Group 16
Brennen Bouwmeester 4446461
Eva Brink Carvalho 4951360
Jason Wang 4788281
Kevin Su 4438108
Omar Quispel 4107950

Future-proof multifunctional roofs

How can the Municipality of Rotterdam improve the implementation of multifunctional roofs to reach the 2030 goal, given the multi-actor nature of the system?

Urbanisten, 2015. *Rotterdam Roofscapes*,
http://www.urbanisten.nl/wp/wp-content/uploads/URBANISTEN_Rotterdam_Rooftop_Potential_EN.pdf

Summary

The increasing intensity of downpours due to climate change has led to increased flooding in Rotterdam (Groenendijk, 2017; Nu.nl, 2018; Rotterdam, n.d.). The Municipality of Rotterdam has proposed the use of multi-functional roofs, which can absorb rainwater and delay or reduce its discharge into the sewage system, as one of its approaches to reduce the risk of flooding in the future. However, it has been unable to achieve this objective to-date due to reluctance to change from roof owners. Though agents such as insurance companies, housing corporations, and water boards also aim to reduce flooding, the Municipality of Rotterdam has thus far been unable to build a coalition with these actors to meaningfully increase the number of multi-functional roofs in Rotterdam. Therefore, the Municipality wishes to analyze the multi-actor problem and provide recommendations to the Municipality to increase the number of multi-functional roofs in Rotterdam.

Using a combination of a comparative cognitive mapping and cooperative game theory, this research has found ways to deal with the critical actors: the Municipality of Rotterdam, the water boards, housing corporations, and insurance companies. The following question has been answered: *“How can the Municipality of Rotterdam improve the implementation of multifunctional roofs to reach the 2030 goal, given the multi-actor nature of the system?”*

Although most of the critical actors have actions they could perform to improve the implementation of multifunctional roofs, only the water boards do not need any kind of compensation for actually performing their action. It is not necessary for the Municipality to make them dedicated as they already have a high interest in the case.

A cooperation with the insurance companies and the housing corporations does, however, require more effort. These actors are not incentivised to contribute to the implementation of multifunctional roofs on their own, as was concluded from their perceptions, the actors are resource dependent on each other to achieve their goals.

The cooperative game theory has shown that when the Municipality works together with the housing corporations and the insurance companies, they can all benefit from this coalition as together they can reach more than their individual actions. How the extra value that is added should be divided remains unclear and should be figured out by the Municipality, housing corporations, and the insurance companies. However, a first step has been taken in improving the implementation of multifunctional roofs, from which the actors can take the next steps needed.

Contents

1. Introduction **4**

2. Comparative cognitive mapping **7**

2.1 Research question and model choice 7

2.2 Model development 8

2.3 Model presentation and discussion 9

Municipality of Rotterdam 9

Water boards 11

Insurance companies 12

Housing Corporations 13

2.4 Analysis results and interpretation 15

2.4.1 Structural properties of the cognitive maps 15

2.4.2 Similarities, conflicts, and resource dependency 16

2.5 Conclusion 19

3. Cooperative Game Theory **20**

3.1 Research question and relevance for client 20

3.2 Model choice 20

3.3 Model development 21

3.4 Model presentation and discussion 25

3.5 Analysis results and interpretation 26

3.6 Conclusion 29

4. Conclusion, recommendations and reflection **30**

Bibliography **31**

Annex A: Actor Network Scan **36**

A.1 Actor list 36

A.2 Actor characteristics 38

A.3 Formal chart 44

Annex B: Comparative Cognitive Mapping **47**

B.1 Cognitive Maps description 47

B.2 Structural properties explanation 48

B.3 Structural properties 48

B.4 Similarity table 50

B.5 Tables of the diagrams 50

Annex C: Sensitivity Analysis for cooperative game theory **52**

Annex D: Group Member Contributions **55**

1. Introduction

Recently, major rain storms have caused sewer overflow, flood damage, and flooded roads in Rotterdam (Groenendijk, 2017; Nu.nl, 2018; Rotterdam, n.d.). These events suggest that Rotterdam's existing water management system is incapable of handling present challenges, let alone projected future demands that are likely to increase due to climate change. Avoiding the adverse effects of climate change will require upsizing the current drainage infrastructure, which is challenging due to the costs involved and the necessary construction work required, or to look at new and innovative ways of storing and transporting water in the city. Either approach will likely run into common obstacles found in urban development such as cost responsibility, competition for limited urban space, and actors with conflicting desires (De Graaf 2007).

Multifunctional roofs as a solution

One innovative solution to managing increased rainfall in cities is the usage of multifunctional roofs, which add value beyond the traditional structural and protective functions of roofs. Roofs that incorporate nature-based water management methods reduce the water discharge rate to the drainage system. Rotterdam specifically describes a multifunctional roof as one that has at least two 'coloured' characteristics. In this research, only roofs that are blue are taken into account because these roofs contribute directly to the decreasing of flood risks. A green roof contributes to the environment by using plants and gives the owners a chance to grow their own plants. Blue roofs help drainage systems process excessive water flow by reducing water discharge from roofs and help prevent floods., and will be broadly referred to as multifunctional roofs throughout the following sections.

Rotterdam began researching the potential of multifunctional roofs to improve the urban quality of life in 2008 (Gemeente Rotterdam, 2008) and introduced a subsidy to roof owners in 2014 to incentivize roof owners to install multifunctional roofs (Gemeente Rotterdam, 2019). However, only 24% of potential roofs have been converted as of 2018 (Gemeente Rotterdam, n.d. -b) The main reason why the innovative roofs have not been implemented broadly yet can be explained by the phenomenon of reluctance to change (Glasersfeld, 1988), which becomes present when any innovation arises. Rotterdam's previous experiences with other public infrastructure projects have highlighted how change is best enabled when there is a distributed effort, drawing upon the resources of diverse sectors of society, to implement the change. The Municipality is looking beyond using subsidies, which will end in 2020, to incent voluntary cooperation from other strategic actors and instead wish to enlist their cooperation. The main goal that the Municipality has set for multifunctional roofs is to have an area of 1 million m² covered by 2030. In order to reach this goal, the Municipality has to reach out to other actors using their facilitative role (Gemeente Rotterdam, 2015).

Results from actor scan

In an initial phase of the project, a comprehensive actor scan was performed, that maps the views of involved actors on multifunctional roofs (Annex A).

Based on the possible actions, level of interest, the objectives and (formal) dependencies of the different actors (Annex A), a power-interest grid has been built in Figure 1 (Enserink et al., 2010). This grid shows both on what level the problem is seen as a priority by the actors and what actors can actually contribute to the problem.

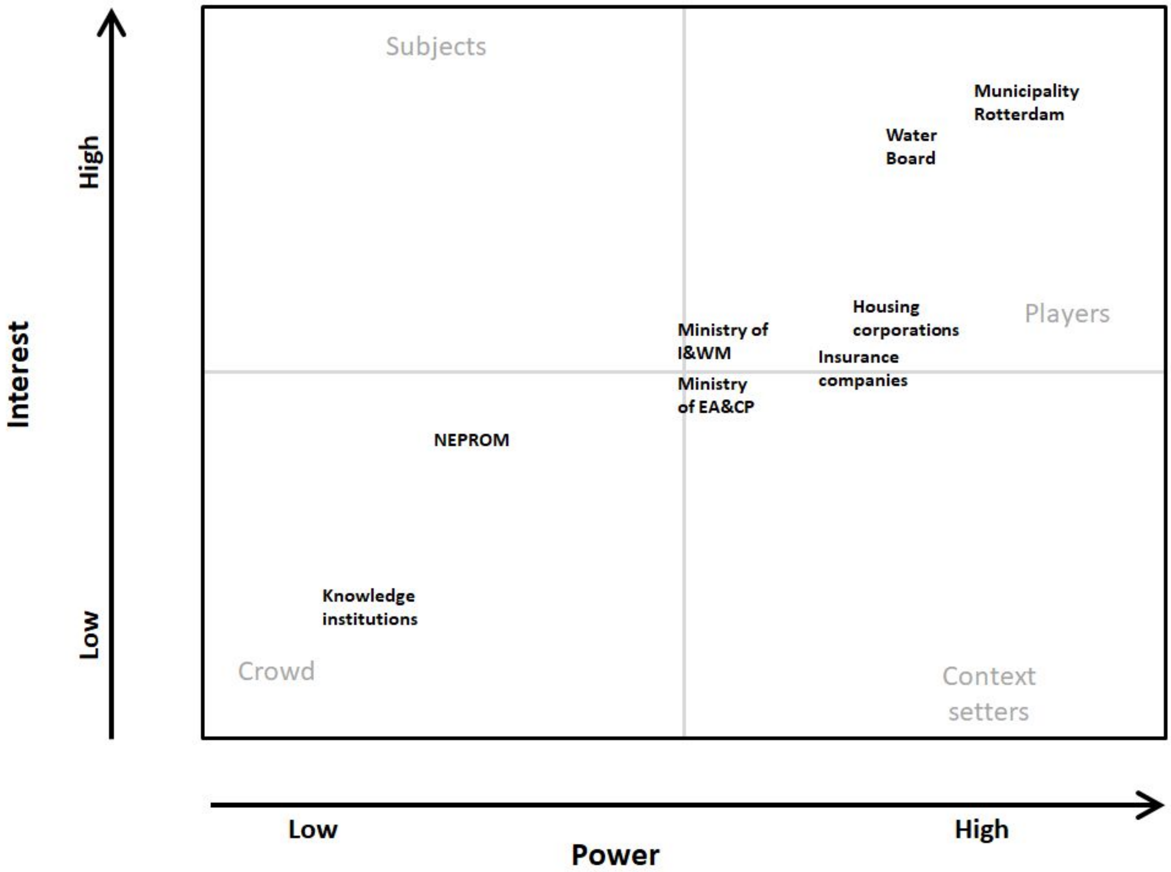


Figure 1: Power-interest grid positioning the actors.

The scan pointed out four involved actors that cannot be ignored. Next to the Municipality itself, the water boards, insurance companies, and housing corporations are seen as indispensable actors for improving the implementation of multifunctional roofs. The power-interest grid strengthens this finding as the critical actors can all be found in the highest power-interest corner of the players. The Municipality can use their many different resources, such as granting subsidies or using their facilitative position (Gemeente Rotterdam, 2015) to improve the implementation. Although, the water boards' goals are on a somewhat higher level (reducing flood risk and improve sustainability), they are closely related to the multifunctional roofs. The water boards can lower taxes for roof owners with a multifunctional roof, which is an action no other actor can perform. Insurance companies can add value in a similar way, namely by lowering premiums for roof owners that carry a multifunctional roof. Although these companies are seen as non-dedicated actors, they could contribute when incentivised to do so. Next to the fact that housing corporations own houses in Rotterdam and thus potential multifunctional roofs, they can also increase demand for multifunctional roofs by lowering rents.

Research questions

To help clarify the problem further, a main research question is defined to guide the analysis process, which is supported by subquestions (1) and (2):

How can the Municipality of Rotterdam improve the implementation of multifunctional roofs to reach the 2030 goal, given the multi-actor nature of the system?

1. What are valuable insights regarding perceptions of critical actors for the Municipality to work with these actors in the implementation of multifunctional roofs?
2. What cooperation between actors can be achieved to help reach the Municipality's goal for multifunctional roofs?

These subquestions, which are answered in chapter 2 and 3 respectively, will together lead to the answer to the main question. To answer the subquestions, two different actor strategy models are used. In chapter 2, comparative cognitive mapping will be used to clarify the perceptions of the critical actors and find in what way these perceptions overlap or contrasting. These conclusions are essential to fully understand actors' moves and what their intentions are, and thus, crucial to know in what way to deal with the critical actors. Chapter 3 looks into cooperative game theory, a tool that is applied when the involved actors largely share the same perspective on the issue, in order to find possible solutions to the problem. Chapter 4 will include a conclusion together with a discussion and some limitations of the project. The chapter ends with recommendations for future steps.

2. Comparative cognitive mapping

This chapter includes the work and the results of the comparative cognitive mapping method. In section 2.1 the research question will be outlined and the relevance for the Municipality will be explained. It also introduces the model and why this specific model is chosen to answer the research question. Section 2.2 provides an explanation of the development of the model. In section 2.3, the model itself is elaborated on and the results of this model analysis will be reported in section 2.4. Lastly, section 2.5 will translate these results into several conclusions that will be used to answer the main research question.

2.1 Research question and model choice

The research question addressed in this chapter is "*What are valuable insights regarding perceptions of critical actors for the Municipality to work with these actors in the implementation of multifunctional roofs?"*.

The critical actors in this research question are based on the findings from the actor scan (Annex A). The four critical actors identified have been divided based on their dedication to the implementation of multifunctional roofs. The two dedicated critical actors are the Municipality and the Water boards. The two non-dedicated critical actors are the insurance companies and the housing corporations. The research questions helps the Municipality to see what makes the current actors dedicated and can gain valuable insights in the perceptions of non-dedicated actors and how to deal with them.

The actor scan has already shown that there are no actors opposing the implementation of multifunctional roofs. However, to reach the target of 1 million m² multifunctional roofs by 2030 it is important to have the non-dedicated actors participate in the implementation of multifunctional roofs. This fits with the facilitative role of the Municipality to reach out to other actors. The model used to answer this research question is comparative cognitive mapping.

Comparative cognitive mapping is a modelling tool used to represent the perceptions of actors for complex problems (Hermans & Cunningham, 2018). The method can be used to create better decision understanding for the Municipality. The model is especially helpful to explain situations in which there are no opposing actors but still, there is limited activity in dealing with the problem. As actors might agree that there is a problem, they can differ in how to solve this and whose responsibility it is to do so. For the case of multifunctional roofs these insights can then be used by the Municipality to move critical actors to be more active in solving the problem. This structural approach helps visualize what an actor finds important and how actions affect the system. Axelrod (2015) also describes the use of comparative cognitive mapping to increase the quality of decision-making.

By detailing the perceptions, the individual maps of each of the critical actors can highlight what the particular actor sees as important in the problem and how different actions can impact their goals. For the Municipality it is important to consider the goals and actions of other actors for the implementation of multifunctional roofs, to get a better understanding of their motives. Further insights can be gathered by comparison of cognitive maps using Dynamic Actor Network Analysis (DANA) software created by Bots (2009). As it helps find similarities, conflicts, and resource dependencies in the perception diagrams. These insights can then help explain the inactivity in the current situation.

2.2 Model development

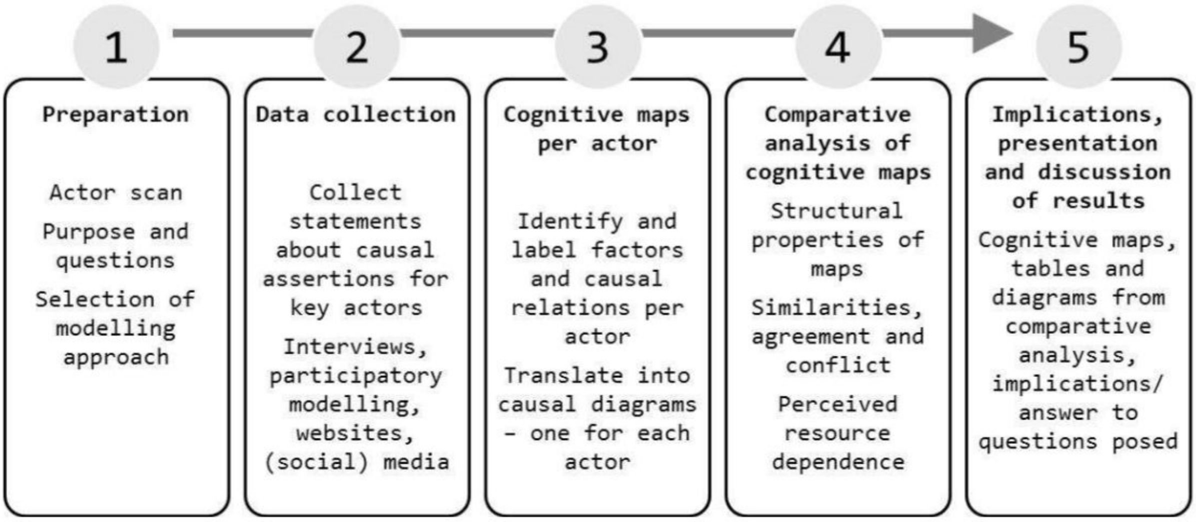


Figure 2. Steps for comparative cognitive mapping borrowed from Hermans & Cunningham (2018)

The steps in Figure 2 are followed to apply comparative cognitive mapping to answer the research question. The preparation step has already been executed in Annex A and section 2.1 where respectively the actor scan, research question, and model choice were discussed.

Data collection

To apply comparative cognitive mapping, it is necessary to research and collect data about each actor's view on the situation and describe it through factors. The data collection performed in this paper is based on literature research in scientific papers and policy documents regarding multifunctional roofs. By exclusively using literature research, the model might be limited in its validity. The model will also be based on certain assumptions, such as similar cases applying to this case, information from previous years still hold true, and the information the actors present are truthful. The trade-off for the limitations is that the data collection process can be performed in a quick manner, limit the influence of the analyst on real-world actor behavior (Hermans & Cunningham, 2018), and gather insights from different sources compared to collection processes such as interviews and workshops. This way a broad view on the actors' perceptions can be analyzed.

2.3 Model presentation and discussion

This model presentation section presents and discusses the cognitive maps made for comparative analysis. The Figures of the cognitive maps are attached with the text highlighting relations and factors relevant for the case. This section gives the structural properties of the maps while 2.5 discusses the comparative results such as similarities, conflicts, and resource dependency. In Annex B.1 an explanation can be found on the meaning of all the parts of the cognitive maps.

Municipality of Rotterdam

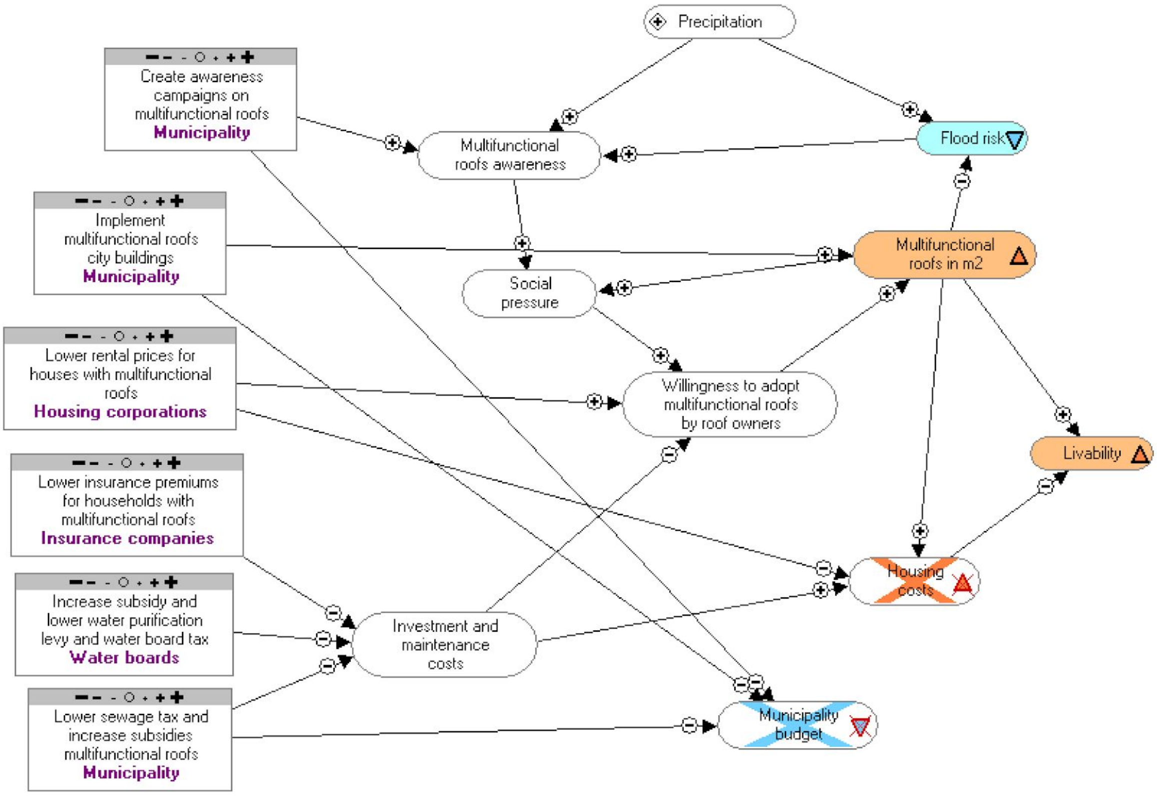


Figure 3. Cognitive map for the Municipality

The actions of the Municipality are the combined action to lower sewage tax and increase subsidies, create awareness campaigns on multifunctional roofs, and implement multifunctional roofs on their own city buildings. The possible actions and goals are based on the finding of the actor scan in Annex A. The specific actions for the Municipality are based on the theory framework of Hulshoff (2009) and Bender (2017). The ‘wortel, preek en stok’ method divides possible actions of government into financial instruments, awareness campaigns, and law enforcement. Hereby, law enforcement for implementation of multifunctional roofs remain impossible due to current laws (Bender, 2017). Firstly, lowering sewage tax and increasing subsidies are combined as they achieve the same goal: financial compensation for the implementation of multifunctional roofs. Secondly, the awareness campaigns can be very direct through media campaigns, workshops but also by setting a good example for the rest by implementing multifunctional roofs for their own Municipality buildings (Hendriks & Hommes, 2016). These are helpful to set a good example for the roof owners but also to communicate the benefits of multifunctional roofs as long as the benefits for the actor themselves remain clear.

The goals of the Municipality are the problem specific objectives which can be found in the actor scan. The main objective for the Municipality is to increase the square meters of multifunctional roofs, however the other goals contribute to getting more insight into the situation. Livability and flood risk are important reasons as to why the Municipality wants multifunctional roofs (Gemeente Rotterdam, 2007; Gemeente Rotterdam et. al, 2013). Municipality budget and the housing costs show the constraints of the Municipality seeing they value efficient policy for every income class.

The actions of the Municipality and other critical actors affect the goals in this cognitive map. Firstly, their own actions all influence the Municipality's budget which means their available funds for other municipal tasks and goals are more limited. The actions awareness campaigns and implementation of multifunctional roofs increase the multifunctional roofs through awareness and social pressure. These actions increase the housing costs without compensating the actors implementing multifunctional roofs, which is only done by the action lowering sewage tax and increasing subsidies. Secondly, actions from other actors can also contribute to the goals of the Municipality. The external factor precipitation increases the flood risk and the awareness, the worse it gets through heavy rainfall the bigger the problem becomes which increases the awareness of the problem.

Water boards

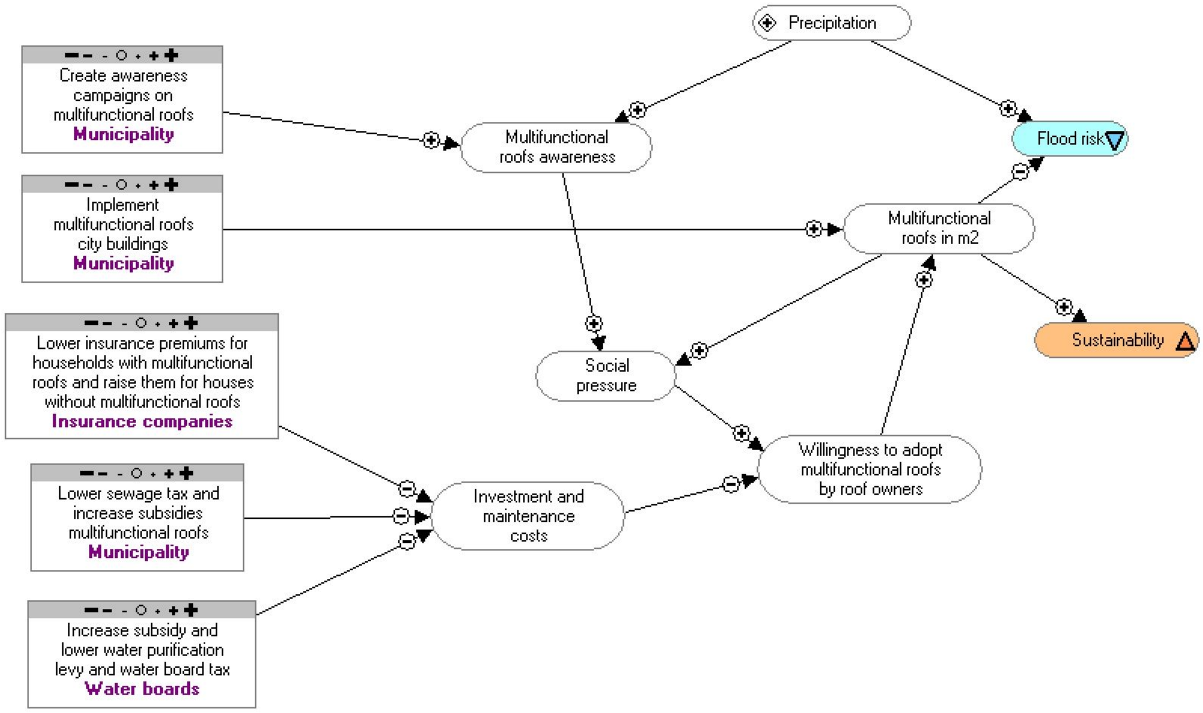


Figure 4. Cognitive map for water boards

The cognitive map of water boards outlines how the organisation thinks about the implementation of multifunctional roofs and how actions taken by them or others influence their goals.

Considering their resources, water boards can then perform a combined action of increasing subsidy and lower water purification levy and water board tax for houses with multifunctional roofs (Waterschapswet, 2018). This action will decrease costs for the roof owners, increasing willingness to adopt them and, therefore, increase the factor “multifunctional roofs in m2”. The increase of this factor will have a desirable effect in both goals of the water boards and, hence, is a change that water boards will want to pursue.

As the organisation responsible for regional water system management and considering the general and specific desired objectives outlined in the actor scan (Annex A), water Boards have as goals decreasing flood risk and increasing sustainability.

The action of financially incentivising the implementation of multifunctional roofs will have a positive impact on both goals the water Boards have. This is also the case for the performance of actions by the other actors. Increasing the implementation of multifunctional roofs can be influenced by all of the actions and has an influence on all of the goals as well.

Insurance companies

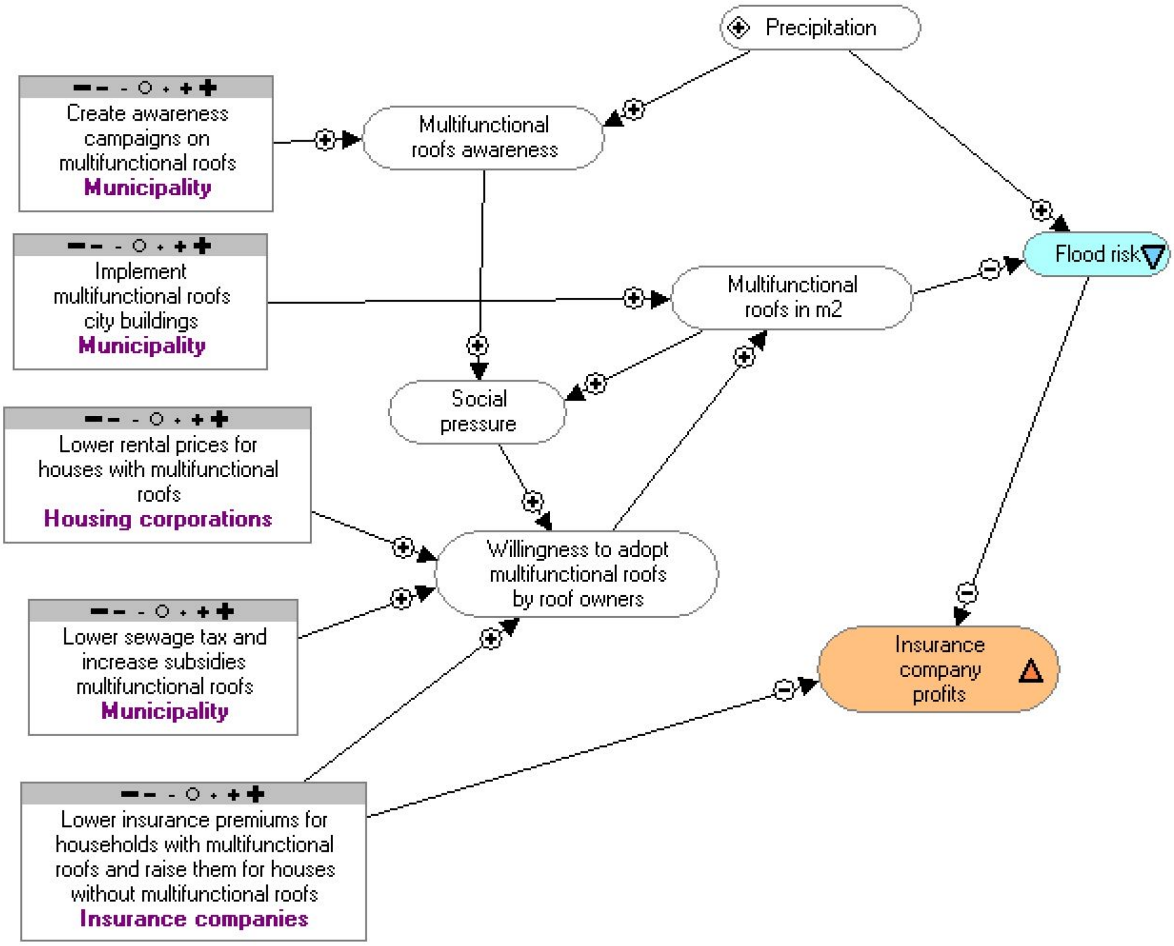


Figure 5. Cognitive map for insurance companies

Like the Water Boards, the insurance companies have only one considerable action to influence the system of multifunctional roofs. In order to influence the number of multifunctional roofs, the companies can lower the insurance premiums for houses that carry a multifunctional roof. Right now insurance companies already base the premiums partly on the type of roof a house carries (Inshared, 2017; Centraal Beheer, 2017), which could be expanded on in the future.

The goals of the insurance companies are based on the perceptions found in the actor scan (Annex A). Insurance companies want to maximise their profit but also care for flood risk as this can influence their payouts in a negative way (Green Deal, 2016).

In order to influence the profit, the insurance companies can change the premiums for households that carry a multifunctional roof. In their perception, an increase in premiums will increase their profit as well. On the other hand, increasing the premium will also lead to fewer multifunctional roofs being implemented, which on its turn leads to a higher flood risk and lower profit because of the extra payouts. This influence increases even more because of the loop where less multifunctional roofs will lead to lower social pressure and thus even less roofs.

Next to the action that the insurance companies can perform themselves, their goals can be influenced by actions of other actors as well. The three actions by the Municipality can all lower the flood risk, which would indirectly lead to a higher profit for the insurance companies. Also the action by the housing corporations of lowering the rents for houses that carry multifunctional roofs can influence the profit indirectly.

Housing Corporations

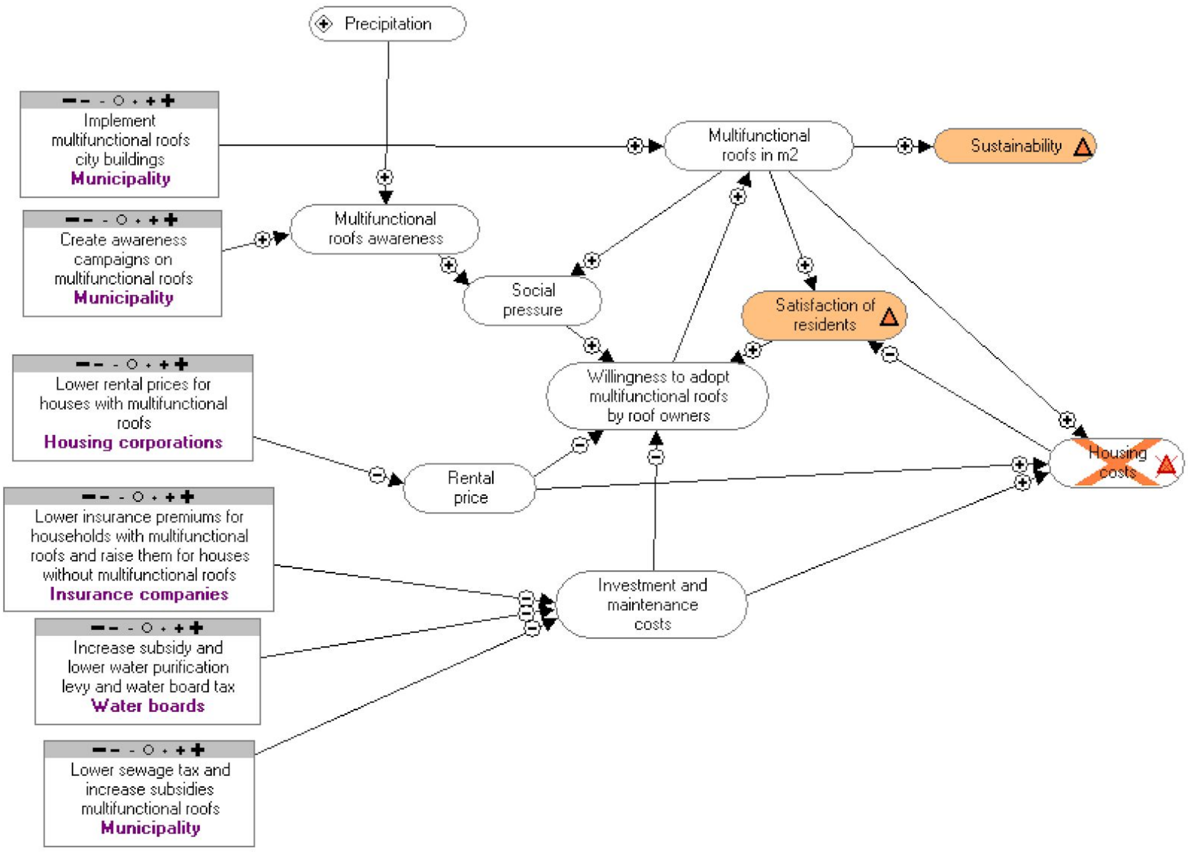


Figure 6. Cognitive map for housing corporations

The last critical actor, housing corporations, have one action that they can perform to influence the system. As housing corporations own some of the houses in Rotterdam, they can decide on the height of the rent they put on these houses (Centraal Planbureau, 2017). Specifically interesting for the system of multifunctional roofs is the lowering of rent for houses that carry a multifunctional roof in order to make these houses more attractive.

The goals of the housing corporations are based on the objectives found in the actor scan (Annex A). The corporations want to satisfy their customers, the residents, but also want to restrict the increase in housing costs. A third objective of the corporations is the sustainability of the houses they own (Woonstad Rotterdam, 2016.; Hendriks & Hommes, 2016).

The lowering of rent by the housing corporations will lead to lower housing costs due to the lower rental price. Next to that, the lower rental price might also lead to residents being more willing to spend their money on other features of their house, such as implementing multifunctional roofs. Both the low housing costs and the high number of multifunctional roofs improve the residents satisfaction, which is desirable for the corporations. A last influence of multifunctional roofs is the increase in sustainability that the roofs provide. However, the housing corporations have low profit margins, which is why it could be difficult to lower rent for houses that carry multifunctional roofs and they would need some kind of compensation for performing this action.

The possible actions of the other actors all influence the housing costs and thus the satisfaction of the customers. Due to the change in the number of multifunctional roofs as a result of the actions by the other actors, also the sustainability of the houses can be influenced by the other actors.

2.4 Analysis results and interpretation

This results section discusses the comparative cognitive mapping analysis. Firstly, the similarity of the factors and paths are calculated. Secondly, after concluding what the actors have in common, it is also important to show where the differences lie. Thirdly, resource dependency will be investigated to see which conflicts the Municipality has to deal with to be able to reach their goals.

2.4.1 Structural properties of the cognitive maps

In this section, the cognitive maps of the actors are examined more thoroughly. For each of the actors the size and detail, density, balance, dilemmas and feedback loops will be examined, which will show more in depth what the actors are dealing with in their perceptions. The explanation of the characteristics of the maps can be found in Annex B.2.

Based on the interpretation from Annex B.3 where the structural properties are explained in more detail, the following conclusions can be drawn.

Firstly, the Municipality has to consider many social values which is why their cognitive map is more detailed compared to the map of the others. Their non-financial actions will increase housing costs without compensating these costs in another way. Therefore, their possible actions have to be combined so that housing costs will not raise too much. There are positive feedback loops which can create self-reinforcing cycles such as social pressure creating more multifunctional roofs and awareness diminishing lowering multifunctional roofs.

Secondly, the cognitive map of waterboards is straightforward as it is in balance and they do not face any dilemma. However, it does provide the same feedback loop as with the Municipality which is the self-reinforcing loop of social pressure. Interestingly enough, the Water boards do not necessarily need any compensation for their contribution towards an increase of implementation of multifunctional roofs as it offers a direct benefit to them.

Thirdly, insurance companies experience a negative influence on their profit when they were to perform their actions of lowering premiums. A dilemma exists for using this action, because in the long run, the action also has a positive influence on the profit because of a decrease in flood risk and thus floods and the payouts they would trigger.

Fourthly, like the insurance companies, also housing corporations need compensation for performing their action of lowering rents. Because of their low profit margin there is little space for lowering these rents. This action does have a positive impact on the implementation of the roofs.

2.4.2 Similarities, conflicts, and resource dependency

Next to the features that can be seen in the individual cognitive maps, it is also interesting to compare the maps of the actors to each other, in order to point out similarities between the perceptions of the actors, but also conflicts and dependencies of resources. In Annex B.3, the numerical values of the diagrams are given. In this section the results of the comparison are reported.

Similarities

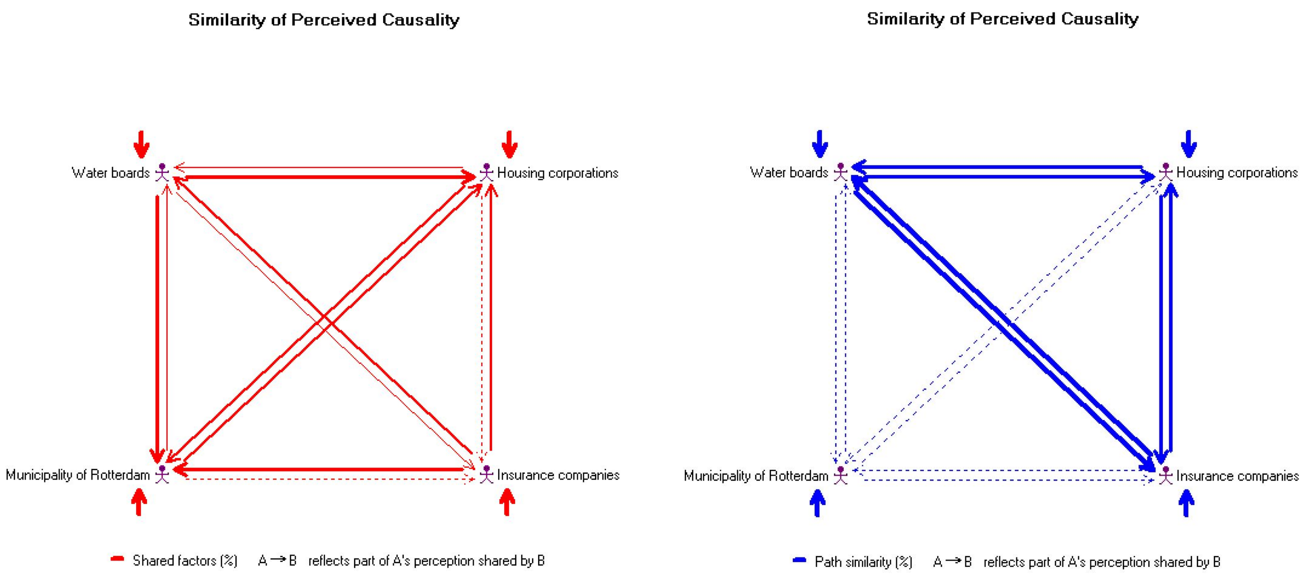


Figure 7. Similarity of factors and paths

The frequency counts of the factors and goals are shown in Annex B.3. Firstly, goals which are shared by more than 1 actor can be used as a reason for the actors to work together (Hermans & Cunningham, 2018). The goals flood risk, housing costs, and sustainability are shared by more than one actor. Flood risk is a goal for the Municipality, water boards, and insurance companies. Housing costs are shared between the Municipality and the housing corporation. Sustainability is shared between the Municipality and the insurance companies. The Municipality shares similar goals with the critical agents.

Figure 7 shows the similarity in shared factors and paths. The lowest percentage for the shared factor diagram is 62% and for shared paths it is 82%. This indicates a very high similar perception across the critical actors. The relative difference between factors and paths might be because every actor in the diagrams has some goals they do not share with others, such as the goal multifunctional roofs in m2 can only be found in the perception of the Municipality. Which means that other critical actors do not prioritize it. As the intermediate paths are very similar the actors do agree how intermediate factors relate to each other.

Goal and action conflicts

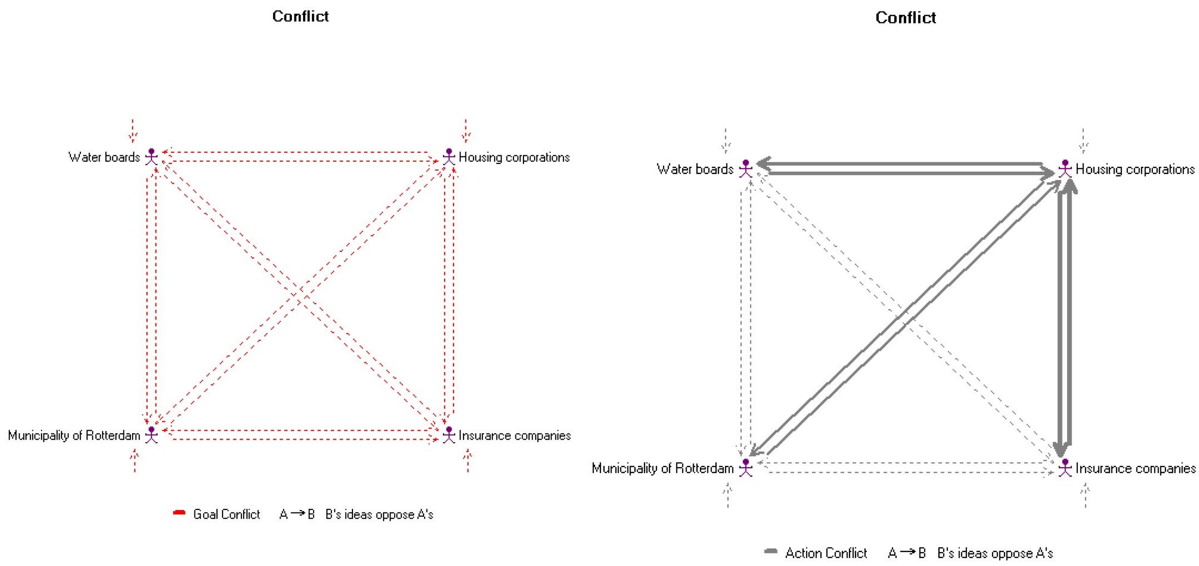


Figure 8. Goal and action conflicts

Figure 8 shows the goal and action conflicts the critical actors perceive. As the goal conflict diagram shows that there are no goal conflicts (every link is set to 0), this means they are not opposed to each other's goals. This joins the expectation of no actors being opposed towards the Municipality, that was found in the actor scan in Annex A. Further analysis does provide that there might be conflict in interests due to exclusive goals they have that will also have to be incorporated. The action conflict diagram does show that certain actions might cause trouble for the goals of the actors. It shows action conflict between critical actors, which means a single dominating action does not exist. This missing "best" action calls for joint actions and cooperation to improve the situation.

Resource dependency

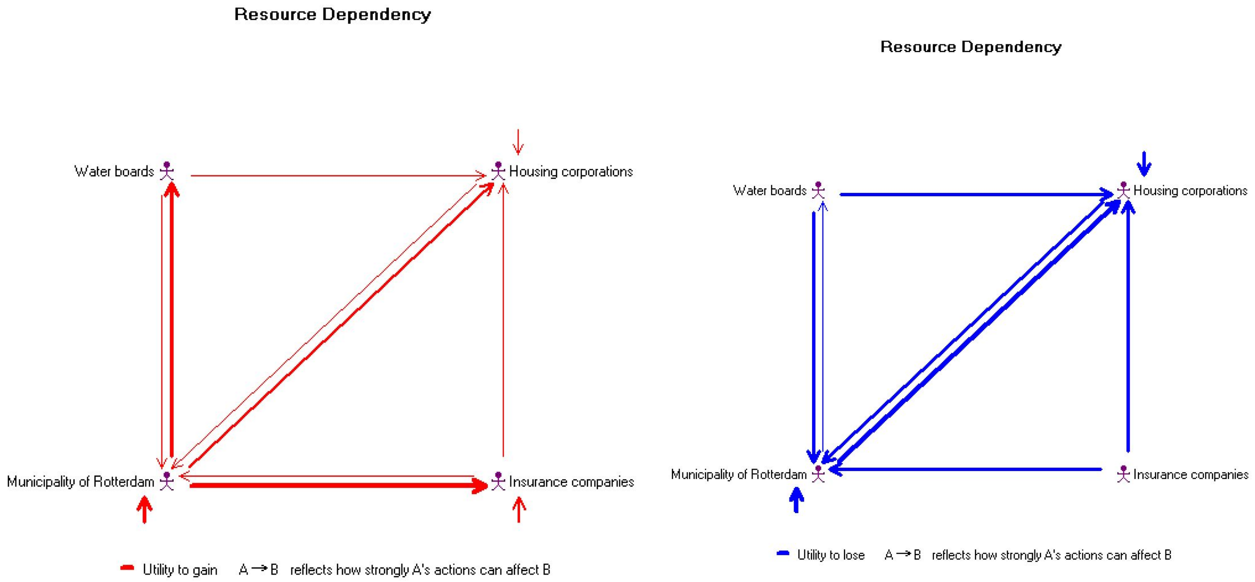


Figure 9. Resource dependency: utility to gain and utility to lose

The resource dependency in Figure 9 illustrates how the Municipality is a strong and important actor, because they can influence the other critical actors. What is also important, is that all the other actors can help the Municipality to realize their goals. The Municipality would be able to work with most of the critical actors in achieving their goals.

2.5 Conclusion

Comparative cognitive mapping has been used to answer the following research question: "*What are valuable insights regarding perceptions of critical actors for the Municipality to work with these actors in the implementation of multifunctional roofs?"*.

The following valuable insights, which helps the Municipality to work with actors in the implementation of multifunctional roofs, were gathered. Firstly, the structural properties of the cognitive maps show that both the housing corporations and the insurance companies need some kind of compensation if they were to perform their actions. This is because a dilemma exists within their own perception for using their action; the usage of the actions will not clearly reach their goals. The Water boards, however, have a much more clear perception on the problem and will not need incentivising to become active in improving the implementation of multifunctional roofs. This is why the cooperation between the Municipality and the Water boards will go smoothly.

Secondly, in the comparison of the cognitive maps similarities, conflict, and resource dependency were used to gather further insights. By looking at the comparison of the perceptions of the critical actors, it has become clear that some sort of cooperation is needed to solve improve the implementation of multifunctional roofs. None of the actors can perform an action that does not hurt another actor in some way, which means a combination of actions should be found that will improve the situation for all critical actors.

Thirdly, the comparison of the perceptions has shown that the critical actors are all dependent on the resources that the Municipality owns, which is why the facilitative role of the Municipality can be key in improving the implementation of multifunctional roofs. Moreover the actions of the Municipality, that make the other actors dependent on the Municipality, do all decrease their budget, which is why the Municipality prefers other actors to use their actions to improve the situation. This again asks for ways to cooperate with the other actors.

The limitations of actor and strategy models are found in Hermans & Cunningham (2018) are also applicable for these results, as non-strategic actors were not taken into account. System agents such as roof owners are not taken into account because they cannot influence the system individually, however they still have interests and certain preferences that is left out of the perception. Other limitations of the study is the validation of the cognitive maps, seeing the critical actors did not have the opportunity to validate the maps.

3. Cooperative Game Theory

Building upon the cognitive maps obtained in the first analysis, it was possible to find overlapping perceptions between actors and possible cooperations. This suggests that productive coalitions could form between actors that share the same perceptions, or are willing to adapt in exchange for some sort of compensation, which could lead to added value to these actors individually in contrast to them working alone. This chapter will apply cooperative game theory to find valuable coalitions between these actors. In section 3.1, the problem context will be outlined and the relevance for the Municipality will be discussed. Section 3.2 provides an explanation of the method and procedure used to answer the second subquestion. In section 3.3, the model is presented and elaborated on. The results of the analysis done with the model will be reported in section 3.4. Lastly, section 3.5 will answer this chapter's research question and translate the findings into conclusions that will aid in answering the main research question.

3.1 Research question and model choice

Through an analysis on the maps obtained in Chapter 2, it was concluded that some of the actors could benefit by cooperating with each other. However, the analysis did not show how these actors could best work together to reach the goal of the Municipality. Cooperative game theory (Hermans & Cunningham, 2018) will be used to answer the following question: *What cooperation between actors can be achieved to help reach the Municipality's goal for multifunctional roofs?*
The cognitive mapping showed that there is room for cooperation between parties. Translating this potential in concrete coalitions and potential benefits per coalition will make it easier for the Municipality to decide which actors to attempt to work with.

Cooperative game theory quantifies the outcomes of each actor working in their own best interest and the marginal improvements they can achieve by working together. It can then provide insight in which actors can benefit from cooperating under different schemes of distributing the rewards of cooperation.

3.2 Model development

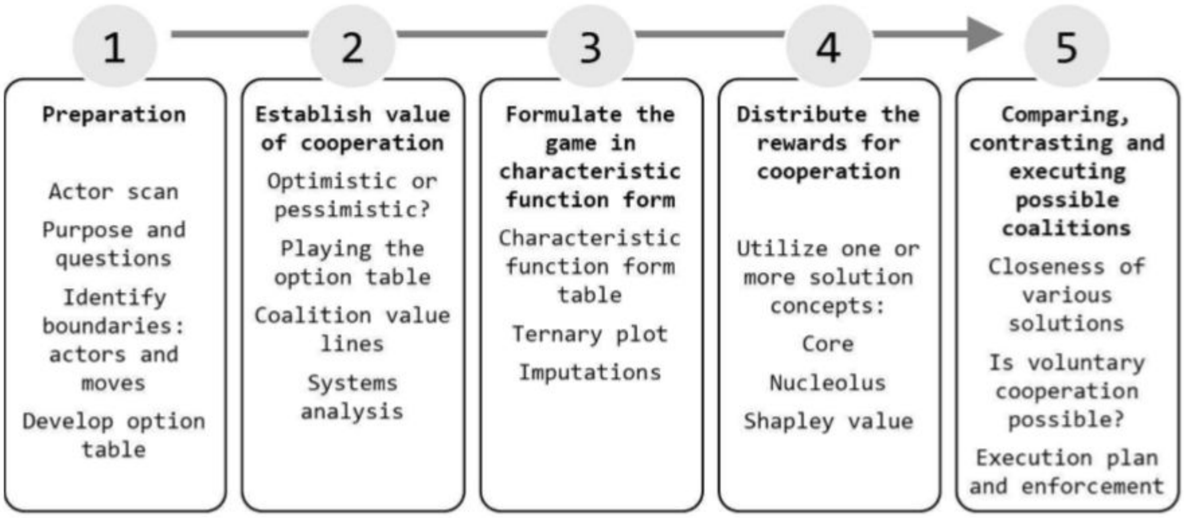


Figure 10. Steps for cooperative game theory borrowed from Hermans & Cunningham (2018)

To correctly apply a cooperative game theory model to this problem, the steps outlined by Hermans & Cunningham (2018) will be followed.

Preparation
First, it is necessary to do an actor scan, identify purpose and questions, define boundaries, and develop an option table including all relevant actors and strategic moves.

Many of these procedural steps were already performed in developing the cognitive maps. By adding a "Do nothing" for each actor, there is an extensive list of possible moves that can lead to a complex cooperative game theory model. To guarantee comprehensibility and efficacy of game theory modelling, the policy arena was simplified to analyze three main actors and their main moves.

- The Municipality's possible actions were reduced to three actions as following: "Lower sewage tax and subsidize multifunctional roofs", "Official enforcement of multifunctional roofs" and "Do nothing";
- The insurance companies have two possible moves: "Lower insurance premiums for households with multifunctional roofs" or "Do nothing"
- The Housing Corporations have two possible moves "Lower rental prices for houses with multifunctional roofs" or "Do nothing".

The following actors were excluded:
- Both the ministry and the water boards, having all their goals included in the cognitive map of the Municipality, will not be part of the game theory;
- The knowledge institutes, as the option "Do nothing" goes against the purpose of their work, will only have one possible move "Share knowledge" and hence won't be part of the game theory approach;

Table 1 summarises all possible outcomes of the included actors and their possible moves. Inaction is colored red, while moves are colored green. Table 2 labels them for easier understanding of what each outcome entails.

Table 1: option table

Outcomes	Municipality of Rotterdam				Housing Corporations		Insurance companies	
	Lower sewage tax and subsidize multifunctional roofs	Create awareness campaigns on multifunctional roofs	Implement multifunctional roofs on government buildings	Do nothing	Lower rental prices for multifunctional roofs	Do nothing	Lower insurance premiums for households with multifunctional roofs	Do nothing
1				x		x		x
2	x	x	x			x		x
3				x	x			x
4				x		x	x	
5	x	x	x		x			x
6	x	x	x			x	x	
7				x	x		x	
8	x	x	x		x		x	

Table 2: Labelled outcomes

Outcomes	**Labels**
1	No action taken, maintaining Status Quo
2	Municipality plays alone, no collaboration
3	Housing corporations play alone, no collaboration
4	Insurance companies play alone, no collaboration
5	Municipality and housing corporations play, insurance does nothing
6	Municipality and insurance companies play, housing corp. does nothing

7	Housing corporations and insurance companies play, Municipality does nothing
8	All actors take actions

Establish value of cooperation

The payoffs were evaluated on the main criteria for each actor as used in the cognitive mapping stage):

- Municipality – cost of implementing policies, flood risk, and housing cost;
- Housing corporations – Housing Cost, Resident Satisfaction;
- Insurance Companies – Profit and flood risk.

The first step is to decide how coalitions treat other actors who choose to act on their own. Shapley & Shubik (1973) call these the alpha and beta values, where the alpha value assumes all actors work together in an optimistic approach to create maximum value. The beta value is a pessimistic approach where different coalitions will do what they can to take away value from each other. Considering the involvement of multiple public actors, only an optimistic approach is considered as the public would not look kindly on competition over public resources.

For each action, the relevant criteria was assigned a positive number, a negative number, or 0 perception based on the cognitive mapping completed previously. Where a move created multiple effects, those effects were summed (only for first-degree feedback effects were included). We also assumed that each actor would deploy all of their moves; the Municipality had three relevant moves. Where a criteria was a constraint, its score could only be 0 or negative. Then, each permutative set of policy actions (coalitions) and their scoring were superimposed with a 0.7 discount to account for overlapping policy. In all of these cases, the marginal additional value of cooperation decreases. For example, if two actor each can convince 100 roof owners to install multifunctional roofs, they may only be able to convince 140 together; roof owners may still be limited in their ability to make some changes.

Lastly, these ordinal rankings were normalized between 0-1 for each actor, summed across all three actors, and finally normalized so that the highest ranking, which has the lowest numerical value, would receive 100 and the lowest ranking, which has the highest number, would receive 0. The following formula was used for each:

$$Y = y/MAX(y_n)$$

Where Y is the ordinal score of y, the score of one policy set, and y_n is the set of all y scores.

Similarly, for the combined ordinal scores,

$$X = Y/MAX(Y_n) \times 100$$

X is the normalized ordinal score of Y (from above) and Y_n is the set of all Y scores.

The aforementioned approach was used to evaluate each coalition. For example, insurance companies valued their individual action as (0,1) and that of housing corporations as (0,1). However, they perceive the I,H coalition as $[0+0, (1+1)\times(0.7)^2] = (0,0.98)$. The results of the comparisons are tabulated in tables 3 and 4.

Table 3: Outcomes evaluation for cooperative game theory

Actions				Criteria							
				Municipality				*Housing Corps*		*Insurance*	
Insurance	Housing	Municipality	Code	Cost to Municipality	Flood Risk	Number of Multifunctional Roofs	Housing Cost	Housing Cost	Resident Satisfaction	Profit	Flood Risk
Lower	Lower	Lower	I,H,M	-1.47	2.45	2.45	-0.49	-0.49	2.45	1.47	2.45
Lower	Lower	Nothing	I,H	0	0.98	0.98	0	0	0.98	0	0.98
Lower	Nothing	Lower	I,M	-1.47	1.96	1.96	-0.49	-0.49	1.96	1.47	1.96
Nothing	Lower	Lower	H,M	-1.47	1.96	1.96	-0.49	-0.49	1.96	1.47	1.96
Nothing	Lower	Nothing	H	0	1	1	0	0	1	0	1
Nothing	Nothing	Lower	M	-3	3	3	-1	-1	3	3	3
Lower	Nothing	Nothing	I	0	1	1	0	0	1	0	1
Nothing	Nothing	Nothing	Phi	0	0	0	0	0	0	0	0

Table 4: Outcomes ordinal ranking for cooperative game theory

Actions				Criteria						Scoring	
				Municipality		*Insurance*		*Insurance*			
Insurance	Housing	Municipality	Code	Subtotal	Relative Score	Subtotal	Relative Score	Subtotal	Relative Score	Sum	Normalized
Lower	Lower	Lower	I,H,M	3.43	1.00	1.96	0.98	3.92	0.65	2.63	100
Lower	Lower	Nothing	I,H	1.96	–	0.98	0.49	0.98	0.16	0.65	25
Lower	Nothing	Lower	I,M	2.45	0.71	1.47	–	3.43	0.57	1.29	49
Nothing	Lower	Lower	H,M	1.96	0.57	1.47	0.74	3.43	–	1.31	50
Nothing	Lower	Nothing	H	2	–	1	0.50	1	–	0.50	19
Nothing	Nothing	Lower	M	2	0.58	2	–	6	–	0.58	22
Lower	Nothing	Nothing	I	2	–	1	–	1	0.17	0.17	6
Nothing	Nothing	Nothing	Phi	0	0.00	0	0.00	0	0.00	0.00	0

Distribute the rewards for cooperation

Comparing, contrasting and executing possible coalitions

Comparing different coalitions can be approached in numerous ways, but the core (stable set), the Shapley value and the Nucleolus are the main ones used to analyze the outcomes of each coalition. These ways of distribution will be calculated using the R language. Each approach is further outlined below.

The core as a stable set
A first classification of possible solutions will split possible solutions from impossible ones. The stable set (Von Neumann & Morgenstern, 1944) should consider good and only good solutions. In this analysis the stable set will be calculated using the core concept (Raiffa, 2002). This concept assumes that any actor will only cooperate if this cooperation can offer it more than the actor could generate on its own. The same goes for smaller coalitions that are considering to join a larger coalition.

Shapley value
When the core has been established, it is important to find a stable solution. One way to do this is using the Shapley value (Shapley, 1953). Shapley tries to fairly divide the benefits of a cooperation between the actors that are part of it. This means that all actors get a reward proportional to what they contribute to the coalition.

Nucleolus
Another way of contributing the rewards that a coalition generates, is to start with the most needy actor, reward this actor and then move on to the next most needy actor. The most needy actor is the one that would gain the most value if they would leave the current coalition. When the difference between the value an actor would receive when working alone is lower than the value this actor receives within the coalition for all actors, a stable coalition has been found.

3.3 Model presentation and discussion

The normalized scores from the multicriteria analysis in 3.2 are used as the basis for cooperative game theory analysis. The scores are presented in characteristic function form in table 5. This table shows the different coalitions that can form and the value that is assigned to their cooperation.
φ = null coalition
M = Municipality of Rotterdam
H = Housing corporations
I = Insurance companies

The scoring is scaled from 0 to a 100 of value gained. The null coalition has no value as no actor manages to achieve their goals. It is assumed that all value is gained when all three actors work together. For the single actor coalitions, the Municipality gains the most value from going it alone. It is apparent that much value is gained in this case from cooperation according to the values found from the multicriteria analysis. Especially the coalition between the Municipality and the housing corporations sees major added value.

Table 5: Characteristic form of simplified game

	V(φ) = 0	
V(I) = 6	V(H) = 19	V(M) = 22
V(I,H) = 25	V(I,M) = 49	V(H, M) = 50

	V(I, H, M) = 100	

3.4 Analysis results and interpretation

Using the characteristic form presented in the previous section, analysis was performed to further scrutinize the potential for coalition forming. The analysis is done based on the three approaches outlined in section 3.2.

Core

The first approach to be covered is the core. The core shows the overview of solutions that are rational for each actor when considering the potential value gained from working alone and from working together. The core is illustrated in Figure 11. This ternary diagram has the core delineated with a red boundary. The core is a relatively large area in this case, which is a result of the amount of value that is gained by these actors cooperating.

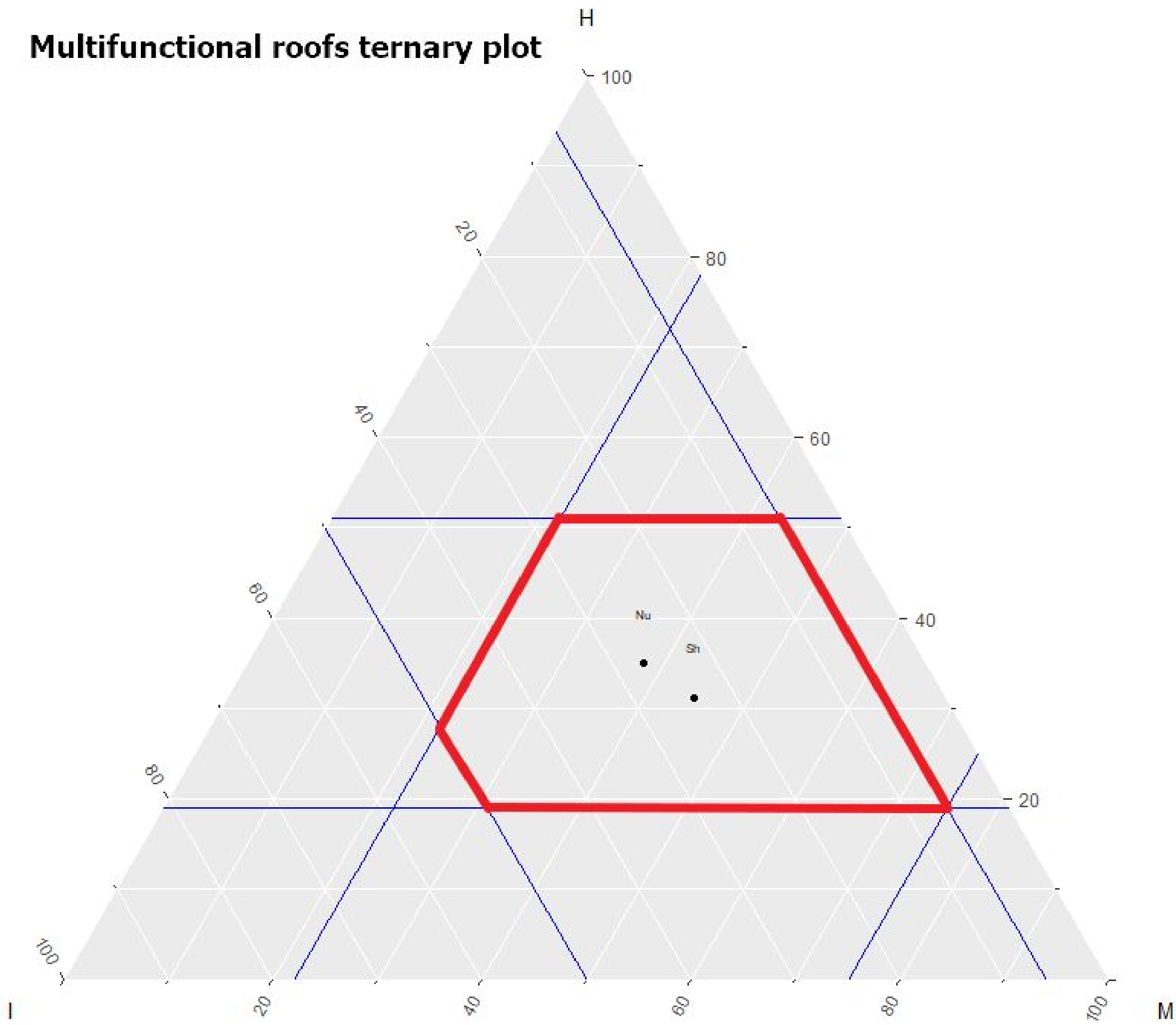


Figure 11. Ternary plot of cooperative game

Shapley value

The Shapley value values actors based on the added value that they bring to coalitions. Figure 12 shows the Shapley value per actor. An important comparison to make is an actor's Shapley value with their own single coalition value. This gives an indication of how much an actor adds to coalitions on average. The Municipality has a coalition value of 22, yet a Shapley value of 44.7. This means that the Municipality is able to add a lot of value to the coalitions that it joins. The insurance companies are also an interesting case as their singular coalition value is 6, while their Shapley value is 24.2. This is not as big a difference as the Municipality, yet it suggests that the insurance companies gain very little from working alone yet a lot from working together. The housing corporations are in the middle with a coalition value of 19 and a Shapley value of 32.2. The housing corporations don't bring as much to coalitions as the other two parties but they still add more than 50% of their initial value.

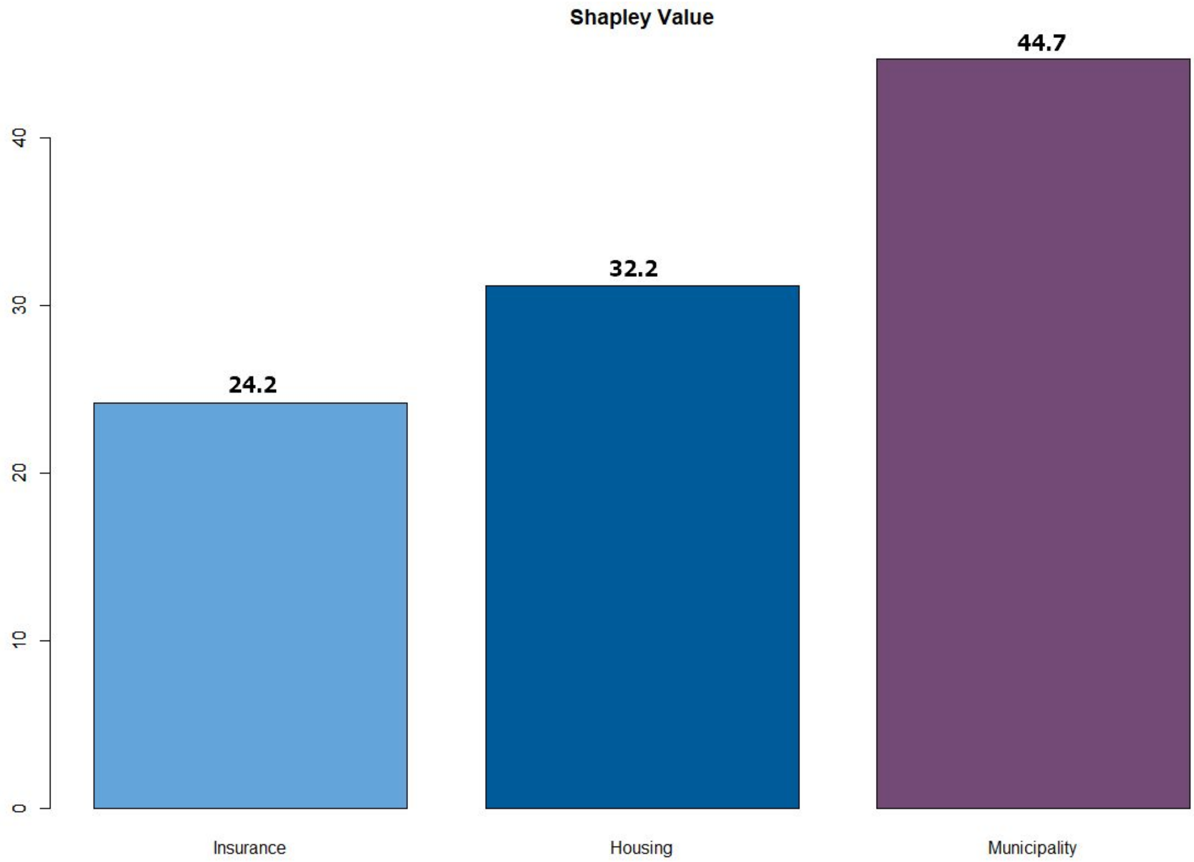


Figure 12. Shapley Value

Nucleolus

The nucleolus is an approach where the most needy coalition member is given more value, until there is no more value to be distributed without taking from one actor to give to another. The nucleolus values for this case are presented in Figure 13. The initial coalition values for insurance companies, housing corporations, and the Municipality are 22, 19, and 6 respectively. Using the nucleolus as the prefered solution would result in an egalitarian distribution of rewards. The insurance companies gain little value from their solo coalition in comparison to the housing corporations and the Municipality, yet with this method of allocating rewards they still gain much of the benefits of cooperation.

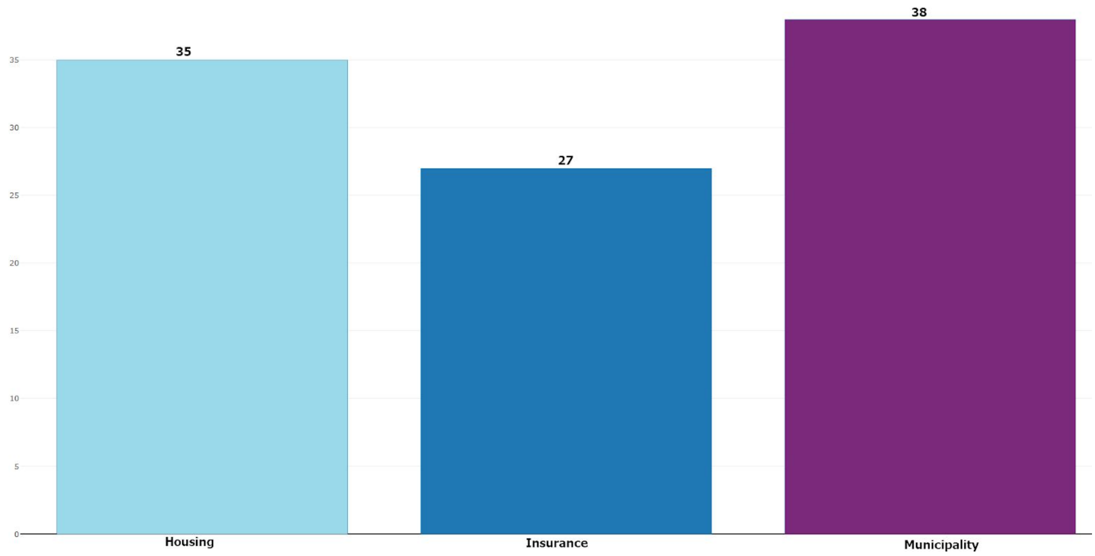


Figure 13. Nucleolus Value

Sensitivity Analysis

Two approaches were used to determine the sensitivity of the characteristic function form outcomes and different methods of scoring the actors' criteria to create the characteristic function form. The approaches are described in detail in Annex D. Overall, they showed that this problem situation is robust to different methods and variations in the outcomes.

In both approaches, the core always existed, showing that there is always potential for cooperation between the actors. However, the closeness of the Shapley value and the Nucleolus varied. In some cases, they were within 5/100 in score for each actor from one another. In other cases, they were separate. Across different scenarios, the values were usually biased more towards the Municipality, as expected.

3.5 Conclusion

This chapter aimed to find valuable coalitions for the Municipality of Rotterdam to improve the implementation of multifunctional roofs. The question that was posed was: *What cooperation between actors can be achieved to help reach the Municipality's goal for multifunctional roofs?*

Cooperative game theory was applied by using R and its GameTheory package. Coalition values were assigned using actor criteria, which were largely based on the cognitive mapping analysis performed in chapter 2. Overall, the analysis showed that there is definitely room for cooperation. A large core was found, which means that there are many different ways of dividing value for all three participants in various coalition permutations. When working together, there are different ways of distributing the rewards of cooperation are possible. The Shapley value can be used if the coalition collectively prefers to distribute the rewards based on respective contribution. In this case, insurance companies would gain lots of value relative to it acting alone, but the overall outcomes would still be biased towards housing corporations and the Municipality. A more egalitarian approach is proposed by the Nucleolus, which showed that relatively equal distribution of the reward value is also possible.

The criteria-based coalition outcome values for each actor also greatly influence the setup of the characteristic function. Since these criteria are largely subjectively quantified, there is no clear way to get a 'correct' set of values. While the relative scoring summation method was primarily used, the sensitivity of the results with regard to a raw scoring and an ordinal scoring scheme were also investigated. In both cases, a core still existed but the preferred method of distributing value varies. The value of cooperation still remains.

A certain amount of author bias is also present when assigning values to criteria for actors. A more accurate analysis could be possible through directly interviewing the actors.

Accurate value creation is also dependent on correctly translating key aspects of the comparative cognitive mapping process. The inclusion of feedback loops in the valuation of criteria proved to be difficult, causing certain criteria to be potentially under or overvalued. In the analysis, we linearly added the outcomes from different potential causal pathways.

Cooperative game theory shows the potential of different coalitions of actors. Even though these potential coalitions were identified, the coalitions still need to be established and enforced in practise. It also works on the basis that there are no clear opponents, which may turn out differently in practise. If an opposing actor does arise, then the conditions of this analysis would not be met.

4. Conclusion, recommendations and reflection

The main research question is *"How can the Municipality of Rotterdam improve the implementation of multifunctional roofs to reach the 2030 goal, given the multi-actor nature of the system?"* which is answered using comparative cognitive mapping and cooperative game theory. Comparative cognitive mapping has been performed first as it identifies important goals which can be used for the coalition values for cooperative game theory.

The comparative cognitive mapping provided valuable insights regarding perceptions of critical actors in the implementation of multifunctional roofs. Recommendations for the Municipality is to involve the non-dedicated critical actors insurance companies and housing corporations. It remains important that cooperation is needed to solve the gap to reach the 2030 goal, seeing individual actions might create action conflict. A combination of actions will improve the situation for all critical actors. It also shows how resource dependent the other actors are on the Municipality for implementation of multifunctional roofs, however the Municipality would prefer other actors to use their resources as the Municipality has a limited budget.

The cooperative game theory analysis showed that there is value to be gained from cooperating. This includes all scenarios executed in the sensitivity analysis, which used different scoring mechanisms and varying coalition values. The exact distribution of rewards is still subjective for the actors involved.

The conclusion from each sub-question is used to answer the main research question. The inclusion of the non-dedicated actors, insurance companies and housing corporations can create added value by working together. Meaning they are willing to cooperate with each other, however it is important for the Municipality to make the first step as they are the biggest contributor to the coalition and have a key role in the arena as other actors are relatively dependent on the Municipality. The distribution of the coalition is also dependent on the values the coalition partners want to enforce. However, a large core was found in which the different ways of coalition value distribution can be found.

The critical limitation of this study is the validation of the actor models, as the methodology used to gather the data is based on literature research and not on interaction with the critical actors. Furthermore, these models are a simplistic representation of reality. The models have factors which are not included, such as the perception of system agents, or how certain model assumptions require numeric translation. However, this also helps increase communication and understandability of these models. Further research would benefit from more interaction with the critical actors.

Bibliography

Axelrod, R. (2015). *Structure of decision: The cognitive maps of political elites.* Princeton university press.

Benders, J. (2017). *"Rotterdamse Groene daken, moeten of mogen?". Stadsontwikkeling Gemeente Rotterdam.* Retrieved 16 January, 2019 from https://www.multifunctioneledaken.nl/files/Rotterdamse-Groene-daken-moeten-of-mogen-J.-Benders-2016.pdf

Bollinger, B., & Gillingham, K. (2012). Peer Effects in the Diffusion of Solar Photovoltaic Panels. *Marketing Science*, *31*(6), 900–912. https://doi.org/10.1287/mksc.1120.0727

Bots, P. (2009). *Overview of DANA*. Retrieved from http://dana.actoranalysis.com/

Centraal Beheer., (2017). *Woonverzekering Voorwaarden.* Retrieved 22 January 2019, from https://www.centraalbeheer.nl/CB%20Downloads/Voorwaarden_Woonverzekering_CB.pdf

Centraal Planbureau., (2017). *Het huurbeleid van woningcorporaties.* Retrieved 23 January 2019, from https://www.cpb.nl/sites/default/files/omnidownload/CPB-Policy-Brief-2017-09-Het-huurbeleid-van-woningcorporaties.pdf

Clark, W. (1952). The Gantt Chart (Vol. 2). London.

De Graaf, R. E., Van der Brugge, R., Lankester, J., Van der Vliet, W., & Valkenburg, L. (2007). Local water resources and urban renewal. A Rotterdam case study. NOVATECH 2007.

Deltares. (n.d.). Over ons - Deltares. Retrieved January 9, 2019, from https://www.deltares.nl/nl/over-ons/

Deltares. (2018). *Deltares Strategisch Onderzoek - Activiteitenplan 2019*. Retrieved from https://www.deltares.nl/app/uploads/2018/11/Deltares-Strategisch-Onderzoek-Activiteitenplan-2019.pdf

Enserink, B., Hermans, L., Kwakkel, J., Thissen, W., Koppenjan, J., & Bots, P. (2010). *Policy Analysis of Multi-Actor Systems*. Portland: Eleven International Publ.

Gemeente Rotterdam., (2008)., Groene daken Rotterdam Maatschappelijke Kosten-batenanalyse. Retrieved 18 January 2019, from https://www.multifunctioneledaken.nl/files/2008_Eindrapportage-MKBA-Groene-Daken-Rotterdam_Arcadis.pdf

Gemeente Rotterdam. (2015). *Gemeentelijk rioleringsplan: Planperiode 2016-2020.* Retrieved 9 December 2018, from https://www.rotterdam.nl/wonen-leven/grp/Gemeentelijk_rioleringsplan.pdf

Gemeente Rotterdam. (2018) *Multifunctionele daken.* Retrieved 4 january 2019 from: https://www.010duurzamestad.nl/wat-wij-doen/lopende-projecten/multifunctionele-daken/

Gemeente Rotterdam. (n.d.-a). Stadsvisie | Rotterdam.nl. Retrieved January 8, 2019, from https://www.rotterdam.nl/wonen-leven/stadsvisie/

Gemeente Rotterdam. (n.d.-b). Multifunctionele daken | Rotterdam.nl. Retrieved January 8, 2019, from https://www.rotterdam.nl/wonen-leven/groene-daken/

Gemeente Rotterdam. (2007). *Stadsvisie Rotterdam: Ruimtelijke Ontwikkelingsstrategie 2030*. Retrieved from http://www.rotterdam-centraldistrict.nl/documenten/STADSVISIEROTTERDAM_2030_dec2007.pdf

Gemeente Rotterdam, Hoogheemraadschap van Schieland en de Krimpenerwaard, Waterschap Hollandse Delta, & Hoogheemraadschap van Delfland. (2013). *Herrijking Waterplan Rotterdam 2: Werken aan water voor een aantrekkelijke en klimaatbestendige stad*. Retrieved from https://www.rotterdam.nl/wonen-leven/waterplan-2/Herijking-Waterplan2.pdf

Getter, K. L., & Rowe, D. B. (2006). The role of extensive green roofs in sustainable development. HortScience, 41(5), 1276-1285.

Glasersfeld, E. V. (1988). The reluctance to change a way of thinking. The Irish Journal of Psychology, 9(1), 83-90.

de Graaf, R., R. van der Brugge, J. Lankester, W. van der Vliet, and L. Valkenburg. 2007. Local water resources and urban renewal: A Rotterdam case study. p. 2189–2196. In Novatech 2007; Sustainable techniques and strategies in urban water management. 25–28 June 2007. Lyon, France.

Graziano, M., & Gillingham, K. (2015). Spatial patterns of solar photovoltaic system adoption: The influence of neighbors and the built environment. *Journal of Economic Geography*, *15*(4), 815–839. https://doi.org/10.1093/jeg/lbu036

Green Deal. (2016). Resultaten Van Het Gezamenlijk Ontwikkelen Van Een Maatschappelijk Verdienmodel. Retrieved January 9, 2019, from http://edepot.wur.nl/375632

Groenendijk, M. (2017, July 30). Veel overlast door zware regenval in Rotterdamse regio. Retrieved January 17, 2019, from https://www.ad.nl/rotterdam/veel-overlast-door-zware-regenval-in-rotterdamse-regio~a6e4417f/

Hendriks, K., & Hommes, S. (2016). *Groene daken in Tilburg: Ervaringen, motieven en opschalingsmogelijkheden*. Retrieved from http://edepot.wur.nl/400304

Hermans, L. M., & Cunningham, S. W. (2018). Actor and Strategy Models: Practical Applications and Step-wise Approaches (1st ed.). Hoboken, NJ, USA: John Wiley & Sons. https://doi.org/10.1002/9781119284772

Hofstede, G. (1991). Cultures and organizations. *Intercultural cooperation and its importance for survival. Software of the mind*. London: McGraw-Hill.

Hoogheemraadschap van Schieland en de Krimpenerwaard. (n.d.). Ons werk. Retrieved January 9, 2019, from https://www.schielandendekrimpenerwaard.nl/ons-werk

Hoogheemraadschap van Schieland en de Krimpenerwaard. (2016). *Met mensen en water: Waterbeheerplan 2016-2021*. Retrieved from https://www.schielandendekrimpenerwaard.nl/media/documenten/2016/Waterbeheerplan20162021.pdf

Hulshoff, A. (2009), De wortel, de preek en de stok: http://www.duurzaamgebouwd.nl/visies/20090612-de-wortel-de-preek-en-de-stok

Inshared., (2017). *De voorwaarden woonverzekering van Inshared.,* Retrieved 22 January 2019, from https://www.centraalbeheer.nl/CB%20Downloads/Voorwaarden_Woonverzekering_CB.pdf

Keeney, RL. 1992. Value-Focused Thinking. A Path to Creative Decisionmaking. Harvard University Press, Cambridge, MA.

Mensink. J,. (2012). *Stadshavens Rotterdam*. Retrieved 9 December 2018, from https://www.gebiedsontwikkeling.nu/artikelen/stadshavens-rotterdam/

Ministerie van Economische Zaken, Landbouw en Innovatie. (n.d.). Ministerie van Economische Zaken en Klimaat. Retrieved January 9, 2019, from https://www.rijksoverheid.nl/ministeries/ministerie-van-economische-zaken-en-klimaat

Ministerie van Infrastructuur en Waterstaat. (2016). Koers I en M 2016-2020. Retrieved January 22, 2019, from http://ledendomein.platformparticipatie.nl/overons/oim-documenten-ledendag/handlerdownloadfiles.ashx?idnv=439501

NEPROM. (2016). *Ruimte maken voor het nationaal geluk: visie van de NEPROM op de nieuwe opgave*. Retrieved from https://www.neprom.nl/downloads/neprom/neprom-ruimte-maken-voor-nationaal-geluk.pdf

Neumann, J. V., & Morgenstern, O. (1944). Theory of Games and Economic Behavior (Princeton University, Princeton, NJ).

NU.nl. (2018, September 5). Hevige regenval veroorzaakt veel wateroverlast in kustprovincies. Retrieved January 17, 2019, from https://www.nu.nl/binnenland/5448023/hevige-regenval-veroorzaakt-veel-wateroverlast-in-kustprovincies.htm

Rai, V., & Robinson, S. A. (2013). Effective information channels for reducing costs of environmentally- friendly technologies: Evidence from residential PV markets. *Environmental Research Letters*, *8*(1). https://doi.org/10.1088/1748-9326/8/1/014044

Raiffa, H., Richardson, J., & Metcalfe, D. (2002). *Negotiation analysis: The science and art of collaborative decision making*. Harvard University Press.

Rijksoverheid. (2018). Beleidsartikel 11 Integraal Waterbeleid - Vaststelling begroting Ministerie van Infrastructuur en Milieu (XII) 2018 - Rijksbegroting.nl. Retrieved January 9, 2019, from http://rijksbegroting.nl/2018/voorbereiding/begroting,kst236766_6.html

Rotterdam. (n.d.). Wateroverlast. Retrieved January 17, 2019, from https://www.rotterdam.nl/wonen-leven/wateroverlast/

Rotterdams Milieucentrum. (n.d.). Rotterdam, de groene daken kampioen!. Retrieved January 9, 2019, from http://www.milieucentrum.rotterdam.nl/site/rotterdam-de-groene-daken-kampioen/

Shapley, L. S. (1953). A value for n-person games. Contributions to the Theory of Games, 2(28), 307-317.

Topsector Energie. (n.d.). *Groen en Gemak. Hoe ontzorg je bewoners bij groene beslissingen?* Retrieved 16 January 2019, from https://projecten.topsectorenergie.nl/projecten/groen-en-gemak-hoe-ontzorg-je-bewoners-bij-groene-beslissingen-00029196

TU Delft. (n.d.). Strategic Framework 2018-2024. Retrieved January 9, 2019, from http://tu-delft.instantmagazine.com/tu-delft/strategic-framework-2018-2024#!/vision-mission-values

TU Delft. (2018). *Impact for a better society: TU Delft strategic framework 2018-2024*. Retrieved from https://d1rkab7tlqy5f1.cloudfront.net/TUDelft/Over_TU_Delft/Strategie/Towards%20a%20new%20strategy/TU%20Delft%20Strategic%20Framework%202018-2024%20%28EN%29.pdf

Tweede Kamer, (2018). Vaststelling van de begrotingsstaten van het Ministerie van Economische Zaken en Klimaat (XIII) voor het jaar 2019. Retrieved 22 January 2019, from https://zoek.officielebekendmakingen.nl/kst-35000-XIII-10.html

Unie van Waterschappen. (n.d.). Groene Daken. Retrieved January 9, 2019, from https://www.uvw.nl/project/groene-daken-in-rotterdam/

Unie van Waterschappen. (2018). waterschapsbelastingen 2018. Retrieved January 22, 2019, from

https://www.waterschapsspiegel.nl/wp-content/uploads/2018/10/Waterschapsbelastingen-2018.pdf

Urbanisten. (2015) Opportunities for a sustainable Rotterdam Roofscape. Retrieved 22 January 2019, from http://www.urbanisten.nl/wp/wp-content/uploads/URBANISTEN_Rotterdam_Rooftop_Potential_EN.pdf

Verbond van Verzekeraars (2018). *Samen werken aan complexe uitdagingen*. Retrieved 15 January 2019, from https://www.verzekeraars.nl/media/4371/vvv_beleidsplan2018_spreads.pdf

Woonstad Rotterdam., (2016), Jaarstukken 2016, Retrieved 22 January 2019, from https://www.woonstadrotterdam.nl/media/548b26c1-f5ce-4549-ab54-2a92f5e87a9f/b19tJA/Downloads/DitisWoonstadRotterdam/Jaarverslagen/Jaarstukken%20Woonstad%20Rotterdam%20incl%20controleverklaring.pdf

Annex A: Actor Network Scan

This Annex covers three different techniques used to organize the actors involved in this problem and categorize them according to the part they play. First a broad actor list is made, which lists potential actors involved with the problem, which will serve as the base for further analysis.

In the second section, actors were tabled together with their objectives and interests and after that with the gap that they have regarding the topic, the existing solution they favour and lastly if they are aligned with the problem owner or not. Using the results of these tables a last table was created, containing the importance of the resources the actors have and also the level of dependency of the actors, which together led to the classifying the actors as critical- and non-critical actors.

In the third section, there is an overview of the water management regulations in place and the stakeholders involved in each one of them. With the information obtained until here, a formal chart was built. The formal chart is a useful tool in this case due to the complicated regulations and provides an important basis for the actions of the Municipality of Rotterdam.

A.1 Actor list

This section contains the actors included in the analysis for the problem. The actors are chosen based on their (potential) role they can play in the implementation of multifunctional roofs. For each actor an explanation is given for their initial inclusion.

Municipality of Rotterdam
As the goal for one million square meters of multifunctional roofs has been set by the Municipality of Rotterdam, they will be present in finding a way to reach that goal. The changing role of the Municipality from an active participator into a facilitator for other parties, leads to other actors being necessary to help reach the goals (Gemeente Rotterdam, n.d.-b).

Ministry of Infrastructure and Water Management
The Ministry of Infrastructure and Water Management can support the Municipality of Rotterdam both in financial ways or help enforce the implementation of multifunctional roofs. The Ministry can achieve this by allowing the municipalities to force strict building codes including multifunctional roofs.

Ministry of Economic Affairs and Climate Policy
The Ministry of Economic Affairs and Climate Policy are looking to create a climate neutral and sustainable Netherlands. They can support the Municipality of Rotterdam financially to help the implementation of multifunctional roofs, which could lead to nationwide initiatives if this case proves successful.

Water boards
According to similar projects (Hendriks & Hommes, 2016), the water boards that have part of Rotterdam under their care (Hollandse Delta and Hoogheemraadschap Schieland, and Krimpenerwaard need to be involved in the implementation of multifunctional roofs, because of their main goal of minimizing incidents that are the consequence of water related

phenomena. Next to that, the waterboards want to achieve this goal as efficiently and sustainable as possible. The water board could share their knowledge with Rotterdam, and lower taxes for roof owners or subsidize them if needed (Unie van Waterschappen, 2018), as well as stimulating the use of multifunctional roofs.

Knowledge institutions

As Rotterdam found out some years ago (Rotterdam, 2015), there is a lack of information with some of the actors that needs to be filled before interaction between those actors are possible. The lack of information is double sided: actors are not aware of existing knowledge which requires better communication but for specific cases there is a need to know the exact impact of multifunctional roofs that have not been developed yet. This needed knowledge on multifunctional houses can come from different knowledge institutes such as Delft University of Technology, the Royal Dutch Meteorological Institute (KNMI) or more water related institutes like Deltares or Stowa. Because it is not clear which of these institutes would be assisting the Municipality and all of these institutes have similar interests and power with regard to multifunctional roofs, the choice has been made to include the more general actor "Knowledge institutes". Although these knowledge institutions are rather neutral concerning the implementation of multifunctional roofs, their knowledge might contribute as was the case in previous, similar projects (Hendriks & Hommes, 2016).

Insurance companies (Verbond van Verzekeraars)

The insurance companies are united in an independent organization called "Verbond van Verzekeraars" in the Netherlands. One of their objectives is to work with stakeholders to look at new risks such as climate risk and play a role in a sustainable and accessible housing market (Verbond van Verzekeraars, 2018). Because flooding causes widespread damage to public and private property that requires insurance companies pay-out insurance claims, they can be an effective ally to the Municipality to involve the insurance companies to incentivize flood-preventing techniques such as multifunctional roofs. Insurance companies have experience in making evidence-based risk analyses; insurers will charge customers with higher risks to pay higher premiums. Though these companies are regulated by the government, they are mostly private.

Housing corporations Rotterdam (Havensteder, Woonbron, Woonstad Rotterdam)

The housing corporations could assist the Municipality by adding multifunctional roofs to new building projects or by changing the roofs of existing houses in Rotterdam. They could be the active actor that receives help from the Municipality as a facilitator. Just like the roof owners, the corporations should have the knowledge to see the potential and benefits of multifunctional roofs, which is lacking at this point (Gemeente Rotterdam, 2015). Although the Municipality decides some of the minimal properties for the houses, multifunctional roofs are can not be legally added to these properties (yet) (Hendriks & Hommes, 2016).

Vereniging van Nederlandse Projectontwikkeling Maatschappijen (NEPROM)

The Vereniging van Nederlandse Projectontwikkeling Maatschappijen is an organisation composed of companies that develop, or redevelop, properties in the Netherlands. The goal of the organisation is to improve cooperation betweens its members and government with the realisation of property related projects. The implementation of multifunctional roofs in both new and existing housing will require private companies that can gain their own value when including these multifunctional roofs in their projects. Because of this the implementation of multifunctional roofs must also be attractive for the involved property developers.

Roof owners
The roofs that are considered for change into multifunctional roofs cannot be seen apart from the houses or companies that they are a part of. The roof owners are not only citizens, but also any big firm or building owner in Rotterdam that could implement a multifunctional roof. The roof owners can, however, not influence the usage of multifunctional roofs other than implementing them, which is part of the system of interest. With this they can be classified as system agents that other actors wish to influence and not strategic actors (Hermans & Cunningham, 2018), which is why they will not be analyzed further.

A.2 Actor characteristics

In this section the list of actors will be analysed regarding their interest in the problem, but also their level of power and their important resources. The usage of the three different tables in this section will point out critical actors that will have to be taken into account in the implementation of multifunctional roofs.

Actor objectives and level of interest
The interest of the actors can be analyzed by looking at their strategic and problem specific objectives (Keeney, 1992). Based on both objectives, a level of interest is formulated per actor. Note that the reported interest does not include a direction; A high interest can mean that the actor is either highly against the implementation or that the actor strongly supports the implementation. An overview of the actor's objectives and interests are shown in table I.

Table I. Actors' objectives and level of interest

Actor	Strategic objective	Problem specific objectives	Interest (L/M/H)
Municipality Rotterdam (Gemeente Rotterdam, 2007; Gemeente Rotterdam et. al, 2013)	- Strong economy of the region - Attractive living city - Safety and comfort	- High area of houses with multifunctional roofs - Minimize flood risk - Efficient distribution of the Municipality budget - Livability of the city - High attractiveness for every income group to live in Rotterdam	- High
Ministry of Infrastructure and Water Management	- High accessibility - High mobility - Clean, safe and	- Low flood risks that help sustain Rotterdams attractiveness	- Medium

(Ministerie van Infrastructuur en Waterstaat, 2016; Rijksoverheid, 2018)	sustainable environment -Effective water management		
Ministry of Economic Affairs and Climate Policy (Tweede Kamer, 2018)	Sustainable and enterprising Netherlands	- Assist with implementation of roofs to stimulate green growth	- Medium
NEPROM (NEPROM, 2016)	- Continuity of organisation and sub organisations - Deliver quality implementation of projects for clients	- Cost efficiently implement multifunctional roofs	- Medium
Water Board (Hoogheemraadschap van Schieland en de Krimpenerwaard, 2016)	- Reliable water infrastructure	- Low flood risk - Sustainability	- High
Knowledge institutions (Deltares, 2018; TU Delft, 2018)	- Qualitatively high knowledge sharing.	- High quality and quantity knowledge base on multifunctional roofs	- Low
Insurance companies (Green Deal, 2016)	- Minimal risks - Low payout - High proift	- Low water damage payouts - High level of reducing water damage risks by other actors	- Medium
Housing corporations (Woonstad Rotterdam, 2016.; Hendriks & Hommes, 2016)	- Affordable housing solutions - Quality housing	- High residents satisfaction - Sustainability - Housing costs	- Medium

table I illustrates that all of the actors involved show at least a medium interest in the problem, except for the knowledge institutes. The goals of this actor are only related to creating and sharing knowledge, which is not strongly related to implementing multifunctional roofs. The difference between actors that are considered to have a medium interest and actors with high interest can be found in the multidisciplinary characteristics of the workfield in which the actors operate or in the geographical scale on which the actor operates. The Ministries have a large geographical space to deal with, which is why their concern for Rotterdam does not go further than medium. Both the knowledge institutes and the insurance companies deal with a wide variety of problems of which flood risk (and thus multifunctional roof implementation) is only one. This also goes for NEPROM, who have more projects to deal with. This leads to their interest not exceeding a medium level. The housing corporations have a relatively overlapping overall objective and specific objective, but due to their low trust in multifunctional roofs (Hendriks & Hommes, 2016), their interest is being considered as only medium. The two players that have a high interest in the problem are the Municipality, which strengthens their role as the problem owner and the Water Board.

Overview of actors' problem perceptions

With the interests and objectives of the actors known, an overview of actors' problem perceptions can be made. table II provides information on how the each actor perceives the seriousness of the problem by looking at the existing gap. Furthermore, it will conclude which perceptions are aligned with the perceptions of the problem owner. If actors have similar causes for the gap and similar favoured solutions they agree on what the exact problem is and how to solve it. It gives insight into potential key actors.

Table II. Overview of actors' problem perceptions

Actor	Existing gap	Causes for gap	Favoured solution	Alignment with problem owner (S/N/O)
Municipality Rotterdam (Gemeente Rotterdam, 2015)	Increase the square meters of multifunctional roofs, from 235.000m² in 2017 to 1.000.000m² in 2030	- Reluctance to change of other actors - The perceptions seem positive, but no one really takes action - Private ownage of roofs makes implementation more difficult	- Increase multifunctional roofs by incentivizing market parties	- Support
Ministry of Infrastructure and Water Management (Rijksoverheid, 2018)	Prevent floods in Rotterdam despite the increased precipitation due to climate change	- Urban space function dilemma's; solving the water problem removes space for other goals - Keep the attractiveness of the city	- Implementation of flood reduction measures while maintaining (or improving) pleasant urban areas	- Support
Ministry of Economic Affairs and Climate Policy (Tweede Kamer, 2018)	Increase implementation of sustainable innovations	- Potential users lack knowledge about advantages - Retrofitting on existing houses necessary - High costs of sustainable solutions compared to traditional solutions	- Implementation of sustainable solutions while the benefits and costs are appropriately distributed	- Support
Water Board	Prevent floods in	- Climate change	- Lower stress on the	- Support

(Hendriks & Hommes, 2016)	Rotterdam despite the increased precipitation due to climate change	increases higher flooding risks - Urban water system cannot deal with intense rainfalls	sewage system using sustainable solutions	
Knowledge institutes (Deltares,2018.; TU Delft, 2018)	Increase knowledge on multifunctional roofs to make it more available to others	- Not involved enough to share their expertise - Not enough trust in roofs by other actors	- Compensation for research into multifunctional roofs	- Neutral
Insurance companies (Green Deal, 2016)	Higher flooding risks increases damages and increases insurance payouts	- Climate change increases higher flooding risks	- Maintain (or lower) the damages created by flooding risks without cutting into profits	- Neutral
Housing corporations (Woonstad Rotterdam, n.d.; Hendriks & Hommes, 2016)	Housing needs to become more sustainable	- Sustainable costs more than traditional methods	- Compensation for the costs created by implementing sustainable solutions	- Neutral
NEPROM	Hard to implement multifunctional roofs in an efficient way	- Little knowledge on effects - Not clear who will pay for the implementation	- Clear responsibilities and knowledge on where and how the roofs should be implemented	- Neutral

table II shows that the alignment with the problem owner differs per involved actor, but is at least neutral for all the actors. The other governmental actors (the Water boards and the Ministries) can be seen as supportive actors. Their interests are aligned with those of the Municipality and they could be helpful when multifunctional roofs are implemented. The remaining strategic actors have a neutral view relative to the view of the Municipality, which means they will probably not oppose the actions of the Municipality, but also will not support it actively.

Critical actors based on resources

With the conclusions from tables I and II in mind, the next part of the scan focuses on the classification of actors as critical or non-critical. Critical actor are impossible to leave out of the decision-making (Enserink et al., 2010), which is why it is important to know what actors should be treated as such. The classification is done based on the resources actors have and the level of importance and substitutability of these resources. The results obtained are outlined in table III.

Table III. Identification of critical actors based on resources

Actor	**Resources**	**Importance of resource**	**Concentration of control**	**Critical actor?**
Municipality Rotterdam (Problem owner)	- Financial: Subsidies - Institutional: Zone policies Environmental Protection Act - Technical: Implement multifunctional roofs for city buildings - Social: Direct link to roof owners	High	High	Yes
Ministry of Infrastructure and Water Management	- Financial: Appropriate budgets - Institutional: Spatial planning act	High	Low	No
Ministry of Economic Affairs and Climate Policy	- Financial: Appropriate budgets	High	Low	No
Knowledge institutions	- Technical: Knowledge on water management	Low	Medium	No
Water Board	- Institutional: Water Act Water Board Act - Financial: Subsidies Taxes	High	Medium	Yes
Insurance companies	- Financial: Lower premiums	High	Medium	Yes
Housing corporations	- Technical: Implement multifunctional roofs - Financial: House rental prices	High	High	Yes
NEPROM	Technical: Develop and execute plans for multifunctional roofs	Low	Low	No

The importance of the available resources actors own, pointed out four critical actors, which can not be ignored. Next to the Municipality, at least the insurance companies, the housing corporations and the water boards should be taken into account for improving the implementation of multifunctional roofs.
Actors that are not critical should not necessarily be ignored, but are less likely to have a key influence on the system. Knowledge institutions could make the implementation a lot easier, but are not necessary to solve the problem, which is similar for NEPROM and the Ministries.

Actor analysis summary
Table IV provides an overview of the actor analysis by classifying the actors based on the results from previous analysis. The implementation of multifunctional roofs has no clear opponents. The involved actors have shown to be largely non-dedicated to the implementation of multifunctional roofs, except for the Municipality of Rotterdam and the water boards.

Table IV. Overview of actor analysis

	Dedicated actors (high interest)		Non dedicated actors (low interest)	
	Critical actors	Non-critical actors	Critical actors	Non-critical actors
Supportive actors	-Municipality of Rotterdam -Water boards		-Housing corporations -Insurance companies	-Ministry of EA&CP -Ministry of I&WM - Knowledge institutions - NEPROM
Opposing actors				

A.3 Formal chart

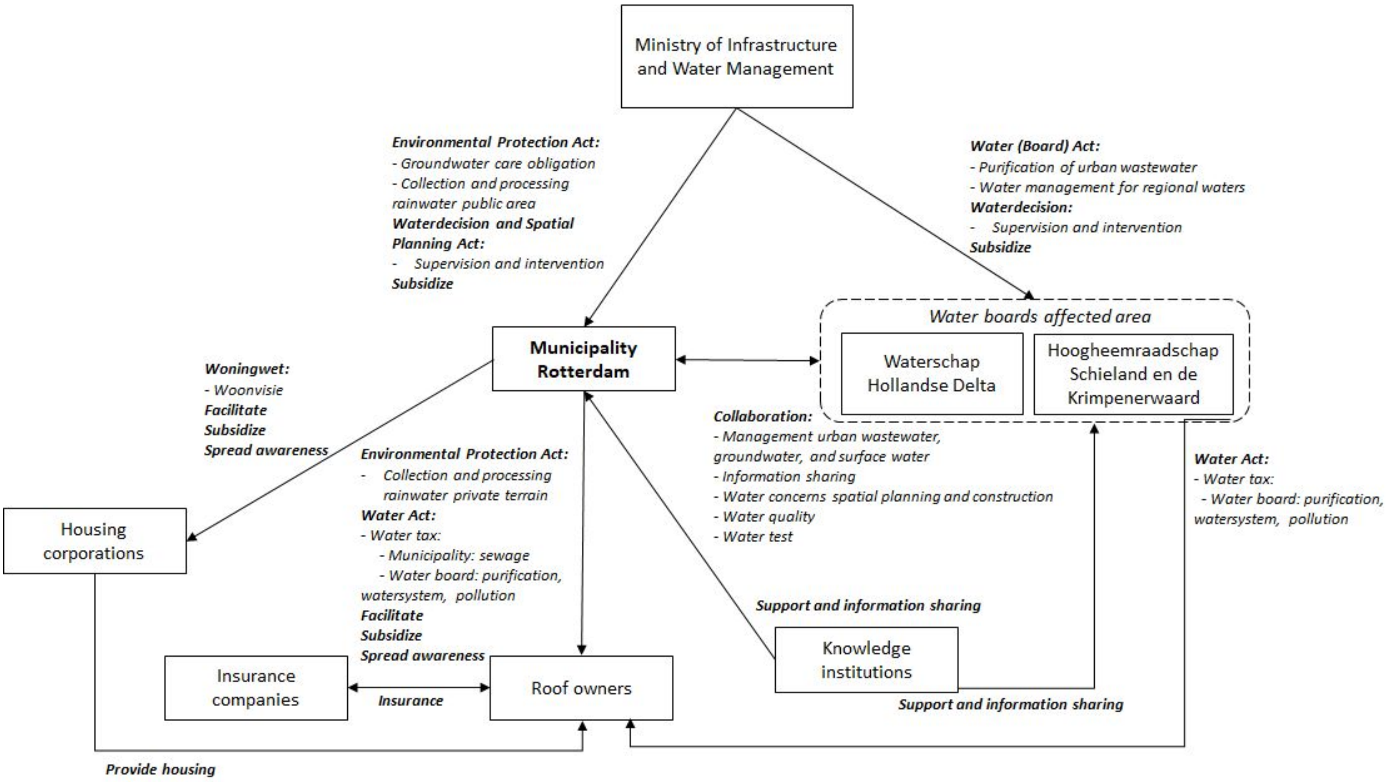


Figure I. Formal chart

The formal chart above shows all existing formal relations between the relevant stakeholders in the multifunctional roof case. In this chart detailed relations of the Municipality of Rotterdam and its surroundings are shown.

Firstly, the Municipality has a lot of informal relations with the stakeholders that are able to help them. Relations with roof owners and housing corporations are more soft as the Municipality moves in a facilitative role (Gemeente Rotterdam, 2015). Facilitation, subsidizing, and spreading awareness are examples of the relations they have with these stakeholders. It could help to make these relations more formal as clarity and responsibility will help in implementing multifunctional roofs more optimally.

Secondly, as expected to be observable in this chart, one can also see that roof owners are affected by most relevant parties even though they can not make strategic moves themselves. However, as mentioned before, they are relevant in this formal analysis as most actors wish to influence them and it is relevant to see how they can do so.

The formal regulations and laws mentioned in the formal chart are specified in table V for further information.

Table V: Overview of regulations

Regulation	**Description**	**Stakeholders**
National		
Water Act[1]	- General rules on water supply, water quality, and water safety - Management of surface water and groundwater rights by water managers - Coherence between waterpolicy and spatial planning - Supervision and intervention power - Rights of taxation	- Ministry of Infrastructure and Water Management - Water boards - Municipality Rotterdam
Water Board Act[2]	- Tasks and authorization of water board - Rights of taxation	- Ministry of Infrastructure and Water Management - Water boards
Environmental Protection Act[3]	- Protection of the environment - Groundwater care Municipality / private - Collection and processing rainwater task	- Ministry of Infrastructure and Water Management - Municipality Rotterdam
Spatial Planning Act[4]	- Policy on spatial planning: structural vision requirement - Norms on spatial planning	- Ministry of Infrastructure and Water Management - Municipality Rotterdam
Drinking Water Act[5]	- Collective water supply of drinking water - Responsibilities preparation drinking water	- Ministry of Infrastructure and Water Management - Water boards
Soil Protection Act[6]	- Sanitation of groundwater - Groundwater care obligation province	- Ministry of Infrastructure and Water Management - Province Zuid-Holland
Nature Protection Act[7]	- Protection of flora and fauna	- Ministry of Economic Affairs and Climate Policy
Water Decision [8]	- Decides water importance during drought - Map waters for Rijkswaterstaat - Practical assignments from the Water Act	- Province Zuid-Holland - Water boards - Municipality Rotterdam

[1] https://wetten.overheid.nl/BWBR0025458/2018-07-01
[2] https://wetten.overheid.nl/BWBR0005108/2018-07-01
[3] https://wetten.overheid.nl/BWBR0003245/2018-07-01
[4] https://wetten.overheid.nl/BWBR0020449/2018-07-01
[5] https://wetten.overheid.nl/BWBR0026338/2015-07-01
[6] https://wetten.overheid.nl/BWBR0003994/2017-01-01
[7] https://wetten.overheid.nl/BWBR0037552/2018-07-01
[8] https://wetten.overheid.nl/BWBR0026872/2018-07-01

	- Supervision and intervention rank order	

Annex B: Comparative Cognitive Mapping

B.1 Cognitive Maps description

Figure II. Element description for cognitive maps

The cognitive maps contain elements such as actions, external factors, factors, goals, and constraints for a better overview. The elements are displayed in Figure II.

Actions represent moves that the actors can make to influence the problem - these will be represented on the left of the map inside a box.

Factors which only have outgoing causal relations, means they can not be influenced by the actor. These factors are referred to as external factors, which mostly are driving forces such as the amount of heavy rain that falls within a certain period. They do influence the system and therefore it can be stated that the actors are dependent on the movement of these external factors.

System factors connect the possible actions to the desired goals and represent how an actor understands the system as a whole and the effects of each action in the process of reaching a goal. These are represented in the middle of the maps and are linked to other factors according to the causal relation between them. If a factor has a positive relation (the increment of the first factor leads to the increment of the factor connected to it), the link is represented with a plus sign. If the causal relation is negative then the link has a minus sign attached.

Goals will be represented on the right of the maps and state the actors' objectives on a specific situation. These goals can be increasing, decreasing or constraining a factor, which will be respectively represented in orange, blue or white with a red cross. Logically, an orange goal means that the actor would like the value, quality or quantity of this goal to increase.

B.2 Structural properties explanation

Comparative cognitive mapping allows individual maps to be analyzed through the structural properties. These properties explanations are based on Hermans & Cunningham (2018).

- Size and detail: gives information how many factors and different causal paths are available in the cognitive map. This can help to see how detailed a map is and the level of aggregation.
- Density: look at how many relations there are in the map, which can help find central factors.
- Balance: looks at the sequence of direct relations which form paths. A map is balanced if these paths are either all positive or either all negative.
- Dilemmas: if an action has both desirable and undesirable consequences in the goals.
- Feedback loops and cycles: shows if there are reinforcing or balancing cycles in the cognitive map.

B.3 Structural properties

Municipality of Rotterdam

The Municipality has the most dense cognitive map compared to the other critical actors, which is because the Municipality has very broad actions and goals. Seeing they have three possible actions compared to one action per actor the for others. Their goals also include the number of multifunctional roofs, flood risk, livability, housing costs, and Municipality budget as they have to consider many social values.

The dilemmas of the actions increase awareness campaigns and implement multifunctional roofs in city buildings, can be found in the increasing number of roofs but at the same time, an increase for the constraint housing costs. This is why it is probably desirable to combine these actions with lowering sewage tax and increasing subsidies because this action lowers the housing costs. The dilemma all actions have is their impact on the Municipality budget which means that the Municipality would prefer the market handle the implementation.

There is a positive feedback loop in which more multifunctional roofs will increase the social pressure which increases multifunctional roofs. The same effect can be seen in solar roof adoption (Bollinger & Gillingham, 2012; Graziano & Gillingham, 2015; Rai & Robinson, 2013). This is a reinforcing cycle, however the Municipality needs to reach a tipping point (De Graaf, et al. 2007) in order to enter this cycle. Another interesting feedback loop is the effect of lowering flood risk through multifunctional roofs which will lower awareness and ultimately less multifunctional roofs. This negative feedback loops shows that when there is no problem anymore the technology will quietly die down. If the Municipality wants implementation to remain for reasons other than flood risk, such as livability, this cycle is important.

Water board

As an organisation with a clear and defined goal (Hoogheemraadschap van Schieland en de Krimpenerwaard, 2016) in line with the reasons to use multifunctional roofs, water board's cognitive map is rather simple and straightforward. With no different paths between two factors, Water boards do not face any dilemma and have a clear understanding of the implementation of multifunctional roofs and its effects on the system.

The only interesting information that can be taken out of the map is the existence of a self-reinforcing loop connecting social pressure, willingness to adopt multifunctional roofs and the existent multifunctional roofs in m2. This loop can be triggered by any of the actions included in the water board map, meaning that Water boards understand the impact of each actor's move and, considering its positive effect in their goals, wish for the execution of those actions. Interestingly enough, the Water boards do not necessarily need any compensation for their contribution towards an increase of implementation of multifunctional roofs as it offers a direct benefit to them.

Insurance companies

Although the highest density of the map of insurance companies can be found in the number of multifunctional roofs, the path from their actions of lowering premiums to the goal of profit, seems an important one as well. As insurance companies experience a negative influence of their contributing action on their goal of making profit, but indirectly also a delayed positive influence through the implementation of more multifunctional roofs, it can be stated that their map is not balanced. This imbalance can be expressed in the dilemma that the insurance companies have to lower the premiums for houses that carry multifunctional roofs or not. Although a feedback loop exists that strengthens the implementation of the roofs and therefore decreases the flood risk, it is unclear if this effect brings more benefits than the lowered profit brings costs.

Housing corporations

The cognitive map of the housing corporations has a high density around the number of multifunctional roofs, as well as two feedback loops that increase the number of roofs and therefore the residents satisfaction. By lowering the rents, the housing costs will decrease and the number of multifunctional roofs will increase leading to higher sustainability, but the low profit margin leaves question marks to the feasibility of performing this action. Although the map is relatively balanced as most actions can lead to all of their goals increasing, perhaps housing corporations might need to receive some sort of compensation in order to cooperate.

B.4 Similarity table

Relevance

	Arena I→	Rotterdam	
	Actor A→	*All actors	
	Factors	**# Occurrences**	**# Goals**
	Create awareness campaigns on multifunctional roofs [Municipality]	4	0
	Flood risk	3	3
	Housing costs	2	2
	Implement multifunctional roofs city buildings [Municipality]	4	0
	Increase subsidy and lower water purification levy and water board tax [Water boards]	3	0
	Insurance company profits	1	1
	Investment and maintenance costs	3	0
	Livability	1	1
	Lower insurance premiums for households with multifunctional roofs and raise them for houses without multifunctional roofs [Insurance companies]	4	0
	Lower rental prices for houses with multifunctional roofs [Housing corporations]	3	0
	Lower sewage tax and increase subsidies multifunctional roofs [Municipality]	4	0
	Multifunctional roofs awareness	4	0
	Multifunctional roofs in m2	4	1
	Municipality budget	1	1
	Precipitation	4	0
	Rental price	1	0
	Satisfaction of residents	1	1
	Social pressure	4	0
	Sustainability	2	2
	Willingness to adopt multifunctional roofs by roof owners	4	0

Figure III. Occurence of factors

The similarity table is used to do a simple frequency count on the factors, actions, and goals for comparative cognitive mapping. This shows if goals are shared between actors or how important a factor is.

B.5 Tables of the diagrams

The tables of the diagrams show the exact numeric scores attributed to the link weights in the similarities, conflicts, and resource dependency diagrams.

Similarity of Perceived Causality

Cell values reflect how much of B's perception is shared by A

		Arena I→		Rotterdam							
		Actor A→		Housing corporations		Insurance companies		Municipality of Rotterdam		Water boards	
Arena II↓	**Actor B↓**	**Factors**	**Paths**	**%Shared factors**	**%Path similarity**	**%Shared factors**	**%Path similarity**	**%Shared factors**	**%Path similarity**	**%Shared factors**	**%Path similarity**
Rotterdam	**Housing corporations**	16	154	100%	100%	62%	95%	81%	82%	75%	95%
	Insurance companies	12	56	83%	95%	100%	100%	92%	84%	83%	100%
	Municipality of Rotterdam	16	142	81%	82%	69%	84%	100%	100%	75%	85%
	Water boards	13	61	92%	95%	77%	100%	92%	85%	100%	100%

Figure IV. Similarity of perceived causality

Conflict

Cell values indicate how strongly A is opposed to B's ideas (table is symmetric)

	Arena I→	Rotterdam							
	Actor A→	Housing corporations		Insurance companies		Municipality of Rotterdam		Water boards	
Arena II↓	**Actor B↓**	**µ Goal Conflict**	**µ Action Conflict**	**µ Goal Conflict**	**µ Action Conflict**	**µ Goal Conflict**	**µ Action Conflict**	**µ Goal Conflict**	**µ Action Conflict**
Rotterdam	**Housing corporations**	0	0	0	0.65	0	0.35	0	0.43
	Insurance companies	0	0.65	0	0	0	0.07	0	0.03
	Municipality of Rotterdam	0	0.35	0	0.07	0	0	0	0.10
	Water boards	0	0.43	0	0.03	0	0.10	0	0

Figure V. Goal and action conflict

Resource Dependency

Cell values indicate how strongly A believes it's goal achievement may be affected by B's actions

	Arena I→	Rotterdam							
	Actor A→	Housing corporations		Insurance companies		Municipality of Rotterdam		Water boards	
Arena II↓	Actor B↓	∑ Utility to gain	∑ Utility to lose	∑ Utility to gain	∑ Utility to lose	∑ Utility to gain	∑ Utility to lose	∑ Utility to gain	∑ Utility to lose
Rotterdam	**Housing corporations**	0.75	1.8	0	0	0.75	1.8	0	0
	Insurance companies	0.75	1.8	1.5	0	0.75	1.8	0	0
	Municipality of Rotterdam	1.5	2	3	0	2	2.3	2	0.75
	Water boards	0.75	1.8	0	0	0.75	1.8	0	0

Figure VI. Resource dependency

Annex C: Sensitivity Analysis for cooperative game theory

In this Annex, the sensitivity analysis for cooperative game theory is executed. The conclusions from this analysis contributes to the strength of the analysis as a whole and shows the robustness of the model.

Two main approaches were used for sensitivity analysis. First, the outcome quantities in the characteristic form were adjusted in various permutations by varying them by +/- 20% each. With seven non-null parameters and three possible sensitivity manipulations to each (including the one with the grand coalition), there are a total of thousands of permutations possible. Instead, a small sample of these were run. This method was used to account for quantitative uncertainties in evaluating each criteria. Two example scenario is shown below.

Table VI: Characteristic form of simplified game with adjusted outcomes sample 1

	V(φ) = 0	
V(I) = 6 ✕ 1.2	V(H) = 19	V(M) = 22 ✕ 0.8
V(I,H) = 25 ✕ 0.8	V(I,M) = 49 ✕ 1.2	V(H, M) = 50 ✕ 1.2
	V(I, H, M) = 100	

Table VII: Characteristic form of simplified game with adjusted outcomes sample 2

	V(φ) = 0	
V(I) = 6 ✕ 0.8	V(H) = 19 ✕ 1.2	V(M) = 22
V(I,H) = 25 ✕ 1.2	V(I,M) = 49	V(H, M) = 50 ✕ 0.8
	V(I, H, M) = 100	

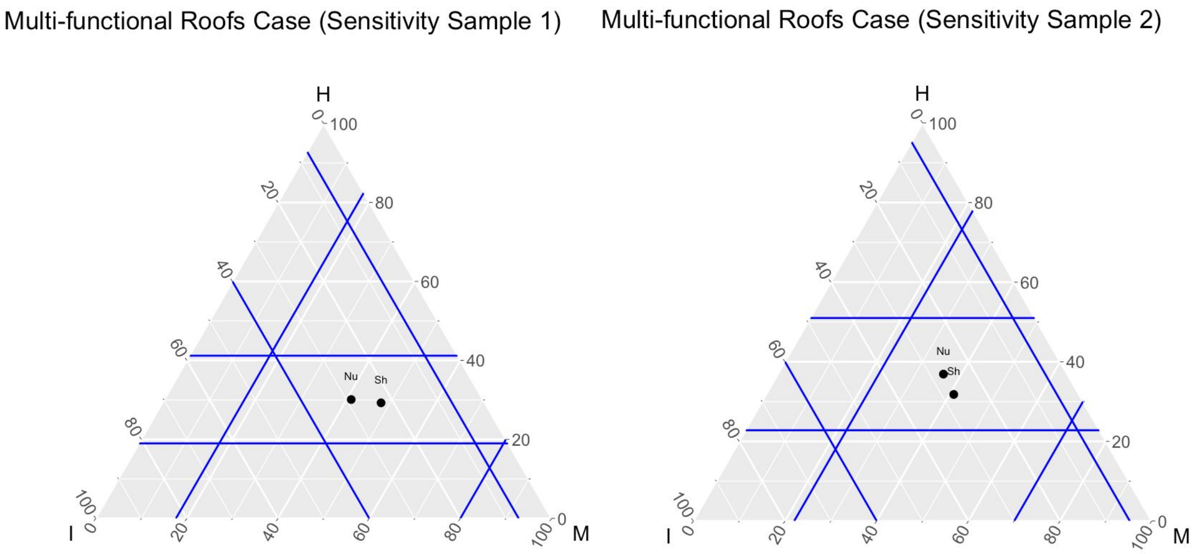


Figure VII: Ternary plot using sensitivity analysis inputs for sample 1 and 2, respectively

In the two samples shown and others that were run, there were no scenarios were a core was only a single point or did not exist. In many of these permutations, the Nucleolus and the Shapley values are closer together, showing the system would be resilient to different preferences in distributing outcomes. However, in most cases, there was a separation with the Nucleolus more centred (a more egalitarian outcome) and the Shapley value still biasing the Municipality the most.

Secondly, two other approaches were used to extract the characteristic form for the problem. Instead of adding the relative scores in each section together, an ordinal ranking system and a raw score summation process were applied. These were applied to account for different structural approaches the Municipality might have taken instead.

The raw score method uses the values from the ‘Subtotal’ column of table 3 (from the main text) instead of the normalized scores. This method results in the characteristic form shown below in table VIII:

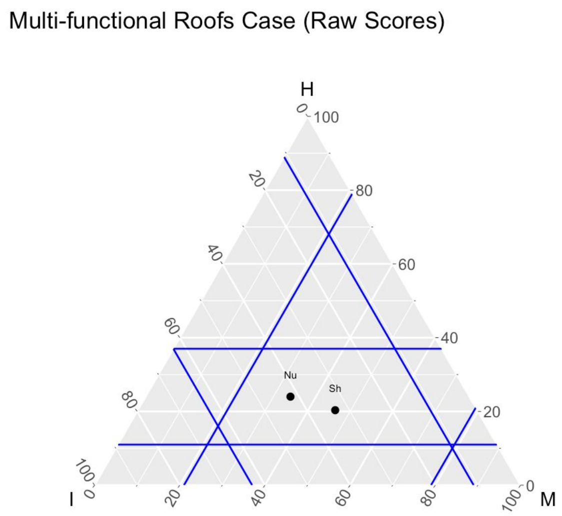
Table VIII: Characteristic form of simplified game using raw score method

	V(φ) = 0	
V(I) = 11	V(H) = 11	V(M) = 21
V(I,H) = 21	V(I,M) = 63	V(H, M) = 37
	V(I, H, M) = 100	

The ordinal ranking method examined the scores for each actor and let each actor assign a preferential ranking to the results. Here, each actor ranked the outcome subtotals and then 0-1 normalized its own rankings, which was then summed together for the overall ordinal sum. This sum was then normalized from 0-100 into characteristic function form.

Table IX: Characteristic form of simplified game using ordinal ranking method

	V(φ) = 0	
V(I) = 13	V(H) = 10	V(M) = 11
V(I,H) = 36	V(I,M) = 57	V(H, M) = 51
	V(I, H, M) = 100	



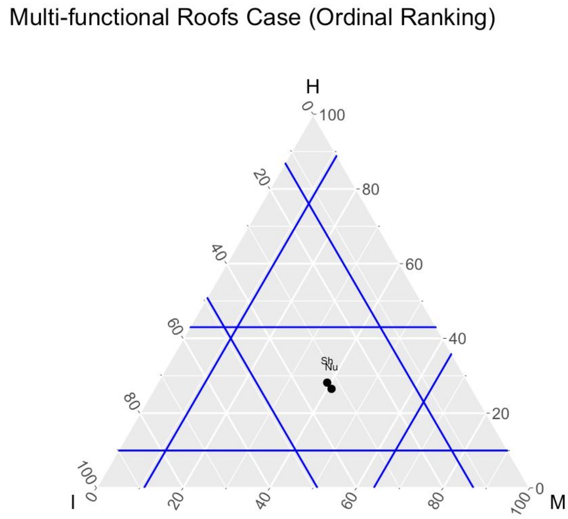


Figure VIII: Ternary plot when using raw scores and ordinal ranking, respectively;

This raw score method also resulted in a core that overlaps with the original analysis but where the Housing Corporations do not contribute to the system as much as they did before. The ordinal ranking system did the same but valued the role of the Municipality less. Both a Shapley value and the Nucleolus exist in both of the other methods. When using raw scores, the two values' outcome was quite similar the baseline outcome and that of the other sensitivity approach. However, when using ordinal ranking, the Shapley value was actually more centred than the Nucleolus. Overall, it is clear that the overall approach is quite robust across different scoring methods.

Annex D: Group Member Contributions

In this Annex, a global explaining on the contributions of all of the group member is shown. Establishing roles can support an equal workload for all members. Even though every group member had knowledge of all steps in the report, some tasks were distributed beforehand.

Roles:
Chair: Brennen Bouwmeester. As chair, Brennen made sure all group members delivered their parts and lived up to expectations. Next to that, he was responsible for the telling of the story within the report from introduction to conclusion.

Secretary: Eva Brink Carvalho. As secretary of the group, Eva was responsible for arranging meetings and taking care of email contact. She was responsible for the last check of the project before it was turned in.

Comparative cognitive mapping leader: Kevin Su. As leader for the first model, Kevin was responsible for the files and calculations used to prepare and perform this model. When results were needed, Kevin performed the steps that had to be taken. He was also responsible for the explanation of the model used.

Cooperative game theory leader: Jason Wang. Similar to the leader of the first model, Jason, as leader of the second model, was responsible for the files and calculations needed to prepare and perform the second model. Similar to Kevin, he was responsible for the explanation of the cooperative game theory method and ran the calculations iteratively when changes were made.

Supportive role: Omar Quispel. When one of the other roles could not be filled by the regular group member, Omar would fill in that role to keep the group performing as good as possible. If no role had to be filled, Omar was responsible for motivation and pick moments for needed breaks in order to keep the motivation level as high as possible. In the report, Omar was responsible for the bibliography.

During the project, the roles of the members changed continuously and almost all parts of the project were supported by all of the members. The appointing of roles did create sense of responsibility for each of the members which had a positive influence on their dedication to the project.