant système d'argumentation abstrait et méthodes de décision multicritères (MCDM), qui permet aux parties prenantes de formaliser le problème de décision en prenant explicitement en compte les diverses opinions exprimées et en assurant leur traçabilité. Dans le cadre du projet ANR REHA-PARCS, nous avons développé une application web (WebAIPA) d'aide à la décision participative en temps réel pour la rénovation du parc immobilier. Nous attendons de cette nouvelle approche qu'elle place la discussion au centre du processus de décision afin de faciliter l'acceptation de la décision finale par toutes les parties.

Mots-clés : Systèmes d'argumentation, Aide à la décision multicritère, Réhabilitation de bâtiments, Modélisation du débat en temps réel, Débat participatif, Outil d'argumentation

Abstract

A web application based on argumentation frameworks and MCDA methods for real-time decision making - application to buildings retrofitting

Collective decisions, which often require the adhesion of different parties involved, is a complex problem. With various dimensions, such as economic, social, cultural, political and environmental, reaching a consensus on a serious subject among stakeholders implies that one has a good overall understanding and argumentation skill. While many methods or tools try to help in such a task, no tool in our knowledge supports real-time debates about thousands of optimized solutions by allowing participants to visualize arguments and identifying opposing points of view to resolve conflicts. In this thesis, we introduced an innovative method (AMHORE) combining abstract argumentation framework with multi-criteria decision methods (MCDM), that allows the stakeholders to formalize the decision problem by taking explicitly into account the diverse opinions expressed and ensuring their traceability. As part of the ANR REHA-PARCS project, we developed a real-time participatory decision support web application for the building stock retrofitting called WebAIPA. We expect this new approach to place discussion at the center of the decision-making process in order to facilitate the acceptance of the final decision by all parties.

Keywords: Argumentation framework, Multiple-criteria decision analysis, Building retrofitting, Real-time debate modeling, Participatory debate, Computational argumentation tool

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INSTITUT DE MÉCANIQUE ET D'INGÉNIERIE
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Dedication

A ma famille,
A ma femme pour son soutien inconditionnel,
A mon fils pour l'équilibre qu'il m'apporte,
A mes parents pour m'avoir guidé,
A mes grands-parents pour m'avoir accompagné,
A mes amis,
A cette force qu'est la curiosité,
Je dédie ce travail.

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Je tiens également à remercier mes collègues et amis doctorants, sans qui les journées au bureau n'auraient jamais eu la même saveur. Merci Alice pour ta constante bonne humeur, source de moral au quotidien. Merci Nathalie, camarade de misère dans notre grand bureau bien vide. Merci Eva, Cécile, Wafaa et Ralph pour ces discussions riches et variées lors de ces nombreuses pauses café.

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Preface

This PhD was funded by the ANR (Agence Nationale de la Recherche) and is a part of the REHA-PARCS project (2015-2020). This project, coordinated by Laurent Mora (I2M) gathers 6 partners: I2M (Institut de Mécanique et d'Ingénierie Bordeaux), LOCIE (Laboratoire d'Optimisation et Génie de l'Environnement), ARMINES (Centre Efficacité énergétique de Mines ParisTech), CEA (Commissariat à l'Energie Atomique et aux Energies Alternatives), CSTB (Centre Scientifique et Technique du Bâtiment) and OTEIS. It aims at elaborating an interactive tool for decision making in the context of the retrofitting of important sets of buildings, and is more specifically dedicated to social landlords. Housing stock retrofitting induces a complex decision problem. To achieve this goal, the REHA-PARCS team proposes a two-steps approach. The first step is the modelling of the sets of buildings, thanks to clustering methods. This consists in identifying main types of buildings within the set under study based on attributes such as target performance, building compactness, etc. Each individual building will be tagged as being part of a building type category with particular attributes. This modeling process of large sets of building enables a detailed analysis of retrofitting solution strategies via simulation tools. The second step is a participative and interactive decision making process based on a specific framework which has been developed to fulfill the requirements of the REHA-PARCS decision problem. This decision process combines a multi-objective optimization and an innovative multicriteria decision support approach which is precisely the subject of this manuscript. The other parts of the project (i.e. clustering and multi-objective optimization approach) resulted in two PhDs, respectively achieved by Yunseok Lee and Yannis Merlet. The present work is a methodological continuation of these two theses, constructing a meta-tool for decision support for social landlords. In addition to REHA-PARCS, this PhD benefit from the CNRS CADAU Project (2016-2019). CADAU aims at proposing a decision support approach, based on argumentation, for participatory urban planning. CADAU which was coordinated by Franck Taillandier (INRAE and formerly Univ. Bordeaux), gathered researcher from I2M (Bordeaux), IATE (Montpellier) and University Laval (Québec, Canada). If this PhD was not a part of this project, CADAU allowed many fruitful exchanges between the three research teams, particularly during a stay in Quebec at Université Laval.

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Introduction [Français]

L'aide à la décision est un domaine de recherche complexe. Il est complexe car il place l'humain en son centre, qu'il soit le décideur, le sujet de la décision, ou impacté par celle-ci. Cela impose de composer avec la subjectivité inhérente à tout être humain. Dans les problèmes de décision réels, il n'y a généralement pas de réponse idéale, mais des solutions plus ou moins adaptées, chacune ayant ses avantages et ses inconvénients. L'aide à la décision n'est donc pas la recherche de la vérité, mais plutôt l'accompagnement d'un ou d'un groupe de décideurs vers une solution qui leur conviendra, qu'ils ou elles considéreront comme la meilleure dans un contexte spécifique. Dans cette perspective, la science de la décision mobilise de nombreux domaines disciplinaires, tels que la gestion, les mathématiques, l'économie, la psychologie, la sociologie, l'ingénierie, la philosophie, etc. En effet, décider est une préoccupation partagée par tous les domaines d'application (ingénierie, économie, psychologie, sociologie...). La recherche scientifique a donc investi le domaine de l'aide à la décision sous de multiples angles, du plus théorique au plus appliqué. Ceci offre un corpus riche et un panel d'outils permettant de répondre à de nombreuses problématiques. Chacune des méthodes, approches ou outils développés présente ses propres avantages et inconvénients. Selon la problématique de décision, l'une ou l'autre méthode est plus ou moins adaptée, et parfois une combinaison de plusieurs méthodes est plus pertinente.

Dans ce travail, nous nous intéresserons à un problème de décision lié au domaine du génie civil : la rénovation énergétique d'un parc immobilier. Ce problème de décision est complexe, car il induit la nécessité de considérer de nombreuses solutions possibles (plusieurs actions possibles pour chaque bâtiment du parc immobilier qui peut en contenir plusieurs dizaines), de nombreux critères impactant la décision (gain énergétique, coût d'investissement, confort des occupants...), plusieurs acteurs dont les préférences sont à considérer (gestionnaire, locataire...), des contraintes sur le problème (temps et budget disponibles, limites techniques, etc.)... La manière classique de traiter un tel problème, comme l'atteste la littérature, est d'utiliser l'optimisation multi-objectif (Merlet et al., 2018, Rivallain, 2013, Wu et al., 2017). Cette approche vise à trouver les solutions pareto-optimales. Cependant, elle ne résout pas le problème de décision, car elle fournit au(x) décideur(s), non pas une solution unique, mais un ensemble de solutions pareto-optimales (parfois plusieurs centaines). Chacune de ces solutions

est elle-même complexe, car elle est composée d'un grand nombre d'actions unitaires (isoler les murs, changer les fenêtres, modifier le système de ventilation...). Il est donc souvent très difficile pour le décideur d'appréhender l'ensemble de ces solutions afin d'en choisir une seule. Ceci est d'autant plus difficile que les décisions prises vont directement impacter différentes parties prenantes, notamment les locataires, ayant leur propre vision des bâtiments. L'idéal serait d'envisager une démarche vertueuse dans laquelle toutes les différents acteurs participeraient directement à la prise de décision.

La littérature fournit trois solutions classiques pour répondre à ce problème : les approches a priori, a posteriori ou interactives (également appelées progressives). L'approche a priori consiste à agréger les fonctions objectif en une seule fonction ; on se ramène alors à un problème d'optimisation mono-objectif. Cette approche simplifie le problème et peut avoir du sens pour une optimisation dans laquelle on veut automatiser la décision. Cependant, le rôle du décideur est alors très limité, au risque de le déposséder de ses prérogatives décisionnelles, ce qui n'est pas souhaitable. Dans notre contexte, nous souhaitons considérer plusieurs parties prenantes qui vont au choix de la solution et impacter réellement la décision ; ce n'est donc pas une approche pertinente dans notre contexte décisionnel. L'approche interactive consiste à faire construire les préférences du décideur au cours du processus d'optimisation afin de le guider. Cela nécessite une forte implication du décideur pendant le processus d'optimisation nécessitant une bonne compréhension de celui-ci, et qu'il puisse exprimer ses préférences directement pendant ce processus. Ceci est souvent difficile lorsque l'on considère des problèmes de décision avec plusieurs décideurs ayant des points de vue différents, voire contradictoires. Cette approche n'est donc pas adaptée au contexte de la rénovation du parc immobilier. L'approche a posteriori consiste à utiliser une méthode d'aide à la décision multicritère après l'optimisation pour aider le décideur à choisir une solution parmi les solutions optimales. Cette approche est intéressante mais nécessite l'utilisation d'un second processus d'aide à la décision. Dans ce travail, nous avons privilégié cette approche qui nous semble la plus adaptée à notre problème décisionnel.

Ainsi, ce travail de thèse porte précisément sur cette étape d'aide à la décision a posteriori, en relation avec l'optimisation ; c'est-à-dire, comment aider un groupe de décideurs à choisir une solution parmi un ensemble de solutions pareto-optimales. L'approche proposée a été mise en œuvre pour le cas spécifique de la rénovation d'un parc de bâtiments. Cependant, elle pourrait être appliquée à d'autres problèmes de décision partageant des caractéristiques communes. Ce point sera plus largement abordé dans la conclusion et notamment lors de la présentation des perspectives de ce travail. Il est à noter que dans ce mémoire, lorsque nous parlerons du problème décisionnel, nous ferons toujours référence au problème de la rénovation énergétique d'un parc immobilier.

Les approches a posteriori sont généralement menées à l'aide de méthodes

d'aide à la décision multicritères : c'est le cas par exemple de (Branke, 2016, Zeelanbasha et al., 2020). Cependant, ces méthodes sont souvent utilisées avec un seul décideur, ou en supposant que le groupe de décideurs a des préférences homogènes et peut être considéré comme un seul décideur. Néanmoins, de nombreuses méthodes multicritères peuvent être, et ont été utilisées dans un contexte multi-acteurs, comme MACBETH (Costa, 2001, Donais et al., 2017) ou ELECTRE (Oberti and Paoli, 2015) par exemple, où un facilitateur mène la démarche de décision avec plusieurs parties prenantes. Cependant, souvent, l'accent n'est pas mis sur le processus de discussion et sur les arguments présentés, mais plutôt sur la construction d'un modèle de préférences commun obtenu par consensus. Il est difficile d'intégrer explicitement dans les cadres mathématiques de méthodes telles que AHP (Saaty, 1984), ELECTRE (Roy, 1990), et MACBETH (Bana e Costa et al., 2005), la richesse des discussions entre les parties prenantes ainsi que la complexité du problème (Bouleau et al., 2004). C'est la principale limite de ces méthodes multicritères dans un contexte multi-décideurs. Nous faisons l'hypothèse que dans un contexte où les oppositions peuvent être fortes, et les opinions tranchées, une méthode qui encourage la discussion peut aider les différents acteurs à adhérer plus facilement à la décision choisie. En effet, en encourageant le dialogue et le débat, nous permettons aux différents acteurs de clarifier leur point de vue. Si cela ne change pas les opinions de chacun, cela peut conduire à une meilleure compréhension du point de vue des autres, et finalement de la décision. Dans cette perspective, nous avons choisi dans ce travail une approche favorisant la discussion entre les acteurs pour aboutir à une décision, tout en assurant la traçabilité de la décision, et en donnant à la méthode proposée un caractère générique et reproductible afin qu'elle puisse être utilisée dans de nombreux cas d'application.

Afin d'atteindre cet objectif, nous proposons une méthode innovante basée sur l'intégration du concept d'argumentation dans un processus d'aide à la décision multicritère. Un argument est un ensemble d'énoncés composés d'une conclusion (recommandation, décision concernant une option) et d'au moins une prémisse, liés par une relation logique. Un système d'argumentation est un modèle formalisant un ensemble d'arguments avec leurs relations. Les systèmes d'argumentation sont utilisés pour comparer des arguments contradictoires et pour évaluer l'acceptation collective des arguments afin de parvenir à une conclusion sur la pertinence d'accepter ou de rejeter une option. La plupart des modèles existants sont basés sur le modèle de l'argumentation abstraite de Dung (Dung, 1995). Un Abstract Argumentation Framework (AAF) est un graphe dirigé composé d'un ensemble d'arguments et d'une relation binaire représentant les attaques (c'est-à-dire l'opposition) entre les arguments (Dung, 1995). Ce modèle permet de faire des inférences sur le graphe d'arguments afin de calculer l'acceptabilité des différents arguments. Il offre ainsi différents avantages : (1) assurer la traçabilité des réflexions et des discussions, (2) mettre en évidence les points de désaccord et les

opinions alternatives, (3) définir les arguments acceptables et inacceptables, et (4) expliquer les différents points de vue. Bien que pertinent d'un point de vue théorique, l'application d'une telle méthode à des décisions réelles est difficile ; la littérature fournit peu d'applications du AAF ; les applications existantes sont liées au domaine juridique (Flouris and Bikakis, 2019) et au domaine agricole (Karanikolas et al., 2018). En effet, l'utilisation du AAF dans un contexte réel conduit à plusieurs difficultés. Afin de rendre son modèle générique, Dung a proposé un modèle abstrait d'argument, sans aucune sémantique. Dans AAF, les notions d'argument ou d'attaque ne sont pas définies ; elles restent des objets théoriques. Pour implémenter une AAF, il est nécessaire de donner une sémantique à ces notions. L'argumentation abstraite est avant tout un objet de recherche théorique ; la plupart des chercheurs travaillant sur cet objet se sont davantage concentrés sur le développement méthodologique que sur son application, ce qui explique aussi que très peu de travaux proposent une application concrète du AAF. De plus, aucun d'entre eux ne propose de combiner les méthodes multicritères avec le AAF, et la littérature n'a pas proposé d'application de cette approche au domaine du génie civil avant ce travail. La question de cette thèse peut être ainsi résumée comme suit : **Comment la combinaison d'une méthode d'aide à la décision multicritère et de l'argumentation abstraite peut répondre au problème de décision posé par la rénovation énergétique d'un parc immobilier.**

Pour répondre à cette question, nous serons confrontés à différents verrous scientifiques. Ces verrous sont : (1) Comment rendre l'argumentation abstraite opérationnelle pour qu'elle puisse être utilisée dans une application réelle, en temps réel, avec un groupe d'acteurs ; (2) Comment l'argumentation abstraite peut être combinée avec une méthode d'aide à la décision multicritère ; (3) Comment cette approche peut être utilisée en combinaison avec l'optimisation multi-objectif dans le problème de la rénovation d'un parc immobilier ?

En répondant à ces questions, nous apporterons des réponses méthodologiques qui seront autant de contributions au domaine de recherche de l'aide à la décision. Ces réponses seront apportées dans ce manuscrit à travers différents chapitres regroupés en deux parties. La première partie est consacrée à l'argumentation et à l'aide à la décision, et notamment à la combinaison de l'argumentation avec les méthodes multicritères. Cette partie a une vocation générique et propose des contributions applicables à tout domaine (et pas seulement au génie civil). La seconde partie se veut applicative, en présentant de manière pragmatique, comment appliquer l'approche choisie à notre problème de décision, à savoir le problème de la rénovation d'un parc immobilier. Ainsi, la première partie traitera des verrous (1) et (2), tandis que la deuxième partie traitera du verrou (3). Plus précisément, la première partie débutera par un chapitre exposant les principes d'utilisation de l'argumentation dans un cadre décisionnel. Dans ce premier chapitre, nous présenterons ce qu'est l'argumentation, et comment elle a été

formalisée pour inférer des décisions. Ceci sera fait à travers la présentation de l'argumentation abstraite. Dans un second chapitre, nous présenterons le modèle d'argumentation que nous utiliserons pour opérationnaliser cette approche. Ce modèle d'argument nous conduira à proposer un ensemble de règles permettant sa combinaison avec l'argumentation abstraite. Ces deux éléments constitueront le modèle AIPA, qui est la première contribution majeure de ce travail. Le troisième chapitre de cette première partie expliquera comment ce modèle peut être utilisé en combinaison avec une méthode multicritère. Il présentera ainsi une nouvelle approche d'aide à la décision, appelée ArguedMCDA, qui constitue la deuxième contribution majeure de cette thèse. Ceci conclura cette première partie de la thèse, qui a une vocation méthodologique. La deuxième partie proposera une application de cette approche dans le cas de la rénovation d'un parc immobilier. Pour cela, dans un premier chapitre, nous présenterons le domaine d'application. Dans un second chapitre, nous expliquerons comment concrètement l'approche développée peut être appliquée à ce problème de décision, conduisant à une nouvelle méthode de décision appliquée : Argued Mcda for HOusing stock REtrofitting (AMHORE). Ceci constitue la troisième contribution majeure de ce travail. Le troisième chapitre de cette deuxième partie proposera une application de l'approche instanciée à une étude de cas. L'étude de cas sera présentée, ainsi que les résultats obtenus, puis, ces résultats et l'approche seront discutés. Le manuscrit se terminera par une conclusion qui rappellera les principaux résultats de ce travail et en tracera des perspectives.

Introduction

Decision support is a complex domain of research. It is complex because it places human at its center, whether she/he is the decision-maker, the subject of the decision, or even simply impacted by it. This imposes to deal with the subjectivity that is inherent to every human being. In the real-life decision-making problems, there is generally no ideal answer, but more or less adapted solutions, each one having its advantages and disadvantages. Decision support is therefore not the search for truth, but rather the accompaniment of one or a group of decision-makers towards a solution that will suit her/him or them, which they will consider the best in a specific context. In this perspective, the decision science mobilizes many disciplinary domains, such as management, mathematics, economics, psychology, sociology, engineering, philosophy, etc. Indeed, deciding is a concern shared by all the fields of application (engineering, economics, psychology, sociology...). Scientific research has thus invested the domain of decision support from multiple angles, from the most theoretical to the most applied. This offers a rich corpus and a panel of tools to answer many issues. Each of the developed method, approach or tools has its own advantages and disadvantages. Depending on the decision problem, one method or the other is more or less adapted, and sometimes a combination of several methods is more relevant.

In this work, we will focus on a decision problem, related to the field of civil engineering: housing stock energy retrofit. This decision problem is complex, because it induces the need to consider many possible solutions (several possible actions for each building of the building stock which can contain several dozen of them), many criteria impacting the decision (energy gain, investment cost, comfort of the occupants ...), several stakeholders whose preferences are to be considered (manager, tenant...), constraints on the problem (time and budget available, technical limitations, etc.)... The classical way to deal with such a problem, as attested by the literature, is to use multi-objective optimization (Merlet et al., 2018, Rivallain, 2013, Wu et al., 2017). This approach will allow to find all pareto-optimal solutions. However, it does not solve the decision problem, because it provides the decision-maker(s) not with a single solution, but with a set of pareto-optimal solutions (sometimes several hundred). Each of these solutions are themselves complex, since they are composed of a large number of unitary actions (insulate the walls, change the windows, modify the ventilation system...). So, it is

often very difficult for the decision maker to grasp all of these solutions in order to choose one. This is all the more difficult because the decisions taken will directly impact different stakeholders, especially tenants, with different visions of the buildings. Ideally, we would like to consider a virtuous approach in which all stakeholders would participate in decision-making.

Literature provides three classical solutions to answer this problem (Jozefowiez, 2013): a priori, a posteriori or interactive (also called progressive) approaches. The a priori approach consists in aggregating the objective functions into a single function; we then come back to mono-objective optimization. This approach simplifies the problem and can make sense for an optimization in which we want to automate the decision. However, the role of the decision-maker is then very limited, at the risk of being dispossessed of his or her decision-making prerogatives, which is not desirable. In our problem context, we would like to consider several stakeholders which want to participate in the choice of the solution and really impact the decision; thus, it is not a relevant approach in our decision context. Interactive approach consists in having the decision maker's preferences constructed during the optimization process in order to guide the optimization process. This requires a strong involvement of the decision-maker during the optimization process and thus a good understanding of it, and that she/he must be able to express her/his preferences directly during this process. This is often difficult when considering decision problems with several decision makers with different and maybe contradictory, points of view. This approach is therefore not adapted to the context of building stock retrofit. The a posteriori approach consists of using a multicriteria decision support method to help the decision-maker choose a solution from among the optimal solutions. This approach is interesting but requires the use of a second decision support process which have to be specifically designed. In this work, we have favoured this approach.

So, this work focused precisely on this a posteriori stage, in relation to optimization; i.e., how to help a group of decision-makers to choose a solution among a set of optimal pareto-optimal solutions. The proposed approach was implemented for the specific case of the retrofit of a housing stock. However, it could be applied for other decision problems sharing common characteristics. This point will be more widely discussed in the conclusion and in particular when discussing the perspectives to this work. Here, when speaking of the decision problem, we will always refer to the problem of the energy retrofit of a building stock.

A posteriori approaches are generally conducted with multi-criteria decision support methods (Branke, 2016, Zeelanbasha et al., 2020). However, these methods are often used with a single decision-maker, or assuming that the group of stakeholders has homogeneous preferences and can be considered as a single decision-maker. Nonetheless, many multicriteria methods can be, and have been used in a multi-actor context, such as MACBETH (Costa, 2001, Donais et al., 2017) or ELECTRE (Oberti and Paoli, 2015) for example, where a facilitator

conducts decision conferencing with several stakeholders. The focus is often not on the discussion process and on the arguments presented but rather on the construction of a common preference model through consensus. It is difficult to explicitly integrate within the mathematical frameworks of methods such as AHP (Saaty, 1984), ELECTRE (Roy, 1990), and MACBETH (Bana e Costa et al., 2005), the richness of the discussions between the stakeholders as well as the problem's complexity (Bouleau et al., 2004). It is the main limitation of these multicriteria methods in a multi decision-makers context. We hypothesize that in a context where opposition can be strong, and opinions clear-cut, a method that encourages discussion can help the various actors to adhere more closely to the chosen decision. Indeed, by encouraging dialogue and debate, we allow the different actors to clarify their point of view. If this does not change everyone's opinions, it can lead to a better understanding of each person's point of view, and ultimately the decision. In this perspective, we choose in this work an approach favouring discussion between the stakeholders to lead to a result, while ensuring traceability of the decision, and giving it a generic and reproducible character so that it can be used in many application cases.

In order to achieve this objective, we propose an innovative methodology based on the integration of argumentation concepts in a multicriteria decision process. An argument is a set of statements composed of a conclusion (recommendation, decision regarding an option) and at least one premise, linked by a logical relation. An argumentation system is a model formalizing a set of arguments with their relations. Argumentation systems are used to compare conflicting arguments and to evaluate the collective acceptance of arguments in order to reach a conclusion about the relevance of accepting or rejecting an option. Most of the existing models are based on Dung's abstract argumentation framework (Dung, 1995). An Abstract Argumentation Framework (AAF) is a directed graph composed of a set of arguments and a binary relationship representing attacks (i.e. opposition) between arguments (Dung, 1995). It allows inferences to be made on an argument graph in order to compute the acceptability of the different arguments. AAF provides different benefits: (1) ensuring the traceability of reflections and discussions, (2) highlighting points of disagreement and alternative theories, (3) defining acceptable and unacceptable arguments, and (4) explaining different points of view. Although theoretically relevant, the application of such a framework to real decisions is difficult and not so common since the arguments in this theoretical context are not properly defined. In fact, literature provides few applications of AAF; there are for instance applications related to the legal field (Flouris and Bikakis, 2019) and agricultural domain (Karanikolas et al., 2018). The use of the AAF in a real context leads to an issue. In order to make his model generic, Dung proposed an abstract model for argument, without any semantics. In AAF, the notions of argument or attack are not defined; they remain theoretical objects. To implement an AAF, it is necessary to give semantics to these notions.

Abstract argumentation is above all an object of theoretical research; most researchers working on this object have focused more on methodological development than on its application, explaining that very little work proposes a concrete application of AAF. Furthermore, none of them propose to combine multicriteria method with AAF, and the literature did not propose any application of this approach to the field of civil engineering before this work.

The question of this thesis can be summarized as follows: **How multiple-criteria decision analysis and abstract argumentation can help to answer the decision problem posed by the multi-objective optimization of a building stock retrofitting.**

This question will be confronted with different scientific locks. These locks are : (1) How to make abstract argumentation operational so that it can be used in a real application with a group of actors in real time; (2) How abstract argumentation can be combined with multi-criteria decision method; (3) How can this approach be used in combination with multi-objective optimization in a building retrofitting action planning problem?

By answering these questions, we will bring methodological answers that will be as many contributions to the research field of decision support. These answers will be brought in this manuscript through different chapters grouped in two parts. The first part is dedicated to argumentation and decision support, including the combination of argumentation with multi-criteria methods. This part has a generic vocation and proposes contributions applicable to any field (and not only to civil engineering). The second part is intended to be applicative, presenting in a pragmatic way, how to apply the chosen approach to our decision problem, i.e. the problem of choosing a strategy for planning the retrofitting of a housing stock. Thus, the first part will deal with locks (1) and (2), while the second part will deal with lock (3).

More specifically, the first part will begin with a chapter outlining the principles of using argumentation in a decision-making framework. In this first chapter, we will introduce what argumentation is, and how it has been formalized to infer decisions. This will be done through the presentation of the framework of abstract argumentation. In a second chapter, we will present the model of argument that we will use to operationalize this approach. This model of argument will lead us to propose a set of rules allowing its combination with abstract argumentation. These two elements will make up the Argumentation Interface for Participatory Approach (AIPA) model, which is the first major contribution of this work. The third chapter of this first part will explain how this model can be used in combination with a multi-criteria method. It will thus present a novel approach to decision support, called ArguedMCDA, which is the second major contribution of this thesis. This will conclude this first part of the thesis, which has a methodological vocation. The second part will propose an application of this approach in the case of building retro. For this, in the first chapter, we will present the field of application. In a second chapter, we will explain how concretely the approach

developed can be applied to this decision problem, leading to a new applied decision method: Argued Mcda for HOusing stock REtrofitting (AMHORE). This is the third major contribution of this work. The third chapter of this second part will propose an application of the instantiated approach to a case study. The case study will be presented, as well as the induced results, and then, these results and the approach will be discussed. The manuscript will end with a conclusion that will recall the main results of this work and will draw up perspectives.

Part 1

Argumentation

Chapter 1.1

Argumentation for decision support

1.1.1 Introduction

In the introduction, we hypothesized that the argumentative approach, and more precisely, abstract argumentation framework (AAF), could be a relevant decision support for participatory approach. In order to be able to justify this assertion, we must first explain what is the Abstract Argumentation Framework (AAF). It requires to introduce the notions of argument and argumentation, before analyzing how researchers in mathematics and computer science have grasped these notions to compose a new field of research: the computational argumentation. We will study this field, tracing a state of the art of computational argumentation tools in order to define whether the literature proposes methods or tools that meet the needs of our decision problem. Without wanting to divulge too much about this analysis, it will lead to the lack of tools adapted to real-time multi-actors decision support (i.e. participatory framework). This will lead us to suggest that abstract argumentation could be an interesting solution to meet this need, but also we will expose the limits that we will have to overcome with it. This will allow us to conclude regarding the existing works, but also to pose the challenges that the method we will propose in the following chapters, will have to meet in order to meet our need for decision support.

1.1.2 Introduction of argumentation

1.1.2.1 What is argumentation

1.1.2.1.1 Argumentation in philosophy

The word "argument" comes from the Latin arguere (to make bright, enlighten, make known, prove, etc.) (Harper, 2020). In usual language, as defined by Cambridge Dictionary, an argument is[1]: (1) a disagreement, or the process of disagreeing; or (2)

[1] https://dictionary.cambridge.org/fr/dictionnaire/anglais/argument

a reason or reasons why you support or oppose an idea or suggestion, or the process of explaining these reasons. By extension, argumentation is a set of arguments used to explain something or to persuade people.

The study of argumentation was already an important topic in antiquity (Breton and Gauthier, 2000). The argumentation theory has known different developments through philosophy and sciences History, and notably in the middle of the XXth century with the works of Toulmin Toulmin (2003) and Perelman and Olbrechts-Tyteca Perelman and Olbrechts-Tyteca (2000) studying the natural arguments in a more descriptive way (Tremblay, 2012). It led to different approaches, which can be combined, to study argumentation (Tremblay, 2012): pragmatic rhetorical, pragmatic, dialectical and logical. The pragmatic approach aims at studying argumentation in a broader context of communication; in this approach, the explicit and implicit expression of arguments is considered. The rhetorical approach studies the impact of argumentation on its audience (e.g. effectiveness in persuasion). The dialectical approach analyzes the context of discursive exchanges between stakeholders and are interested in the structure of the exchanges and its internal rules. Finally, the logical approach analyzes the form and validity of arguments, as well as the supporting or attacking relationships between them.

In the present work, we are interested in argumentation in a decision-making context, from the expression of arguments in natural language to the determination of the validity of arguments. Indeed, decision-making can be seen as an activity aiming at building valid arguments through which the actors involved in a decision-making process, will seek to establish that a subset of possible options, possibly containing only one option, is the best. In a decision support context, several approaches are relevant: the pragmatic approach, which allows us to account for the way an argument is expressed in natural language, the dialectical approach which is interested in the structure of exchanges, and the logical approach which seeks to determine the validity of arguments; the latter, as we shall see, is the one most explored in mathematics/computing science, because it is the easiest to implement in computer logic. According to this perspective, we can define an argument as a set of statements consisting of a conclusion and at least one premise, linked together by a logical connection (Breton and Gauthier, 2000). An argument will support or discredit an option or another argument.

1.1.2.1.2 Argumentation in debate

Since Antiquity, it has been considered that argumentation requires a situation of controversy in which the different stakeholders express arguments in order to defend their opinion or attack the adverse opinion (Emediato and Damasceno-Morais, 2019). Argumentation is based on representations (topics) that somehow connect the participants, either through sharing (doxic connivance) or through opposition (dissonance) (Emediato and Damasceno-Morais, 2019).

Stakeholders can provide arguments or be the aim of arguments. But if argumentation is built around controversy, it is also built on agreements and consensus, allowing participants to be members of a community of discourse (Perelman and Olbrechts-Tyteca, 2000).

So, argumentation takes place in an interactional framework and in a space of interdiscursivity (Emediato and Damasceno-Morais, 2019). Interdiscursivity refers to how discourses circulate, or alternatively drift, and how they are dialectically exported (decontextualized) and imported (recontextualized) between various sites and occasions of enunciation, and notably during a debate (Tracy et al., 2015). Argumentation implies an intersubjective investment in which the arguing person position herself/himself in a social dialogue, regarding consensus (belonging to a community) and disensus (reaction to the discourse of others). Plantin Plantin (2009) presents the argumentation as an activity taking place in a space organized by a tension between enunciative and interactional work; the speaker built a continuous planned intervention in which she/he chains together good reasons and exposes a "coherent world"; the consistency of this coherent world is not insured, because the coherence is only internal to the stakeholders vision. The argumentation is then the opposition between the "coherent worlds" defend by the stakeholders, or a sharing of antagonistic visions on the world which is more or less coherent.

Through debates and controversies, one can thus not only analyze the debated elements that meet with consensus or dissensus, which is useful in a decision-making framework, but also better understand the positioning of the different stakeholders, their points of view on the subject of the debate and on the world, and their preferences. Debates and the analysis of the induced argumentation is therefore a very rich tool in terms of decision support. It is for this reason, and because arguments carry an internal logic, that the field of artificial intelligence has become interested in argumentation.

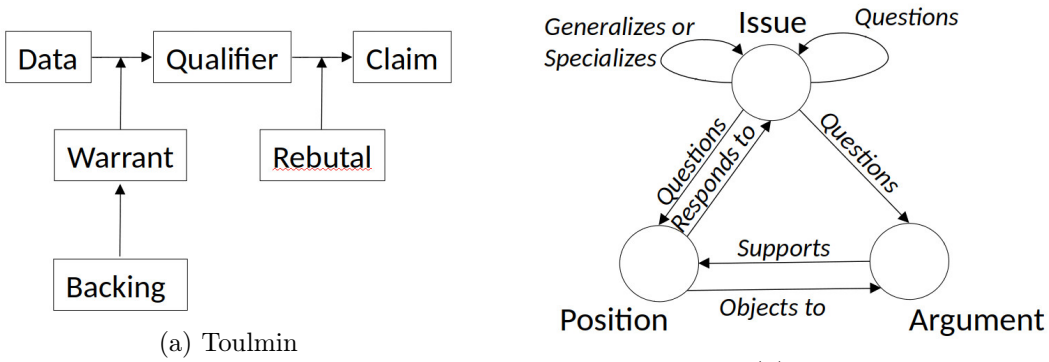
1.1.2.2 Argumentation in computer science

In the 1990s, the study of argumentation theory was extended to computer science and artificial intelligence (Bench-Capon and Dunne, 2007). Then, Argumentation has become a major subject of artificial intelligence in the last two decades (Diller et al., 2018). Computational argumentation has largely benefit from the computer development and a very large number of tools have emerged in the last twenty years. This led to the development of numerous approaches and models based on arguments. These models and approaches have different objectives (decision-aiding, analyze speech...) and different interpretations and uses of the notion of argument according to their domain of application. It composes a rich corpus of knowledge spreading from different disciplines (computer science, linguistic, etc.). The common point of all these tools is to propose a formalization of the arguments and argumentation. Some are only interested in modelling and representation of the argument (e.g. argument mapping), others allow to make

different inferences with (e.g. defining acceptable arguments, shared arguments...) and to draw conclusions from an argumentative debate, or to automatically extract arguments from natural language (argument mining). In this section, we will analyze computational argumentation, regarding firstly the models of argument, then, the argument visualization and finally the logic reasoning.

1.1.2.2.1 Models of arguments

Computational argument used different models of argument, depending on the aim of the tool. Literature provides several theoretical models of arguments; the most used are Toulmin argument model Toulmin (2003) and IBIS(Ebadi et al., 2009) (Figure 1.1.1). Toulmin's argument model provides a set of categories allowing to represent the logical structure of arguments organized in a graphical form (Figure 1.1.1a). Toulmin's model is composed of six concepts: Datum, Claim, Warrant, Rebuttal, Backing and Qualifier. A datum is a fact or an observation about the situation under discussion. It is the basis of a claim, which corresponds to controversial, observation, prediction, or characterization. Datum and Claim are linked by a Warrant which corresponds to an inference rule. The tuple $\langle Data, Claim, Warrant \rangle$ corresponds to the inferential core of the argument. The Qualifier defines the stance toward a claim or registers the degree of certainty. Rebuttal indicates the conditions under which the claim can be taken as true. Backing of an argument is some knowledge structure which serves to justify the warrant. The IBIS (Issue-based information system) model consists of three elements (Figure 1.1.1b): Issue, Position and Argument. Issues are questions which are at the center of the debate, e.g. "What should we do about X?" where X is the issue that is of interest to a group. Positions are potential answers to the issue. Arguments can be Pros (arguments for) or Cons (arguments against) a position. IBIS elements are usually represented as nodes, and associations between elements are represented as directed edges (arrows).



(a) Toulmin

(b) Ibis

Figure 1.1.1: Toulmin and IBIS argument models

These models are really useful to analyze arguments in a debate or as a theoretic support to build an argument. But the use of such argument models (Toulmin or IBIS) in a context of a debate in participatory approaches is quite complex. Indeed, the different stakeholders have limited knowledge of theoretical argumentation and it has been shown that conflict resolution cannot be solved with complex argument structures due to the human argumentation process (Sillince and Saeedi, 1999). Moreover, since participatory approach requires real time debate, to argue and identify the type of argument at the same time would drastically increase the complexity for non-experts. Therefore, regarding our decision problem, we suggest to use a simpler model. Some works propose for instance to use only a dual consideration of arguments: an argument supports or defeats an idea (pros and cons principle) (Amgoud et al., 2008). But these works does not consider the nature of the argument itself (e.g. is the argument is the object of the debate or a statement about this object). It could lead to some misunderstanding of the notion of argument. As a conclusion, we state that the literature lacks of an intermediary model of argument, sufficiently simple to be used in real time by any stakeholders, but sufficiently complete to avoid misunderstanding about its meaning.

1.1.2.2.2 Formalizing argumentation

In a debate between different stakeholders, each argument is not only related to the subject matter, but also to some of the other proposed arguments forming an argument structure. This process of argumentation is informal and does not follow logical or mathematical reasoning (van Bruggen et al., 2003). This lead generally to ill-structured problems (Reitman, 1965, Simon, 1973) which: 1) have an ambiguous and incomplete problem specification; 2) lack clear-cut criteria to evaluate whether a solution has been reached, implying that there are no stopping rules; 3) make use of several potential information sources that may be used to represent problem spaces although it is unclear which ones should be used and how they should be integrated; and 4) have neither a complete enumeration of applicable operators nor a predetermined path from initial state to goal state. This issue lead to the development of different tools and methods aiming at representing the argumentative structure; these tools belong to the Computer-Supported Argumentation Visualization (CSAV) domain. It has a double objective: ensure that the participant to the debate is able to understand the structure of the argumentation and ensure that this structure is consistent according to logical reasoning, which is interpretable by computers. In this perspective different argument modeling and visualisation software propose to formalize, model and display the argument structure (Kirschner et al., 2003, van Bruggen et al., 2003, Yun et al., 2016). All these tools allow to provide an argument mapping which is a visual representation of the structure of an argument. The argument map varies according to the approach and model used, but they can include the conclusions,

the premises, the objections, the counterarguments, the rebuttals (Davies, 2012)... In terms of application, the argument mapping tools (and CSAV) can be used to analyze an argumentative debate, to teach argumentation (e.g. in a legal course), to help structuring arguments... This capacity of representation of the argumentation is really interesting in a debate, in order to help the facilitator to structure the debate. Furthermore, it can be completed with a tool able to perform inference on the argumentative structure.

1.1.2.2.3 Argument inferred information

The computational argumentation systems can provide more information than just a formalization of the arguments. Different approaches, methods and tools were provided in order to infer knowledge from the formalized argument or set of arguments. These inferences can consist in providing information on the state of arguments (e.g. accepted or rejected) and/or to define a "winner" (Karacapilidis et al., 2009). As we previously exposed with the argument definition (i.e. a set of statements consisting of a conclusion and at least one premise, linked together by a logical connection), argument lays on a logical structure. The same result can be given regarding the argumentation which is composed of a set of connected arguments. They are two levels of validity regarding argument: internal (is argument valid in itself) and external (is argument valid in relation with other arguments). So, two types of approaches exist in computational argumentation (Besnard et al., 2020): structured argumentation and abstract argumentation. Structured argumentation are about building arguments and identifying their relationships, whereas abstract argumentation consider that a set of arguments in interaction is given without considering the way they were built or their meaning. Structural argumentation question the internal validity of an argument: an argument is structurally valid if considering that all its premises are true, the conclusion is necessarily true. At the opposite, an argument is non-valid if even the premises are true, the conclusion is not necessarily true. A sound argument is a valid argument with true premises, whereas an unsound argument has at least one false premise. Abstract argumentation focuses on computing the validity of an argument, in relation to other arguments. In abstract argumentation, the internal consistency of the argument is not questioned; an argument in itself is assumed to be valid. However, an argument which is attacked by a valid argument is considered as non valid. The validity of the arguments is then defined from the set of arguments depending on their relation (attack and support). These two approaches produce a high number of works proposing to use structural argumentation logic (e.g. (Franqueira and Horsman, 2020, Hahn, 2020, Yu et al., 2015)) or abstract argumentation logic (e.g. (Amgoud et al., 2008, Dung, 1995, Flouris and Bikakis, 2019)) to assess the validity of an argument. Some works (but many less) are positioned at the interface of these two approaches as (Prakken, 2010). An exhaustive state of the art regarding works using one of these two

approaches, or a hybrid approach, is not within our reach. However, it is worth noting that many works in artificial intelligence have attempted to propose, based on internal or external logic, to evaluate the validity of arguments. We will be able to largely rely on this work to reach our goal.

1.1.2.2.4 Argument mining

Argumentation mining aims at automatically extracting arguments from unstructured textual documents. It becomes an important domain of research since mid-2010s, due to its potential in processing information in innovative ways (Lippi and Torroni, 2016). In a decision-making context, the interest of such approach is very important. It could allow, during a debate, to automatically model the arguments expressed by the participants, using predefined structure (e.g. Toulmin argument model, abstract argumentation...). Argument mining process is composed of two stages: Arguments' extraction and relations' prediction. The first stage consists in the identification of arguments within the natural language text. This involves the detection of the argument components (e.g. claim, premises) and the identification of their textual boundaries. The second stage consists in predicting what are the relations holding between the arguments identified in the first stage. This second stage is particularly challenging. It requires a high-level knowledge representation and reasoning issues.

Many approaches shave recently been proposed to address these two stages as Support Vector Machines (SVM) (Niculae et al., 2017, Stab and Gurevych, 2017), Naïve Bayes classifiers (Duthie et al., 2016), or other methods and techniques inherited from deep learning (Lytos et al., 2019) ... But the remaining work to make them really operational in a context such as a real time debate between citizens is still enormous. We are only in the early stages and no work can accomplish such a task today. This is all the more true since most of the work is positioned on a text in English and to our knowledge, there is no argument mining work attacking the French language. Obviously, language is not neutral in the use of these approaches and the multilinguality issue is still to solve (Cabrio and Villata, 2018). The use of argument mining in our context is then a perspective but not yet possible. In our work, the arguments must be manually structured according to a predefined argument structure.

1.1.2.3 Conclusion on Argumentation

In this section, we explored the notions of argument and argumentation, from concepts used and analyzed by philosophers and linguists to their used in Artificial Intelligence. Obviously, these notions are particularly rich and this section has just scratched the surface of their meaning, but it has laid the groundwork for how these concepts can be used in this work. Before getting to grips with them, we need to study the way in which researchers have used the argumentation through

the development of tools dedicated to different objectives, and in particular to decision support. Thus, the next section proposes a state of the art of argumentation tools for decision support.

1.1.3 A state of the art on argumentation tools for decision support

1.1.3.1 Methodology

In this part, we investigate tools for argumentation, specifically dedicated to decision-making. In order to establish a perimeter for this study, we consider only tools which are presented or discussed in scientific publications. The research is then based on an analysis of the scientific literature: paper presenting a specific tool or comparing/analyzing a set of tools. The research methodology was based on the following steps: (1) Identification of the target: computational tools for argumentation-based decision support, (2) Scientific database search, using the keywords "Tool and Argumentation and Computer and Decision-making" on Scopus (33 documents) and ISI Web of Science (22 documents). (3) Selection of tools: we extracted all the tool described or cited in these articles, (4) Tool Analysis. To ensure the relevance of analyzed paper, the following conditions to limit the set of papers were used: (i) we consider only papers from journals and conferences, (ii) we consider only papers written in English, (iii) we limit the perimeter to papers presenting implemented tools and (iv) we consider autonomous tools (e.g. we exclude extension calculation engines for abstract argumentation frameworks as Bistarelli et al. (2018)). Based on these considerations, 25 articles were collected. This set of papers presents 37 tools that will be analyzed in this section. Table 1.1.1 provides the list of tools and the corresponding references. We distinguished 7 main purposes for the tools:

- CSAV (Computer-Supported Argument Visualization): enables to formalize and graphically represent the different arguments
- CSCA (Computer-Supported Collaborative Argumentation): allows a group of stakeholders to formalize arguments
- CDM (Collaborative Decision-Making): allows a group of stakeholders to make decisions based on arguments
- CP (Collaborative Planning): allows a group of stakeholders to collaboratively plan a project
- ABDM (Argument-Based Decision-Making): supports decision-making, basing the decision on arguments

- ABD (Argument-Based Design): supports design process for a product, basing it on arguments
- AR (Argumentation Reasoning): enables to automatically perform reasoning on arguments

Tool	**Purpose**	**Reference**
ABEL	AR	(Haenni and Lehmann, 2003)
AREL	ABD	(Tang et al., 2007)
ArgTrust	ABDM	(Parsons et al., 2013)
Argue!	ABDM	(Verheij, 2003)
Argumap	CP	(Sidlar and Rinner, 2007)
ArguMed	ABDM	(Verheij, 2003)
Argvis	CSAV	(Karamanou et al., 2011)
CADo	ABD	(Suthers, 2001)
CoGui Dung	ABDM	(Doumbouya et al., 2015)
COLLAGREE	CSCA	(Ito, 2014)
ConArg	AR	(Bistarelli and Santini, 2011)
CoPe_it!	CDM	(Pironet, 2006)
Debate Dashboard	CSCA and CDM	(Iandoli et al., 2012)
Deliberatorium	CSAV	(Klein, 2011)
DeLP	AR	(Chesñevar et al., 2006)
Discourse Graph	CDM	(Evangelou and Karacapilidis, 2007)
Design rationale	ABD	(Brissaud et al., 2003)
DREAMER	ABD	(Martinie et al., 2010)
DRed	ABD	(Poorkiany et al., 2016)
ECOBioCap	ABDM	(Tamani et al., 2015)
EDEN	ABDM	(Marashi and Davis, 2007)
EVID	AR	(Causey, 2003)
Gorgias-B	ABDM	(Kakas et al., 2018)
Hermes	CDM	(Karacapilidis and Papadias, 2001)
ICAS	CDM	(Sirrianni et al., 2018)
Portfolio generation tool	ABDM	(Spanoudakis and Pendaraki, 2007)
Pendo	CSAV and ABDM	(Introne and Iandoli, 2014)
SAKE	CSCA	(Lukac et al., 2008)
SEAS	CSAV	(Lowrance et al., 2008)
SI-COBRA	AR	(Nieves et al., 2006)
SAVW	CDM	(van der Werf et al., 2017)
SPeCS	CDM	(Pinto et al., 2001)
WBIA	ABD	(Xiaoqing Frank Liu et al., 2006)
WePWEP	CP	(Simão et al., 2009)
Zeno	CSCA	(Gordon and Karacapilidis, 1997)

Table 1.1.1: Computational tools for argumentation

1.1.3.2 Analysis

The 37 tools propose, each, a support for decision-making, more or less directly, based on the modeling of arguments. However, few are really relevant regarding our application context, i.e. real-time debate support in a participatory perspective. Collaborative planning (CP) and Argument-Based Design (ABD) are specifically dedicated to a precise decision task (respectively planning and design) which does not correspond to our objective which considers participatory decision-making in a more general way. Some other tools, such as EcoBioCAP is based on a database that is not generic and includes some specificities related to the application domain (biodegradable and bio-sourced packaging for EcoBioCAP). Its use in another context would thus require adaptation work for each new domain of application. Furthermore, it is not currently available or freely accessible online. This last point is a major limitation of the use of several of these tools. Indeed, some tools were developed into a project and were not maintain and/or made available after the end of their respective project. Moreover, our application context requires a tool capable of formalizing arguments with an interface usable in real time debate. Some of the cited tools do not provide such an interface and require to enter command lines (e.g. SI-COBRA, ABEL, DeLP) or text files (e.g. Argumap, SAKE). These tools are not relevant in our context.

We can divide the remaining tools into two categories: argument representation tools and argument reasoning tools. The first category contains tools which aim only to formalize arguments and argument debate. Most of CSAV, CSCA and CDM belong to this category. For instance, Argvis, CoPe_it! and SPeCS do not provide any inference engine. These tools are useful to structure and understand argument structure, but not to generate new knowledge from inference. We assume that being able to perform automated reasoning on the argument structure is very useful in a real-time debate context. Indeed, this can make it possible to highlight, in real time, the points of conflict, the preferred solutions, the key arguments, etc. Such information can enrich a debate.

Regarding applications, two questions arise: Are these tools actually used (i.e. on real case studies) and if yes, with which purpose and in which context. A first observation is that among the 37 tools that are referenced, only few have been the subject of an application (or have at least one application referenced in the articles). For instance, literature provides no application for ConArg. This demonstrates that many of these tools are positioned at a theoretical level without being intended to be used for real applications. Few domains have been addressed by these tools, e.g. housing market trend (Pendo), cryptography (ABEL)... None of these tools have been used for real-time debate case-study.

1.1.3.3 Conclusion

None of the tools presented here are able to meet the requirements needed (real time argument input, inference engine, output usable in real-time debate, etc.). It is therefore necessary to develop an argument computational tool dedicated to real-time debates. In this perspective, we make the assumption that abstract argumentation framework provides enough inference rules - when a semantic is given to arguments (i.e. hybrid approach between structural and abstract argumentation) - to find out either a solution in an debate or pinpoint a conflict.

1.1.4 Argumentation frameworks

1.1.4.1 Abstract argumentation framework

The AAF or Dung's Argumentation Framework (DAF), developed by Dung (1995), is based on the principle that an argument is considered acceptable as long as no other argument attacks it or if attacked, it is defended by other arguments. Dung defines an AAF as an oriented graph where nodes are arguments and edges are attacks between arguments (Figure 1.1.2). The term "argument" should not be misunderstood with the common interpretation such as "a set of statements composed of a conclusion and at least one premise, linked together by a logical link" (Breton and Gauthier, 2000). In Dung's framework, an argument is an abstract notion which has no semantic meaning; it can represent a data, a proposal or anything else. The notion of attack has also no direct semantic meaning; it is also an abstract concept. Based on these principles, Dung provides different definitions.

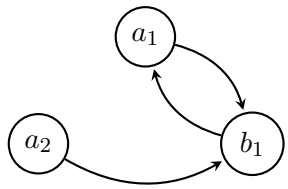


Figure 1.1.2: Attack graph

1.1.4.1.1 Definitions

Definition 1. *An argumentation framework is a pair $AF = \langle A, R \rangle$ with:*

- *A, a set of arguments,*
- *R, the binary relation on A such as for an argument a_i attacking a_j , $(a_i, a_j) \in R$.*

Definition 2. *A set of arguments $S \subseteq A$ is said conflict-free iff $\forall a_i, a_j \in S$, the arguments do not attack each other: $(a_i, a_j) \notin R$.*

Definition 3. *An argument $a_i \in A$ is acceptable with respect to a set $S \subseteq A$ iff $\forall a_j \in A$, if a_j attacks a_i then a_j is attacked by S. Being attacked by a set S means being attacked by an argument in S.*

Definition 4. *A set of arguments $S \subseteq A$ is admissible if and only if S is conflict-free and each argument in S is acceptable with respect to S. The empty set is always admissible.*

1.1.4.1.2 Semantics of acceptation

Dung called extension a set of arguments sharing common properties. Each extension is built according to different rules called semantics.

Definition 5. *A set $S \subseteq A$ is a preferred extension of an argumentation framework if and only if S is admissible and maximal (for set inclusion).*

Definition 6. *A set $S \subseteq A$ is a stable extension if and only if S is admissible and $\forall a_i \in S, \forall a_j \in S, (a_i, a_j) \in R$.*

Lemma 1. *A stable extension is therefore an admissible set that attacks all the arguments that do not belong to it. It means that a stable extension is a preferred extension but the reciprocal is false.*

Definition 7. *A set $S \subseteq A$ is a complete extension iff S is admissible and each acceptable argument with respect to S belongs to S.*

Lemma 2. *A preferred extension is complete.*

Definition 8. *A set $S \subseteq A$ is a grounded extension if it is the smallest (for set inclusion) complete extension. A grounded extension is unique.*

Based on these definitions, Dung provided two inference rules in order to define the accepted arguments: credulous and skeptical. In a credulous inference, an argument is accepted if it belongs to at least one preferred extension. In a skeptical one, an argument is accepted if it belongs to the grounded extension. To sum up, the acceptability of arguments according to Dung's AAF as its belonging to preferred (credulous) or grounded (skeptical) extension. Compute these extensions allows, thus, to assess the validity of the arguments.

1.1.4.1.3 Existing tools for extensions computation

Performing the computation of the extension requires to use a specific inference engine able to perform credulous and skeptical inferences. This is a hard computational problem. But fortunately for us, many research teams have already tried to solve this problem. The result is a large number of algorithms dedicated to the calculation of extensions. Even better, each two years, a contest, called

ICCMA (International Competition on Computational Models of Argumentation) is organized to decide between the algorithms[2]. This leads the teams to constantly progress, making the best use of the algorithmic evolution's resulting from theoretical computer science. In this part, we will not make an exhaustive list of the available algorithms, but we will just present some of them which seems to us particularly interesting with regard to our problem.

- Argmat-dvisat (Pu et al., 2015)
- mu-toksia (Niskanen and Järvisalo, 2020)
- CoQuiASS (Lagniez et al., 2015)
- ConArg (Bistarelli and Santini, 2011)

Argmat-dvisat is a division-based algorithm framework to compute the reasoning problems in abstract argumentation. It is based on SAT solvers (SAT for satisfiability). It firstly divides the argumentation framework into an ordered sequence of sub-frameworks on which it is easier to compute extensions, according to the directionality of argumentation. Then, each sub-framework is computed based on its previous sub-frameworks in the sequence using SAT solvers. The solutions of the whole argumentation framework is obtained by integrating the solutions of the sub-frameworks.

mu-toksia compute the extensions by calls to a Boolean satisfiability (SAT) solver. The system makes use of incremental SAT solving throughout the implementation: a SAT solver is instantiated only once during a single run of the program, allowing for maintaining the state of the solver from one call to another. mu-toksia obtained the best results in the ICCMA in 2019 [3], notably regarding preferred and grounded extensions.

CoQuiAAS is based on different Constraint Programming techniques dedicated to argumentative reasoning. It uses Boolean SAT solver and Maximal Satisfiable Sets (MSS) extraction to solve extension computation. CoQuiAAs has gone through 3 iterations, the last one (V3) having participated in the 2019 competition.

ConArg is a Constraint-programming solver oriented to the solution of problems related to extension-based semantics in Abstract Argumentation. It exploits Gecode, a C++ toolkit dedicated to constraint-based applications. The properties required by semantics are encoded into constraints, and arguments are assigned to true if belonging to a valid extension for that semantics. The solutions search benefits from well-known techniques as local consistency, different heuristics for trying to assign values to variables, and complete search-tree with branch-and-bound.

To conclude regarding the extensions computation tools, we can state that many efficient tools are available and are in constant progress. Most of these tools are in

[2]http://argumentationcompetition.org/index.html
[3]http://argumentationcompetition.org/2019/results/results-main.html

opensource, or at least, freely available. Some are lightly more efficient than other, depending on the considered problem and extension, but globally, they are all very efficient. We can rely on them to compute extensions without needing to develop a new extension computation engine.

1.1.4.2 Derived argumentation frameworks

Dung's work had a major influence on computational argumentation. Although his work is always used and studied, some researchers have point different limitations of this work, notably in order to be consistent with natural argument acceptance in a decision making context (Amgoud and Besnard, 2013, Caminada and Wu, 2011). For instance, Dung's model assumes that every argument is as strong and certain as other. Each time there are two opposing arguments, the situation is not decided and remains status quo (Bourguet, 2010). The use of the Dung model often induces a situation of conflictual argument which can considered as a limitation in a decision making context in which a solution must be found. To overcome these limitations different new argumentation framework were developed (Amgoud and Vesic, 2009). We propose, here, a non-exhaustive set of argumentation frameworks derived from Dung's AF: bipolar argumentation framework, Value-base argumentation framework and Probabilistic Argumentation Framework.

1.1.4.2.1 Value-base argumentation framework

Faced with the problem of the non-solvency of two mutually attacking arguments, Bench-Capon and Dunne (2007) proposed an extension to the system developed by Dung by integrating a value-based system. They stated that in real debate (notably in legal domain), an argument may attack another argument without defeating it, because the arguments can be related to different values (e.g. promote equity, protect the environment...). According to the importance one gives to these values, the attacks are more or less effective. The Value-based argumentation framework allow these values to be ranked to reflect the preferences of the audience to which the arguments are addressed, and then to nuance the attack of the arguments.

1.1.4.2.2 Bipolar argumentation framework

Most of the argumentation systems only define a defeasibility relation between arguments. It is within this framework that Amgoud et al. (2008) propose a complete study of an argumentation system integrating the notion of bipolarity where there are two types of information independent of each other and diametrically opposed. Three types of bipolarity are thus defined. The first type of bipolarity expresses the fact that a negative element is a reflection of a positive element, they are thus mutually exclusive. The second (bivariate double bipolarity) type expresses the fact that it is necessary to have two separate scales of representation of the two elements even if they are derived from the same data.

Thus an item of information can be both positive and negative in a given time without exclusivity. Finally the last type (heterogeneous bipolarity), expresses that although the two elements do not derive from the same data, they can be both positive and negative at the same time; however, it requires a minimum consistency between these two elements. Applied to the system of argumentation, bipolarity represents the fact that an argument can attack or support a given argument. While support was described by Dung (1995) as the attack of an attack of conclusion, support with the bipolar framework is defined as a new relationship that opposes the attack. Thus, with this framework, two relations are considered (attack and support) that allow to refute and support a conclusion.

1.1.4.2.3 Probabilistic Argumentation Framework

Some works have been done to extend the Dung model by assigning probabilities to argument attacks or extensions. The two main approaches for adding probabilistic information to the AAF are the constellation (Hunter, 2014, Li et al., 2012) and the epistemic approaches (Polberg et al., 2017, Thimm, 2012). The constellation approach processes uncertainty in the topology of the graph by assigning probabilities about the structure of the argument graph and may be useful for representing the point of view of different people. In the epistemic approach, the structure of the argument graph is fixed and uncertainty is processed by assigning beliefs to arguments, meaning the extent to which each argument is believed. For instance, the probabilistic abstract argumentation framework (PrAAF) proposed by (Li et al., 2012), belonging to the constellation approach, consists in defining probabilities over the structure of the AAF by assigning probabilities to either the arguments or/and attacks of the AAF. The probability estimates the extent to which an argument is justified (resp. not justified) in the argument graph; each graph has a chance of being the real argument model. PrAAFdefines a probability distribution over the space of possible argument graphs called possible worlds representing a scenario that may occur in reality. Given a probabilistic argumentation framework $\langle Args, P_{Args}, Atts, P_{Atts} \rangle$, a possible world, denoted w, is an abstract argumentation framework $w = \langle Args', Atts' \rangle$ such that $Args' \subseteq Args$ and $Atts' \subseteq Atts \cap (Args' \times Args')$ assigned by a probability $P(w)$ such that $\sum_w P(w) = 1$. This approach has the ability to represent naturally many different uncertain scenarios through possible worlds assigned by probability distributions.

1.1.4.2.4 Which Argumentation framework for our decision problem?

We presented in this section different argumentation frameworks derived from Dung's. Each of them intends to answer Dung's Framework limitations, given it additional features. It could be interesting, regarding our decision problem to consider one of these frameworks. However, we decide to use the standard Dung

Abstract Argumentation framework. Three main arguments support this choice. Firstly, Dung is sufficient to express the weakness of an argument and/or its uncertainties. Indeed, when an argument appears as weak or not well founded, it is possible to add a new argument attacking it. For instance, it is possible to add an argument as: "Your argument must be nuanced, because..." or "Your argument is uncertain, because...". The interest is that the participant who exposes such an argument must herself/himself argues for the weakness of the argument. It is more in line of our approach that just setting a parameters related to the argument modeling the uncertainties or weakness. Secondly, AAF does not require additional information while all other frameworks require to set parameters related to argument and/or attack (value of uncertainty, weight of the argument...). This pose a double problem in a real time debate context. Indeed, firstly, it poses the question of who has to define these parameters (e.g. the weight of the argument). Secondly, it requires time inducing a stop in the debate which may interfere with the natural flow of discussions. In our approach, we want the exchanges between the actors to be at the heart of the method and therefore to hinder them as little as possible. Finally, the last argument regarding the use of AAF is more pragmatic. Thanks to the ICCMA, many powerful inference engines are available ensuring a computation of the extension in real time, even with a large number of arguments. Inference engines dedicated to the other frameworks are not so efficient and are more consuming in terms of computing time, potentially limiting, as soon as the number of arguments becomes large, calculations in real time.

Thus, the approach we used in this work is based on the Dung's AAF. However, this point will be more largely discussed in the general Conclusion, which provides some perspectives to this work.

1.1.4.3 Using an abstract argumentation framework in collective decisions

We stated that AAF should be interesting to support participatory approach. In this section, we will present an overview of the literature pertaining to AAF in a participatory approach or collective decision-making. In order to identify and analyze relevant papers, we performed a search in Scopus and ISI Web of Science for papers dealing with AAF. Thus, not all papers proposing approaches, methods or tools using other models of argumentation for participatory or collaborative decision making approaches are considered. We used the following queries (Table 1.1.2).

Keywords	Scopus	ISI Web
abstract & framework & argumentation & decision	94	78
abstract & framework & argumentation & decision & participatory	0	0
abstract & framework & argumentation & decision & collective	4	1
abstract & framework & argumentation & decision & collaborative	1	1
abstract & framework & argumentation & decision & debate	2	2

Table 1.1.2: Number of results by searching on Scientific database

The first observation is that while there is a significant number of papers dealing with abstract argumentation for decision-making, very few have focused on participatory aspects, collective decision making or debate. Most of the works related to abstract argumentation can be classified into four categories: (i) new argumentation frameworks based on the AAF, (ii) theoretical/conceptual analysis of an AAF and its properties, (iii) algorithm and implementation and (iv) application to a problem. Papers in the first category are dedicated to providing new methodological developments regarding argumentation frameworks, as for instance, using imprecise probability (Morveli-Espinoza et al., 2019) or Attack-Incomplete Argumentation Frameworks (Baumeister et al., 2018). The second category gathers theoretical work aiming at demonstrating properties of AAFs, such as the study of the theoretical relationship between formal concept analysis and abstract argumentation (Amgoud and Prade, 2013). The third category corresponds to work aiming at improving abstract argumentation inferences, such as Cerutti et al. (2019) or Niu et al. (2018). Finally, in the last category, many papers describe how to instantiate AAF approaches to real world decision context. For instance, Pazienza et al. (2019) use abstract argumentation to predict financial analysts' recommendations in earnings conference calls and Santini and Yautsiukhin (2016) to support the administration of security in computer networks. Although very relevant since they provide methodological and/or operational contributions to make AAFs more efficient, none of the published literature answers the research questions posed in this thesis. We have therefore focused on papers dedicated more specifically to participatory approaches, or debate analysis, or collective decisions. As a result of our literature search using these different key words (Table 1.1.2), 9 papers were found (2 were common to the different queries). Among these 9 papers, two correspond to conference abstracts, and one is not related to AAFs. Therefore, only 6 papers remained. Two of these 6 papers provide new methodological developments regarding argumentation frameworks (first category). The first one proposes a practical argumentation semantics (Kido, 2012). It allows to integrate, in addition to Dung's theoretical argument (what to believe), practical arguments (what to do). The authors provide new extensions considering these two types of argument. The distinction between these two types of argument is interesting to analyze decisions. However, it is mainly a methodological contribution, hardly usable in

our context (real time debate in participatory decision-making). The second methodological contribution proposes to combine AAFs with Issue-Based Information System (IBIS) argument models to support debates on design alternatives (Baroni et al., 2015). The model is implemented in a visualization tool dedicated to a pool of experts discussing different choices of design alternatives. This method uses a quantitative evaluation for argument and different rules and functions are provided to compute the score of each argument (level of acceptability). It is an interesting approach to support discussions between a pool of experts (mainly engineers) whose emphasis is on the assessment of alternatives. The notion of an argument's score can be debated: Who gives the score? What is the meaning of an intermediate score in terms of argument validity? Furthermore, the tool is not intended for real-time debates with many participants; issues such as computation time and distributed interface are not discussed. However, some interesting points from this paper can be highlighted: a structured model of argument coupled with the AAF and a graphical interface to visualize the argumentative structure. In the second category (theoretical contribution), Booth et al. (2014) discuss the computational complexity of AAFs combined with labelling. This provides a better understanding of the notion of computational complexity for AAFs. In the third category, Alfano et al. (2019) deals with algorithm and its implementation. The authors provide an algorithm to compute the grounded semantics extension based on an updating approach. It is an incremental algorithm, useful in dynamic contexts where argumentation frameworks are continuously updated to consider new information and also interesting for real time computation of extensions. Bilo Doumbouya et al. (2016) is at the intersection of the second and third categories. It provides a method to compute accepted arguments based on the properties of AAFs. The principle is to combine mathematical properties (e.g. symmetry, asymmetry, strong connectivity and irreflexivity) of AAF graphs to compute extensions. As the previous paper, it proposes an interesting strategy to accelerate extensions computation which is useful for real-time debate, but it is not sufficient to answer this thesis's objective.

Finally, Karanikolas et al. (2018) has the most applied objective and proposes a procedure to support collective decision making for applications in agriculture. The authors combine Computational Social Choice (CSC) and AAFs in order to reach the best decision regarding issues in agricultural engineering; the approach was implemented in a tool called Ecobiocap. The principle is to propose to participants to express their preferences regarding alternatives. CSC is used in order to aggregate these preferences and rank alternatives. The use of argumentation consists of discussing the top alternatives and preferences. However, the paper focuses on the CSC part of the model, and the use of Argumentation is just mentioned and not detailed. Furthermore, it is not intended for real-time debate, and it is not centered on discussions but uses a voting system. Finally, it does not provide a visualization of the results meaningful for all participants.

1.1.5 Conclusion

Several conclusions can be drawn from this state of the art and more generally from this first chapter. First, computational argumentation has little addressed the issue of participatory approach by providing support for real time debate between stakeholders. More specifically, if AAFs could be interesting by its capacity to infer information, no method or tool using AAF has been proposed for participatory approach. The question of the use of AAFs for such an approach may therefore arise. However, if the identified articles do not answer the question, they can be used to develop possible answers by giving ideas on how to design such a tool: (i) A specific model of argument must be defined in order to give a meaning to this notion for all participants, (ii) inferences provide by AAF can give interesting information to make decision or/and to understand the issues of the debate, (iii) specific rules/inferences must be developed in order to used the model of argument with the AAF, (iv) the tool should be able to perform the calculation in real-time during the discussion, and (v) to provide a simple and clear visualization of the argumentative structure. These five points are the subject of the the next chapter which develops a new model of argument and then associated rules in order to use AAF inference, then, the implementation of this model in a web application is exposed.

Chapter 1.2

An argumentation interface for participative approach

1.2.1 Introduction

In the previous chapter, we analyzed the state of the art regarding computational argument approach for participative decision support. We conclude on the lack of available approach, method and tool to support such decision problem while abstract argumentation could be relevant in this decision context. This chapter provides an innovative argumentation model in order to support participative decision approach. It is the first major contribution of this thesis. We developed a simple but restrictive model of argument and implemented it in a software tool called Argumentation Interface for Participatory Approach (AIPA). AIPA is based on Abstract Argumentation Framework (AAF) to support participatory decision by ensuring a more or less objective conflict analyzer. The method and tool support real-time debates for non-expert users, which is unprecedented in the literature, as we showed based on a review of the literature in computational argumentation tools. In a first section, we will expose the argument model that AIPA used. Then, we will present the definition related to AIPA and the translation rules allowing to use the AAF inference. Finally, we will propose an example of application for AIPA in order to illustrate its functioning and its interest.

1.2.2 Designing an argumentation model for non-experts : Argued Discussion Model

We raised in the previous chapter the need to propose a specific model of argument dedicated to our objective due to the inadequacy of the existing models, such as Toulmin (2003) and IBIS (Ebadi et al., 2009) regarding participatory decision support. The use of argument structures in a context of a debate in

participatory approaches is quite complex. Indeed, the different stakeholders have limited knowledge of theoretical argumentation and it has been shown that conflict resolution cannot be solved with complex argument structures due to the human argumentation process (Sillince and Saeedi, 1999). Moreover, since the objective is to focus on real-time debates, to argue and identify the type of argument at the same time would drastically increase the complexity for non-experts. Therefore, we propose the Argued Discussion Model (ADM), a simpler model that shares the ideas of support and defeat relations from a bipolar framework (Amgoud et al., 2008), and implements the argument concept in a way usable in a real context of live debate.

Definition 9. *An argument is an abstract concept referring to a proposition - a declarative sentence that can be either true or false. It is either a Conclusion or a Statement (which is also an abstract concept).*

Remark 1. *The word "argument" has a wide range of definitions and can lead to confusion. In the ADM, an argument is an extension of the AAF argument, meaning an ADM argument can be used in the AAF.*

Definition 10. *An Argued Discussion Model (ADM) is a pair $AD = \langle A, T \rangle$ with:*

- *A, a set of arguments with:*
  - *C, a set of Conclusions such as $C \subseteq A$,*
  - *S, a set of Statements such as $S \subset A$ with $S \cup C = A$ and $S \cap C = \emptyset$ with:*
    - *S_f, a set of StatementFor where $S_f \subseteq S$,*
    - *S_a, a set of StatementAgainst where $S_a \subseteq S$,*
    - *$S_a \cup S_f = S$ and $S_a \cap S_f = \emptyset$,*
- *T, the binary relation $T \subseteq S \times A$ such as for a Statement s_i targeting (or being about) a_i, we have $(s_i, a_i) \in T$ with the following properties:*
  - *T is irreflexive such as $\forall\ s_i \in S$, $(s_i, s_i) \notin T$ - meaning no argument can target itself,*
  - *T is asymmetric such as $\forall\ s_i \in S$ and $\forall\ a_i \in A$, if $(s_i, a_i) \in T$, then $(a_i, s_i) \notin T$ - no argument can be targeted by an argument it targets,*
  - *T is functional such as $\forall\ s_i \in S$ and $\forall\ a_i, a_j \in A$, if $(s_i, a_i) \in T$ and $(s_i, a_j) \in T$, then $a_i = a_j$ - which means a Statement is targeting at most one Argument,*
  - *T is not injective such as $\forall\ s_i, s_j \in S$ and $\forall\ a_i \in A$, if $(s_i, a_i) \in T$ and $(s_k, a_i) \in T$, then $s_i \neq s_k$ - an argument can be targeted by more than one Statement,*

- *T is not surjective such as $\forall\ a_i \in A$, $\exists\ s_i \in S$ such that $(s_i, a_i) \notin T$ - an argument doesn't have to be targeted,*

- *T_f, is the binary relation $T_f \subseteq S_f \times A$, subset of T such as $T_f \subseteq T$ with T_f being transitive such as $\forall\ s_{fi}, s_{fj}, s_{fk} \in S_f$, if $(s_{fi}, s_{fj}) \in T_f$ and $(s_{fj}, s_{fk}) \in T_f$, then $(s_{fi}, s_{fk}) \in T_f$ - meaning if one makes a StatementFor (S_{f1}) toward a StatementFor (S_{f2}) that is already targeting a StatementFor (S_{f3}) then S_{f1} approves also S_{f3},*

- *T_a, the binary relation $T_a \subseteq S_a \times A$, subset of T such as $T_f \subseteq T$ with T_f being not transitive such as $\forall\ s_{ai}, s_{aj}, s_{ak} \in S_a$, if $(s_{ai}, s_{aj}) \in T_f$ and $(s_{aj}, s_{ak}) \in T_f$, then $(s_{ai}, s_{ak}) \notin T_f$, meaning if one makes a StatementAgainst (S_{a1}) toward a StatementAgainst (S_{a2}) that is already targeting a StatementAgainst (S_{a3}) then S_{a1} doesn't reject S_{a3}.*

Example 1. *Throughout this example, we assume a public consultation about increasing fuel tax of a group of citizens. Let A_i be an instance of Argument concept, an argument (though non-implementable) put forward is A_1 - "Increasing taxes reduces fuel consumption and therefore pollution" or A_2 - "Increasing taxes penalizes the poorest citizens".*

Definition 11. *A Conclusion is a particular proposition pertaining to a given decision, i.e., resolving a question. It can be an alternative, a goal or a choice and it is always a final step in the discussion.*

Example 2. *(Example 1 - continued) A Conclusion is C_1 - "Fuel tax should be increased". Another is C_2 -"Fuel taxes should be decreased".*

Definition 12. *All Conclusions are mutually exclusive. As a result (disjointness), there should not be any logical disjunction "or" in a Conclusion to avoid inconsistency.*

Example 3. *(Example 2 - continued) The two Conclusions C_1 and C_2 are disjoint.*

Definition 13. *There is always a "Negation" Conclusion:*

- *Let C_{Neg} be a Negation Conclusion and C_i be a Conclusion,*

- *$C_{Neg} = \neg(C_1 \vee C_2 \vee ... \vee C_n)$.*

Example 4. *(Example 3 - continued) Following this list of Conclusions:*

- *C_1 - "Fuel tax should be increased",*

- *C_2 - "Fuel tax should be decreased".*

The Negation Conclusion would be C_{Neg} - "Gas taxes should not be increased nor decreased".

Lemma 3. *Since there is always a "Negation" Conclusion, there are always at least two Conclusions - C_{Neg} and C_i.*

Remark 2. *With the exception of the two Conclusions required (Lemma 3), any number of Statement or Conclusion can be added at any time in any order.*

Example 5. *(Example 4 - continued) As the first Conclusion C_1 - "Fuel tax should be increased" was expressed, there is automatically a C_{Neg} - "Not (Gas taxes should be increased)" - or written differently - "Gas taxes should not be increased" where $C_{Neg} = \neg C_1$.*

Definition 14. *A Statement is an abstract concept referring to an assertion or a denial. It is declined into StatementFor (assertion) or StatementAgainst (denial). A StatementFor should be understood as "I agree with this argument because ..." and inversely for a StatementAgainst.*

Lemma 4. *Since a Statement is in agreement or disagreement with an argument (a Conclusion or another Statement), it cannot exist without being linked to the "about" relation shown as the binary relation T in the Definition 10, thus explaining the functional property.*

Remark 3. *Since the Conclusions are, by definition, mutually exclusive (Definition 12), a Conclusion is therefore different from a Statement. The goal of mutual exclusion is to ensure the identification of a Conclusion that satisfies every participant or to encourage participants to reach a consensus in the absence of a common Conclusion.*

Lemma 5. *Since $S \subset A$ and $C \subseteq A$ (Definition 10), only Conclusion elements can exist without being linked to other arguments.*

Example 6. *(Example 2 - continued) A citizen adds a StatementFor Sf_1 - "Increasing taxes reduces fuel consumption and therefore pollution" about C_1 - "Fuel taxes should be increased" but someone disagrees with him/her and adds a StatementAgainst Sa_1 - "This can only be true if credible and accessible alternatives to petrol cars are proposed, which is not the case today" about Sf_1.*

The ADM is partially represented in Figure 1.2.1. The top concept can be either a Conclusion (i.e., debate issue) or Statement (i.e., pros or cons assertions regarding an argument). Statement is always about a Conclusion or another Statement divided into StatementFor and StatementAgainst. In a debate, there is always a Negation Conclusion that is the complement of all the other Conclusions. Since every concept is based on an Argument, we can integrate this model in AAF engines by converting the "about" relation into attacks in order to obtain AAF extensions (notably sets of preferred and grounded extensions).

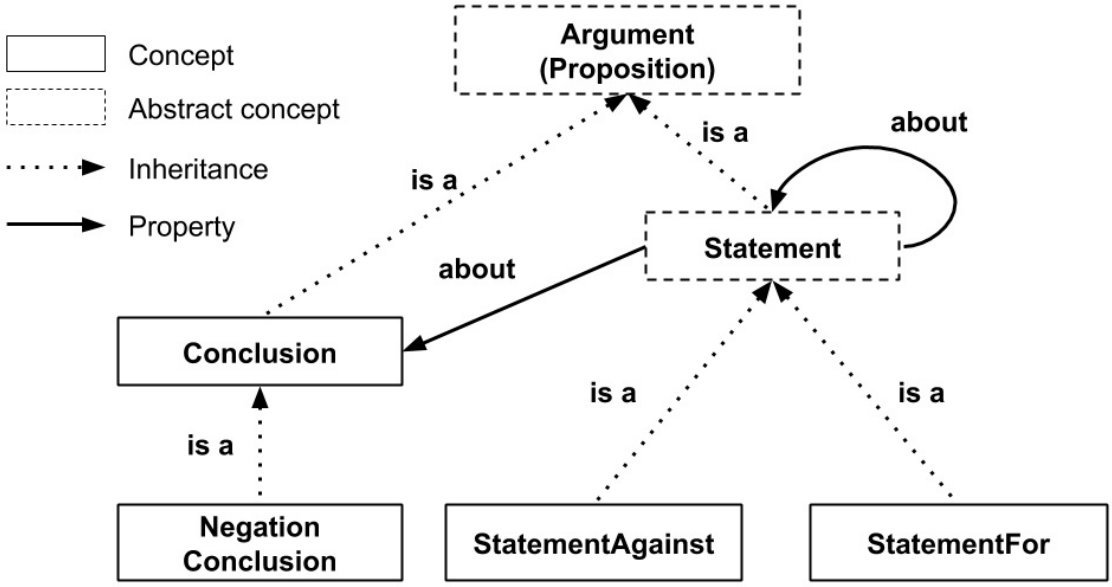


Figure 1.2.1: Partial representation of the ADM

1.2.3 Analyzing debate in real-time with AIPA

1.2.3.1 General principles

As discussed above, we designed a tool called AIPA that combines the ADM (argument model) with inferences developed by Dung in order to support participatory approaches in real-time for non-expert users. In AIPA, only the ADM graph is stored, every time an Argument (Statement or Conclusion) is added or removed, a corresponding AAF graph is generated according to a chosen "translation" into a graph of attacks (Section 1.2.3.2). The resulting AAF graph is recomputed every time a change occurs in the ADM graph, a Statement or a Conclusion can be made out of sequence, without order or time constraint. AIPA provides, in real-time debates, the following elements:

1. A trace - if wanted - of the debate,
2. The debate's current status: "Conclusion accepted", "Conflictual Conclusions" and "All Conclusions rejected",
3. Statement which is in/out of favor for every Conclusion,
4. Statements accountable for the current debate status.

Traceability A trace corresponds to the graph itself and its recording. AIPA records the different arguments, who makes them and when. Due to the ADM definition, a StatementFor or StatementAgainst is always posterior to its target

(Conclusion or Statement). Thus, the resulting graph takes the form of a tree, facilitating its understanding by the participants and other stakeholders outside of the debate. Furthermore, the information regarding the three first elements can easily be represented on this graph.

Debate status AIPA, by combining ADM with AAF inferences, provides relevant information to the stakeholders during the debate in real-time (processed in seconds). To address the real-time characteristic, we use engines developed for extensions computing, from which we chose four depending on their availability, efficiency for a given semantic, platform compatibility (GNU/Linux & Windows) and development ease. They all have been interfaced with AIPA in order to switch seamlessly according to our needs. Three were found via the International Competition on Computational Models of Argumentation (ICCMA'17) (Gaggl et al., 2020): Argmat-dvisat, Argmat-sat and ConArg. The last one being DungOMatic (Snaith et al., 2010). The computed extensions are then combined with our model (ADM) in order to provide an assessment of the debate in real-time. This assessment is done through grounded and preferred extensions from which we establish three graphs status.

Definition 15. *The rules determining the graph status are defined as follows:*

- *Accepted: If only one Conclusion is included in the grounded extension,*
- *Conflictual: If there is no Conclusion in the grounded extension and if more than one Conclusion are included in the preferred extensions,*
- *Rejected: If there are no Conclusion in grounded extension and no Conclusions in the preferred extensions.*

InFavor function Since the binary relation between only StatementFor is transitive and the one between only StatementAgainst is not (Definition 10), we use as shown in the algorithm 1 the negation of the binary operator XOR (exclusive or) in order to determine whether the selected Statement contributes positively to a given Conclusion or negatively. A Conclusion is reached (or not which means not in favor of) by iteration through a function "getTarget()" that returns only one Argument (Statement or Conclusion) aimed by a Statement (parameter of the function). The nature of an argument (StatementFor, StatementAgainst of Conclusion) is ascertained by a boolean function called "isInstanceOf()". This function is displayed as "isInstanceOf(Argument, StatementFor/StatementAgainst/Conclusion)" and returns true if the argument is the specified concept.

```
Data: A Statement s, a Conclusion c
Result: Return a Boolean, if True then the Statement s is in favor of the
        Conclusion c
Boolean res = isInstanceOf(s, StatementFor);
Statement temp = s;
while NOT(isInstanceOf(getTarget(temp), Conclusion)) do
    temp = getTarget(temp);
    res = NOT(res XOR (isInstanceOf(temp,StatementFor)));
end
if getTarget(temp) != c then
    res = NOT(res);
end
return res;
```

Algorithm 1: Algorithm to determines if a Statement is in favor of a Conclusion

Results explanation AIPA aims at providing an explanation of the results (i.e., the status of a Conclusion). By explanation, we mean highlighting the Statements that are behind the graph status result. To this end, a translation from our model has to be done in order to obtain a Dung graph for determining the debate status (Section 1.2.3.2), then explaining the debate status (Section 1.2.3.3).

1.2.3.2 Translation rules

The connection between Dung's extensions and the model is done by translating (or converting) our argument model to an AAF graph, thus the "interface" in AIPA. Although one could choose to change any translation regarding the meaning he/she would expect from the debate (and the model used), the restrictions imposed by the model led to fixed translation of several concepts.

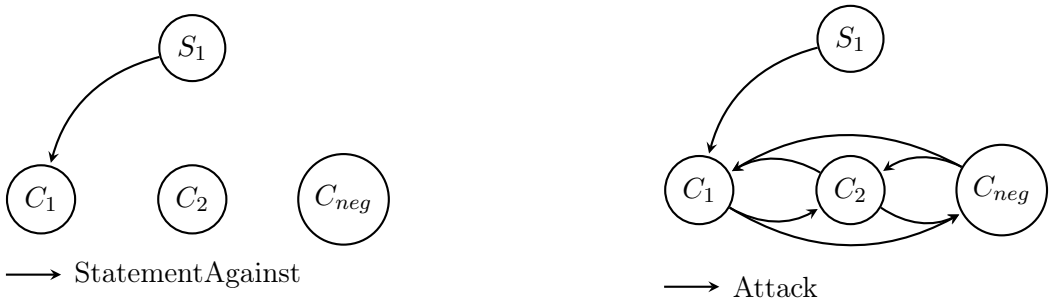
Remark 4. *Since we convert an ADM graph to an AAF graph, we emphasize the fact that an edge in an ADM graph is always mentioned as "about", "target" or "aim", whereas the word "attack" refers to an edge in an AAF graph.*

1.2.3.2.1 Conclusion translation

Definition 12 imposes mutual exclusivity between Conclusions. This is ensured by making each Conclusion attack each other Conclusion, thus allowing either one Conclusion or none to emerge from the grounded extension (Figure 1.2.2). Figure 1.2.2a provides an instance of debate with 3 Conclusions including the Negation Conclusion C_{neg} and 1 StatementAgainst. Figure 1.2.2b presents the resulting Dung's graph using the Conclusion translation.

Remark 5. *For better readability, StatementFor and StatementAgainst are distinguished by the format of every arrow. A StatementFor S_{f1} about a*

Conclusion C_1 would be shown as a node containing S_1 with a dashed arrow going toward the node C_1 and StatementAgainst S_{a1} would be represented using simple arrow (Figure 1.2.3a for both case).



(a) Debate Model

(b) Dung translation of figure 1.2.2a

Figure 1.2.2: Model translated to Dung's Framework

Due to the Conclusion exclusivity definition (Definition 3), a distinction is made between Statement that targets Conclusion and Statement that targets other Statement.

1.2.3.2.2 StatementAgainst translation

As stated in Definition 14, a StatementAgainst is a denial of another argument, therefore, StatementAgainst is directly translated into an argument with an attack on the target of the StatementAgainst. Because a StatementAgainst is always about only one argument (Conclusion or Statement), A StatementAgainst generates only one argument and one attack in the Dung's graph (Figure 1.2.2).

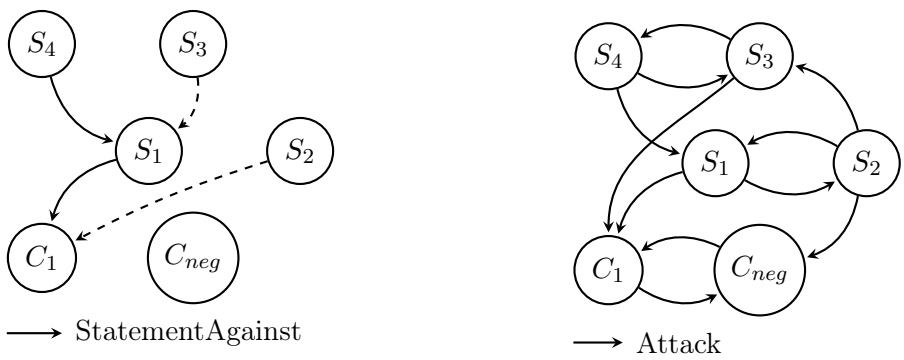
1.2.3.2.3 StatementFor translation

Given that the AAF considers only attack and not support relation, one would ask the meaning of a StatementFor: Is the StatementFor a support that should strengthen another argument? Should the StatementFor be the exact opposite of an attack? Can we be in favor of something without being against its contrary? There are several valid answers to these questions. In order to consider these different possibilities, AIPA provides two different translations for StatementFor, called Support and Optimistic translation. The person in charge of the debate (more probably the facilitator) will choose his/her preferred one according to his/her needs. These translations are heavily linked to the meaning we give to different situations in the debate. They are detailed below.

1.2.3.2.4 Support translation

This translation focuses on being as neutral as possible, i.e., every conflict needs to be solved in order to get a joint accepted Conclusion and Arguments are equals in importance. If the purpose is to find a common goal in a very "objective" manner where every argument matters, this translation should be used. As said before (section 1.2.3.2.1), this translation has two cases, one where a StatementFor is about Conclusion and the other when a StatementFor is about another Statement. In both cases, every StatementFor attacks every StatementAgainst of the same level (they target the same argument) and converserly. The other translations work as follows:

- StatementFor about Conclusion
  - A StatementFor attacks every Conclusion that it doesn't target (or it isn't about).
- StatementFor about Statement
  - If a StatementFor S_f target a Statement S, then S_f attacks every arguments attacked by S (thus support translation).
  - If a StatementFor S_f target a Statement S, then every argument that attack S also attack S_f.



(a) Debate Model 2

(b) Dung support translation of figure 1.2.3a resulting in a Conflictual status (C_1 & C_{neg})

Figure 1.2.3: Model 2 translated to Dung's Framework with the support translation

Figure 1.2.3a provides an instance of debate with 2 Conclusions and 4 Statements. Figure 1.2.3b presents the resulting Dung's graph using the support translation. The computation of the grounded extension (GE) and the preferred extensions (PE) via Dung's engine results in:

- $GE = \emptyset$

- $PE = \{\{S_4, C_1, S_2\}, \{C_{neg}, S_3, S_1\}\}$

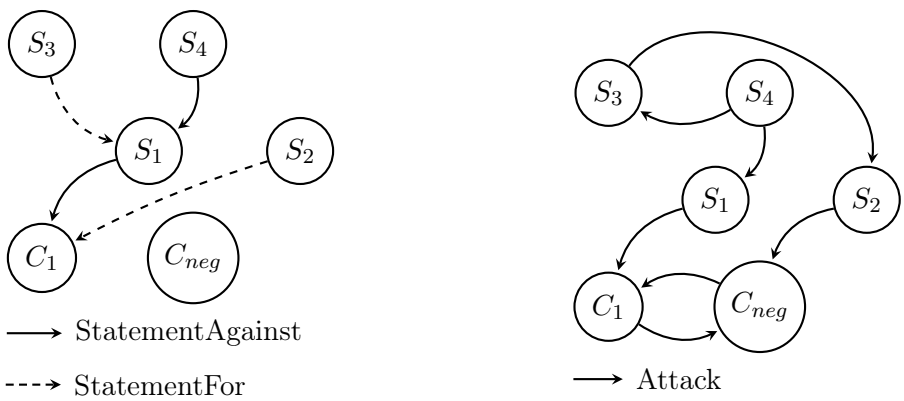
Thus, in this example, neither of the Conclusion is accepted. According to Definition 15, they are conflictual. In this case, the debate should continue in order to provide more arguments to solve the conflict.

Remark 6. *The reader may notice that cycles of attacks appear in Figure 1.2.3b, these cycles are one of the reasons there are multiple preferred extensions in the AAF (Bench-Capon (2016)).*

1.2.3.2.5 Optimistic translation

Acknowledging the need to find a consensual solution without resolving every conflict, we propose another translation, called optimistic translation, where only arguments which are not in conflict are taken into account. Two cases have to be distinguished as in support translation for the StatementFor as follows:

- StatementFor about Conclusion
  - A StatementFor attacks every Conclusion that it doesn't target.
- StatementFor about Statement
  - A StatementFor is attacked by every StatementAgainst sibling (Statement which shares the same target).
  - A StatementFor attacks every opposite sibling of its target, meaning a StatementFor that target a StatementAgainst will attack in AAF graph every StatementFor of the same level.



(a) Debate Model 2

(b) Dung optimistic translation of figure 1.2.4a resulting in a "Accepted conclusion" status (C_1)

Figure 1.2.4: Model 2 translated to Dung's Framework with the optimistic translation

Figure 1.2.4a shows the same graph used in the previous translation. We applied however the optimistic translation (Figure 1.2.4b) resulting in different sets for the grounded extension (GE) and the preferred extensions (PE):

- $GE = \{S_4, C_1, S_2\}$
- $PE = \{\{S_4, C_1, S_2\}\}$

Following Definition 15, Conclusion C_1, belonging to the GE, is accepted with the optimistic translation. This small example provides the difference between the two translations. Whereas the first translation led to conflicting Conclusions, this second translation resolves the debate by giving C_1 as accepted. Thus the choice of a translation will depend on the objective: if the emphasis is on the debate and one wants the debate to really lead to a consensual solution, the support translation will be preferred; if, however, it is necessary to settle the debate and reach a Conclusion, the optimistic translation will be preferred.

1.2.3.3 Providing indications regarding the graph status

Since there are two specific translations for a StatementFor (support and optimistic) and three debate status available (accepted, conflictual and rejected), there is a maximum of eight achievable outcomes to explain. However, in our case, only the accepted debate status differs for the explanations according to the chosen translation.

Definition 16. *In a support translation, a Statement explains an accepted Conclusion if it's included in the grounded extension and if it's in favor of the accepted Conclusion (algorithm 1).*

Definition 17. *In an optimistic translation, a Statement explains an accepted Conclusion if it's included in the grounded extension and it matches one of the following rules:*

- *The Statement is a StatementFor*
- *The Statement is a StatementAgainst and matches one of the following rules:*
  - *the Statement has no siblings (other Statement aiming at the same target)*
  - *the Statement is targeted by at least one StatementFor*
  - *all siblings of the Statement are StatementAgainst or follow all of the following rules:*
    - *the sibling of the Statement is at least targeted by one Statement*
    - *the sibling of the Statement is only targeted by a StatementFor*

Example 7. *Figure 1.2.4 led to the result C_1 as an accepted Conclusion with S_4 (SF) and S_2 (SA) included in the grounded extension ($GE = \{S_4, C_1, S_2\}$). Since only S_2 is compliant with the Definition 17, S_2 is the reason behind C_1 being the accepted Conclusion.*

Since there are at least two conflictual Conclusions, we provide explanations (Definition 18) according to the selected conflictual Conclusion.

Definition 18. *In support and optimistic translations, a Statement explains a conflictual Conclusion if it's in favor of this Conclusion and it's included in the union of every preferred extension that contains a Conclusion.*

Example 8. *Figure 1.2.3 shows a conflictual result with two preferred extensions: $\{S_4, C_1, S_2\}$ and $\{C_{neg}, S_3, S_1\}$. Having Conclusion in both extensions means every Statement included in either one will explain the conflict when combined with the inFavor function. In this exemple, C_1 has a conflictual status because S_2 and S_4 exists and CNeg shares the same status due to S_1 and S_3.*

Definition 19. *In a support and optimistic translation, a Statement explains a rejected Conclusion if it's in favor of this Conclusion and it's included in the union of every preferred extension that does not contain a Conclusion.*

1.2.4 Implementation

ADM and AIPA were implemented in a web application tool called WebAIPA, which displays, in real-time, any changes in the debate graph. Figure 1.2.5 shows the ADM graph of the AipaForum debate. Arrows representing a StatementAgainst are colored in red and StatementFor are colored in blue. Conclusion and Statements nodes have their own colors depending on the AAF extensions results. Green Statement is a Statement that contributes to an accepted Conclusion. Grey Statements means that they are conflicting, and white Statements do not contribute to the current status of the graph. By hovering over a Conclusion, Statements in favor of the Conclusion will be highlighted by a blue circle while Statements not in favor will be highlighted by a red circle. Finally, the user can change the translation used (support or optimistic) and see the new status of the graph. (Definition 15).

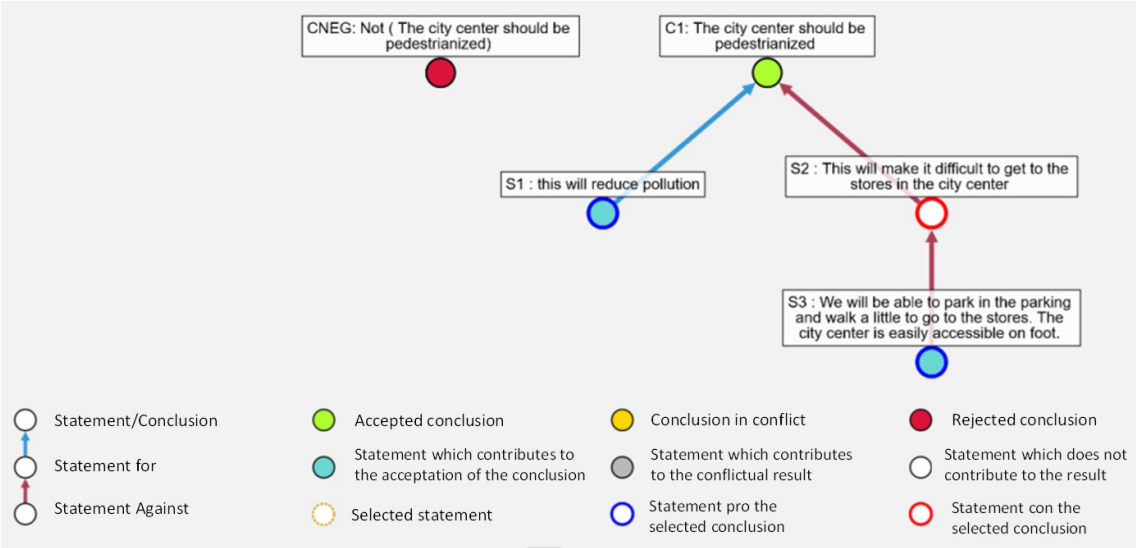


Figure 1.2.5: Excerpt of WebAipa graph view

WebAipa is interfaced with a custom-made forum (AipaForum) through a REST-like API (web services for interoperability between systems) to WebAIPA with the aim of providing the current state of the debate and a graph representation of the forum. Both representations have their arguments connected to one another in order to keep track of the debate and to be able to go from a representation to another. Participants had access to the forum where they had to formulate their arguments and to WebAIPA, allowing them to see the induced argumentation structure. Each time an argument is added or removed, AIPA provides new information on the argument acceptability thanks to AAF inferences. The replies are indented so every Statement are below the other Statement or Conclusion they target. As soon as a new reply is made, the corresponding Statement is also created in WebAipa.

The forum, WebAIPA and AIPA engine worked in real-time allowing users to move from one to the other without loss of information, i.e., as soon as an argument was formulated, it was represented in the argument graph. This allowed participants to add their arguments in the forum (a classical format and well mastered by the participants) and to see the influence of their arguments on the acceptability of the Conclusions as well as to understand the argumentation structure.

1.2.5 Applications

In order to illustrate the applicability of our tools we present two case-studies. The first is in the context of a debate regarding the choice among four urban development projects. This exercise using fictitious projects aims at showing how our tools can be used in real-time in a debate framework. The second application is within a participatory process for a real urban development project, namely the choice of a

where to build a new route for a tramway. In this case, AIPA was used a posteriori to formalize the arguments and analyze the debates that took place on an online forum during the participatory process.

1.2.5.1 Application 1: real-time debate

In order to illustrate the functioning of AIPA and its potential benefits in real-time, we applied it to a debate related to an urban planning project around Bordeaux University. The participants in the debate were asked to discuss and choose between four fictitious projects for the development of this area:

- Naturalia (C_1): a solution that gives priority to the natural environment and respect for fauna and flora,
- Cyber Campus (C_2): a solution based on new technologies and links to industry,
- Mobility (C_3): a solution highlighting the problems of travel and mobility, facilitating access for all on campus,
- Agora (C_4): a solution that places human relations at the centre and proposes arrangements to facilitate exchanges and proximity.

Eight members of the University participated in the debate using AipaForum; they had different profiles (age, gender...) and functions (student, professor, researcher, technician...) representing a wide range of opinions. Participants interacted individually with the system by adding Statements without restrictions on the number of arguments.

The first author presented the projects to the participants along with an explanation of what Statements represent and how to use the forum. Everyone was free to get involved and spend her/his time in this time frame. There was no limit to the number of arguments per participant.

The forum, WebAIPA and AIPA worked in real time allowing participants to move from one to the other without loss of information, i.e., as soon as an argument was formulated through the forum (Figure 1.2.6), it was represented in the argument graph (Figure 1.2.7). This allowed participants to add their argument in the forum (a very classical format and well mastered by the participants) and to see the influence of their arguments on the acceptability of the conclusions as well as to understand the argumentative structure. Although it is generally possible to add at any time a new Conclusion, e.g. a new project (which could eventually induce a compromise), we chose to deactivate this capability since we wanted the participants to reach a consensus with the help of AIPA, Statements however could be added anytime about an another Statement or a Conclusion.

AipaForum has been linked through a REST-like API (web services for interoperability between systems) to WebAIPA with the aim of providing the

current state of the debate and a graph representation of the forum. Both representations have their arguments connected to one another in order to keep track of the debate, and to be able to go from a representation to another. Participants had access to the forum where they had to formulate their arguments and to WebAIPA allowing them to see the induced argumentative structure. Each time an argument is added or removed, AIPA provides new information on the argument acceptability thanks to AAFinferences. In this application, the support translation (see subsubsection 1.2.3.2.4) has been chosen as no due-time was required and every conflict had to be taken into account.

Figure 1.2.6: Excerpt of user interface for the WebForum regarding the "Cyber Campus" project

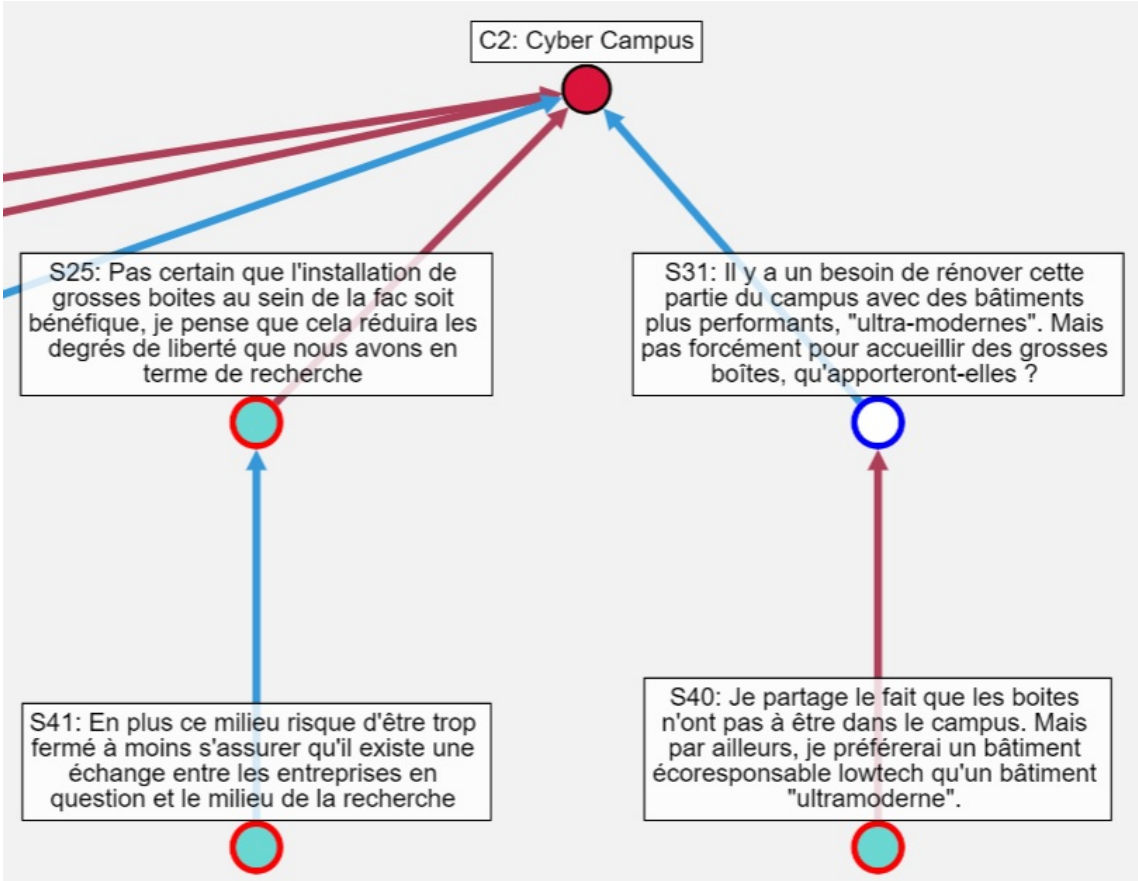
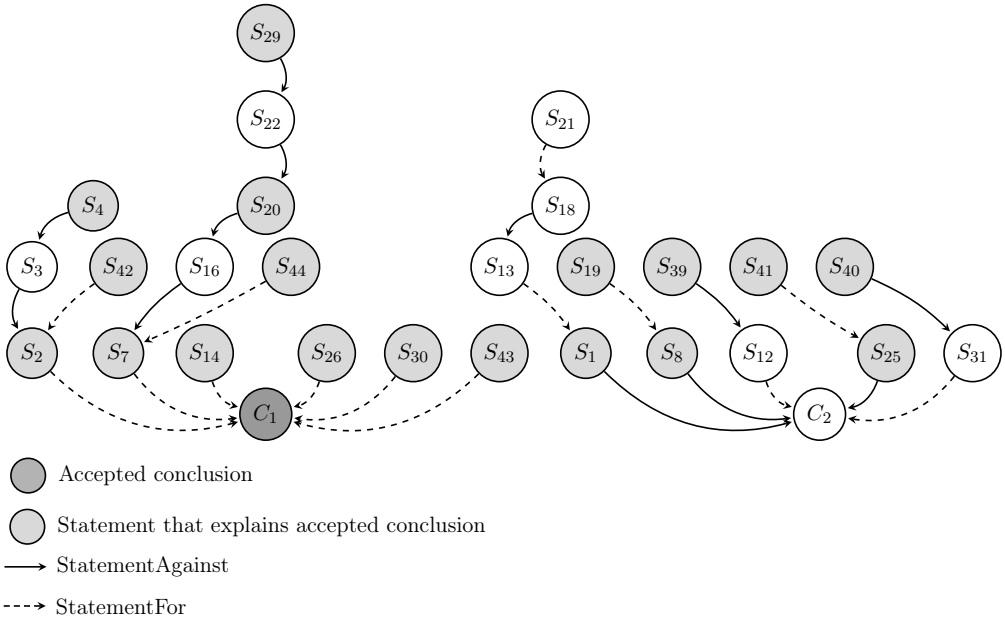


Figure 1.2.7: Excerpt of user interface for the WebAIPA graph regarding the "Cyber Campus" project

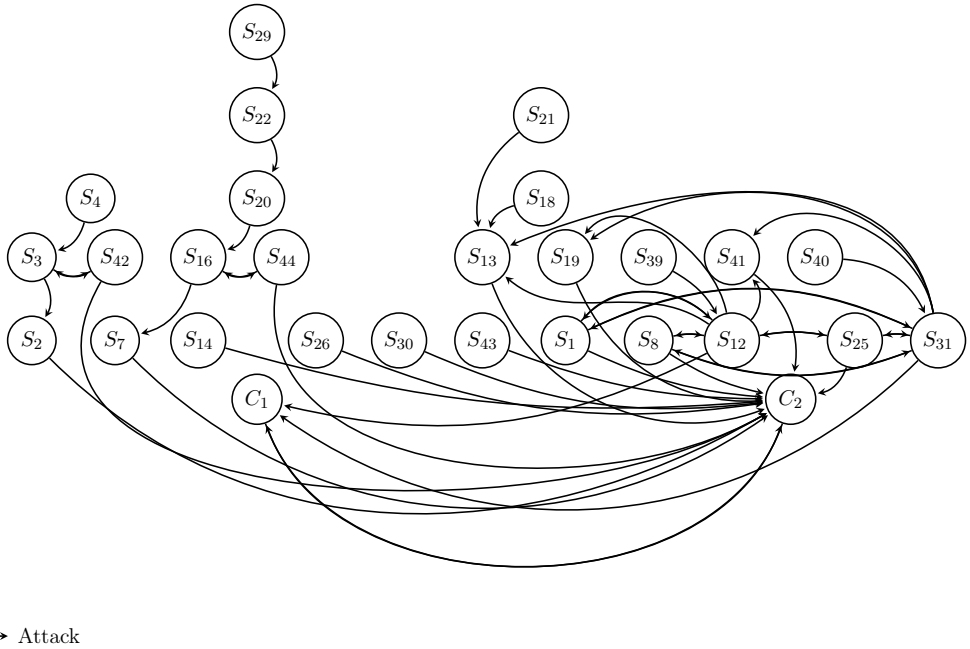
The participants expressed 44 arguments. The number of arguments per participant ranged from 3 to 8, distributed as follows: Naturalia (14), Cyber campus (12), Mobility (10) and Agora (8). Figure 1.2.8a presents a partial representation of the argument graph regarding two conclusions C_1 (Naturalia) and C_2 (Cyber campus). The AIPA graph was translated into a AAFgraph according to Support translation (Figure 1.2.8b). In order to ensure the readability of the figure, the double attack between StatementAgainst/For of the first level (directly after the Conclusions) was not represented on this figure. Despite being more restrictive, this translation led to the "Conclusion Accepted" result for Naturalia project. All the others conclusions were then rejected (only one conclusion can be accepted).

A debriefing followed the debate. In the application case, WebAIPA was combined with AipaForum in order to evaluate the accessibility and the potential of AIPA. Globally, the participants appreciated the support of the argumentation structure and the information given by inference in a forum type platform. However, the combination of the forum with AIPA, albeit usable by

non-specialists, has limitations. Some participants expressed their accordance with a Statement without an explicit argument by a simple “I agree”/“I disagree”. Such expressions cannot currently be used as arguments in AIPA since they are incomplete. They do not provide a rationale for the agreement/disagreement. An alternative would be to integrate, in AIPA, a framework such as the weighted-based framework (Dunne et al., 2011) by adding a preference concept in the model (like/dislike). Other relevant argumentation frameworks are the attitude-computing approach inspired by social psychology as implemented in Thomopoulos et al. (2020) or the social choice oriented approach (Bisquert et al., 2019). Furthermore, some participants, had difficulty expressing their arguments. For example, some Against Statements did not target the right argument for their purpose. Another issue is the argument itself, since normally in a debate, people rarely describe to their position in one argument as formalized in AIPA (Statement). They often nuance a general assertion or denial, e.g. "It’s a good thing to have pedestrian areas, but at the same time it’s not convenient for parking." This natural human behavior, observed on the forum, cannot be directly translated into an argument in AIPA. In fact, AIPA expects simple arguments that express a single idea. This limitation does not mean than it is not possible to express complex arguments, rather that an argument composed of several ideas must be broken down into several arguments. If we consider the previous example, the argument "It’s a good thing to have pedestrian areas, but at the same time it’s not convenient for parking." has to be broken down into two AIPA arguments: "It’s a good thing to have pedestrian areas" and "It is not convenient for parking." Finally, the WebAipa interface was also found to be perfectible regarding explanations about conflicts.



(a) Partial representation of the AIPA graph regarding the "Cyber Campus" project with results and explanations after support translation



(b) Dung support translation of Figure 1.2.8a

Figure 1.2.8: Model 2 translated to Dung's Framework with the support translation regarding the "Cyber Campus" project

In order to address these limitations, the use of a facilitator seems necessary, as advocated in Seker (2015). The facilitator would ensure a good use of the tools by ensuring that arguments are correctly formalized in AIPA. In addition, obviously, the facilitator should have to fulfil her/his traditional duties by ensuring the proper conduct of the debate, ensuring a good distribution of speaking time among the participants, refocusing the debate when necessary, etc. In this perspective, AIPA would be a support for the facilitator to help her/him focus the debate on the arguments that seem important and assess the collective acceptance of the conclusions. Furthermore, the tool by its graphic representation can enable the facilitator to quickly show the state of the debate.

On a positive note, participants felt that the tool helped to refocus the debates by highlighting the important arguments, i.e., those that carried the debate forward. This made it possible to focus on these arguments without trying to add elements against arguments that were already discarded.

1.2.5.2 Application 2: participatory approach

In order to illustrate the second anticipated benefit of AIPA, namely summarizing, a posteriori, debates for transparency purposes, we applied it to a real case in urban and transportation planning.[1] Bordeaux Metropole planned to extend the tram track in order to connect new cities in the metropolis, and notably Saint-Médard-en-Jalles which will be the new terminus of the line. Four routes were proposed by the urban planning team. The choice between these routes was the subject of a participatory process in which citizens were asked to give their opinions on these routes. The participatory process regarding this tram track extension lasted three years (2017-2019) and through many meetings with the participation of hundreds of citizens. The participatory approach also used a web forum for the online collection of citizens' opinions on the various routes submitted for discussion. 435 people participated in the exchanges on this forum through 676 messages.

In order to represent the discussions on the forum, we conducted an exhaustive content analysis of the 676 messages, and formalized them as input arguments through WebAIPA. The analysis of these messages allows us to note several limitations of the way the forum was used, making the debate and the positions of the participants difficult to understand. Indeed, we can observe that: 1) some messages do not propose any arguments, nor do they express any opinion, 2) some messages are very long, composing a complex argumentation set that is difficult to apprehend directly, 3) many arguments are proposed several times (strong redundancy), 4) there is a lack of interaction between the messages, often not allowing for constructed exchanges.

The formalization of the arguments was done manually by extracting them from the different messages. This led to 173 different arguments in WebAIPA.

[1] https://participation.bordeaux-metropole.fr/content/extension-de-la-ligne-d-du-tramway-vers-saint-medarc

Several lessons can be learned from this application. First, even with 173 arguments, results were obtained instantaneously. Therefore, our tool is adapted to a real debate context in which a high number of arguments are expressed. Second, the graph structure of AIPA highlights the links between arguments which facilitates the identification of conflicts and oppositions. For example, AIPA provided the set of pro and con arguments for each route, making it easy to identify the arguments for and against each proposal. Finally, AIPA provided the status of each Conclusion (tram route) as well as the arguments that explains this status. As a matter of fact, in this appplication, the four routes are in conflict, i.e., none of them are accepted. In fact, each route has a set of arguments for it and against it with two of routes facing very strong opposition. No consensus was possible and the Bordeaux Metropole finally decided in 2019 to abandon these routes and to opt for a bus system rather than a tramway.

In this application, AIPA could not support the construction of a consensus since it was used a posteriori, however its use has allowed to structure and clearly represent the debate for maximum transparency thereby facilitating the understanding of what was said and how. The main limitation of this application is the need for a manual argument extraction phase. This however, could have been overcome if the participants had used AipaForum directly, which was not possible since it was not available in 2017. Another alternative worth exploring to reduce the burden of manual argument extraction is the use of argument mining to create AIPA compatible arguments.

1.2.6 Conclusion

In the previous chapter, we posed two research questions: (i) can a decision-support tool, based on argumentation, support a participatory decision-making approach, and (ii) does an abstract argumentation framework combined with an argument model enhance the efficiency of such a tool ?

To answer these questions, we have developed and presented a tool based on argumentation meant to support a real-time debate analysis. The tool, called AIPA, is an interface between argument from natural language via the Argued Discussion Model (ADM) to AAF abstract argument. While abstract argumentation frameworks provide inferences, our tool provides a meaning. By combining these two approaches, AIPA allows to structure in a simple way the arguments in the debate, to define the acceptable arguments, to give information on pro/cons arguments, on conflicting situations and on key arguments. It provides a tree-like representation of the argument structure easy to follow to all participants of the debate no matter how well she/he masters the argument theory.

The proposed cases studies allowed us to illustrate the method and obtain feedback. The approach based on AAF and the tool globally convinced the participants in the debate. However, the experimentation revealed the need for a

facilitator to ensure proper use of the tool. AIPA is better suited to real debate discussions when guided by a facilitator.

Then, the natural question that arises regarding building retrofit decision making is: can AIPA be used to address this decision problem? The answer can only be nuanced... Indeed, this approach perfectly meets the need for a participatory and interactive approach as outlined in the introduction. On the other hand, AIPA is confronted with a limit that makes it impossible to use it directly in our case, i.e., the number of solutions. AIPA is relevant when the number of conclusions (i.e. alternative solutions to debate) is rather low (for instance, 4 solutions in the presented application). But, it is impossible to conduct such approach with more than 10 solutions... Indeed, the participants to the debate have to well apprehend all the possible solutions and to expose arguments regarding these different solutions. Yet, in the building retrofit problem, as we exposed before, the number of potential solutions can be huge, even considering only pareto-optimal solutions (more than one thousand). Applying directly AIPA on these solutions is therefore not relevant. For this reason, we propose to combine AIPA with a multicriteria decision aiding method (MCDA). The next chapter will expose how AIPA and MCDA can be combined, and will discuss the interest of this approach.

Chapter 1.3

Coupling MCDA methods with AIPA: ArguedMCDA

1.3.1 Introduction

In the previous Chapter, we presented Argumentation Interface for Participatory Approach (AIPA) an argumentation tool dedicated to participative decision-making. We also concluded on the need of coupling AIPA with a Multiple Criteria Decision Analysis (MCDA) method in order to be able to consider a problem with numerous alternatives. In this Chapter, we will expose how this coupling works. In a first section we will provide a state of the art regarding MCDA methods. In a second section, we will expose the method we proposed to couple MCDA with AIPA; we called this approach the ArguedMCDA. Finally, in the third section, in order to illustrate the functioning of the ArguedMCDA, we propose a simple case study.

1.3.2 MultiCriteria decision analysis

1.3.2.1 Why multicriteria?

Decision support only makes sense in relation to the modeling of decision problem. No decision support approach, method or tools are relevant regarding all the possible decision problems (Taillandier, 2018). As we state in the introduction, the building stock retrofit decision problem is complex. This assertion can be extended to most of civil engineering systems and decision problems (Taillandier, 2018). This complexity is due in particular to the competition between conflicting objectives (minimize cost, maximize comfort...). Is it then possible to aggregate these different objectives into a single criterion? We assume that using a single aggregated criterion would alter the richness of the decision problem. To support this hypothesis, we can quote the Bouyssou's arguments in favour of multi-criteria modelling (Bouyssou, 1990). The first argument is the possibility of considering "axes of meaning" (Roy, 1996), shared by the different stakeholders, around which they can justify and argue

their preferences. It is very difficult to find shared axes of meaning, when they aggregate very diverse dimensions with little in common. The second argument is to manage, at the level of each axis of meaning, the elements of uncertainty, imprecision and poor definition affecting the data of the problem. This avoids the effects of cumulative errors and significantly improves the quality of the data definition. The last argument is to clarify the notion of compromise that lies behind each decision. This compromise, which is inherent to any choice, can be formalized, reflected and assumed in a multicriteria perspective. Regarding these arguments and our decision problem, the use of a multicriteria decision support method appears as more relevant than considering a single criterion.

1.3.2.2 The different approaches of MCDA

The literature presents numerous methods for multi-criteria decision support. Roy (1996) proposes to classify these methods into three categories: synthesis criterion, synthesis outranking, interactive process. The first category includes all methods that are based on the aggregation of all the criteria into a single synthetic criterion. The second category includes methods that enable a decision to be made by pairwise comparisons of the alternatives. The last category includes approaches that are are based on the step-by-step improvement of an initial decision.

1.3.2.2.1 Synthetic criterion

The first approach proposes to use a function that aggregates, into a single value, the values on each criterion of an alternative. It results in optimizing this function; it corresponds then to a typical monocriterion problem. A weighting system is generally used to take into account the importance of the different criteria in relation to each other. The synthesis criterion often takes the form of an additive or multiplicative formula (Roy, 1996). Three problems emerge from this type of method. The first is a problem of commensurability (Ben-Mena, 2000). Each criterion must be given in a comparable scale. This difficulty can be overcome by using a standardized utility (Brauers, 2007). Reducing all the criteria to a single overall score induces another drawback. This tends to block the decision on the aggregate value without considering the diversity of cases that come together under the same overall score. The detail of the scores is then masked by the overall score. The third problem is the attribution of weights. It is extremely difficult for the decision-maker to determine weights for the different criteria that are consistent and truly in line with his or her wishes. Different methods can assist the decision-maker in this regard (Marques Pereira, 2003). But they are generally quite complex and can be difficult to implement. The methods belonging to this American-inspired approach are widely used in the literature and make it possible to solve many problems. It is sometimes simply the only ones that can be used (Schärlig, 1985). We present the list of the most widespread methods as

established by Martel (1999): MAUT (Keeney and Raiffa, 1993), SMART (Weiss and Weiss, 2008), UTA (Jacquet-Lagreze and Siskos, 1982), TOPSIS (Hwang and Yoon, 1981), AHP (Saaty, 1984) and GP (Charnes et al., 1955).

1.3.2.2.2 Synthetic outranking

The second approach aims in a first step at building outranking relationships representing the preferences of the decision-makers. The principle is in fact to compare two by two each possible alternative and to define on each criterion whether one of the alternatives outperforms the other. The preferences are established according to these outranking relationships allowing to make a synthesis of these outranking relationships. Several decision-making problems can be solved by this approach (Roy, 1996): selection of the best alternative, assignment of the alternatives in predefined categories, prioritization of alternatives, and description of alternatives. This approach overcomes the problem of the incompatibility of criteria. However, it does not evacuate completely the problem of weighting and may pose a problem of clarity (Ben-Mena, 2000). The aggregation system can be difficult to justify because it is less intuitive and direct than for methods of synthetic criterion approach. Indeed, the aggregation here only concerns the result of the comparisons between alternatives and not the alternatives itself. The results are thus more difficult to explain (Schärlig, 1985). There are many methods belonging to this approach (Siskos et al. (1984) reference 167 of them in 1984), most of which are of French inspiration. Martel (Martel, 1999) defines as the main methods belonging to this category: ELECTRE (Roy, 1990), PROMETHEE (Brans et al., 1986), ORESTE (Roubens, 1982) and QUALIFLEX (Paelinck, 1978).

1.3.2.2.3 Interactive process

The third approach is to take a starting solution (as good as possible) and see if it is possible to improve it. This is especially used when the number of alternatives is very large (Ben-Mena, 2000). It is done using a local and repetitive system of exploration of alternatives. This generally involves an exchange between the decision-maker, who must judge the relevance of the solution, and the decision-making system. New solutions can be built automatically or through experts. When the decision-maker is satisfied with the solution, the process stops. Computerized systems are often used for this type of approach because they allow iterations to be carried out quickly. One of the challenges then becomes the human/machine interface. There are a very large number of methods in this category, based on more or less sophisticated algorithms. Some of them borrow from the approaches described above. Thus, we find interactive methods based on the Multi-Attribute Utility Theory (for example (Köksalan and Bilgin Özpeynirci, 2009)). Some methods are based on the exploration of solutions (Benayoun et al., 1971) while others favour interactivity (Zionts, 1980). This type

of method is, in practice, not very widespread (Kaliszewski, 2004) and have been replaced often by interactive multiobjective optimization which shares the same principle and adds efficient optimization algorithms.

1.3.2.3 Which approach or method should be used?

The interactive approach, as we exposed in the introduction regarding interactive multiobjective optimization, is not adapted to this context of decision with several decision-makers with different (and sometimes conflicting) points of view. But, even without this approach, literature provides numerous MCDA methods. The choice of a particular method among these methods can have an important impact on the result (Zanakis et al., 1998). Up to now, it exists no process or method to select the best multi-criteria decision method/tool (Ishizaka and Nemery, 2013), but (Guitouni and Martel, 1998) suggest different points to be studied in order to choose a relevant decision-aiding method: the number of decision-makers, the preferences of decision-makers between pairwise comparisons and trade-offs, the quantity and the quality of the available inputs, the compensation degree of the method, the respect of the fundamental hypothesis of the method and the decision support system. In addition, we must recall that each method has its drawbacks and no method can be relevantly applied to all problems (Taillandier, 2018). We want in this first part of the manuscript propose an approach as generic as possible, usable to any participative or controversy decision-making. So, we prefer to let the choice of the MCDA method opens. For each problem, according to the criteria by Guitouni and Martel (1998), we will select the most relevant method. Our approach, combining argumentation and MCDA is valid with most of the MCDA methods; we will exposed it in the next section.

1.3.3 Methodology

1.3.3.1 Why combining MCDA with argumentation

MCDA methods have already be used in participatory or collaborative decision context. For instance, Norese (2006) proposes to use ELECTRE in a participative way to select the best sites to build waste-treatment plants, and Dolan (2008) suggests the use of AHP in shared decision-making between patients, clinicians and other stakeholders. But if theoretically, they can support collaborative, as we stated in the introduction, these methods have some shortcomings regarding participative decision-making or controversy decisions. Indeed, they are useful to formalize the trade-off between the opinions between the different stakeholders, but they do not allow to formalize the building process of these trade-off. The points of view of the different stakeholders are only formalized via a set of parameters as weight on criteria; it does not allow for else to understand the choice of these parameters. However, when one wants to focus on the discussion and

exchange between the actors, the justification is more important than the result itself. It is precisely the arguments put forward by participants that allow us to understand the thinking each of them. It is very important when using a MCDA because the main challenge is undoubtedly the structuring phase since decision problems are often quite difficult to deal with, and alternatives and criteria are rarely readily available (Belton and Stewart, 2010, Franco and Montibeller, 2011, Marttunen et al., 2017). Therefore, structuring and formalizing a decision problem to fit into a MCDA framework can be difficult, notably in a controversy context where the following pertinent questions are justified at the end of the process:

- Are the criteria retained relevant for all the stakeholders?
- Are the alternatives constructed relevant for all the stakeholders?
- What does the common preference model represent?
- Where are the traces of the discussions pertaining to the previous questions?

In addition, the final recommendation obtained by a MCDA method could be also be subject to discussion: Is it really acceptable for all the stakeholders? Why was such a decision reached by the MCDA method? Does it really reflect the decision-makers preferences? To address these questions, some argumentation techniques for the explanation of MCDA results have been applied at a more theoretical level (Amgoud et al., 2005, Labreuche, 2011). But these works remain theoretical and have been designed not to support the decision-making, but a posteriori to understand the decision.

Notwithstanding the approach that is used, there are, to our knowledge, no tools available to help organize the outcomes of discussions, in real time, in a way to ensure traceability, encourage more discussion, and provide the rationale behind the decisions made in a multicriteria setting. In order to remedy this situation, particularly during the structuring phase of a MCDA process, we propose to use AIPA, resulting in an approach we called ArguedMCDA. Approaches combining argumentation, MCDA and computational social choice have been successfully used in other application domains, especially concerning the sustainability of agriculture, food and environment systems, research (Bisquert et al., 2017, Thomopoulos et al., 2015). However, there are still no tools to date that have succeeded in combining decision-aiding technique with participatory argumentative approaches, making them operationally usable for any participatory context.

Our main interest in developing ArguedMCDA is to assist the stakeholders in the structuring phase of the decision problem and in the final discussion about the solution proposed by MCDA. This approach is based on the dynamic modeling of arguments and on the explicit formalization of the opinions and preferences of the stakeholders in order to conduct a transparent decision process and to arrive to a jointly constructed and acceptable decision. It is in line with the philosophy

of computer-supported collaborative decision making (Karacapilidis and Papadias, 2001, Scheuer et al., 2010) and with Dix et al. (2009) and Simari (2011) who raise the pertinent questions of: "What does an argumentation-theoretic approach add over and above decision theory? How can one integrate argumentation tools with classical decision theory and other existing models of decision making?". Possible answers to these questions were proposed in Ouerdane et al. (2010) as research avenues, and will find a possible answer in this Chapter.

1.3.3.2 ArguedMCDA Process

Discussions to help structure a multiple criteria decision problem consist mainly of four phases (Figure 1.3.1). We will detailed the different phases in the next paragraphs. However, we need to begin by selecting a MCDA method. Indeed, the process is the same whatever the method, but some of the phases depend on it. We have chosen a simple method adapted from the lexicographic method. The lexicographic method considers the criteria one by one, in order of preference, without any compensating effect. The alternatives are compared on the preferred criterion: the best solution on this criterion is place at the first position. In the event of a tie, the same operation is done on the second preferred criterion and so on. This method requires a strict ranking of the criteria. We modifies this aspect by adding a procedure to rank alternatives in case of equal preferences between two or more criteria. Indeed, we do not want to force to choose among criteria if the participants in the debate think that they are equally important to each other. To manage equal preferences among criteria, we propose the following process:

1. We normalize the performance of the alternatives on each criterion, while considering at 1 the best performance and 0 the worst performance among the set of alternatives.

2. We sum the normalized performance of alternatives regarding criteria of the same importance. We call aggregated criteria the criteria grouped by importance.

3. We perform the lexicographic ranking of alternatives considering the aggregated criteria.

Obviously, this method has many drawbacks, notably its lack of compensation, but it has the merit of being simple, requiring few parameters and being easily understandable by all. We will discuss with more details the choice of the MCDA in the conclusion, but for this chapter and the following ones, we will use this modified lexicographical approach as MCDA method.

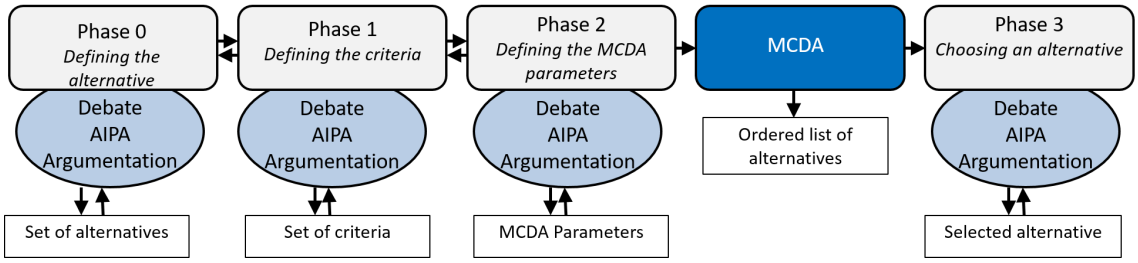


Figure 1.3.1: ArguedMCDA process

In phase 0, the stakeholders build the set of alternatives; i.e. the possible solutions to answer the decision problem. In some decision problems, this phase is not necessary. For instance in the building retrofit problem, the alternatives correspond to the pareto-optimal solutions are obtained from the optimization. But sometimes, this phase is required. For instance, in urban planing decision problem, the urban planners could prefer that some solutions are directly proposed by the citizen, or at least than citizen discuss the alternatives, before assessing them. Indeed, it allows to ensure that the set of alternatives is judged sufficient by everyone, knowing that the assessment phase could require important resources. If needed, this phase takes the form of an argued discussion, in which the possible alternatives are formalized as conclusion. Because, at this level, the choice of an alternative does not exclude the other (the aim is to build the set of alternatives and not to select one), each alternative choice corresponds to an instance of discussion. It means that all the alternatives are considered as a conclusion facing its Cneg. For instance, one conclusion could be "The solution A has to be considered in the MCDA process", and Cneg "The solution A has not to be considered in the MCDA process". Then the stakeholders discuss the different conclusions (i.e. alternatives), using AIPA arguments Statementfor and StatementAgainst. For each new argument, AIPA recompute the argument graph in order to define the accepted conclusions (part of the grounded extension), i.e. the alternatives to consider in the MCDA process. This phase results in a list of alternatives.

In the next phase, the stakeholders construct the list of criteria. They can: (a) propose a new conclusion (i.e. propose a new criterion) or refine an existing one (e.g. breakdown economic criterion into investment cost and maintenance cost), (b) propose a statement for or against a conclusion. For example, for (a), if a stakeholder wished to add a new criterion “Cultural”, she/he adds a new conclusion “Use Cultural criterion”. An example of a new statement (b) is: “Cultural is part of Social, it should not appear as a new criterion but as part of the already existing Social criterion”. Each time, a stakeholder proposes a new argument (statement or conclusion), AIPA provides the acceptable conclusions (i.e. considered criteria). The proposed list of criteria is constantly updated and presented to the stakeholders. As for the alternatives, due to the no-exclusiveness of the criteria, each criterion is

considered as a debate instance in AIPA, each criterion facing its Cneg (as for the alternatives). Furthermore, we assume that data regarding the different chosen criteria are available; for instance, if the project cost is considered as a criterion, it is possible to define the cost of each project. If not, an argument to not consider an argument could be "This criterion cannot be assessed."

When all the stakeholders are in agreement regarding the list of criteria or if no one wants to propose new arguments, phase 2 can begin: it focuses on the criteria parameters (e.g. weight, thresholds, etc.). Globally, in this phase, the stakeholders have to propose conclusions enabling to compare criteria; for instance: “Social should be privileged compared to economic criterion”. As in the previous phase, they can add new conclusion as a refinement of old ones or add statements. Obviously, the parameters depends on the selected MCDA method. For instance, a simple weighted sum requires to define the weight of each criterion, and ELECTRE III (Roy, 1996) requires for each criterion a weight and three thresholds (veto, preference and indifference). More the method requires a high number of parameters, more this phase is long. However, the method parameters allows to integrate more precisely the preferences of the decision-makers. They are a trade-off to find between precision and complexity. Thanks to the modified lexicographic method we had chose to use, few parameters have to be defined: only an ordering between the criteria according to the importance given to them. Concretely, in the ArguedMCDA, using this lexicographic method, the importance of criteria are compared by pair; each pairwise comparison corresponds to an instance of debate. For instance, if we consider three criteria, namely C1, C2 and C3; three debate instances are open: C1 Vs C2, C1 Vs C3 and C2 Vs C3. For each debate, the possible conclusions are: Ci>Cj, Ci=Cj or Ci<Cj, each conclusion being exclusive. The participants to the debate will propose statement in order to defend their point of view. This phase results in the definition of the MCDA parameters. Using our lexicographic approach, it consists in the criteria ordered by preferences with possible ties. In case of inconsistency, (e.g. C1>C2, C2>C3 and C3>C1), the participants are alerted and the discussion continues until the inconsistency is resolved. If it is not possible, all the concerned criteria are considered as being of the same importance.

Based on the criteria preferences and assuming that the evaluations of the alternatives on these criteria are possible, the alternatives can be then ranked by a MCDA method. The ranking is only based on MCDA and does not require a debate. The decision-making process can finish here, if the participants want to consider directly these results (i.e. the best alternative according to the MCDA method). But, according to our philosophy which consists in letting the decisions to the participants, we see the MCDA ranking, not as a final result but as an additional information to discuss. So, in the last phase, the stakeholders may discuss the results. They choose the alternatives to discuss; by default the top ranked alternatives are considered (the 3 better). But the participants can add or remove alternatives to discuss. This last debate consists in one instance with all

the considered alternatives as a conclusion (e.g. "Alternative i is the best"). One statement is automatically created to support the best ranked alternative (SF: "This alternative is the best ranked by the MCDA"). The stakeholders can propose new statements to support or attack conclusions or other statements. The final word is always given to the different stakeholders and must be the subject of a real discussion. This phase results in the selection of one alternative. It is the end of the decision-making process.

The aim of this approach is to place the discussion at the center of the process in order to facilitate the acceptance of the final decision by all parties. In addition, it keeps the traceability of the reasoning that lead to a preferred solution; any participant can, at any moment, read the arguments (close to natural language) and understand the choice of a conclusion. One important point is that the process is iterative. During the discussion, any participant can propose new arguments which may impact the acceptable solution (e.g. list of criteria, alternatives ranking, etc.). It is then often possible to return to previous phases. In practice, the different phases correspond to meetings between stakeholders. Each phase does not necessarily correspond to one meeting; the number and duration of these meetings depend on the phase, the number of stakeholders, etc. The format of the meeting and debate depend on the context of decision, which has to be well analyzed before the beginning of the decision-making process.

1.3.4 Application to a simple illustrative case-study

In order to illustrate how ArguedMCDA can be used, we propose a simple example inspired by a real case [1]. Bordeaux Metropole planned to extend the tram track in order to connect new cities in the metropolis, and notably Saint-Médard-en-Jalles which will be the new terminus of the line. Several routes were proposed by the urban planning team. The choice between these routes was the subject of a participatory process in which citizens were asked to give their opinions on these routes. The real participatory process regarding this tram track extension lasted several years and induced hundreds of arguments with the participation of several dozens of participants. For this application, we will largely simplify this decision process in order to be clear and illustrative. As a first simplification, we consider only five categories of stakeholders: the mayor (M), the technical services (T), the citizens (C) and a nature protection agency (N). The description of this case study will be made according to the different phases of the ArguedMCDA process, in the following sections.

[1] https://participation.bordeaux-metropole.fr/content/extension-de-la-ligne-d-du-tramway-vers-saint-medard-en-jalles

1.3.4.1 Discussion on alternatives

Three different routes were proposed by Bordeaux Metropole (routes 1, 2 and 3). Route 1 is an extension of line D from the Cantinolle station in Eysines, along the Bordeaux-Lacanau cycle path. Envisaged over 4.2 kilometers, the D line would border several residential areas to the south and a natural area to the north. It would run along the Bordeaux-Lacanau bicycle path, while retaining it. Route 2 is an extension of line A via the road to Feydit. This route is longer than route 1 (6.7 kilometers), but it would cross important zones of activity. However, it has to be integrated into the existing road network and coexist with the heavy road traffic recorded on the busy roads. Route 3 is also an extension of line A, but via avenue de Mazeau. This route is the longest of the three (6.9 kilometers), but it requires less land acquisition than route 2. Before any evaluation of these routes, Bordeaux Metropole presented them in a public consultation meeting. The different participants discussed about them. The mayor and the technical services who imagined these routes defended the choice of these three projects. Citizen proposed a new alternative (route 4) to complete the set of routes and provided arguments regarding the different routes; route 4 is, as route 1, an extension of the line D, but using a more urban route through Le Taillan-Médoc. The Nature protection agency also participated in the debate formulating arguments. The different arguments, in AIPA format i.e. conclusions, statementfor and statementagainst), are presented in Figure 1.3.2. As exposed in the previous section, each conclusion related to an alternative faces its Cneg.

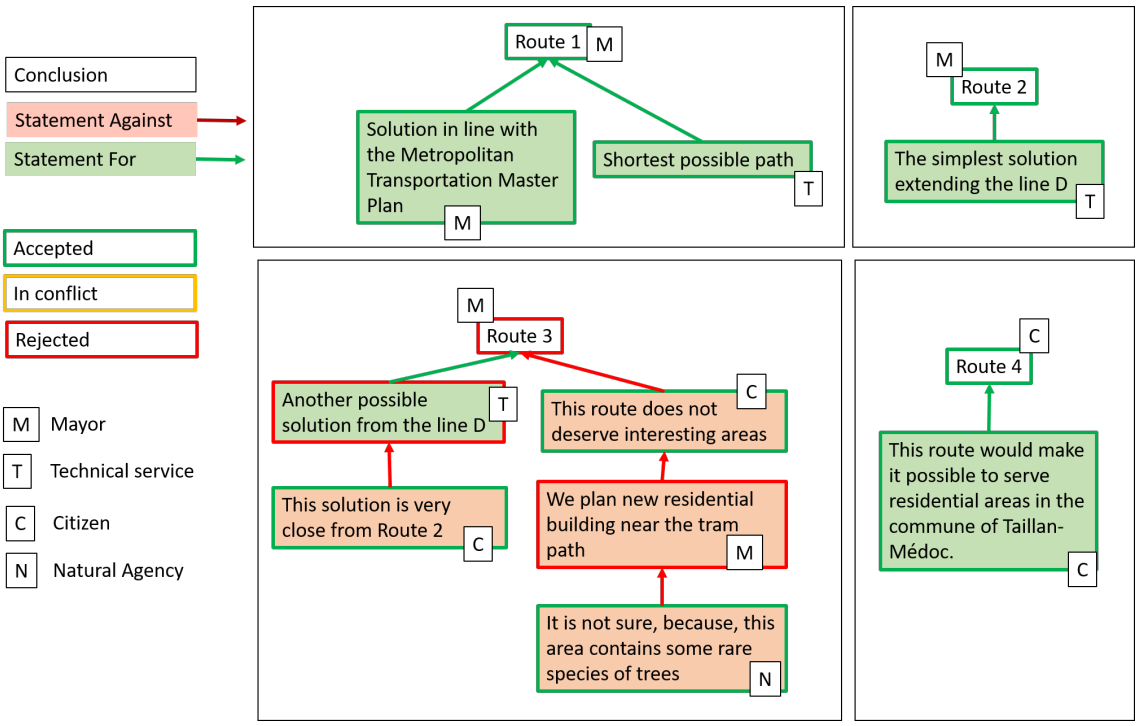


Figure 1.3.2: Discussion on alternatives

As a result, three route conclusions are computed as accepted (i.e. belongs to the grounded extension): route 1, 2 and 4. This result is obvious, because all these conclusions have only supporting statements. Route 3 was rejected and its Cneg accepted. The only argument supporting it "Another possible solution from the line D" was attacked by its lack of difference with Route 2. Furthermore, this route was also directly attacked by the argument "This route does not deserve interesting areas". This last argument was attacked, but considered as valid because its attacker was rejected. Finally, 3 alternatives are considered: Route 1, Route 2 and Route 4.

1.3.4.2 Discussion on criteria

The second discussion is about the criteria that should be used, and any participant can propose a conclusion (i.e a new criterion). The Mayor put forward the conclusions “The investment cost should be a criterion” and "The potential attendance should be a criterion". The nature protection agency submitted criterion regarding the environmental aspects, through the impact of the different routes on ecosystems. Citizens suggested that the travel time and parking have also to be considered. Finally, 5 criteria were discussed as exposed in Figure 1.3.3. As for alternatives, each conclusion related to a criterion faces its Cneg.

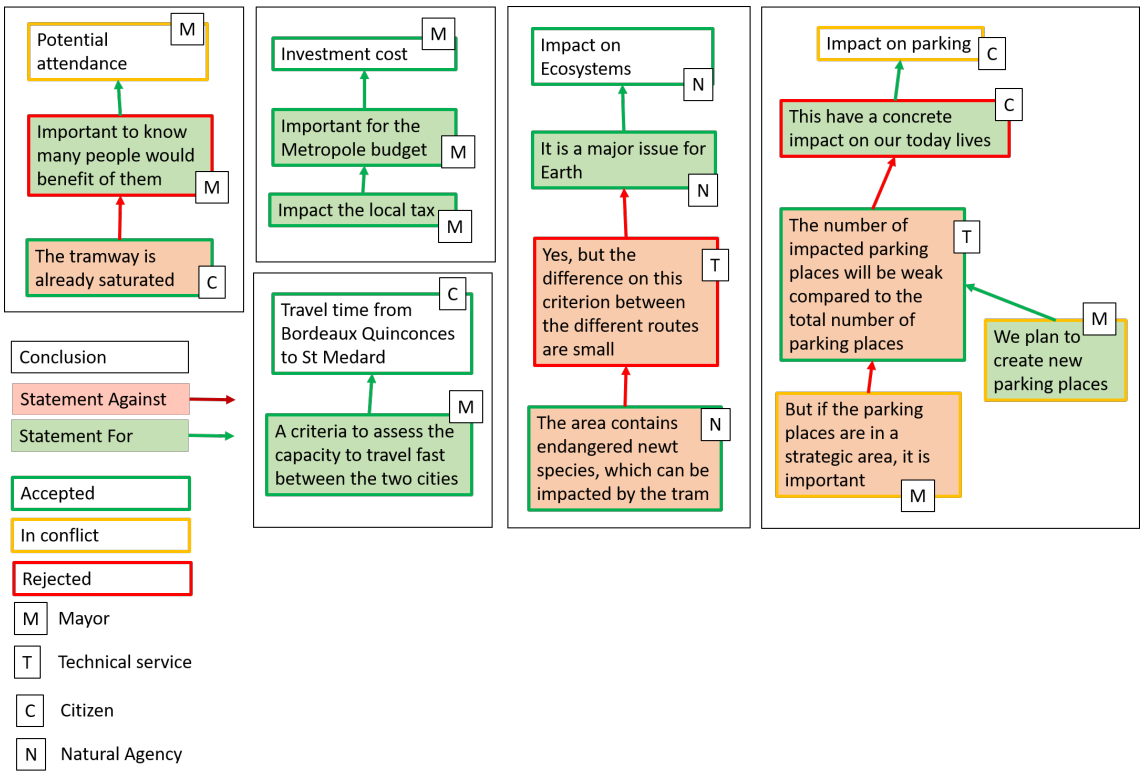


Figure 1.3.3: Discussion on criteria

Among these 5 criteria, 3 were accepted. Investment cost and Travel time were not attacked and benefited from arguments supporting them. They are consensual and are logically considered as criterion. The third criterion to be accepted was the impact on ecosystems. The choice of this criterion was more discussed. The nature protection agency, which proposed this criterion, argued this choice, by the importance of this issue for Earth, and indirectly humankind. The Technical services nuanced this aspect regarding the potential gain, but the nature protection agency attacked this statement by recalling that the area shelters rare and endangered species of newts. This counterattack allowed the conclusion (i.e. criterion on ecosystem impact) to be accepted. The two rejected criteria were related to parking and to attendance. The attendance was attacked by argument on the saturation of the tram which was already judged as too crowded. The parking induced more discussions. The technical service and the mayor argued that the parking is not a criterion to consider because, few parking places will be impacted and new parking places are planned whatever the route. So, to conclude, three criteria remained: Ecosystem Impact, Investment Cost and Travel Time.

1.3.4.3 Discussion on criteria importance

The third discussion concerned the importance of each criterion. The lexicographical approach is used here; as exposes in the previous section, it means than discussion on the MCDA parameters concerns the ordering by preference of the criteria. Considering the three criteria (Cost, Time and Ecosystem), it consists in three debate instances: Cost Vs Time (Figure 1.3.4), Cost Vs Ecosystem (Figure 1.3.5), and Time Vs Ecosystem (Figure 1.3.6). In the first debate, the accepted conclusion was "Time and Cost was of equal importance". In the second, it was "Impact on ecosystems is less important than Cost" and in the last debate instance: "Impact on ecosystems is less important than Time". During the debate, the nature protection agency defended the environmental criterion, but it has to face the argument from citizen which were more pragmatic (on everyday life) and from the Mayor and its technical service which set the priority on the cost, assuming that cost is the main lever of action for Bordeaux Metropole. Because, Citizen and Mayor points of view are more compatible, and because they brought adequate arguments, the criteria regarding Time and Cost won. So the final ranking is: Time and Cost, then Ecosystems.

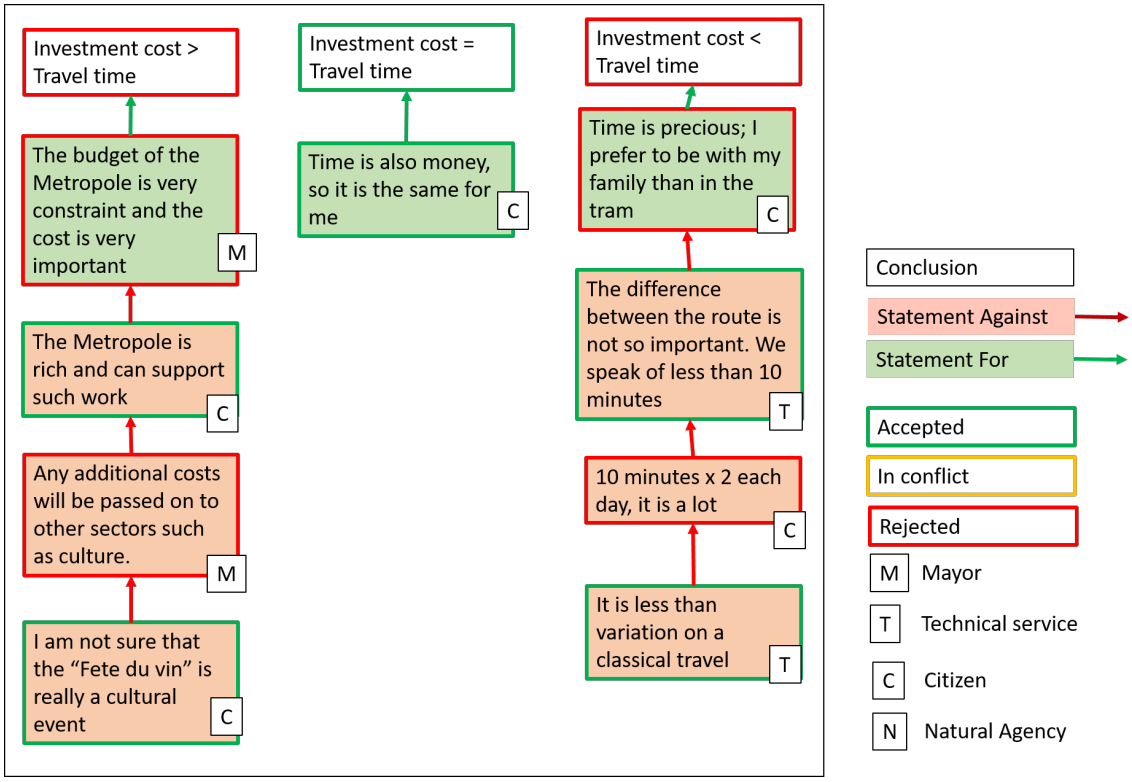


Figure 1.3.4: Discussion on Investment Cost Vs Travel Time

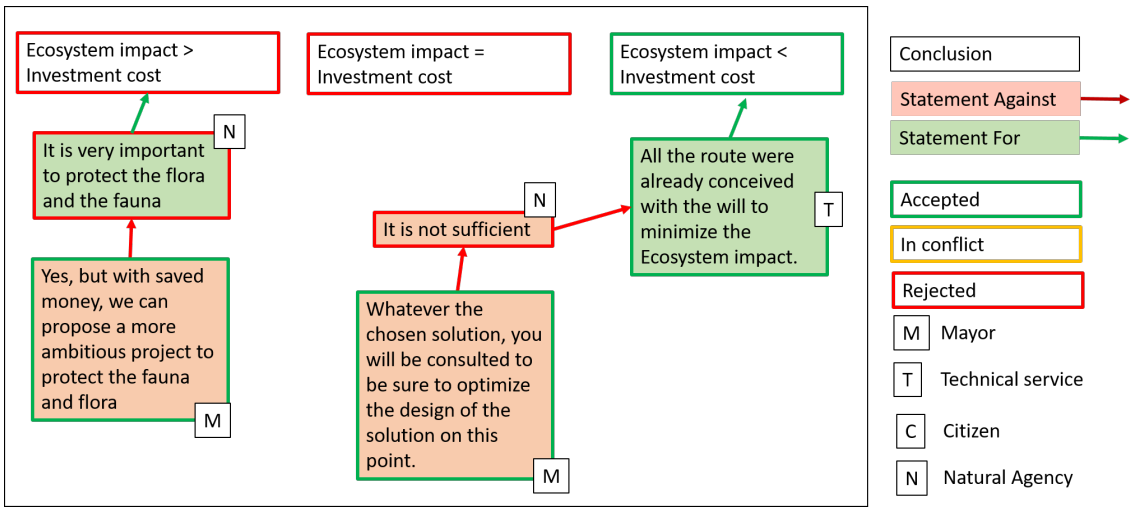


Figure 1.3.5: Discussion on Investment Cost Vs Ecosystem Impact

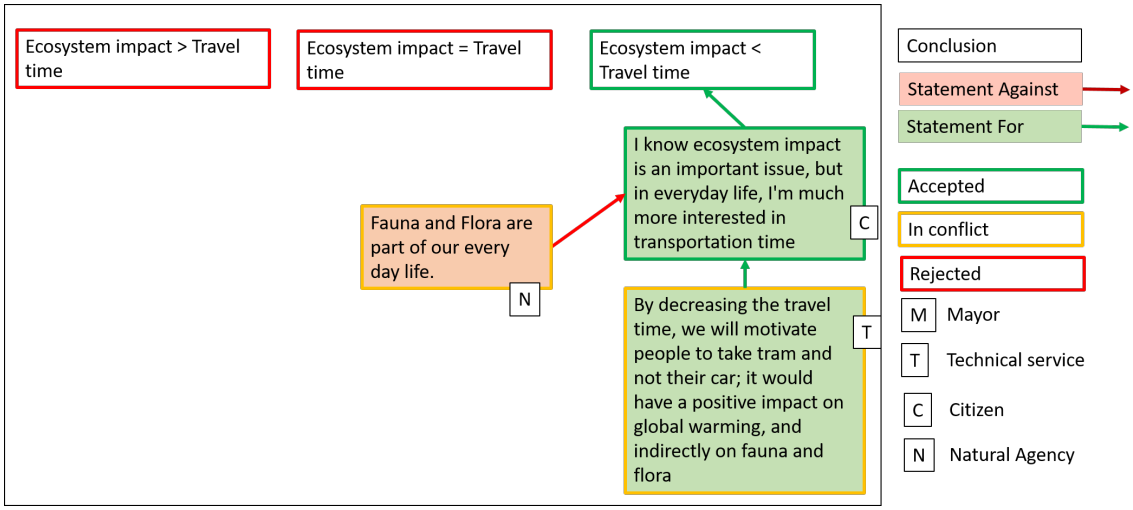


Figure 1.3.6: Discussion on Travel Time Vs Ecosystem Impact

1.3.4.4 Running MCDA method

The performances of each considered alternatives on the selected criteria are given in Table 1.3.1. Based on these performances and the preferences regarding the criteria (i.e. criteria ranking), we can rank the three alternatives using the proposed lexicographic method.

The method consider in a first step the preferred criteria, i.e. Cost and Time. The normalized values (NV in the table) for these two criteria are summed, and the ranking is established from this summed value, using a descending ranking. The last criteria (Ecosystem) is used in case of equality; but it is not necessary here.

Alternative	Cost in M€ (NV)	Time in min (NV)	Ecosystem from 0 to 10 (NV)
Route 1	54.3 (1.0)	48 (1.0)	4 (0.0)
Route 2	101 (0.0)	66 (0.0)	1 (0.75)
Route 4	81 (0.43)	53 (0.72)	2 (0.5)

Table 1.3.1: Performances of alternatives in Tram Route example

The ranking obtained by the MCDA method is: (1st) Route 1, (2nd) Route 4, (3nd) Route 2.

1.3.4.5 Discussion on MCDA results

The last phase consists in discussion on the MCDA results. When beginning this phase, each considered alternative is used as a conclusion in the form "Route i should be chosen" (Figure 1.3.7). The Route 1 which was the first ranked, benefited automatically from a StatementFor "First rank solution". The stakeholders can discussed directly on the alternatives in this phase. For instance, a citizen state that "Route 1 may be the best solution, but wouldn't it be better to propose an extension of tramway line D going to the airport rather than to Saint Medard?" So it proposes to enlarge the discussion on the necessity of this extension to Saint Medard and why the extension to airport is not privileged. But the argument from the nature protection agency, on the role of airport, in climate change counterattacked this argument. Finally, the Route 1 is still accepted after the conclusion. Thus, it should be the chosen solution.

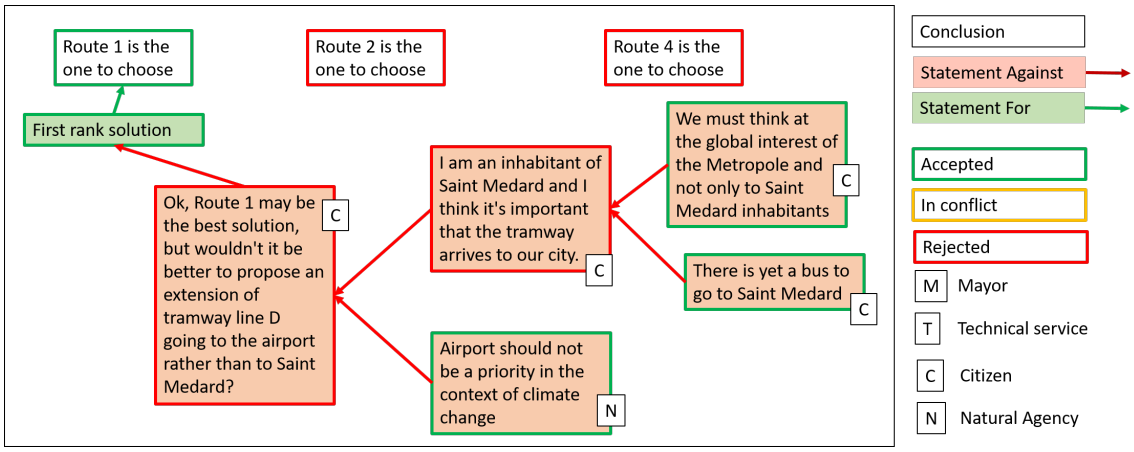


Figure 1.3.7: Discussion on the MCDA results

1.3.4.6 Conclusion on the example

Throughout section 1.3.4, we have shown a complete example of the ArguedMCDA use. In the real participatory approach regarding the extension of the tram track, in addition to the public participative meetings, Bordeaux Metropole opens a web

forum in which citizen were invited to debate. Hundreds of arguments were exchanged in this forum. For this application, we simplified a lot this case in order to make it easy to follow. The issue here was to be illustrative and not to provide a real decision support or analyze the actual decision process. Obviously, regarding the simplicity of the application, one can argue that the use of the ArguedMCDA was not justified. For instance, an argumentative approach could have been used directly. However, two points justify this approach. Firstly, in the real case, Bordeaux Metropole used also a MCDA assessment of the different alternatives. It allowed to structure all the information on the different alternatives in a way easily understandable by anyone, making it easy to find the pros and cons of each alternatives. It is one of the main interest of MCDA method; even before the application of an algorithm to rank, categorize or otherwise, the structuring of the problem in the form of a table giving the performances of the alternatives on the criteria, is already very interesting in terms of reflections for the different stakeholders (Taillandier, 2018). Secondly, we used a simplification of the real case; in the real case, they were many more alternatives and criteria. It is difficult for a stakeholder to grasp all of this information using directly the argumentative approach without the MCDA structuring. The MCDA method can greatly assist them in this. We recall than in our real context of application (building retrofit), we will be confronted to a high number of alternatives (i.e. the pareto-optimal solutions).

1.3.5 Conclusion

In this chapter, we proposed an innovative approach to couple argumentation with multicriteria decision analysis in order to support the problem structuring phase. MCDA is useful to structure the decision problem and to rank alternatives. Argumentation allows to justify the MCDA formalization, to expose the different points of view of the stakeholders, and to ensure the traceability of the debate. By keeping a trace of the discussions, it allows to help justify choices that have been made thereby maximizing transparency. The complete approach, including AIPA and its combination with MCDA was implemented on the WebAIPA platform. This platform is operational and allows to perform, in real time, all the ArguedMCDA process. A question which may arise, is how to use it concretely, facing a decision problem. This question has not an only answer. As we exposed in the introduction of this chapter, how to conduct a decision support approach, can only be done in relation to a particular decision problem. If tools or methods can be adapted to many problems, the approach implemented must necessarily be adapted to the specific context of the decision. It is in this sense that the second part of this manuscript is dedicated to the description of this decision-making context, and to the application of the tools and models presented in this first part to our issue of retrofitting social building stock.

Part 2

Building retrofitting

Chapter 2.1

Context of application

2.1.1 Introduction

Any decision support approach must include an analysis of the decision problem. An effective decision-support strategy cannot be implemented without a clear understanding of the problem that must face decision-makers. This analysis should clarify different aspects and issues of the decision-making problem: who are the decision-makers, what is the decision-making process (decision chain, time to make the decision, role in the decision, etc.), what are the possible alternatives, what are the data, the information available, what are the constraints, the objectives, the criteria, the decision-makers' preferences, etc. In this chapter, we will describe the different characteristics of the decision problem related to housing stock retrofit.

2.1.2 Issues related to housing stock retrofitting

2.1.2.1 Societal issue

Construction industry represents about 44% of energy consumption and 21% of total CO2 emissions in France (CGDD, 2012); these values are close in the European Union (Dall'O' et al., 2012). However, the annual replacement rate of the building is less than 1% (Pelletier, 2008). In order to reduce the energy consumption of the buildings, it is essential to improve the existing buildings. Dall'O' et al. (2012) estimates that in the European Union, it is possible to reduce the energy used by the residential sector up to 24.8%, just considering the envelope retrofitting. The challenge of building retrofitting is thus essential in achieving the objectives induced by the climate change. But, the building retrofitting is confronted to several barriers, notably in France (Itard et al., 2008): the lack of examples and knowledge, financial barriers and, for the social housing sector the fact that the investor is not the one who profits from the lower energy use. In a more general way, there is a lack of methods and practices to determine the "right strategy" and to consider the sociological, human, societal and environmental dimensions... The challenge

is therefore to implement processes, methods of analysis and actions to make the retrofitting of existing building stocks attractive, credible, easier and more effective. This issue is present for each type of housing stock, but it specifically important for social housing stocks (Sdei et al., 2015). Indeed, first of all, social buildings in France are often old (building from 70s and 80s) and very deficient in terms of energy losses. They therefore represent an important source of energy savings. Another important point is that the cost of energy consumption is a very important issue for the occupants (Tzortzopoulos et al., 2019); indeed, these buildings are primarily intended for people in precarious situations or at least those who can benefit from housing assistance from the State. The cost of energy consumption can therefore be a very important issue for them; this refers to the issue of energy insecurity. Finally, social housing stock benefits of a simpler decision process. Indeed, on the one hand, the buildings all share the same function: they are residential buildings to rent. On the other hand, in this case, there is a single owner with the possibility of having a strategy for the whole building stock; this is a much simpler case than the management of mixed-owner building stocks. For this reason, this work, as the REHA-PARCS project, focuses on social housing stocks. Because the social housing management is strongly dependent from the country and its culture and local regulations and laws, we will more precisely consider in this part the French context of the social housing. Obviously, the french context is close to many others and the methodology could be reproduced in other countries, but, in order to limit the perimeter of the knowledge, we will limit this study to french social housing.

2.1.2.2 Operational issue

In general, the social landlords benefit from a strong experience and knowledge regarding their housing stocks. In addition, several tools and methods were made available for building in order to assess their energy performance and, sometimes, to suggest actions to minimize the energy consumption. For instance, the regulatory framework, through thermal regulation (RT) and energy diagnosis (DPE), offers methods for evaluating energy consumption. But these methods, if they are relevant at building scale, are not scalable to the whole housing stock. In fact, the definition of strategies at the scale of the whole housing stock is still poorly structured and often relies on either economic contingencies (the available budget being fixed, how best to exploit it), or under constraint (e.g. replace an equipment out of service, urgency regarding structures...). The available tools and/or methods used by the social landlords lack a global vision and do not provide any formalized multicriteria analyses or strategic perspective. It is therefore necessary to propose tools and methods to qualify the existing stock and above all to develop complex retrofitting strategies over long periods of time in order to be able to make the best decisions. To design such tools, we have n a first step to analyze the decision problem. So the next section will be dedicated to the description of this decision problem (i.e defining the stakeholders, the criteria and the context of decision).

2.1.3 Decision problem characteristics

2.1.3.1 Stakeholders

The decision regarding the retrofitting of social housing involves several stakeholders. We can distinguish three types of stakeholders: the landlord himself, the tenant, and the project manager associated with the companies in charge of carrying out the work. Obviously, this categorization is general and not necessarily adapted to all contexts. All housing stock do not have the same size (number of buildings) nor the social landlord the same skills. Thus, the work and the project management can be carried out by third parties or internally, depending on the situation. We will thus focus on the most general case, involving the three groups of stakeholders: social landlord, construction team (including project manager) and the tenant.

2.1.3.1.1 Social landlord

Social landlord build, purchase, renovate, and manage housing rented to families in "modest condition". They can grant their guarantee to tenants wishing to become homeowners. Finally, they must act in favor of the objective of social mix. In order to compensate for the service of general interest that they perform, the State grants them tax exemptions and specific aid.

In 2016, France around 740 social housing organizations were referenced, managing more than 5M of housing (DataLab, 2019), representing about 14% of French households. This stock is administered by three main types of organization: public housing authorities, which own 49% of the stock, social housing companies, which manage 44%, and local public companies, including semi-public companies, which manage 4.5% of the stock (ANCOLS, 2016). Each of these types of organisation have their own constraints and their way to manage heavy renovations or new building construction. To design and perform maintenance and renovation work, the social landlords may use external project managers and construction companies, or even delegated project management, depending on the internal skills they have.

Since 2002, the social housing organizations must establish a Strategic Management Plan (SMP)) in order to impose them to have a long term thinking on the stock's management program. The SMP is based on a technical diagnosis, but also takes into account the commercial attractiveness and profitability of each property in order to define relevant strategic orientations for the housing stock. Depending on the organization's investment capacity, a multi-year action plan has to be built, defining for each building the actions to be implemented, and in particular the forecast investment level. In addition, since 2010, social landlords have been required to sign a (Social Utility Agreement (SUC)) with the State and the main communities in whose territories they own housing. The SUC is closely linked to the SMP, as it sets out commitments relating in particular to the

dynamics of the housing stocks and the sustainable development. The law of January 27, 2017 relating to equality and citizenship, stipulates that the SUC has to include a "statement of service rendered" and a "statement of social occupation" of the buildings, based on national data regarding the considered territory (des Dépôts, 2020). The specifications of the SUC evolved in order to improve the equity and territorial governance of social housing allocations by implementing the reinforcement of the Dalo law related to the attribution of the social housing. The aim was also to promote mobility in the social housing stock and access by disadvantaged households to attractive neighborhoods through the reform of the SUC and the strengthening of the solidarity rent supplement. Finally, to strengthen democracy in social housing, social landlords have to finance tenant representatives to carry out their function within the framework of the rental consultation plans. The consultation with tenants is also strengthened at the level of the building concerned by the planned works and then in the elaboration of the SMP (des Dépôts, 2020). This last point justifies the choice of a participatory approach for the building retrofit decision problem.

2.1.3.1.2 Tenant

The National Agency for the Control of Social Housing (ANCOLS) is a public administrative establishment. ANCOLS has for mission to control and to evaluate in a more global way the action of all social housing operators. In order to perform this mission, it performs studies to analyze the structure of households occupying French social housing. We will present in this section some information from these studies. Firstly, the tenants of the social housing stock are relatively old. Only 8% of the tenants are less than 30 years old (for 25% in the private housing stock) and 24 % are over 65 years old (for approximately 15% in the private housing stock). In addition, they are 42% of families with children (27% in the private stock), including 17% of single-parent families (9% in the private stock) in private housing stock. Large families, with at least 3 children, represent in particular 10 % of the social tenant households. They are half as numerous (5 %) in the private stock (ANCOLS, 2016).

However, the employment situation of households occupying social housing differs little from that observed in the private housing stock. In half of the cases, at least one adult has a stable job, 10% of households have only precarious jobs, and 17% have no job at all, and nearly a quarter, 23%, are retired. This distribution is close to that observed in the private sector, with the same geographical distribution and type of housing (ANCOLS, 2016). If the employment situation of tenants are close between social and private housing, the incomes of tenants in the social sector are lower. Their reference tax income is on average €17,500 per year, compared to €25,800 for all metropolitan tax households. 25% of households in the social sector are in a situation of poverty, compared to 18% of those in the private sector. 36%

of households in the social housing stock and 25% of those in the private housing stock are living in poverty at a threshold of 60% of the median (ANCOLS, 2016).

This information made it possible to better qualify the characteristics of the tenant population. As mentioned above, there is a particular issue regarding the participation of tenants in decisions on building actions.

2.1.3.1.3 Work team

As we exposed before, according to the internal capacity of the social landlord, the retrofitting works can imply or not, external companies. In France, the main document which concerns the public work is the law no.85-704 of July 12, 1985 relating to public project management and its relationship with private project management, known as the MOP law. This law describes the phases of the design process, the documentary productions associated with each phase and the respective obligations between the public client and the project manager. This law was repealed by the ordinance no.2018-1074 of November 26, 2018, but the main elements of this law have been integrated into the "Code de la Commande Publique". Although its scope of application only concerned contracts concluded between public and private companies, this document still constitutes a consensual reference for organizing project process for many types of works. We will not expose here in more details this organization, but we will assume that the retrofitting works will be structured as described in the MOP law, including the role of the different stakeholders in the project management (client, project manager, contractors, design office...).

2.1.3.2 Decision process

As discussed in the previous section, social landlords have an obligation to provide tenants with housing in a condition suitable for their use and meeting the challenges of sustainable development. It go through the renovation of buildings, which is an important mission for social landlords. This is part of the strategic park management plan that social landlords must establish. As we explained, this plan contains a set of actions planned over several years to renovate the buildings. The challenge is therefore to help the social landlords to design this plan, by helping them to choose and plan these actions. Of course, this plan is carried out under a budgetary constraint. In addition, the regulatory texts are pushing social landlords to integrate more participation in decision-making by asking them to fund tenant representative associations and by asking them to participate in the development of the strategy. Obviously, there is a gap between the intentions of the laws and their concrete application in the field; the implementation of a participatory approach is still very limited today. However, we can assume that if landlords have a tool to carry out such an approach, they would be more willing to actually implement it. The issue is therefore to be able to propose a method of decision support intended for social

Table 2.1.1: Extract of the unitary action list

Type	Solution	Supplementary information
Envelope	insulation on the inside of the walls	Polystyrene 16cm
Envelope	insulation on the inside of the walls	Polystyrene 11cm
Envelope	insulation on the inside of the walls	wood fiber 19cm
Envelope	insulation on the outside of the walls, under cladding	glass wool 18cm
System	generator replacement for hydraulic heating systems	300-800kW
System	generator replacement for hydraulic heating systems	800-2000kW
System	CMV replacement	dual-flow CMV with energy recovery

landlords to build, in a participative way (i.e. by integrating the tenants), the strategic plan. This plan must meet different objectives corresponding to various criteria.

2.1.3.3 Alternatives

The Strategic Management Plan (SMP) is a mandatory process for social housing organizations. It aims at anticipating the evolution of the housing stock and adapt the housing supply to the demand and the environment. The SMP aims to optimize the management of social housing over the long term and meets several strategic objectives in the area of social housing as optimizing the attractiveness of the public housing stock in order to obtain the best possible occupancy rate and the integration of environmental constraints in the long-term management of stock. We assume that these two aspects are linked: by improving the energetic performance of the buildings, the landlords make their housing more attractive. In this perspective, the REHA-PARCS project, and so this thesis, focus on the energetic performance aspect. Thus we will consider strategies in relation to the improvement of the building efficiency regarding energy consumption, while considering the impact of this strategy on the criteria that matter for the landlord (i.e. not only energy consumption). The operationalization of the SMP is carried out through a multi-year action plan. This plan is composed of a set of unitary actions planned yearly. As previously mentioned, these actions will be related to energy issues. The unitary actions can be divided into two types: actions on the envelope and actions on systems. The REHA-PARCS project referenced 64 actions on the envelope and 83 actions on the system. In order to illustrate the notion of unitary action, the Table 2.1.1 exposes an extract of the unitary action list.

To sum up, 147 unitary actions were identified. An alternative (i.e. a multi-year action plan) is composed of a set of unitary actions implemented on specified building and scheduled over several years. Obviously, it is not possible to implement on one building the 147 actions (e.g. implementing 2 types of insulation for the same walls). A matrix of combination was built during the REHA-PARCS project by energy experts to consider the impossible combination. But, even considering these impossibilities, the number of possible combinations of unitary actions per building

is enormous(over several billions). In addition, we have to consider the scheduling on several years and the numbers of building (several tens, or even several hundreds depending on the lessor). There are two main conclusions regarding the alternatives: (1) It is not possible to build all the possible alternatives (i.e. all the possible plan) due to combinatorial explosion, (2) an alternative is already complex by itself to grasp (i.e. composed of a set of unitary actions on different buildings over different years).

2.1.3.4 Criteria and Objectives

In its first intention, the REHA-PARCS project aimed at supporting building retrofitting in order to improve the energy performance of buildings in a context of climate change. However, decisions taken on these criteria alone may degrade other aspects such as comfort or other environmental impact of the building (through impact transfer) and have a significant cost. Furthermore, a series of interviews during the project revealed that social landlords do not carry out "purely thermal" operations; the challenge for them lies in assessing performance of actions in a more large field than simply energy. However, the issue of energetic performance, is nevertheless an important issue for most of the social landlords, notably because of the energy precariousness of the tenants. Thus, decision support must be based on a variety of criteria that give an indication of the performance of the strategies under consideration. These criteria should be quantifiable at least on an ordinal scale. The set of criteria should be able to cover the concerns of the different stakeholders and enters a sustainable development logic to be in line with the last regulation. The task 1 of the REHA-PARCS project aims at providing such set of criteria. In a first step, a list of objectives that a social landlord could consider via the SMP was built Table 2.1.2.

Each of these objectives could be translated into a criterion. However, there are to be confronted to the issue of the assessment of these criteria, i.e. evaluate, for a considered strategy, its performance regarding the criterion. For some of these criteria, it is obvious (e.g. cost of rehabilitation), for others, it is very challenging (e.g. Quality of use). Globally we can distinguish three cases:

- criteria that we can assess directly from the data already available
- criteria that we can compute using a specific assessment model
- criteria that have to be expertly assessed

In addition, the REHA-PARCS project focuses above all on the energy saving actions. In a pragmatic way, from these objectives, considering the assessment issue and the project objective, we considered a limited set of 13 criteria Table 2.1.3.

Most of these criteria are relatively easy to assess because they depend on available indicators which are easy to compute (e.g. the total cost of actions). But

Table 2.1.2: List of objectives

Domain	**Objective**	**Sub-objective**
Social	Improve urban quality	Improve the neighborhood attractiveness
Social	Improve urban quality	Increase security
Social	Improve urban quality	Facilitate accessibility (transportation)
Social	Improve building quality	Improve the quality of the residence
Social	Improve building quality	Improve the quality of the common areas
Social	Improve building quality	Improve the quality of housing
Social	Improve building quality	reduce management difficulties
Social	Increase social value	Improving the quality of use
Social	Increase social value	Increasing social equity
Social	Increase social value	Increasing gender equity
Social	Increase social value	Improving accessibility for people with reduced mobility
Social	Increase social value	Facilitating social relationships
Social	Increase social value	Improving participation
Social	Protect resident health	Improving indoor air quality
Social	Protect resident health	Improving water quality
Social	Protect resident health	Reduce exposure to electromagnetic fields
Social	Protect resident health	Reducing risks (fire, explosion...)
Social	Improve comfort	Improve visual comfort
Social	Improve comfort	Improving thermal comfort
Social	Improve comfort	Reduce noise
Social	Improve comfort	Reduce odors
Social	Improve comfort	Improving well-being (e.g. floor space)
Economic	Reduce cost	Reduce the cost of rehabilitation
Economic	Reduce cost	Reduce the cost of operation
Economic	Reduce cost	Reduce the cost of maintenance
Economic	Reduce cost	Reduce the cost of demolition
Economic	Increase value	Facilitate the adaptation of spaces
Economic	Increase value	Facilitate the adaptation of uses
Economic	Increase value	Increase the sale value of the building
Environment	Conserve resources	Saving energy
Environment	Conserve resources	Preserving raw materials
Environment	Conserve resources	Saving water
Environment	Conserve resources	Controlling land use
Environment	Protect the ecosystems	Preserving health
Environment	Protect the ecosystems	Protecting Biodiversity
Environment	Protect the ecosystems	Protecting the climate
Environment	Protect the ecosystems	Improve outdoor air quality
Environment	Protect the ecosystems	Reducing waste
Environment	Protect the ecosystems	Reducing the risks related to radioactivity
Environment	Protect the ecosystems	Protecting rivers and lakes
Environment	Protect the ecosystems	Protecting forests
Cultural	Increase aesthetic value	Improve architecture and image
Cultural	Increase aesthetic value	Improve site integration
Cultural	Preserve heritage	Respect historical sites
Cultural	Preserve heritage	Integrating the memory
Cultural	Preserve heritage	Increasing cultural value

Table 2.1.3: List of criteria

Domain	Criterion	Indicator
Social	Neighborhood attractiveness	Number of actions on the facade
Social	Quality of use	Number of system actions
Social	Indoor air quality	Number of CMV actions
Social	Thermal comfort	Degree.h of discomfort
Social	Noise	Number of windows actions
Social	Odors	Number of CMV actions
Social	Floor space	Surface floor after action
Social	Inconvenience of the work	Duration of the actions
Economic	Investment cost	Total cost of the actions
Economic	Energy consumption cost	Total cost of saved energy on the considered time horizon
Economic	Sale value of the building	Total monetary add value of the actions
Environment	Energy consumption	Energy consumption
Environment	Global warming potential	Equivalent CO2 emissions

this is not the case for criteria related to energy consumption, thermal comfort and climate change. These criteria have to be calculated from a thermal model. While consumption can be determined with relatively simple static models, if we assume an approximate result is sufficient, this is not the case for thermal comfort, which requires the use of a dynamic thermal model. This type of model is quite demanding in terms of calculation time. It is an element that constitutes an important methodological lock, when it is coupled with a huge amount of possible alternatives.

2.1.3.5 Complexity of the decision problem

Decision-making complexity can be defined through different characteristics (Keeney, 1982): (a) multiple and intangible objectives or criteria, (b) difficulties in identifying the right options (i.e. possible solutions), (c) lasting consequences impacting many stakeholders, (d) significant uncertainties, (e) a multidisciplinary context, (f) multiple decision-makers, and (g) interactions between decisions. Taillandier (2018) proposed a metric to assess the complexity of a decision problem based on 6 indicators: number of criteria, number of alternatives, decision impact, uncertainties, number of decision-makers and interactions. If we consider these different indicators to assess the complexity of the problem, we have :

- More than 11 potential criteria (complexity: high),
- More than 10 000 alternatives (complexity: very high),
- The decision have a strong impact regarding economic criteria and via the energy precarity on resident life (complexity: high),
- The uncertainties are presented, notably regarding the medium and long term consequences (complexity: high)

- There are several decision makers (complexity: average),
- There are some interactions between the decision (complexity: average).

As a conclusion, the problem has a high complexity. It induces the need to use a dedicated decision-support approach to help the decision-makers to build and selected the action plan they prefer.

2.1.4 State of the art regarding the social housing stock retrofitting

Building retrofitting is a major environmental issue and a complex decision problem. It has mobilized numerous research teams. For instance, (Nielsen et al., 2016) identified 43 decision support tools to select renovation project for buildings in design or pre-design phases. These tools compose an interesting corpus, relevant for many renovation decision support contexts. However, all these tools consider only one building and are not be extended to a set of buildings (and could not be). The same comment could also be made for other existing methods/approaches which have been proposed in the literature, as Multiple Criteria Decision Analysis (MCDA) (Taillandier et al., 2016), optimization (Armand-Decker et al., 2014, Juan et al., 2010, Xu et al., 2015), cost-benefit analysis (Friedman et al., 2014), etc. These approaches, although interesting, do not answer completely the decision support issue. Indeed, all these methods and approaches consider a single building and not a housing stock. Furthermore, they do not consider the multi-year planing of the actions. These two points greatly increase the complexity of the problem In parallel, different approaches, methods and tools were developed for helping a real property manager in building an action plan for buildings. But these methods are confronted to three drawbacks corresponding to three different ways to deal with complexity: (1) the limitation to a specific field such as concrete buildings (Chiu and Lin, 2014) or the frontage renovations (Flores-Colen and de Brito, 2010), (2) the use of a single criterion (Morelli et al., 2014), and (3) the limitation to a few number of alternatives which induces a comparison of renovation alternatives rather than planing actions(Ibn-Mohammed et al., 2014, Kutut et al., 2014). The method REMIND based on an interactive approach (Taillandier et al., 2014), or those proposed in (Taillandier et al., 2017) based on Multi-Objective Multidimensional Knapsack optimization are not impacted by these drawbacks. But none of these two approaches allow to be combined with a thermal simulation to compute the energy consumption and the comfort. In addition, they were not intended to participatory approach, considering only one decision-maker.

To synthesis, we have many methods which aims at providing a decision support regarding energetic actions at building scale, and many methods which aims at building an action plan at real property scale, but very few which combine these two features. To our knowledge, the optimization of a multi-year action plan dedicated

to the retrofitting of a housing stock, coupled with a model able to compute energy gain and comfort, is still a challenge to meet. This challenge is even greater if considering not only a "technical" approach aimed at experts, but rather, a tool that is part of a participatory approach, in which exchanges between the different stakeholders are brought to the forefront. This is precisely the objective of the REHA-PARCS project.

2.1.5 The REHA-PARCS proposition

The REHA-PARCS project aims at proposing an approach, methods and tools to allow managers to analyze their building stock and help them establish a retrofitting strategy. The project proposes a generic approach that can be applied to any type of building stock, but in order to reduce the field of knowledge and to propose tools that are truly adapted to the study context, it will be developed within the more specific framework of social housing stocks. In this section, we will present the REHA-PARCS strategy in order to solve this complex decision problem, and how the method and tools we presented in the first part of the manuscript find a place in this strategy.

2.1.5.1 A three-steps process

The question that the REHA-PARCS project seeks to answer is that of developing a relevant multi-year strategy for the retrofitting of a social building stock, using collaborative decision-making approach. This raises different sub-issues such as the characterization and modeling of the buildings, the evaluation of the performances before the application of actions or those expected after their implementation, and the decision support considering the combinatorial explosion of possibilities (combination of unitary actions on each building and planned per year), and the will to use a participative approach. To solve these issues, REHA-PARCS proposed to use a three-step approach which is structured as exposed in Figure 2.1.1. The main steps are: (1) reference buildings identification, (2) multi-objective optimization, and (3) decision support.

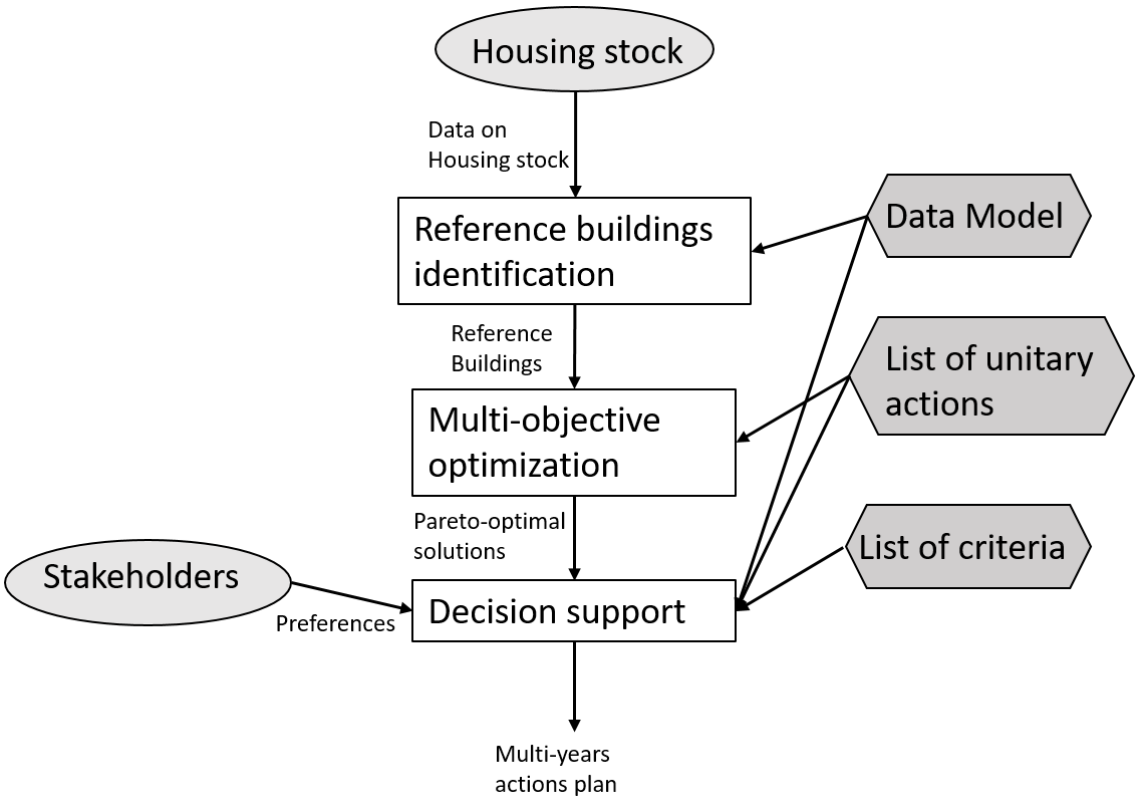


Figure 2.1.1: Synoptic of the REHA-PARCS process

We will present the three steps in the following sections.

2.1.5.2 Reference buildings identification

As we previously state, one of the main difficulties regarding the housing stock decision problem is to consider the whole set of buildings of the housing stocks. While accurate measurement and efficiency estimation of energy retrofit actions are possible for an individual building, it is very difficult at the housing stock scale. A possible strategy in order to reduce the complexity of the problem consists in identifying reference buildings which can be representative to a set of buildings of the housing stock; it will allow to reduce the number of buildings to consider. Indeed, these reference buildings can then be used for thermal simulations, which is the aspect which requires the most important computation time. In order to identify these reference buildings, a statistical classification (clustering) was chosen for this project. Statistical classification is based on the identification of clusters or homogeneous subsets within the building set. It is constructed from the mathematical analysis of building attributes (energy consumption, geolocation, etc.). The clustering is performed on the decision space (i.e. parameters of the building), but also on the objective space (performance of the building after the

implementation of the unitary actions). Among the variety of clustering algorithms, K-means was selected. The objective of K-means algorithm is to find a set of clusters which minimize the residual sum of squares (Hartigan and Wong, 1979). In addition, the elbow method (Ketchen and Shook, 1996) is used to define the number of clusters. The methodology goes through 4 steps (Lee et al., 2016, Rivallain et al., 2019). In a first step, the decision space to consider is selected in order to reduce the dimension of the considered database. All the selected variables are normalized and then, a clustering is applied to the reduced decision space. This step results in a first partitioning of the buildings. Then, each cluster is cleaned by removing all the outliers regarding one specific variable of the decision space. The normalization and clustering approach are then applied but this time considering the objective space for each cluster. The number of clusters is calculated from a constraint on one parameter of the objective space concerning the exceedance of its maximal standard deviation. In addition, if this constraint is not satisfied, a new clustering with only two clusters is again applied to the objective space. The main limitation of this approach is that it requires a high quantity of data which are often unavailable. The generation and then analysis of a virtual stock can help to overcome this problem (Nikolaou et al. 2009). A virtual building data base, representative of building from housing stocks, was generated with three attribute groups, i.e. morphology of buildings, energy features such as envelope and energy system, and energy performance. It was based on the TABULA/EPISCOPE project results which provided standard typologies for the European building stocks (TABULA Project Team 2012). This virtual base was used to create the building typology and to identify reference buildings. The approach consists then in categorizing each building of the real housing stock in the pre-defined categories built on the virtual base data. This phase results in a set of reference buildings which are representative of the building stock.

2.1.5.3 Optimization

A solution to build an optimal action plan would be to establish all possible action plans before selecting the most relevant ones. But it is combinatorial: the number of possible actions on each building is large (near hundred), a housing stock is composed of tens even hundreds of buildings. It results in a huge (over billions) number of possible plans of actions. Due to the combinatorial explosion, the establishing of all combinations is not possible in a reasonable time, even less with the time to compute the thermal simulation. In addition the plan includes several years on which the actions have to be scheduled. Finally, the different objectives of the stakeholders, which were exposed in Table 2.1.2, are conflictual; for instance, increasing the energy gain (objective to maximize) requires to increase the importance of the works, and then the investment cost (objective to minimize). There is no chance to get one plan of actions that is optimal on every objective of all the stakeholders. The objective of the planning of the retrofitting action of a

housing stock is to determine an optimal plan of actions that is a trade-off between objectives while respecting the budget constraint. For that, facing the combinatorial explosion of all possible solutions, the multi-objective optimization approach has been retained. The multi-objective optimization consists in searching among a set of alternatives (in our case the possible actions plans), the so-called "optimal" alternatives in the sense of Pareto, i.e. those that are not dominated by any other alternative on all the objectives. There are two approaches to solve this type of problem: full analytical optimization and meta-heuristics. Analytical solutions explore all the alternatives and allow to find the true optimal solutions but require a significant amount of computation time as the complexity of the problem increases. They are not suitable for solving complex problems (numerous input parameters, interactions, etc.) such as that posed by the retrofitting problem. As a consequence, the problem solving via meta-heuristics has been retained, and more particularly the genetic algorithms are used (Holland, 1992).

One source of complexity in this decision problem is that the evaluation of some of the objective require to perform thermal simulation. The multiobjective optimization is coupled then with a thermal simulation, which is used to assess the solution during the optimization, as it was used in Rivallain (2013) (already dedicated to a building retrofitting) or in Recht (2016) (dedicated to the design of a new building). These works coupling between dynamic thermal simulation (carried out with COMFIE Peuportier and Sommereux (1990)) and the NSGA-II genetic algorithm Deb et al. (2002) have been extended to adapt to the complexity of a building stock to be renovated over several years Pannier et al. (2020) in order to be used in the REHA-PARCS project. In addition, the REHA-PARCS optimization approach benefits from the previous step (i.e. identification of the reference buildings). Indeed, considering the whole set of real buildings would be very time-consuming; limiting the simulation to the reference building (e.g. less than 10 buildings in general) is much more economical in terms of calculation time.

In the REHA-PARCS project, three objectives are considered to be optimized Merlet et al. (2018):

- Energy: energy requirement for heating
- Summer overheating: indicator based on adaptive comfort
- Cost: investment cost for the work

These objectives were defined by the REHA-PARCS team, and considered sufficient to ensure the interest of the optimized action plan. They ensure that the action plans are technically relevant. In addition, the optimization considers 2 types of constraint Pannier et al. (2020): a global constraint on the budget (i.e. the total cost of the actions must not exceeded the budget constraint), and an annual budget constraint (i.e. the cost of the actions on one year must not

exceeded the budget by year). If the budget of one year is not spent, it is carried over to the following year.

This second step results in a set of pareto-optimal solutions (i.e. action plans), optimizing the considered objectives and respecting the considered constraints.

2.1.5.4 Decision support

The decision step consists in defining the action plan which seems the most interesting among the set of pareto-optimal solutions defined in the previous step. To perform this step, we use the ArguedMCDA that we presented in the part 1, which was instantiated to the retrofitting of the housing stock. The description of this applied method called Argued Mcda for HOusing stock REtrofitting (AMHORE) (Argued MCDA for HOusing stock REtrofitting) will be the subject of the next chapter.

2.1.6 Conclusion

In this chapter, we presented the decision problem regarding the social housing stock retrofitting. We exposed the specific issues related to this domain and analyzed the decision problem. Then, we presented the decision support strategy used in the REHA-PARCS project in order to solve this problem. We finished on the evocation about the decision support stage which is the main subject of this thesis. The next chapter will develop the description of this step, by instantiating the approach presented in the first part to this problem, providing a innovative method called AMHORE.

Chapter 2.2

Application to a case study

2.2.1 Introduction

In this last chapter before the Conclusion, we will applied the Argued Mcda for HOusing stock REtrofitting (AMHORE) method that we proposed in the Chapter 2.2 to a realistic case study. It is not a real case study but a virtual housing stock. The choice of a virtual housing stock can be justified by two main reasons. Firstly, most of social landlords are reluctant to have their data published. It is easy to understand the problem: many social building are aging and few of their managers want to see the shortcomings of these buildings disclosed. This would have meant masking data, making the didactic aspect of the example application less relevant. The second problem posed by the use of a real stock is even more pragmatic, as it concerns the availability of data. As we have said, the method proposed here is part of a broader framework of decision support (REHA-PARCS process): the starting point is the identification of reference buildings, then the optimization of action plans by using these typical buildings, and finally the decision support approach proposed in this work is carried out. Thus, AMHORE can only be used if the preliminary stages have been performed; it is these stages that will provide the data necessary for its implementation. However, the previous works were only realized on the virtual park. It is thus quite naturally that we have taken up the same application in this work. This does, however, presuppose an important limitation. Our approach is intended to be participatory, involving several stakeholders in the decision-making process. Here, by positioning ourselves on a virtual park, the stakeholders are also virtual. In practice, we have simulated the actors' game ourselves through role-playing, giving the arguments that, we imagine, could have been given by real stakeholders.

In a first section, we will present the case study and the results we obtained thanks to AMHORE. Then, we will discuss these results and more generally the proposed approach.

2.2.2 Applying AMHORE to a case study

2.2.2.1 Presentation of the case study

We built a case study from a virtual social housing stock. This stock of 21 buildings was defined from data of the Public Housing Office of Montreuil (OPHM). It is intended to be representative of a real stock of social housing due to the morphology and energy classes of the modelled buildings. In this example, the optimization approach has already been applied. The details of the optimization phase regarding this virtual housing stock and the results are presented in (Pannier et al., 2020). We will thus start from the 216 solutions (i.e. action plan) belonging to the pareto front. We refer the reader to the article (Pannier et al., 2020) for the details of these strategies. Globally, the unitary actions on the buildings composing the strategies concern: wall insulation, replacement of windows, ventilation and heating systems.

2.2.2.2 Preamble

It is obviously impossible to discuss all the 216 solutions directly using the argumentative approach. Indeed, it would results in a discussion with 216 conclusions and in addition each solution (i.e. action plan) is in itself complex (set of scheduled unitary actions implemented to buildings). We will therefore apply the approach proposed in the previous Chapter, i.e. AMHORE. In a real approach, the different stakeholders should be involved in the argumentation process leading to the construction of the decision-making model. We have positioned ourselves here on a virtual park, therefore without real stakeholders. The arguments will therefore also be virtual, proposed by the REHA-PARCS team, in a "role-playing game" in which they have interpreted 3 roles: that of the head of the management department (called Manager in the following), that of a technical services manager (called Technician in the following), and finally that of a tenant representative (called Tenant in the following). Obviously, this has an influence on the process that we will discuss in the discussion section of this chapter.

The process follows the 4 steps presented in the previous Chapter: criteria selection, preference parameters setting, MCDA running and alternative selection. Each of these steps, except the MCDA running, corresponds to discussion using Argumentation Interface for Participatory Approach (AIPA). These discussions which allow the building of the argumentation graphs are at the center of the proposed approach. An important point consists in the choice of the translation rule for AIPA; i.e. the rules used to generate the Dung Abstract Argumentation Framework (AAF) graph from the AIPA graph. For this application, we selected the support translation rule which was described in the Chapter 1.2.

In the following section, we will detailed step by step, the construction of an argumentation graph, then, we will provide the results of the different steps.

2.2.2.3 Example of the construction of an AIPA graph for criterion selection, step by step

In order to explain the construction of one of these argumentation graphs, we consider the discussion on the "Inconvenience of works" criterion (Figure 2.2.1). This discussion is part of the first step, i.e. criteria selection. The question discussed here is: Should we consider the criterion "inconvenience of works"?

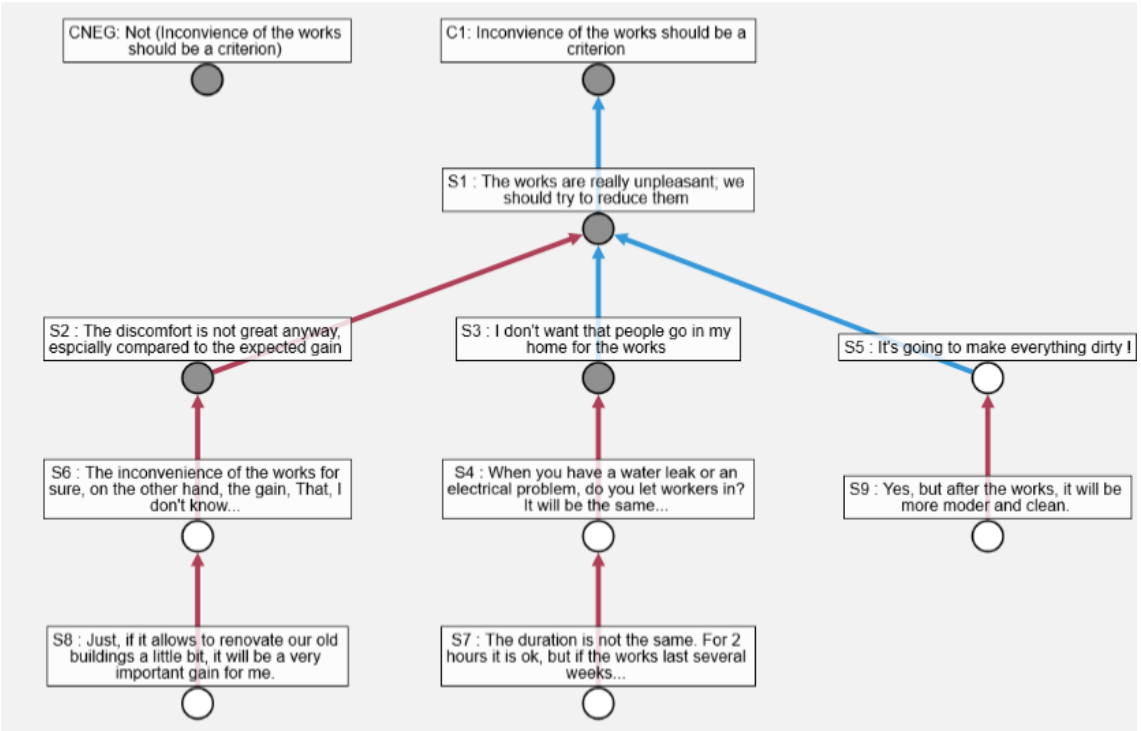
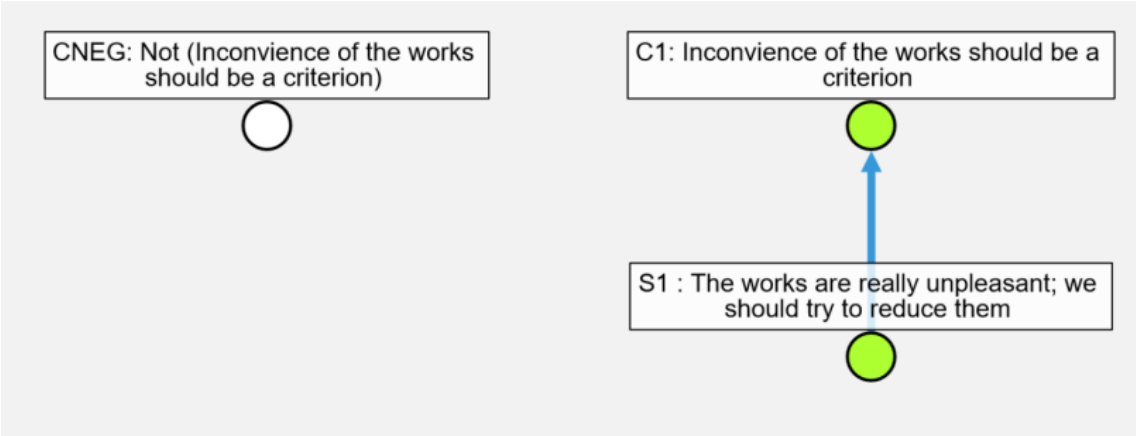


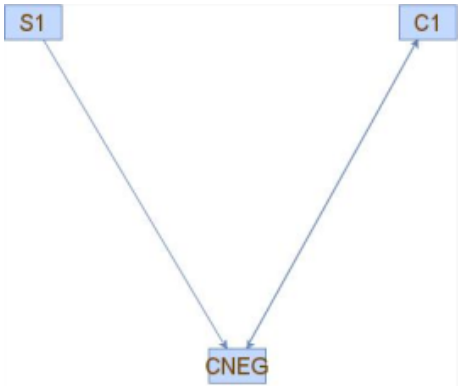
Figure 2.2.1: Argument graph related to "Inconveniences of works" criterion with the webAIPA interface

The first argument expressed is by Tenant to defend the Inconvenience of work criterion : (S1) "The works is really unpleasant; we should try to reduce them". This is obviously a StatementFor targeting the conclusion (C1) "The Inconveniences of works should be a criterion". This StatementFor would allow conclusion C1 to be accepted. Supposing that it would be the first discussion about criteria, and that we ant to finish this step here, it would be the only criterion retained for the following steps.

The green color of the AIPA argument graph on Figure 2.2.2a indicates the accepted arguments which contribute to the acceptation of the conclusion. For instance, in this example, the statement S1 is accepted and allows the conclusion C1 to be also accepted. This result is computed from the determination of the extensions on the Dung translated graph. In this example, we used the support translation rule (see Chapter 1.2 for the details on this translation). We will discuss in the discussion



(a) AIPA model

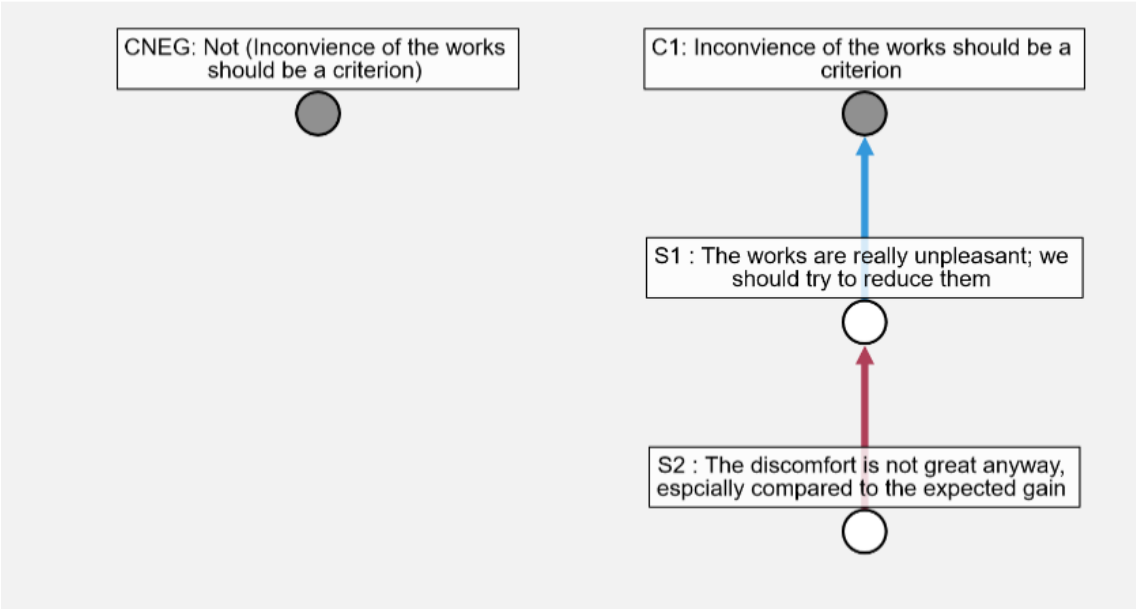


(b) Dung translation

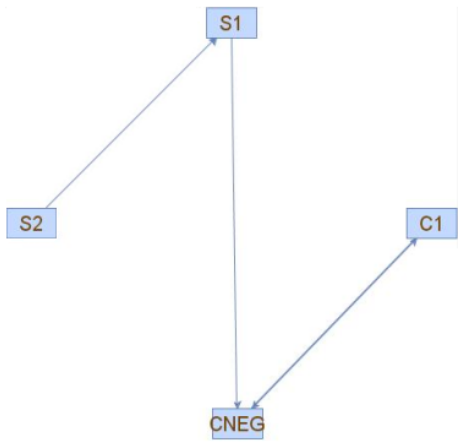
Figure 2.2.2: Argument graph related to "Inconveniences of works" criterion with 1 statement

section of this chapter, the impact of the choice of this rule. The StatementFor S1 is translated by the support translation rule into an attack against Cneg on the Dung graph, making Cneg not accepted and then, C1 accepted. This case is relatively simple and could have been deduced directly from the AIPA graph, but this is much more complicated with more statements (see for instance Figure 2.2.1). But before analyzing this graph, we will continue to describe how it was constructed.

A new statement (S2) expressed by Technician attacks the statement S1 : "The discomfort of the works is not so important anyway, especially compared to the expected gain". This statement is translated into an argument attacking S1 in the AAF. Because of this new argument, S1 is no longer accepted. C1 becomes defenseless, putting it back on the same level as Cneg. Thus, the two conclusions (C1 and Cneg) are in conflict (neither one prevails over the other)Figure 2.2.3.



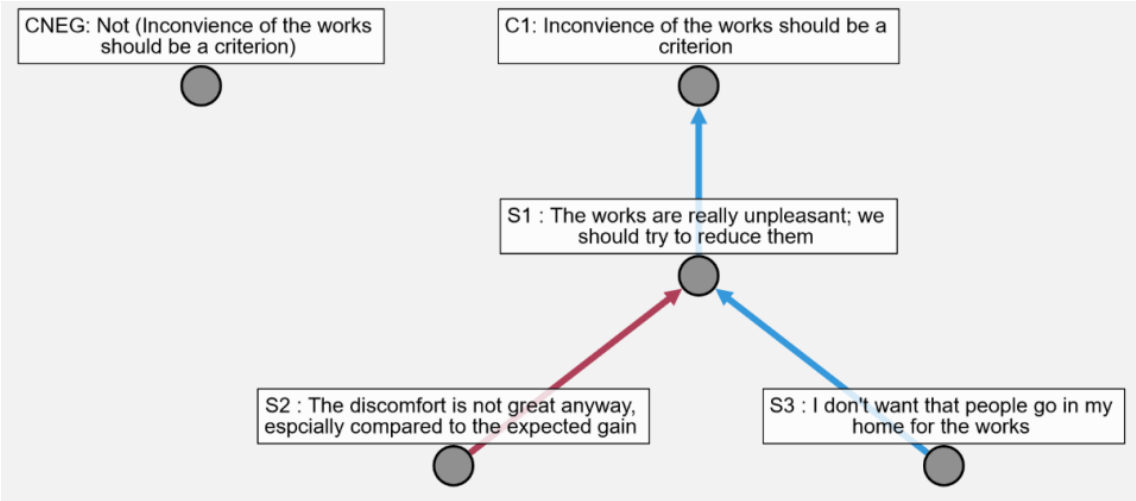
(a) AIPA model



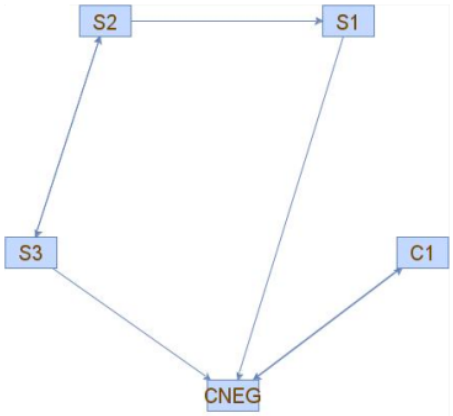
(b) Dung translation

Figure 2.2.3: Argument graph related to "Inconveniences of works" criterion with 2 statements

Tenant adds a new statement (S3) supporting his previous statement "I don't want that people go in my home for the works". Because, we use in application the support translation, this new statement is translated in the AFF as an argument attacking S2 and Cneg, and attacked by S2. This argument which defends S1 is opposed to S2 which attacks S1. This opposition leads to a conflictual situation between these two arguments which are considered as "in conflict". Because of this conflict, the status of S1 is not decided and is also considered as "in conflict", and so are C1 and Cneg Figure 2.2.4.



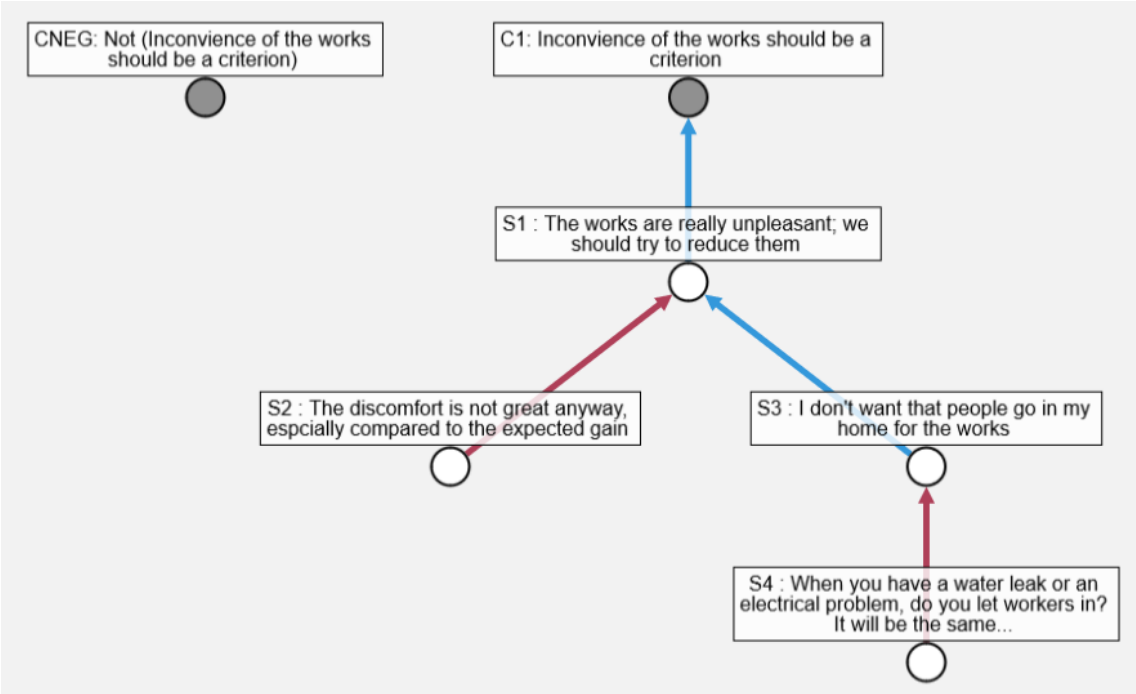
(a) AIPA model



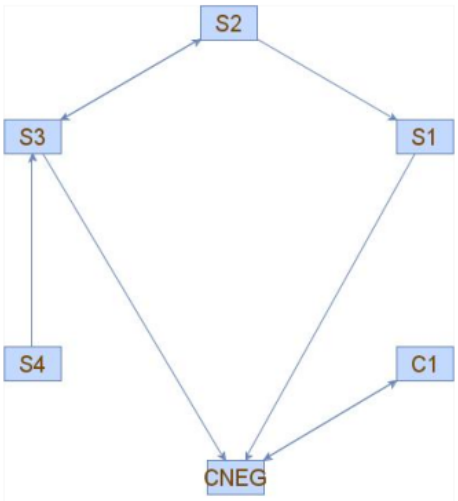
(b) Dung translation

Figure 2.2.4: Argument graph related to "Inconveniences of works" criterion with 3 statements

A new argument (S4) attacking the previous statement (i.e. S3) is proposed by Manager; it is about the fact that sometimes, it is necessary to let worker enter to perform works (e.g. water leak). By attacking S3, this argument solves the previous conflict between S2 and S3. Indeed, S3 is now not accepted. Without this support, due to the attack of S2 which remained valid, the statement S1 is no more accepted and the conclusions are in conflict Figure 2.2.5.



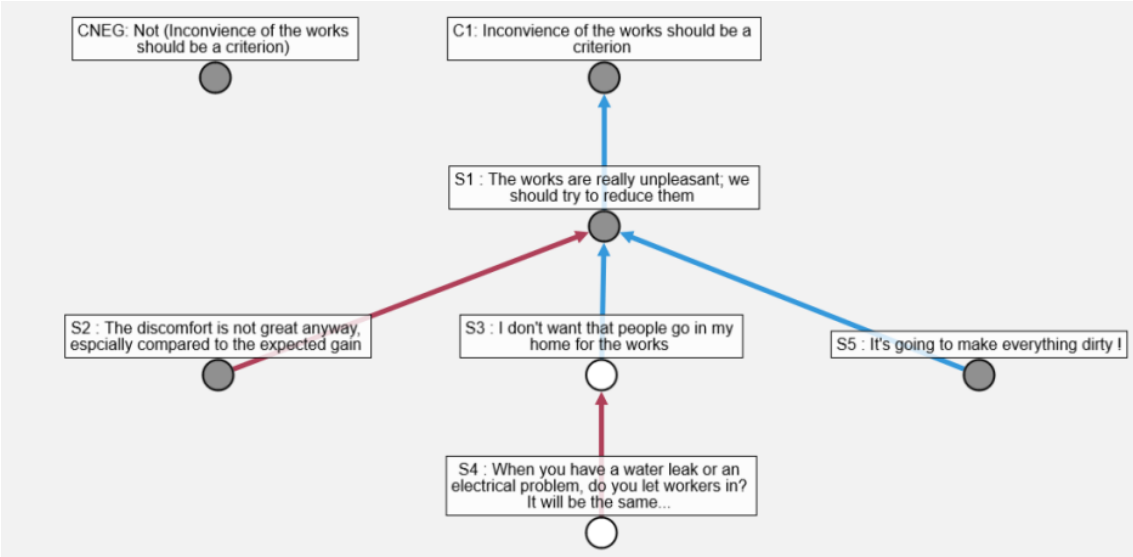
(a) AIPA model



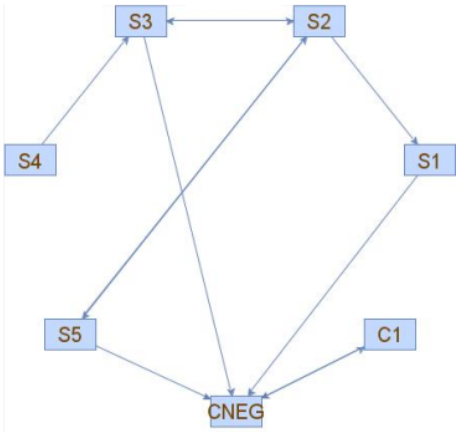
(b) Dung translation

Figure 2.2.5: Argument graph related to "Inconveniences of works" criterion with 4 statements

Tenant proposes a new statement (S5) regarding the dirt brought by the works which support S1 Figure 2.2.6. This new situation is close to those of Figure 2.2.4 with two arguments in conflict (one StatementFor and one StatementAgainst) about the same argument.



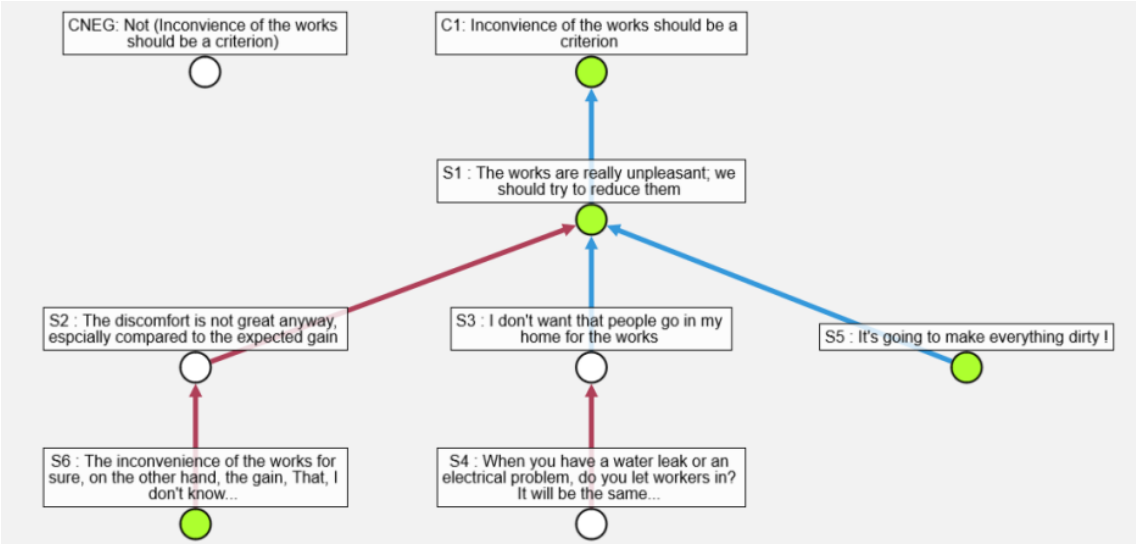
(a) AIPA model



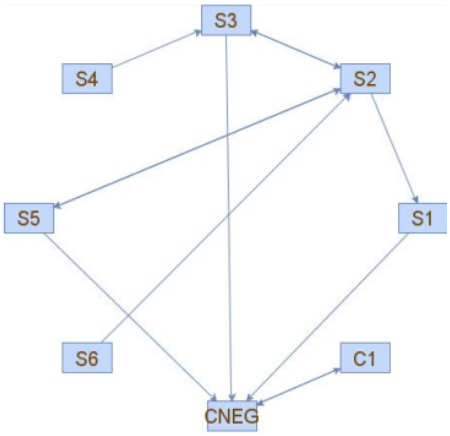
(b) Dung translation

Figure 2.2.6: Argument graph related to "Inconveniences of works" criterion with 5 statements

Tenant brings then an argument (S6) which attacks S2, claiming that the benefit from the works is uncertain whereas the inconvenience is sure. This statement modifies the situation and the results allowing the conclusion C1 (i.e. the choice of the inconvenience criterion) to be accepted. Indeed, S2 was the main argument which avoids S2 to be accepted and so C1. Figure 2.2.7 exposes the new situation with in green the accepted arguments in favor of C1.



(a) AIPA model

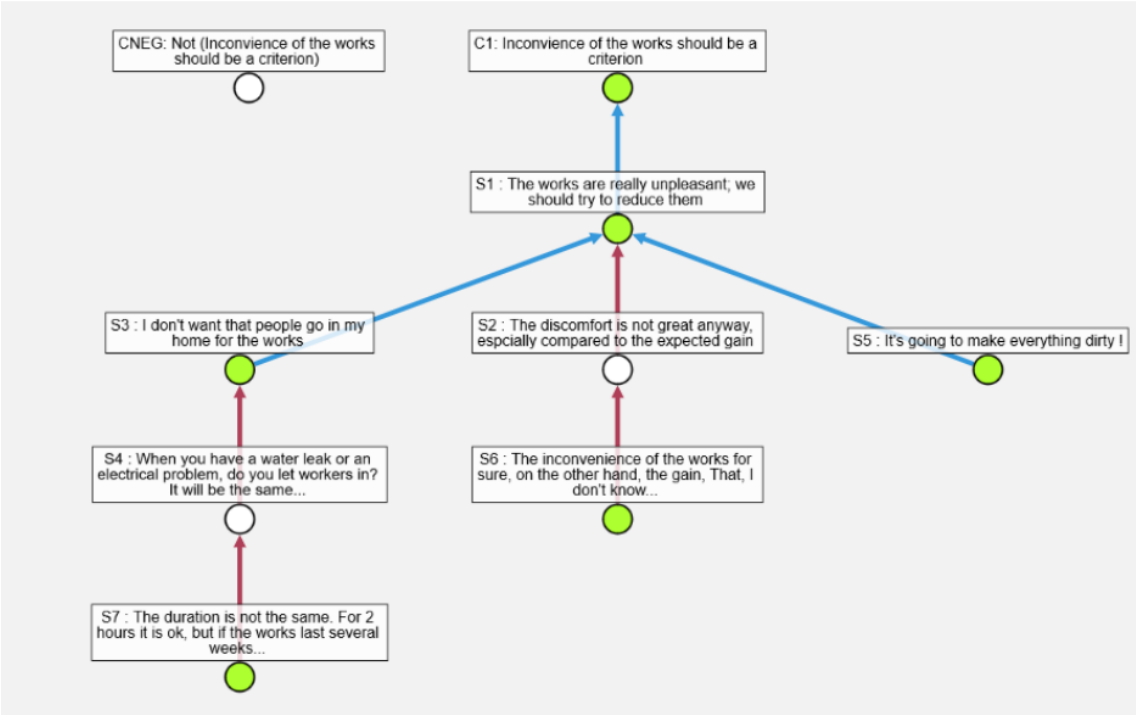


(b) Dung translation

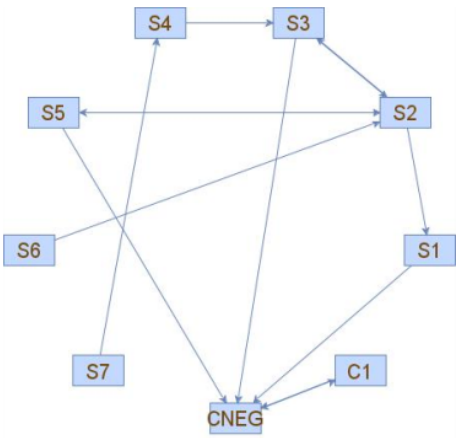
Figure 2.2.7: Argument graph related to "Inconveniences of works" criterion with 6 statements

Tenant answers a previous argument estimating that the comparison between urgent interventions and works which can last several weeks are not the same. This new argument (S7) corresponds to a statement against S4. This new argument is indirectly in favor of C1; this information is given by AIPA by selecting the conclusion we want. So, because C1 was already accepted, this new statement does not modify the results on the conclusion, but it allows S3 to be valid Figure 2.2.8. It can be note that the discussion has to be as free as possible, a participant can provide a statement about any previous argument, without any restriction. Obviously, a statement always relates to a previous argument (statement or conclusion), ensuring a tree-like form to the graph structure, but this is the only restriction (logical of

course). However, the facilitator can conduct the debate as he or she wishes, in particular to avoid having the participants camp around certain positions and the dialogue "going around in circles".



(a) AIPA model

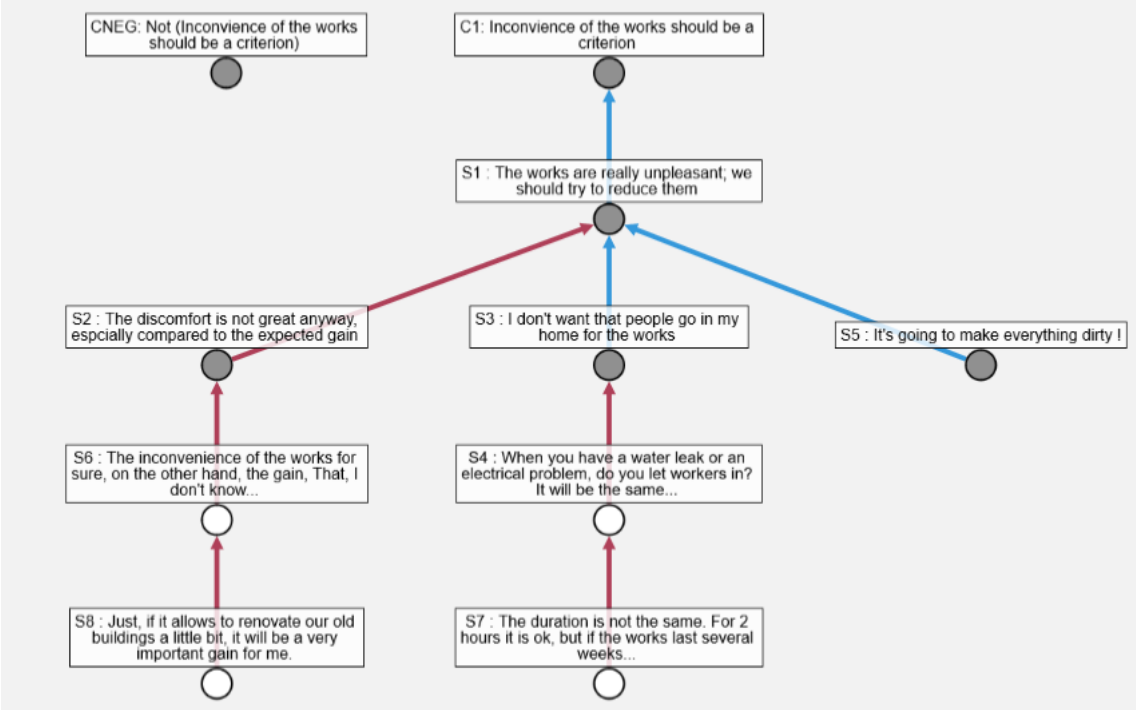


(b) Dung translation

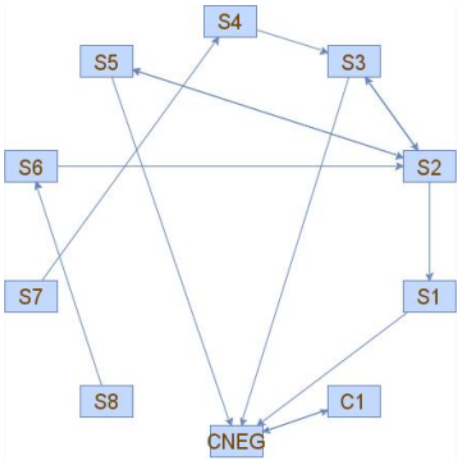
Figure 2.2.8: Argument graph related to "Inconveniences of works" criterion with 7 statements

A statement (S8) against S6 is provided by Technician, arguing the benefits of the works. This statement by making S6 not acceptable modifies the conclusions

status: C1 is no more accepted, and is now in conflict with Cneg (Figure 2.2.9). Indeed, S6 is a key argument, because it allows to defend S1 (the C1 support) from S2. Without this support, S1 becomes in conflict because, as previously, of the conflict between S2 and (S3 + S5).



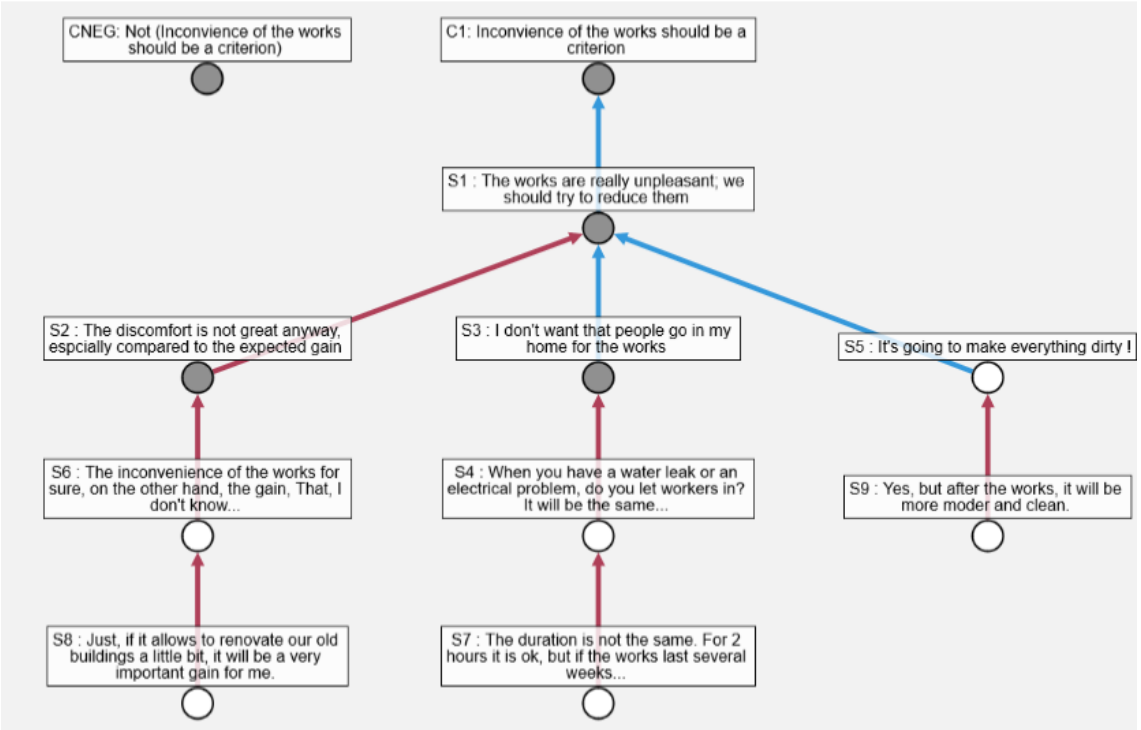
(a) AIPA model



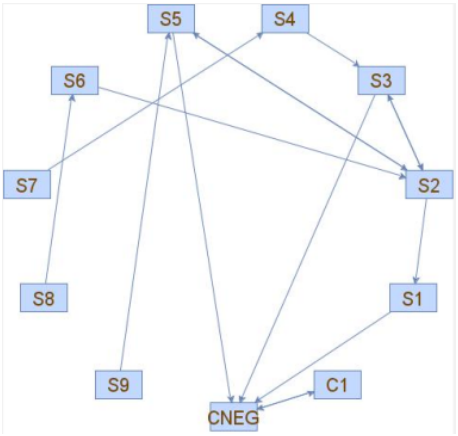
(b) Dung translation

Figure 2.2.9: Argument graph related to "Inconveniences of works" criterion with 8 statements

Finally, a last argument (S9) is provided by Manager to attack S5, arguing that after the works, the building and apartments will be more modern and clean. This last argument which is (indirectly) against C1 do not modify the results regarding C1, which were already not accepted, but it modifies the status of S5 which was "in conflict" and is now "not accepted". Figure 2.2.10.



(a) AIPA model



(b) Dung translation

Figure 2.2.10: Argument graph related to "Inconveniences of works" criterion with 9 statements

Criterion	Indicator	Discussed (Yes/No)	Selected (Yes/No)
Neighborhood attractiveness	number of actions on the facade	No	No
Quality of use	number of system actions	Yes	No
Indoor air quality	number of CMV actions	No	No
Thermal comfort	degree hour of discomfort	Yes	Yes
Noise	number of windows actions	No	No
Odors	number of CMV actions	No	No
Floor space	surface floor after action	No	No
Inconvenience of the work	duration of the actions	Yes	No
Investment cost	total cost of the actions	Yes	Yes
Energy consumption cost	total cost of energy	Yes	Yes
Sale value of the building	total cost of the actions	No	No
Energy consumption	total energy consumption	Yes	Yes
Global warming potential	equivalent CO2 emissions	Yes	Yes

Table 2.2.1: List of criteria

As a result, in this discussion, which brings together 9 statements, the conclusion "Inconvenience of works should be a criterion" is not accepted. It means that, based on this discussion, this criterion will not be used in the Multiple Criteria Decision Analysis (MCDA) process.

2.2.2.4 Results

2.2.2.4.1 Step 1. Criteria selection

The first step of the decision process is to select the considered criteria among the pre-built list available in the knowledge base. Of course, it would be possible to add new criteria, not yet defined in the knowledge base, but this implies also defining the associated evaluation rules. The list of criteria implemented in the knowledge base now has 13 criteria Table 2.2.1.

It is not necessary for participants to discuss all of the criteria. By default, a criterion is considered "not selected". At the very least, a participant must express one argument to defend the choice of the criterion in order for it to be retained. We recall that since the criteria are not mutually exclusive, in AMHORE there is one discussion instance per criterion. Among the 13 criteria, as presented in the Table 2.2.1, 8 criteria were discussed. It led to 8 argument graphs.

In order to illustrate the results, we present the argument graph related to the energy consumption Figure 2.2.11 criterion, and the graph related to the quality of use Figure 2.2.12. The energy consumption was defined as a criterion to consider; i.e. the conclusion "the energy consumption should be a criterion" is accepted in the AIPA graph. AIPA gives the set of arguments which explain the acceptation of this conclusion; in this example the explicating arguments are: S4, S3, S9, S1 and S7; they are in green color in the AIPA graph (Figure 2.2.11). Indeed, S1 is the main argument of this structure: by its support to C1, it allows this conclusion to be accepted.The two statements S3 and S4 which target S2 allow this argument to be

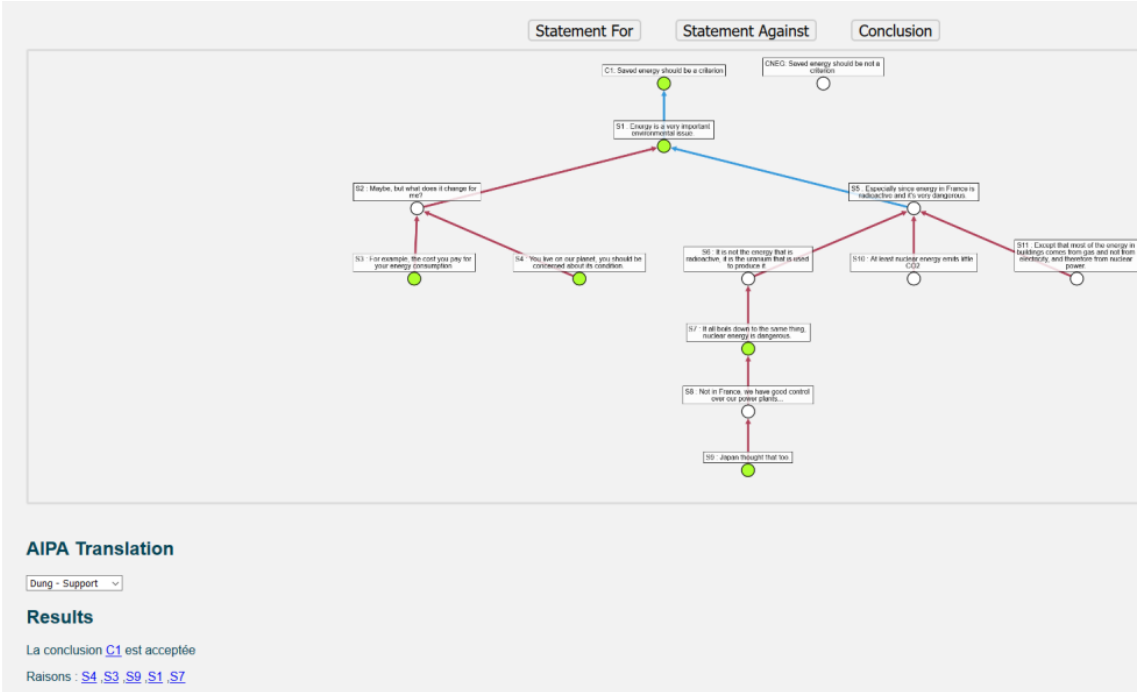


Figure 2.2.11: Argument graph related to the Energy consumption criterion selection

not accepted whereas S2 attacks S1 which is support the choice of the saved energy as a criterion. So S3 and S4 can be viewed as counterarguments defending S1 against S2. In addition, S7 attacks S6 which itself attack the statement S5 supporting S1. It is then a counterattack defending S5 and so S1. Finally, S9 allows to attack S8 which attacks S7. Without this argument, S7 would be considered as not acceptable.

The second example we want to use to illustrate the process is the discussion related to the quality of use. This criterion was discussed but not selected, as shown in the argument graph Figure 2.2.12. The criterion was not accepted because, the conclusions C1 ("The quality of use should be a criterion") and Cneg are in conflict. In this case, AIPA provides as an additional information the arguments to attack to solve the conflict. These arguments correspond to those which are in conflict. In this case, because the conflict situation concerns only C1 and Cneg; it is formalized on the AIPA graph by the grey color of the node. By attacking one of these two arguments it is possible to solve the conflict, and so to make accepted the opposite argument.

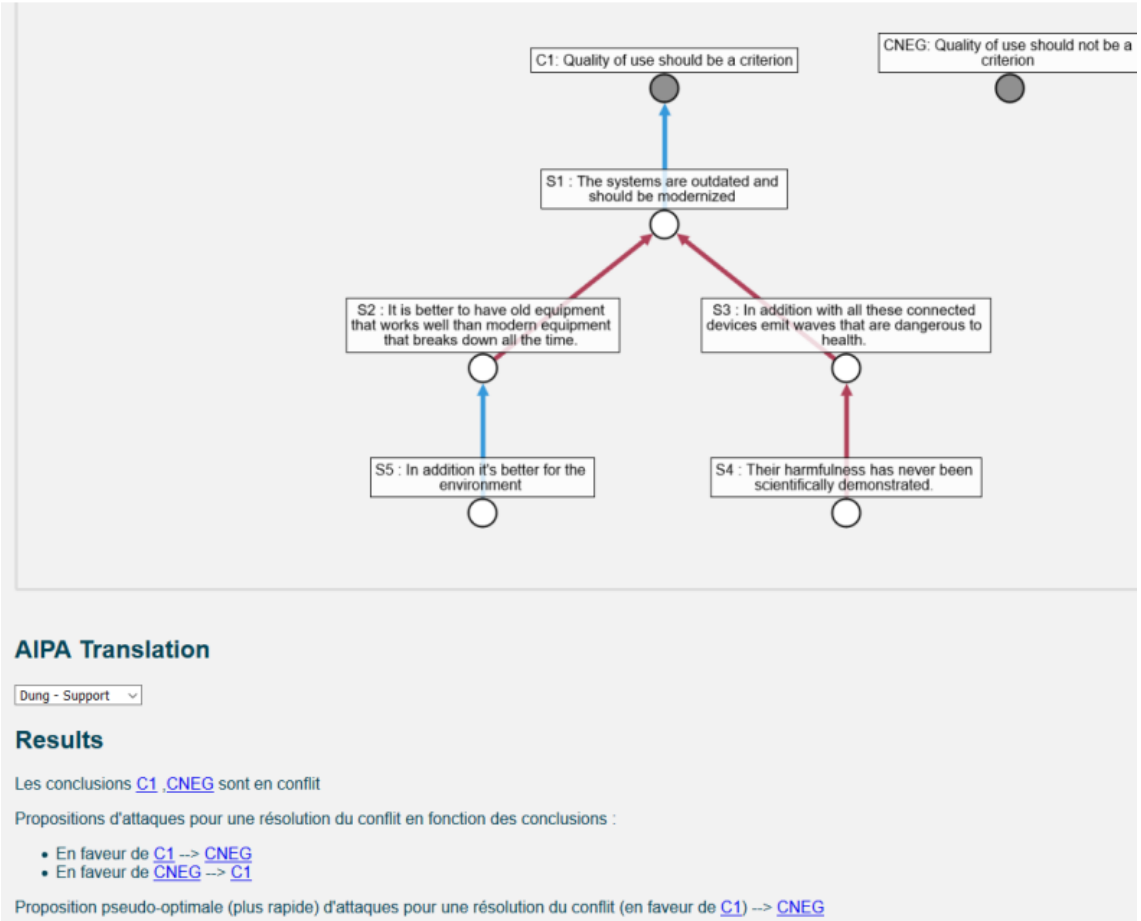


Figure 2.2.12: Argument graph related to the Quality of use criterion selection

During this phase, 8 criteria were discussed; during these discussions, 43 statements have been expressed. It made it possible to put forward 4 criteria, which will be selected: the investment cost of the strategy, the saved energy, the greenhouse gas emissions and the thermal discomfort.

2.2.2.4.2 Step 2. Preferences parameters

Phase 2 (i.e. definition of the parameters) consists in formalizing the preferences of the different stakeholders. Because, we used the lexicographic approach, the preferences are modeled as a ranking between the criteria importance. The stakeholders therefore had to express arguments to construct the order of importance of the criteria. The proposed method makes it possible to manage equality between the preferences of the criteria. Moreover, by default all criteria are equal as long as no argument has been expressed. The starting point is the situation: saved energy = discomfort = CO2 = investment. As it was explained in the previous chapters, to construct this ordering, the criteria are compared in

pairs. Thus, with 4 criteria, 6 discussions must be carried out: energy Vs discomfort, energy Vs CO2, discomfort Vs investment and CO2 Vs investment. For each, there are three possible conclusions corresponding to the three comparators: $<$, $=$ and $>$. As example, we presented in Figure 2.2.13, the discussion which aims at comparing the saved energy criterion and the comfort criterion. This discussion results in the prioritization of the energy criterion on the comfort criterion. The statements which explained this result are S6, S3, S5, S9 and S4.

One question that may arise is the difference between making a StatementFor X>Y, and a StatementAgainst Y>X. From the moment that these conclusions are in strict opposition, it is indeed possible to think that these two statements would be identical. However, there is a nuance between these two choices, due to the presence of the third conclusion "X=Y". A StatementFor will induce a posture putting the argument defended in front of all the others with which it opposes, whereas the statement against will express an attack on only one argument. For example, here, the argument S6 which claims that environmental issues are more important than personal comfort, is, in this debate, a statement for C3 (Energy > Comfort). In the Dung translated graph, this argument attacks C1, C2 and Cneg. If it was expressed as a statement against C1 (Comfort > Energy), it would be translated into an attack against C1 and only against C1 (C2 and Cneg would be not targeted). It is important to consider this point when formalizing a statement in AIPA. This point, as the importance of the structure of argumentation will be more deeply discussed in the discussion section.

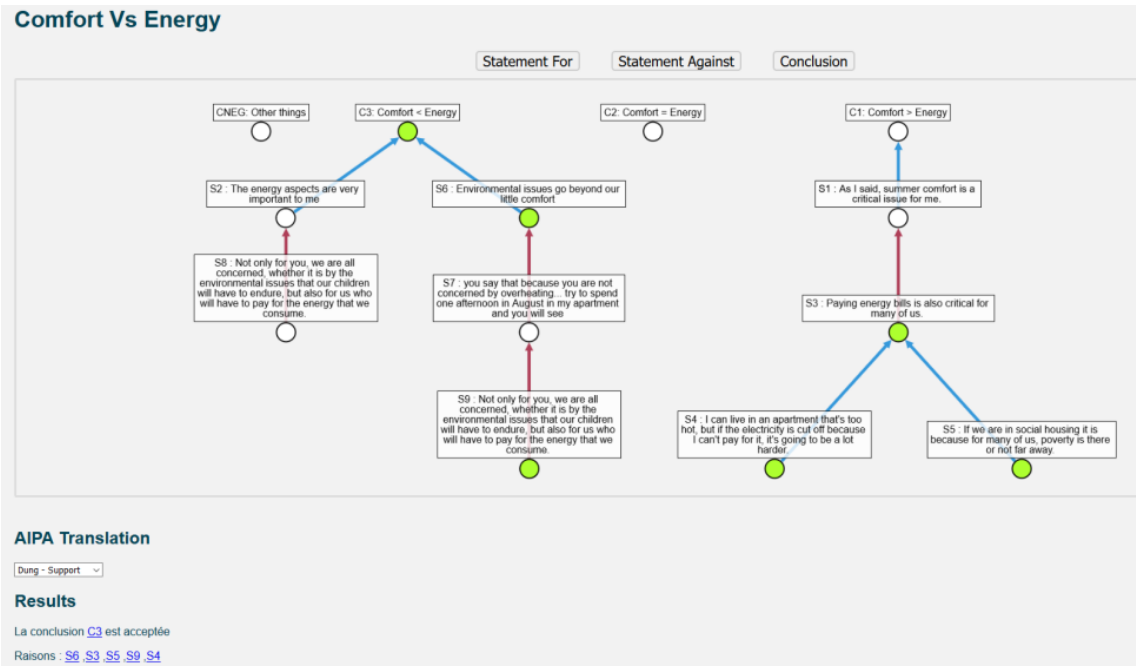


Figure 2.2.13: Argument graph related to the comparison between Comfort and Energy criteria

Table 2.2.2: Top 20 Ranked alternatives

Rank	Id	Energy (MWh)	Discomfort (h)	CO2 emissions (TeqCO2)	Investment cost (k€)
1	St1	17271	21196	5116	13305
2	St2	17955	18393	5049	13154
3	St3	18835	17464	5541	13148
4	St4	19079	19130	5436	12985
5	St5	19316	18097	5440	12960
6	St6	19983	21005	6178	12927
7	St7	20220	19082	5323	12801
8	St8	20533	18194	5579	12770
9	St9	25291	15280	5667	12234
10	St10	25569	8618	5701	12194
11	St11	25713	9935	5711	12119
12	St12	25861	14915	5748	12064
13	St13	26901	11808	5575	11861
14	St14	29307	7050	6591	11794
15	St15	29954	11352	7068	11757
16	St16	31019	6679	5844	11676
17	St17	31344	15386	5958	11279
18	St18	32126	15113	6283	11254
19	St19	32413	13011	5796	10972
20	St20	32965	13227	5476	10910

In total, in this phase, 41 arguments were expressed. The final result of this phase is as follows: energy > discomfort > CO2 > investment.

2.2.2.4.3 Step 3. Running the MCDA

Based on the results of the previous phases, and thanks to the MCDA method, we are able to rank the different alternatives. The Table 2.2.2 lists the top 20 alternatives among the 216 pareto-optimal solutions; i.e. those which were the best ranked by the MCDA.

2.2.2.4.4 Step 4. Discussion the MCDA results

This last phase let the different stakeholders discuss the MCDA results. As we explained before, the participants can estimate that the results from the MCDA are acceptable and end the process at this point. So they would select the best ranked solution (here, St1). But sometimes, they prefer to discuss the alternatives ranking. We consider in this example that the different stakeholders prefer to discuss the MCDA results.

Initially, even before the discussions begin, due to the results of the MCDA, the graphs presented in Figure 4 are generated automatically. By default, AMHORE propose to discuss the 3 best ranked solutions; however, it is possible to add or to remove alternative to discuss. At the beginning, the strategies St1, and St2 and St3 are discussed. This graph naturally proposes to accept the conclusion "Strategy 1 (St1) should be selected" due to its top-ranking.

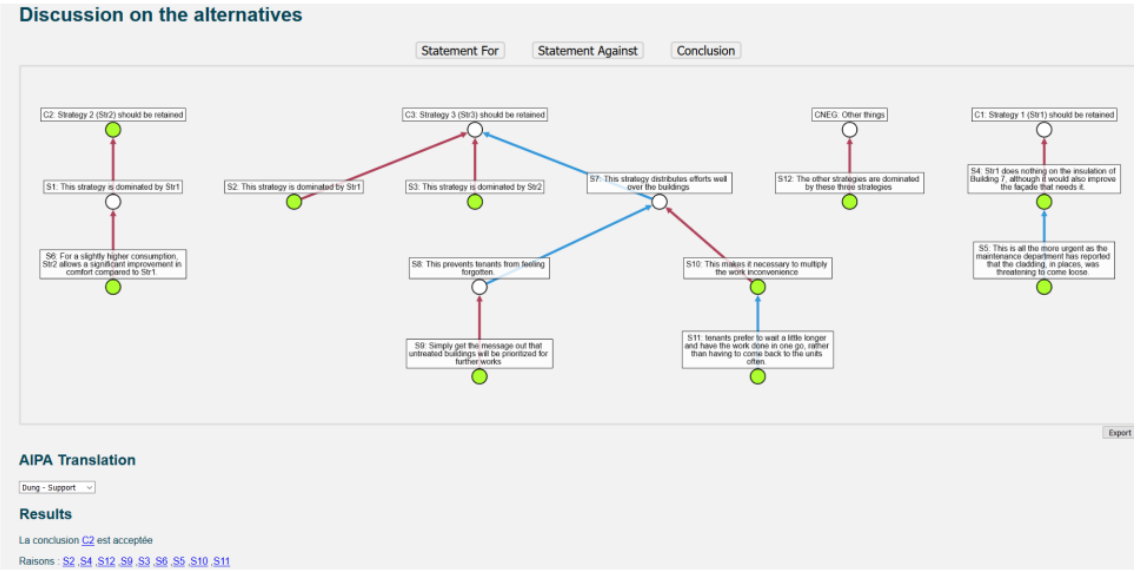


Figure 2.2.14: Argument graph related to the discussion on the alternatives

The different participants will be able to put forward arguments. In this application, 12 new arguments were expressed during the discussions, as shown in Figure 5. This led to a modification of the results; with these new arguments, strategy 2 (St2) was chosen on the basis of the calculation of extensions by Dung's approach. Indeed, the conclusion C1 which propose to select St1 (the best ranked solution) was attacked by a statement and not defended. At the opposite, a statement defend the choice of the strategy 2 (conclusion C2). It is always possible for one of the participant to add another statement which will potentially modify the results. The participants can also add a new alternative to discuss (for instance Str4, or a variant of an existing alternative, e.g. St1bis). This is considered as a new conclusion by AIPA which will be confronted to the other conclusions and Cneg. Here, we consider that all the members of the decision team are satisfied by the results and the debate ends on the selection of the Str2 action plan.

2.2.3 Discussion

Several points can be discussed regarding the used method. Some concern the global methodology and other specific features. We will expose these different elements of discussion in this section. The issue is not to be exhaustive regarding all the elements of the method, but, at least to promote reflection on points which appear to us as very important.

2.2.3.1 Discussion related to the AMHORE process

2.2.3.1.1 Interest of the ArguedMCDA approach

The interest of coupling the MCDA with the argumentative approach is to better justify the choices that are made; the choice of criteria and parameters are crucial for the results. However, the discussions that guided these choices are rarely formalized in the classic use of the MCDA. AIPA responds to this need and thus fills a gap in the traditional MCDA. In addition, we advocate an approach that puts discussions at the forefront. We believe that in this way the results are better accepted, or at least understood, by the various stakeholders, and this could increase the acceptability of the retrofitting project. Moreover, with this approach, one can integrate parameters or elements that are difficult to integrate in a classical MCDA (e.g. singular situation for a building). This is why we believe that Phase 3 is important: the final choice is left to discussion, the MCDA is a sorting aid, but does not give the answer. Of course, our approach also has limits. It requires more involvement from the different stakeholders than a classical decision support method. It also requires a form of benevolence, or at least a willingness to maintain a dialogue. In a situation of conflict between participants, the debate can turn short, each one remaining stuck on her/his positions without accepting the discussion. In such cases, the contribution of a facilitator is crucial.

2.2.3.1.2 Leading the discussions

The role of the facilitator The debate should be as free as possible during each phase. For example, a participant can express an argument on the "Cost of Investment" criterion, then talk about the "Comfort" criterion, and then return to the "Cost of Investment". However, the facilitator must still be able to structure the debate, not by forcing the subjects, but rather by emphasizing the points that seem important. In the same principle, the different phases of the AMHORE process are successive, but it is always possible to return to a previous phase. For instance, the debate on the preferences may bring up the need to add a new criterion. The facilitator has the role to lead the process and can propose to re-open a previous debate if some of the participants want to add new arguments. Of course, it must not be a technique used by participants to block the process. The facilitator must estimate the legitimacy of this re-open of the debate. It has a key role in the process.

Impact of the role playing game For the application, we could not test AMHORE in real conditions. Indeed, we have simulated the game of the stakeholders by proposing ourselves the arguments. This induced several differences compared to a real use of the tool and model. First of all, there was no need to do any facilitator work. Obviously, even if we simulated contradictory opinions, we always made sure to respect the arguments of others and to follow the

rules of the debate. This can be much more complex in a real situation, especially if there are particular tensions or actions that are highly controversial. Moreover, in all simulated discussions, there has always been a clear outcome (i.e., a conclusion that is ultimately accepted). It may happen that the discussions do not lead to an accepted solution (e.g. all conclusions are in conflict), without the possibility of adding new arguments to advance the debate, with each participant remaining entrenched in his or her position. In this case, the Dung system may show its limitations. One response may be to use a different AAF. This point is discussed in a following section.

2.2.3.1.3 Added value of WebAIPA interface during the debate

The construction of the argumentation graphs based on discussion between the decision team members is the central points of the method we proposed. In this perspective AIPA is a strong support to ensure the good processing of the debate. In order to argue this assertion, we will detailed the information that AIPA gives and which appear to us as relevant for the facilitator to lead the discussion and for the participant to understand the issues of the debate.

This first information is the graph representation which facilitate the following of the debate and the positioning of the arguments. By forcing the participants to explicit their arguments in a dedicated form, the participants must expose and clarify their thoughts to the other participants. It favors the reflection and clarification, and so the exchanges between the participants. The argumentative structure in a tree-like form is also useful for understanding the participant's reasoning by presenting structured and explicit information, are more easily understood by all.

The second information provided by AIPA, simply through the color set on the nodes is the acceptation of arguments. By using a simple code: green, white and grey which are respectively used for accepted, non accepted and in conflict arguments, AIPA allows all to rapidly understand the key arguments. The facilitator can, for example, put forward the arguments (statement and conclusion) that are accepted, in order to focus the debate on them. Assessing acceptability is therefore of real interest in the debate, and not simply to define the status of the conclusions. For instance, in Figure 2.2.15, arguments C1, S1, S2 and S6, in green, are accepted and the other, in white, are not accepted.

In addition to this information, AIPA makes it possible to track all the arguments in favor of a conclusion. By clicking on a conclusion, a simple blue/red code indicates the pros/cons arguments. For example, in Figure 2.2.15, arguments pro C1 have a blue border (e.g. S3 and S6) and those against C1 have a red border (e.g. S4 and S5). This makes it possible to quickly grasp the pros and cons arguments for a conclusion, again making it easier to guide the debate.

Finally, a last piece of information given by AIPA is the list of arguments explaining a result as we already exposed. For example in Figure 2.2.15, the statements which explained the acceptation of C1 are S1, S2 and S6. This

information can help the participant to understand a result, and the arguments which make it founded.

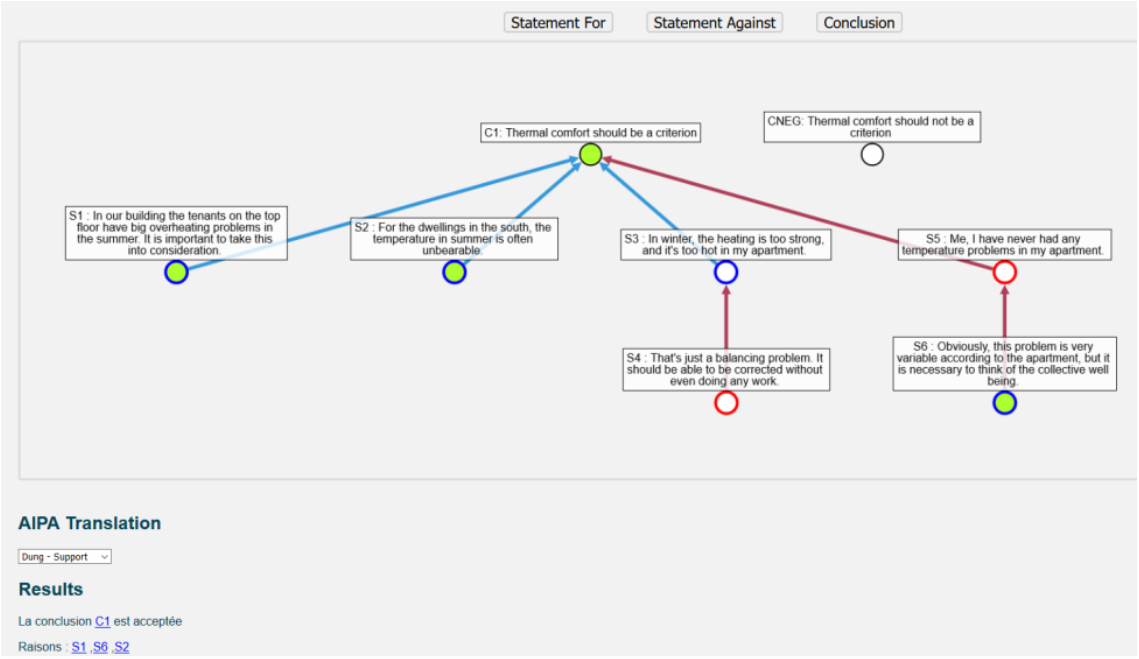


Figure 2.2.15: Example of the pros/cons visualization in AIPA

2.2.3.2 Methodological discussion

2.2.3.2.1 MCDA method

The AMHORE approach is independent of the multi-criteria method used. However, it is still necessary to specify the method to be used, in particular to define the parameters of the method, including how the preferences of the decision-makers are formalized. In a first approach, we choose a lexicographical method. This approach has a major advantage: it requires few parameters. On the other hand, it also has many drawbacks, starting with its non-compensatory nature. If we consider two alternatives A1 and A2, with A1 slightly better than A2 on a criterion C1 considered to be the most important, but much worse on all the other criteria, A1 will be preferred to A2 with our approach. This is obviously open to criticism. Its non-compensatory nature means that certain compromise solutions may be completely rejected. To answer this point, it should be recalled that the ArguedMCDA approach can be used regardless of the MCDA chosen. For example, ELECTRE (Roy, 1990) and AHP (Saaty, 1984) could replace the lexicographical method, which was chosen here simply for its simplicity. However, a method such as ELECTRE III (Roy, 1990) requires many parameters increasing the length of the discussions on the parameters. This is obviously not desirable and can blunt the motivation of the participants. There is therefore a trade-off to be made between the number of parameters and the

finesse of the chosen MCDA. In this, AHP or PROMETHEE (Brans et al., 1986) could be a good choice.

2.2.3.2.2 Dung AAF

For AIPA, we have chosen to use Dung's classical AAF, rather than its derivatives, which allow us to take into account the values of arguments or attacks, their uncertainties... We justified this choice with two main arguments: the limited number of parameters and its capacity to emphasis the discussion. Indeed, regarding the first point, the Dung AAF does not require any additional parameters or value related to the argument in addition to the argument itself. It is really important in a live debate context in which a facilitator will have to enter the argument in the tool. Furthermore, it avoids the problem of how and who have to enter the parameters (e.g. the strength or the uncertainties related to an argument). In addition, it is based on the assumption that the conflict can be solved by the discussion. It is an optimistic vision on the debate that we advocate. The application, due to the use of "played" stakeholders, did not allow to test this hypothesis. But, we know that sometimes when opinions are too conflicting, this posture is not tenable. For these situations, the used of other argumentation frameworks, such those proposed in the Chapter 1.2 (e.g. value based framework) could be an alternative to consider. This point is discussed in the perspective section of the Conclusion of this manuscript.

2.2.3.2.3 Explicative argument

As exposed before, AIPA provides a list of arguments that explain the acceptance of a conclusion. Technically, this corresponds to the accepted statements that are in favor of a conclusion. However, the explicating arguments set does not correspond to the arguments necessary to obtain a result. We can consider an example to illustrate this point. if we consider the Figure 2.2.16 graph, we can remark that C3 is the accepted conclusions and it is explained by S1, S3, S6 and S5.

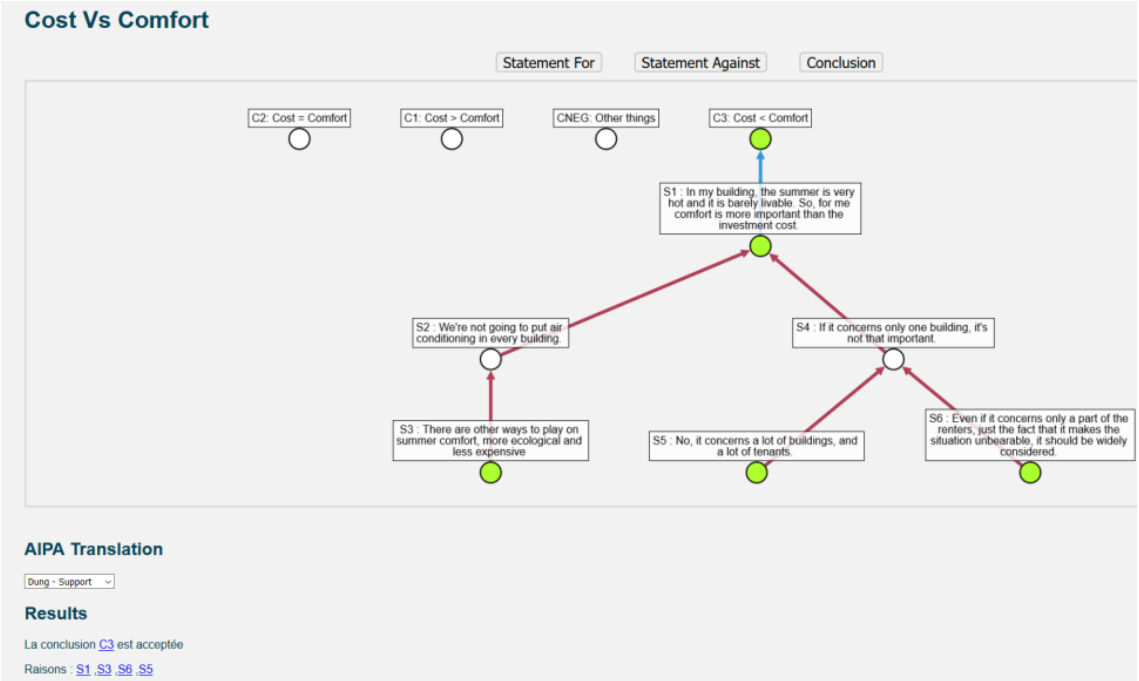


Figure 2.2.16: Argument graph related to the comparison between Comfort and Energy criteria

For example, here, statements S5 and S6 are valid arguments going in the direction of C3; this is the reason why they belong to the explicative arguments set. But if one of them were absent, the result would remain the same. The arguments which are required for C3 to be accepted are S1, S3 and (S5 or S6). However, we can state that the required arguments to explain a results is a set of statements belonging to the explicating arguments. This statement is just an observation based on the analysis of numerous argument graphs. However, a mathematical demonstration would be required in order to ensure its validity. It was not performed during this PhD and remains on open question.

2.2.3.2.4 Sensitivity and validation

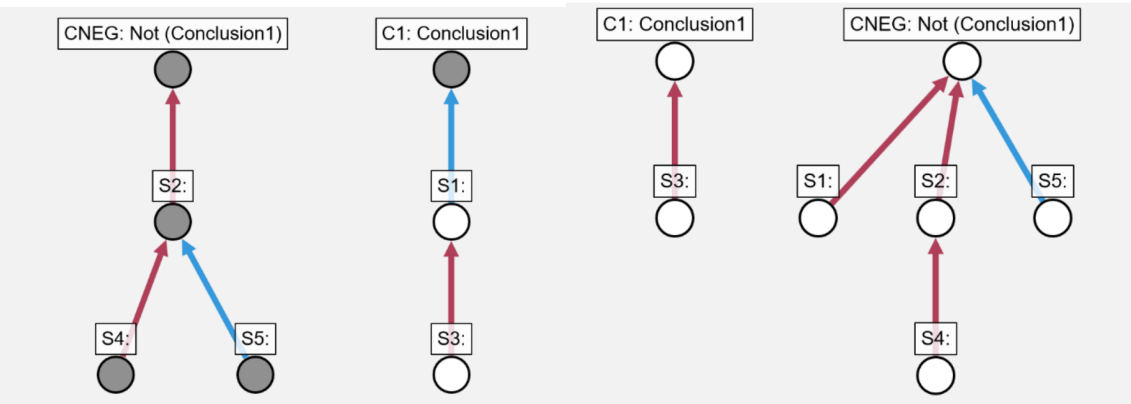
Validation A classical issue in science is related to the validation of the results. In decision support, the notion of validation has a special meaning, where there are no observation with which to compare results. At best, we can have results that decision-makers would like to obtain, or that they would find logical to obtain, but this does not tell you what the "right solution" should be (Taillandier, 2018). However, it would be possible to test the approachin real conditions and collect the opinions of the different participants involved. The validation would then not be quantitative, but qualitative, focusing on the perceived contribution by the stakeholders. This would be very interesting to do, but could not be during this thesis. It remains a perspective.

In addition, it is strongly recommended to conduct sensitivity and robustness analyses (Roy, 2013). Conducting such analyses often requires facing two difficulties: calculation time and the intervention of the decision-maker(s). For the first point, this is particularly problematic for optimization approaches as those used in REHA-PARCS. Merlet et al. (2018) raised the question of the robustness and sensitivity of its optimization approach in the perspective of the thesis, without answering it. But, regarding AMHORE, it is not the main difficulty. As we exposed, AMHORE was designed to perform real time calculation in order to be able to be used in real time debate. The real difficulty is regarding the second point, because sensitivity and robustness analyses require repeating the process a large number of times and this is obviously impossible with a real decision-maker. The modeler can do a random exploration. it can be useful to ensure the consistency of the approach and detect main failure or inconvenience, but it provides little information on the actual robustness or sensitivity of the approach. Some authors advocate the use of automated decision-making (Wu and Tiao, 2018). This makes sense in many operations research methods, but makes not with an approach such as AMHORE, which is primarily dialogue-based and very difficult to automatize. One can artificially construct argument graphs, but then one loses all connection with semantics. For these models, only tests and experiments can provide interesting feedback on the results. Of course this does not prevent us from asking questions about the sensitivity of the model to certain parameters. In this perspective, we will question, in the following, the impact of the translation and of the structure of the graph.

AIPA translation AIPA provides different translations. In the Chapter 1.2, we presented the support and the optimistic translations. One question that could then arise would be the impact of the choice of translation on the results. The entire application was made with support translation. In order to see the influence of this choice, we can recalculate the results using the optimistic translation. The results with this translation are exactly the same as those obtained with the support translation. Indeed, in the case of these graphs, the change of translation did not induce any change on the conclusions accepted or not. However, this does not mean that this can be generalized to all examples. As we exposed in the Chapter 1.2, the optimistic translation is more permissive, allowing to solve some conflictual situations; i.e. with some graph configuration, an conclusion can be accepted with the optimistic translation and not with the support translation (the reverse never being true). Thus as we exposed, the choice of a translation will depend on the will or not, to leave the debate to resolve the conflicting cases on its own or if it is considered that the method should be involved. However, as the example has shown, this is not necessarily such an impacting choice; in fact, it is above all the argumentative logic that is put forward whatever the translation. Thus, the results often converge, even if it remains an important modeling choice. It should be noted

that this also has an impact, and a stronger one, on the explanations. It is therefore a challenge for the facilitator to understand the impact of these two translations to select the mos appropriate.

Graph structure Another point which can be discussed is the AIPA graph structure. Indeed, for some statements, several choices are possible regarding their formalization; e.g. Is this statement a support for this conclusion or an attack against an opposed argument? Is this statement attack the conclusion or the statement supporting it? Making different choices regarding the argumentative structure impacts the results. The question that arises is the sensitivity of the method to these modeling choices. In order to illustrate this point, we consider Figure 2.2.17 which illustrates two variants of an example of AIPA graph. In the first variant, S1 supports C1 and is attacked by S3, and in parallel, Cneg is attacked by S2 which was attacked by S4 and supported by S5. In the second variant, S2 and S4 have the same structure, but the they are some modifications regarding the other argument while keeping the argumentative logic; here, S1 attacks Cneg (and not support S1), S3 attacks directly C1 (and not S1), and finally, S5 supports Cneg (and not S2). For this example, the support translation was used, but the results are equivalent with the optimistic translation. Neither conclusion is accepted regardless of the structure (or translation). In the first case, the conclusions are in conflict and in the second case they are not accepted. This obviously makes sense, but the logic of having neither of the two accepted conclusions is respected.



(a) First variant of an example of AIPA graph (b) Second variant of an example of AIPA graph

Figure 2.2.17: Two variants of an AIPA graph

Obviously, a single example is not enough to draw a global lesson. We tend to think, from all the graphs treated and analyzed during this thesis, that the argumentative logic tends to prevail and ensures an overall coherence of the results, limiting the impact of the graph structure if the meaning of the graph is preserved.

However, this question deserves, of course, a deeper treatment and further analyses. The sensitivity to the structure of the graph thus remains an open question.

2.2.4 Conclusion

In this Chapter, we presented an application of the AMHORE method, which is an instantiating of the ArguedMCDA approach dedicated to help social landlords developing a strategy for retrofitting their housing stock. The application allows to highlight the functioning and the interests of the AMHORE method. However, the exploitation of the results was limited by the fact that we were not able to conduct the experiment in a real setting with real stakeholders. We had to be satisfied with an application on a virtual park for which we ourselves played the role of the various stakeholders. In spite of the limitations of this exercise, it was nevertheless useful both to illustrate the approach and to expose the results that AMHORE would allow to obtain. Finally, this application also highlighted the limits or at least points of discussion of the approach. These aspects may give rise to perspectives. We will come back to them in the General Conclusion of this manuscript.

Conclusion

In the introduction to this thesis, we expressed an hypothesis that we have pursued throughout this work: the combination of multi-criteria decision aid and abstract argumentation can help to answer the decision problem posed by the multi-objective optimization of the retrofitting of a building stock. This assumption was confronted to three scientific locks: (1) How to make abstract argumentation operational so that it can be used in a real application with a group of stakeholders in real time; (2) How abstract argumentation can be coupled with multi-criteria decision method; (3) How can this approach be used in combination with multi-objective optimization in a building retrofitting planning problem?

Summary of the chosen approach

The objective that we tried to pursue was to give arguments in favour of this hypothesis and solve the scientific locks. Through the 2 parts and the 6 chapters, we developed approaches, methods and tools in this objective. In the first chapter, we provided a state of the art regarding computational argumentation and concluded on the lack of methods and tools dedicated to participatory approach. We also highlighted the interest of abstract argumentation framework (Abstract Argumentation Framework (AAF)) to answer this need. Based on this statement, in the second chapter, we presented Argumentation Interface for Participatory Approach (AIPA), a model which operationalize the AAF to support participative decision-making. AIPA allows to formalize in live debate the arguments of the participants and provides different meaningful information as the acceptability of the arguments or the arguments which explain a result. AIPA was applied to an application case in order to illustrate its functioning and interest. In the third chapter, based on the observation that the use of AIPA is not in itself sufficient in case of numerous alternatives, we proposed to couple AIPA with a Multiple Criteria Decision Analysis (MCDA) approach, proposing a new approach called ArguedMCDA.The first part, with these three chapters, was then dedicated to provide new decision aiding approaches combining argumentation and MCDA. These elements can be used together (MCDA + AIPA) or separately (e.g. the argumentative approach alone) and for any domain of application.

The second part of the manuscript was dedicated to instantiate these approaches

to the domain of the building retrofitting.In this objective, in a first Chapter, we presented the decision problem related to the planning of the building retrofitting of social housing stock. Based on this analysis, we proposed in the second chapter of the second part an approach called Argued Mcda for HOusing stock REtrofitting (AMHORE), based on the ArguedMCDA to answer the need posed by the problem of the building retrofitting.Finally, the last chapter of this second part provided an application of AMHORE to a virtual housing stock. This allows us to illustrate the functioning of the method but also to discuss the results and the approach itself.

Contribution

If we were to summarize the scientific contributions of this thesis, we could evoke :

- Argued Discussion Model (ADM) (Argued Discussion Model): A model of argument allowing to make the link between natural language and AAF.
- AIPA : A model dedicated to supporting participatory decision support approaches based on AAF and ADM.
- ArguedMCDA (Argued MultiCriteria Decision Aiding): A decisional approach approach combining argumentation (AIPA) and multi-criteria decision support.
- AMHORE (Argued Mcda for HOusing stock REtrofitting): A participative approach dedicated to the planing of building retrofitting for housing stock.
- WebAIPA: The implementation of the previous approaches and models; it is an operational prototype which was implemented as a web application.

Each of these contributions has been the subject of a detailed presentation in this manuscript and has benefited from examples in order to explain their value. We have also tried to expose the limits of these methods and tools through discussions. These contributions have or will be valued through articles. However, this work does not intend to provide a definitive answer to the question posed and the limits explained are as many new avenues of research. These elements are the subject of the last part of this conclusion, which will aim at exposing the research perspectives.

Perspectives

This manuscript, like all research work, does not seek to close doors and debate, but rather to open them. The elements provided are already as many contributions to research field and to decision support, but they also raise questions, leading to new projects and works. In a first section, we will discuss the methodological perspectives in order to consolidate the proposed approach or at least that could

complement it. Secondly, we will look at how and what the results of this work can be used, particularly in other contexts than that of building retrofitting for housing stock.

Methodological perspectives

The previous chapter dedicated to the application of AMHORE allowed to ask several methodological questions that are still pending. We will detail the perspectives that this offers.

MCDA We have highlighted the limitations of the MCDA approach we used (i.e. the lexicographical approach), notably because of its non-compensatory nature. We thus concluded on the need to propose other MCDA methods. As we have said, even if theoretically most of the methods can be used in the Argued MCDA framework, the number of parameters is a limiting factor; it is indeed difficult to push the decision team to discuss in detail all the parameters if they are very numerous. If this is conceivable in a setting with a limited number of decision-makers with similar opinions, it is very difficult to contain discussions that lead to strong opposition and thus a lot of arguments. The use of the argumentative approach could become very tedious if the parameters to be discussed are too numerous. We have therefore suggested that approaches such as AHP and PROMETHEE (or ELECTRE I or II) could be adapted. These methods have the advantage of being widely tested, easily implemented, and require no significant resources in terms of computational time. The principle would therefore be to implement these methods in WebAIPA and let users choose the MCDA they prefer. From a methodological and implementation point of view, this does not induce any particular difficulties because these methods are very well documented and there are even libraries already available in different languages to implement them. The main difficulty would come from the interface to be created in order to ensure that these methods are easily usable by users. This is a work that could be done quickly.

AAF We use in AIPA the Dung's AAF. We justified this by two main arguments: the limited number of parameters and its capacity to emphasis the discussion. But, when opinions are too conflicting, the use of this AAFmay lead to blocking situations. A way to solve this problem would be to use another argumentation framework as those exposed in the Chapter 2.1 (e.g. value based argumentation framework, bipolar argumentation framework...). These frameworks are well documented and are supported by available inference engine. But all these frameworks require additional information (e.g. value, strength or uncertainties of arguments or attacks), and the question arises as to how to access this information. There is no single answer to this question. We propose here three propositions that could answer this question. The first is simply a question of the framework of use. So far, we have advocated the use of AIPA in a live debate in a

participatory approach. However, AIPA can be used in other contexts where adding information is much less problematic. For example, we present in the following sections an application of AIPA in forensic engineering, where a panel of experts must investigate the failure of a structure. In this application, AIPA is combined with an evaluation of uncertainties by experts who can take the time to fill in the necessary information (i.e. uncertainties on statements). This application is more detailed in a next section. The second proposition consists in assessing the strength of the statements. To do so, we propose to couple AIPA with a like system already widely used in social networks. Indeed, the current system takes note of the arguments, but not of the infatuation it arouses. A way to consider it, would be to use a system for the participants to the debate to show their support or their opposition to an argument, not by proposing a new statement, but with a like or a dislike on a statement. The like and dislike would be used to compute the value of a statement. This requires an interface for the participants to formulate their likes/dislikes, and the capacity for AIPA to translate the AIPA graph into an AAF considering a value on the argument and/or attack. Finally, the last proposition consists in integrating a voting system to solve blocking situation. With this proposition, we keep the Dung AAF to compute the acceptability of the conclusion. But, when a conflict between argument occurs and cannot be solved by discussion, the facilitator can ask for a vote; the participants would have to select among the arguments in the balance, the one that has their preference. The result of the vote would be translated into a new argument solving the conflict. This approach is interesting because it does not fundamentally change the approach used. On the other hand, it raises the question of the representativeness of the decision-making team, the power of decision and the confidentiality of votes. It would be necessary to find suitable modalities to propose such an arrangement, and to provide the appropriate interface.

Translation In this document we have proposed two translations to move from the AIPA formalism to AAF: support and optimist. In the previous chapter, we proposed some elements for discussion on the impact of the choice of translation on the results. Sensitivity to this choice remains to be analyzed and is already a perspective. But in addition to this one, we have also created two more translations called defensive and passive. These last two translations offer other ways of handling StatementFor. We have chosen not to present them in this manuscript because their interpretation is more complex and we ourselves would need more time to fully understand their meaning and measurement. In perspective, we could thus analyze these two new translations so that we could also propose them in AIPA.

Validation As we discussed in Chapter 2.2, the question of validating our approach is a sensitive issue that is both important and difficult. It is important because, like all scientific work, it must be a guarantee of the results that the method can

produce. However, it is complicated because the method can hardly be automated. If it is not possible to validate the approach entirely, it is possible on the other hand to validate some elements. In order to perform such validation, we need two elements: applications with feedback from the participants to ensure the relevance of the approach and tests on the model to ensure its consistency. For the first point, an experiment has to be set up; we already think about the way to organize it, but we still need to move on the work. Regarding the second point, we are going to create a set of test graphs to test the consistency of the rules we introduced in AIPA, test the different translations, etc. For this point also, the experimental design has been thought through but not yet implemented.

Applicative perspecives

As a testimony of the richness and the interest of the approaches we developed in this work, it was and will be used in other decision-making contexts. We will cite here four projects or works that partially or completely reuse the decision support approach developed within the framework of REHA-PARCS:

Past projects

PICS-CADAU project (2017-2019) CADAU used the Argued MCDA approach which were developed in this thesis, in order to provide decision support in urban planning. Indeed, urban planning is an important issue for all cities. Nonetheless, designing an urban planning project in a sustainable development perspective, where economic, social and environmental dimensions must be taken into account, is a quite complex endeavour. The presence of multiple stakeholders with different points of views and different objectives must be considered explicitly. To address this challenge, the CADAU team which gathered researchers from University of Bordeaux, INRAE and University Laval, proposed to use the Argued MCDA to decision making process. This project allowed fruitful exchanges around Argued MCDA and contributed to the version presented in this manuscript. Moreover, it allowed to demonstrate the interest of this approach in a new decision context, i.e. the urban planning.

FEREC-CAIRN (2019-2020) The CAAIRN project aimed at developing approaches to characterize and improve the acceptability of infrastructures by local inhabitants. During this project, the team which gathered researchers from Aix-Marseille University and INRAE focused in particular on infrastructures dedicated to flood and urban stormwater management. The work has led to several advances and offered new insights on the issue of infrastructure acceptability. In particular, the task 4 of the CAAIRN project proposed to use AIPA in order to formalize and analyze the controversies on infrastructure project. The proposed approach has been implemented on a real infrastructure project in

order to illustrate the process and to demonstrate the interest of the results produced. The project CAAIRN propose thus a direct use of the method developed in this thesis, but applied to a new object: the analyze of controversies. It demonstrated that AIPA has a real interest to answer this question.

Current projects

ADEME-ANR-MAIF-MANA (2019-2022) The MANA project is a continuation of the CAAIRN project. It continues to deal with the acceptability of flood-related infrastructure, but this time it focuses on the management strategies based the concept of nature-based solutions (NBS). NBSs are defined by the European commission as solutions which are "inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience". Numerous works (projects, articles, etc.) have demonstrated the interest of NBS, particularly in a context of climate change, however, their concrete implementation often proves to be complex. In particular, this raises the problem of social acceptance and appropriation of NBSs by local residents. This leads to the need for NBSs to be part of a global, participatory and integrated vision of risk management. It is necessary to accompany the different stakeholders in a decision-making process that will allow them to be involved in the NBS project. To do this, the project team, which gathers researchers from Aix-Marseille University and INRAE, will combine three approaches: participatory modeling and simulation, agent modeling, and Argued MCDA. The work developed in this thesis will be then re-used and combined with a Agent-based model to develop an innovative participatory approach.

Forensic engineering (2020) Civil engineering structures are regularly confronted with failures that can lead to catastrophic consequences. It is important, after a failure, to be able to identify the origin and the sequence of factors that led to it. This failure analysis by experts, called forensic engineering investigation, generally leads to the drafting of an expert report. These reports do not inform on the processes that guided the experts to a conclusion and the uncertainties involved. This work, which took the form of a paper published in ECAM (Engineering, Construction and Architectural Management), proposed a new methodological approach to formalize the opinions of experts in forensic engineering, based on argumentation. The research consists in combining AIPA with the theory of imprecise probabilities to take into account epistemic and stochastic uncertainties in order to support forensic engineering investigation. This work, proposed by INRAE researchers, is the first use of the AAF for forensic engineering in civil engineering. Furthermore, it provided an innovative model based on imprecise probability for AAF called IPAS which can be coupled on the AIPA formalism.

A conclusion on these perspectives These different applications of this work, whether of AIPA or Argued MCDA have demonstrated the interest of the approach proposed in this thesis. Far from being an isolated work, it can be seen that it can lead to other research projects, concerning new fields, and/or bringing the proposed methods in new ways. This work is therefore very promising and has thus laid the foundations for a new decision support approach that should be widely developed.

Conclusion [Français]

Dans l'introduction de cette thèse, nous avons posé une hypothèse qui a traversé l'ensemble de ce travail : "la combinaison d'une méthode d'aide à la décision multicritère et de l'argumentation abstraite peut permettre de répondre au problème de décision posé par l'optimisation multi-objectif de la rénovation d'un parc immobilier". Cette hypothèse était confrontée à trois verrous scientifiques : (1) Comment rendre l'argumentation abstraite opérationnelle pour qu'elle puisse être utilisée dans une application réelle avec un groupe d'acteurs en temps réel ; (2) Comment coupler l'argumentation abstraite avec la méthode de décision multicritères ; (3) Comment utiliser cette approche en combinaison avec l'optimisation multi-objectifs dans un problème de planification de la rénovation d'un parc immobilier ?

Résumé de l'approche choisie

L'objectif que nous avons tenté de poursuivre était de donner des arguments en faveur de cette hypothèse et de résoudre les verrous scientifiques posés. A travers les 2 parties et les 6 chapitres de ce manuscrit, nous avons développé des approches, des méthodes et des outils dans cet objectif. Dans le premier chapitre, nous avons dressé un état de l'art de l'argumentation computationnelle et conclu sur le manque de méthodes et d'outils dédiés à l'approche participative. Nous avons également souligné l'intérêt du cadre d'argumentation abstrait (Abstract Argumentation Framework (AAF)) pour répondre à ce besoin. Sur la base de cette affirmation, nous avons présenté dans le deuxième chapitre Argumentation Interface for Participatory Approach (AIPA), un modèle qui opérationnalise le AAF pour de l'aide à la décision participative. AIPA permet de formaliser dans un débat en direct les arguments des participants et fournit différentes informations importantes aux participants comme l'acceptabilité des arguments ou l'ensemble des arguments qui expliquent un résultat. AIPA a été appliqué à un cas d'application afin d'illustrer son fonctionnement et son intérêt. Dans le troisième chapitre, partant du constat que l'utilisation de AIPA n'est pas en soi suffisante en cas de nombreuses alternatives, nous avons proposé de coupler AIPA avec une approche d'aide à la décision multicritère (Multiple Criteria Decision Analysis (MCDA)), en proposant une nouvelle approche appelée ArguedMCDA. La

première partie, avec ces trois chapitres, a donc été consacrée à fournir de nouvelles méthodes et approches d'aide à la décision combinant argumentation et MCDA. Ces éléments peuvent être utilisés ensemble (MCDA + AIPA) ou séparément (par exemple l'approche argumentative seule) et cela pour tout domaine d'application.

La deuxième partie du manuscrit a été consacrée à l'instanciation de ces approches au domaine de la rénovation des bâtiments. Dans cet objectif, dans un premier chapitre, nous avons présenté le problème de décision lié à la planification de la rénovation des bâtiments d'un parc de logements sociaux. Sur la base de cette analyse, nous avons proposé dans le deuxième chapitre de la deuxième partie une approche appelée Argued Mcda for HOusing stock REtrofitting (AMHORE), basée sur le ArguedMCDA pour répondre au problème décisionnel de la réhabilitation des bâtiments. Enfin, le dernier chapitre de cette deuxième partie a fourni une application de AMHORE à un parc immobilier virtuel. Cela nous a permis d'illustrer le fonctionnement de la méthode mais aussi de discuter des résultats et de l'approche elle-même.

Contribution

Si nous devions résumer les contributions scientifiques de cette thèse, nous pourrions évoquer :

- Argued Discussion Model (ADM) : Un modèle d'argument pour une discussion argumentée permettant de faire le lien entre le langage naturel et AAF.
- AIPA : Un modèle dédié à l'aide à la décision pour les approches participatives basé sur AAF et ADM.
- ArguedMCDA (Argued MultiCriteria Decision Aiding) : Une approche décisionnelle combinant l'argumentation (AIPA) et l'aide à la décision multicritère.
- AMHORE : Une démarche participative dédiée à la planification de la réhabilitation des bâtiments d'un parc immobilier.
- WebAIPA : L'implémentation informatique des approches et modèles précédents ; il s'agit d'un prototype opérationnel qui a été implémenté en tant qu'application web.

Chacune de ces contributions a fait l'objet d'une présentation détaillée dans ce manuscrit et a bénéficié d'exemples afin d'en expliquer l'intérêt. Nous avons également tenté d'exposer les limites de ces méthodes et outils au travers de discussions. Ces contributions ont été ou seront valorisées par des articles. Cependant, ce travail n'a pas vocation à apporter une réponse définitive à la question initiale posée et les limites exposées sont autant de nouvelles pistes de

recherche. Ces éléments font l'objet de la dernière partie de cette conclusion, qui visera à exposer les perspectives de recherche de ce travail.

Perspectives

Ce manuscrit, comme tout travail de recherche, ne cherche pas à fermer des portes, mais plutôt à en ouvrir. Les éléments produits sont autant de contributions au domaine de la recherche et à l'aide à la décision, mais ils soulèvent aussi des questions, pouvant conduire à de nouveaux projets et travaux. Dans une première partie, nous aborderons les perspectives méthodologiques afin de consolider l'approche proposée ou du moins qui pourraient la compléter. Dans un second temps, nous nous intéresserons à l'utilisation des résultats de ce travail dans d'autres contextes que celui de la réhabilitation des bâtiments d'un parc immobilier.

Perspectives méthodologiques

Le chapitre précédent consacré à l'application d'AMHORE a permis de poser plusieurs questions méthodologiques qui restent en suspens. Nous allons détailler ici les perspectives que cela offre.

MCDA Nous avons mis en évidence les limites de l'approche multicritere que nous avons utilisée (à savoir l'approche lexicographique), notamment en raison de son caractère non compensatoire. Nous avions conclu sur l'intérêt d'avoir recours à d'autres méthodes multicritères. Comme nous l'avons dit, même si théoriquement la plupart des méthodes peuvent être utilisées dans notre approche, le nombre de paramètres nécessaires à la méthode est un facteur limitant ; il est en effet difficile de pousser les participants à discuter en détail de tous les paramètres s'ils sont très nombreux. Si cela est concevable dans un cadre avec un nombre limité de décideurs ayant des opinions proches, cela se révélerait beaucoup plus complexe et fastidieuse en cas de fortes oppositions induisant ainsi de nombreux arguments et de long débats sur chaque paramètre. Nous avons donc proposé d'avoir recours à des approches proposant un nombre limité de paramètres telles que AHP et PROMETHEE (ou ELECTRE I ou II). Ces méthodes ont l'avantage d'être largement éprouvées, faciles à mettre en œuvre et ne nécessitent pas de ressources importantes en termes de temps de calcul. Le principe serait donc d'implémenter ces méthodes dans WebAIPA et de laisser les utilisateurs choisir la méthode multicritère qu'ils préfèrent. D'un point de vue méthodologique et d'implémentation, cela n'induit pas de difficultés particulières car ces méthodes sont très bien documentées et il existe même des bibliothèques déjà disponibles dans différents langages pour les implémenter. La principale difficulté viendrait de l'interface à créer pour faire en sorte que ces méthodes soient facilement utilisables par les utilisateurs. C'est cependant un travail qui pourrait être réalisé rapidement.

AAF Nous utilisons dans AIPA l'AAF de Dung. Nous l'avons justifié par deux arguments principaux : le nombre limité de paramètres et sa capacité à mettre en valeur la discussion (lé résolution du conflit doit venir de là). Mais, lorsque les opinions sont trop conflictuelles, l'utilisation de ce modèle peut conduire à des situations de blocage. Une façon de résoudre ce problème serait d'utiliser un autre modèle d'argumentation comme ceux exposés dans le chapitre 2.1 (par exemple, le modèle d'argumentation basé sur les valeurs, le cadre d'argumentation bipolaire...). Ces modèles sont bien documentés et bénéficient de moteurs d'inférence disponibles. Mais tous ces modèles nécessitent des informations supplémentaires (par exemple, la valeur, la force ou les incertitudes des arguments ou des attaques), et la question qui se pose de savoir comment accéder à ces informations. Il n'existe pas de réponse unique à cette question. Nous proposons ici trois propositions qui sont autant de piste spour y répondre. La première est lié au contexte d'utilisation. Jusqu'à présent, nous avons préconisé l'utilisation de AIPA dans un débat en direct dans une démarche participative. Cependant, AIPA peut être utilisé dans d'autres contextes où l'ajout d'informations est beaucoup moins problématique. Par exemple, nous présentons dans les sections suivantes une application de AIPA dans le domaine de l'ingénierie forensique, où un panel d'experts doit enquêter sur la défaillance d'une structure. Dans cette application, AIPA est combiné avec une évaluation des incertitudes par des experts qui peuvent prendre le temps de renseigner les informations nécessaires (c'est-à-dire les incertitudes sur les statements). La deuxième proposition consiste à évaluer la force des arguments. Pour ce faire, nous proposons de coupler AIPA avec un système de "like" déjà largement utilisé dans les réseaux sociaux. En effet, le système actuel prend note des arguments, mais pas des soutiens qu'il suscite. Une façon de les considérer serait d'utiliser un système permettant aux participants au débat de montrer leur soutien ou leur opposition à un argument, non pas en proposant un nouvel argument, mais en "likant" ou "dislikant" un argument. Ces éléments seraient utilisés pour calculer la force des statements. Cela nécessite une interface permettant aux participants de formuler leurs like/dsilike, et la capacité pour AIPA de traduire le graphe AIPA en un AAF considérant une valeur sur l'argument et/ou l'attaque. Enfin, la dernière proposition consiste à intégrer un système de vote pour résoudre les situations de blocage. Avec cette proposition, nous conservons le AAF de Dung pour calculer l'acceptabilité de la conclusion. Mais, lorsqu'un conflit entre arguments survient et qu'il ne peut être résolu par la discussion, le facilitateur peut demander un vote ; les participants devront choisir parmi les arguments en conflit, celui qui a leur préférence. Le résultat du vote se traduirait par un nouvel argument qui viendrait résoudre le conflit en soutenant l'argument plebiscité par les participants. Cette approche est intéressante car elle ne change pas fondamentalement l'approche utilisée. En revanche, elle pose la question de la représentativité des participants, du pouvoir de décision et de la confidentialité des votes. Il serait nécessaire de trouver des modalités adaptées

pour proposer un tel dispositif, et de prévoir l'interface adéquate.

Traduction Dans ce document, nous avons proposé deux traductions pour passer du formalisme de AIPA au formalisme AAF : "support" et "optimist". Dans le chapitre précédent, nous avons proposé quelques éléments de discussion sur l'impact du choix de la traduction sur les résultats. La sensibilité à ce choix reste à analyser et constitue déjà une perspective. Par ailleurs, nous avons également créé deux autres traductions dites "defensive" et "passive". Ces deux traductions proposent d'autres manières de traiter le StatementFor. Nous avons choisi de ne pas les présenter dans ce manuscrit car leur interprétation est plus complexe et nous aurions nous-mêmes besoin de plus de temps et de recul pour bien comprendre leur sens et ce qu'elles induisent. En perspective, nous pourrions ainsi analyser ces deux nouvelles traductions afin de les proposer également dans AIPA.

Validation Comme nous l'avons évoqué au chapitre 2.2, la question de la validation de notre approche est une question sensible, à la fois importante et difficile. Elle est importante car, comme tout travail scientifique, elle doit garantir de la qualité des résultats que la méthode peut produire. Mais elle est compliquée car la méthode peut difficilement être automatisée. S'il n'est pas possible de valider entièrement l'approche, il est en revanche possible de valider certains éléments. Pour effectuer cette validation, nous avons besoin de deux éléments : des applications en contexte réel avec un retour des participants pour s'assurer de la pertinence de l'approche et des tests sur le modèle pour s'assurer de sa cohérence. Pour le premier point, une expérience devrait être mise en place ; nous avons déjà réfléchi à la manière de l'organiser, mais il nous faut encore avancer dans sa mise en oeuvre. En ce qui concerne le deuxième point, nous allons créer un ensemble de graphes de test pour vérifier la cohérence des règles que nous avons introduites dans AIPA, tester les différentes traductions, etc. Pour ce point également, le plan d'expérience a été pensé mais il n'a pas encore mis en œuvre.

Perspectives d'application

En démonstration de la richesse et de l'intérêt des approches que nous avons développées dans ce travail, nous pouvons évoquer le fait que ces travaux ont été et seront utilisés dans d'autres contextes décisionnels. Nous citerons ici quatre projets ou travaux qui réutilisent partiellement ou totalement l'approche d'aide à la décision développée dans le cadre de REHA-PARCS.

Projets passés

Projet PICS-CADAU (2017-2019) CADAU a utilisé l'approche MCDA argumentée qui a été développée dans cette thèse, afin de fournir une aide à la décision dans le domaine de l'aménagement urbain. En effet, l'aménagement

urbain est un enjeu important pour toutes les villes. Néanmoins, concevoir un tel projet dans une perspective de développement durable, où les dimensions économiques, sociales et environnementales doivent être prises en compte, est une entreprise complexe. La présence de multiples parties prenantes ayant des points de vue et des objectifs différents doit être prise en compte de manière explicite. Pour relever ce défi, l'équipe du CADAU qui regroupait des chercheurs de l'Université de Bordeaux, de l'INRAE et de l'Université Laval, a proposé d'utiliser le ArguedMCDA pour ce nouveau contexte. Ce projet a permis des échanges fructueux autour de ce modèle et a contribué à la version présentée dans ce manuscrit. De plus, il a permis de démontrer l'intérêt de cette approche dans un nouveau contexte de décision, à savoir l'aménagement urbain.

FEREC-CAIRN (2019-2020) Le projet CAAIRN visait à développer des approches pour caractériser et améliorer l'acceptabilité des infrastructures par les habitants. Au cours de ce projet, l'équipe qui regroupait des chercheurs d'Aix-Marseille Université et de l'INRAE s'est notamment intéressée aux infrastructures dédiées à la gestion des inondations et des eaux pluviales urbaines. Les travaux ont permis de réaliser plusieurs avancées et d'offrir un nouvel éclairage sur la question de l'acceptabilité des infrastructures. En particulier, la tâche 4 du projet CAAIRN a proposé d'utiliser AIPA afin de formaliser et d'analyser les controverses sur les projets d'infrastructures. L'approche proposée a été mise en œuvre sur un projet d'infrastructure réel afin d'illustrer la démarche et de démontrer l'intérêt des résultats produits. Le projet CAAIRN propose donc une utilisation directe de la méthode développée dans cette thèse, mais appliquée à un nouvel objet : l'analyse des controverses. Il a démontré que AIPA a un réel intérêt à répondre à cette question.

Projets en cours

ADEME-ANR-MAIF-MANA (2019-2022) Le projet MANA s'inscrit dans la continuité du projet CAAIRN. Il continue à traiter de l'acceptabilité des infrastructures liées aux inondations, mais cette fois-ci, il se concentre sur les stratégies de gestion basées sur le concept de solutions fondées sur la nature (SFN). Les SFN sont définies par la Commission européenne comme des solutions qui sont "inspirées par la nature, fournissent simultanément des avantages environnementaux, sociaux et économiques et aident à renforcer la résilience du territoire". De nombreux travaux (projets, articles, etc.) ont démontré l'intérêt des SFN, notamment dans un contexte de changement climatique, cependant, leur mise en œuvre concrète s'avère souvent complexe. Cela pose notamment la question de l'acceptation sociale et de l'appropriation des SFN par les riverains. Il en découle la nécessité d'inscrire les SFN dans une vision globale, participative et intégrée de la gestion des risques. Il est nécessaire d'accompagner les différentes parties prenantes dans un processus décisionnel qui leur permettra de s'impliquer

dans le projet des SFN. Pour ce faire, l'équipe MANA, qui regroupe des chercheurs d'Aix-Marseille Université et de l'INRAE, utilisera la combinaison de trois approches : la modélisation et la simulation participatives, la modélisation agent et le ArguedMCDA. Les travaux développés dans cette thèse seront ainsi réutilisés et combinés avec un modèle à base d'agents pour développer une approche participative innovante.

Ingénierie forensique (2020) Les structures de génie civil sont régulièrement confrontées à des défaillances qui peuvent avoir des conséquences catastrophiques. Il est important, après une défaillance, de pouvoir identifier l'origine et la séquence des facteurs qui y ont conduit. Cette analyse de la défaillance par des experts, appelée investigation forensique, conduit généralement à la rédaction d'un rapport d'expertise. Ces rapports ne renseignent pas sur les processus qui ont guidé les experts vers une conclusion et sur les incertitudes que l'investigation comporte. Ce travail, qui a pris la forme d'un article publié dans ECAM (Engineering, Construction and Architectural Management), propose une nouvelle approche méthodologique pour formaliser les avis des experts en ingénierie forensique, basée sur l'argumentation. La méthode consiste à combiner AIPA avec la théorie des probabilités imprécises pour prendre en compte les incertitudes épistémiques et stochastiques afin d'aider à l'investigation en ingénierie forensique. Ce travail, proposé par des chercheurs de l'INRAE, est la première utilisation du AAF pour l'ingénierie forensique en génie civil. En outre, il a fourni un modèle innovant combinant probabilités imprécises et AAF appelé IPAS qui peut être couplé au formalisme AIPA.

Une conclusion sur ces perspectives Les différentes applications de ce travail, que ce soit de AIPA ou de ArguedMCDA ont démontré l'intérêt de l'approche proposée dans cette thèse. Loin d'être un travail isolé, on constate que les travaux menés dans le cadre de cette thèse, peut déboucher sur d'autres projets de recherche, dans de nouveaux domaines, et/ou apportant des innovations méthodologiques. Ce travail est donc très prometteur et a ainsi posé les bases d'une nouvelle approche d'aide à la décision qui devrait être, nous l'espérons, suivie et développée dans le futur.

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