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An agent-based study of the influence of institutional design on the robustness of collective action on community gardens

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An agent-based study of

the influence of institutional design on the robustness of collective action on community gardens

By

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Preface

Before you lies the thesis report “An agent-based study of the influence of institutional design on the robustness of collective action on community gardens”. This report the result of a graduation project to fulfil the graduation requirements for the Master Program in Industrial Ecology at Delft Technical University and Leiden University.

This thesis would not have been here without the support of many people. Firstly, I would like to thank my supervisors Amineh Ghorbani, Arthur Feinberg and Rolf Künneke for great guidance and feedback, and for providing an exceptionally robust feeling of support.

Additionally, this research builds heavily on information provided by willing experts. Nicole Rogge has been of great help in providing her dataset and comments regarding assumptions and results. I am also very grateful for the help from gardeners at Gandhi Tuin and Vredestuin, who took the time to elaborately explain the characteristics of the gardens and reflect on the results and use of the model in practice.

Also, I want to thank my friends. When I felt like living under a rock, you were there to pull me out for some energising fun, coffee or tea, or to join under the rock for fruitful brainstorms.

Finally, I thank my parents for being wonderful examples, always being there for me and supporting me throughout all my years of study.

E. Hooijschuur
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Summary

Green spaces can contribute to the adaption of our cities to developments resulting from climate change in many ways, therefore municipalities aim to increase the share of natural areas. Public spaces can be managed in different ways. In many cases the land is either owned and managed by the government or by a private party. However, governmental management can be expensive and neglected under financial pressure, while on the other hand too much privatisation can lead to a loss of valuable public space (Foster, 2011). A third way green spaces can be managed is through collective action. Inhabitants can voluntarily contribute to the management of a green space they do not own. Not only does this avoid the problems regarding financial pressure and loss of public space, user participation in public green space is also shown to foster local knowledge and learning, increased use of the space, and a boost in environmental awareness and human-nature relationships (Fors, Molin, Murphy, & Bosch, 2015b).

However, collective action can be vulnerable to free-riding when volunteers take too much harvest or do not properly maintain the garden. Free-riding is a problem typical for common pool resources (CPRs). CPRs are resources with both high difficulty of excluding potential beneficiaries and high subtractability of use, traditional examples are forestries and fisheries (Ostrom, 2005). Community gardens can be interpreted as a CPR, as their vision is often to be open to anyone and the yield taking of one volunteer decreases the yield available for others. However, community gardens are also different from traditional CPRs because volunteers have multiple motivations of which some, such as food, are subtractable, while others, such as social time, are not (Rogge & Theesfeld, 2017). The design principles were identified by Ostrom as underlying principles in robust traditional CPR governance systems (Ostrom, 2005). As community gardens share some characteristics with traditional CPRs, these design principles might be applicable.

In this research, an Agent-Based Model (ABM) is developed in order to gain insight in the effect of the design principles on the robustness of collective action on community gardens. The model is based on the design principles, Institutional Analysis and Development Framework and the Theory of Reasoned Action. Information on collective action on community gardens was extracted from literature, a recently developed database (Rogge, 2017), and case study Gandhi Tuin. In the model, agents base their decision to join gardening on a set of motivations. When an agent chooses to join the gardening, it interacts during the gardening with the other agent that chooses to volunteer. After the gardening session, the agent evaluates its experience on which it bases it’s next decision to join. This results in the emergence of groups maintaining the garden. Design principles influence the interactions during gardening. Their implementation in the model is based on their implementation on real community gardens, and on the influence the implementations have according to literature.

Results were analysed with correlation tables and decision trees predicting the chance for collective action to sustain as found by the model. The model indicated that for the conditions of Gandhi Tuin, the amount of sanctioning, the amount of rule violation and conflict are important variables influencing the robustness of collective action, which was confirmed by the gardeners interviewed. This indicates that monitoring, plot boundaries, collective-choice arrangements and conflict-resolution mechanisms are beneficial. However, we also learnt that the impact of a single design principle depends largely on the other regulations in place. Although design principles can have a tendency for a positive or negative impact, the decision trees showed that combinations of design principles can lead to surprisingly robust or vulnerable collective action. We therefore conclude that it is more useful to look at influences of combined design principles in specific situations than at influences of design principles in general. Most findings were validated by both gardeners and an academic expert on community gardens.

The scientific relevance of this research involves two types: the providing of insights in the influence of design principles on community gardens, and the example of a method to study such problems. This research provides both a more detailed view on the influence of the design principles on collective action on community garden, as a more specific view on the robustness of collective action. It also provides a first example of an ABM of collective action on community gardens and an ABM of design principles. The model can be used as a basis to study more influences on collective action of community gardens, or more effects of the implementation of design principles. The modelling and visualisation of the impact of design principles can be of use for researchers interested in CPRs in general.

The outcomes of this research can be useful in practice as the result facilitate insight in the likeliness of collective action on a garden to sustain under certain institutional conditions. Additionally, the results provide a practical insight of risks and opportunities under institutional conditions.

Further research could test our model on other community gardens and develop similar models for other CPRs. Additionally, empirical research could be done to find precise influences of design principles on community gardens.

1. Introduction

In this chapter, I will introduce the problem addressed by this research. First I introduce the topic, after which a research gap becomes clear. Then, research questions addressing the research gap are discussed.

1.1 Background

Although much attention goes to reducing green house emissions, climate change is already happening. Research by the World Wide Fund for Nature showed European cities are warming, and the PBL Netherlands Environmental Assessment agency found that climate change causes Dutch biodiversity to be harmed, extremely hot days to become more common and intense precipitation to happen more often (Gill, Handley, Ennos, & Pauleit, 2007; PBL Netherlands Environmental Assessment Agency, 2012).

Green spaces can contribute to the adaption of our cities to these effects. They can contribute to biodiversity conservation (Colding et al., 2013), to moderating urban summer temperatures by evaporation, shading and transpiration of vegetation, (Kleerekoper, van Escha, & Salcedo, 2011; Wolch, Byrne, & Newell, 2014) and to facilitating the runoff of storm water (Wolch et al., 2014). Additionally, green space can contribute to replenishing ground water, filter air, remove pollution and attenuate noise (Wolch et al., 2014). It is therefore not surprising that municipalities aim to increase the share of natural areas in the city in order to improve biodiversity and water quality (Gemeente Amsterdam, 2013; Gemeente Rotterdam; Gemeente Utrecht, 2017; Openbaar Groen Rotterdam, 2016).

Public spaces such as green spaces can be managed in different ways. In many cases the land is either owned and managed by the government or by a private party. However, these approaches know some disadvantages. Governmental management can be expensive and neglected under financial pressure, while on the other hand too much privatisation can lead to a loss of valuable public space for the community (Foster, 2011). A third way green spaces can be managed is through collective action. Inhabitants sometimes voluntarily contribute to the management of a green space they do not own. Not only does this avoid the problems regarding financial pressure and loss of public space, community gardens have several additional benefits. User participation in public green space among others is shown to lead to fostering local knowledge and learning, increased use of the space, and a boost in environmental awareness and human-nature relationships (Fors, Molin, Murphy, & Bosch, 2015a).

When a garden is managed collectively, the garden itself and the yield that is grown on the garden show some characteristics of common pool resources (CPRs). Table 1.1 shows the four types of goods in terms of excludability and subtractability, in which CPRs are resources with both high difficulty of excluding potential beneficiaries and high subtractability of use. This means it is difficult or undesirable to exclude people from the resource, and that consumption of one user diminishes the possibilities for other users (Ostrom, 2005). The vision of community gardens often includes to welcome anyone who would like to join, a membership of some sort often is not necessary (Butler, 2013). We can see the difficulty of exclusion from both taking yield and enjoying the garden therefore as high. Also, when a user takes yield or contributes to gardening, this can diminish the possibilities for other users. Subtractability of use can therefore also be seen as applicable. Recently, community gardens are indeed described as CPRs, for instance together with park conservancies and neighbourhood foot patrols. These commons in the city are referred to as 'urban commons' (Foster 2011).

A well known threat for CPRs is the tragedy of the commons. Garret Hardin described this tragedy in his classical story, which tells about farmers grazing their cows in a commonly owned pasture. Because each farmer benefits with adding more cows to the pasture, too many cows are added and the resource is depleted (Wilson, Ostrom, & Cox, 2013). The story indicates that when it is difficult to exclude potential users who lack incentives to conserve or sustainably use the resource, the resource will be depleted (Foster, 2011). This behaviour of users is called free-riding: they do not contribute to the maintenance of a resource and take a share of the good at no cost (Moreira, Pacheco, & Santos, 2013).

Problems of free-riding are indeed observed on community gardens, it appears as taking too much harvest or as a lack of efforts to maintain the garden. Guitart et al. (2012) summarised the results of studies on community gardens and mentions volunteer drop off as a challenge that community gardens face, next to future land access, soil contamination, a lack of water, safety issues, funding, cultural differences issues, neighbourhood complaints and waiting lists. Charles (2012) mentions the appearance of annoyance when people take more yield than others. These issues can diminish the willingness of the whole group to contribute, which harms the functioning of collective management (Butler, 2013).

Table 1.1: the four types of goods (Ostrom 2009)

Difficulty of excluding potential beneficiaries	Subtractability of Use: high	Subtractability of Use: low
high	Common-pool resources: groundwater basins, lakes, irrigation systems, fisheries, forests, etc.	Public goods: peace and security of a community, national defence, knowledge, fire protection, weather forecasts, etc.
low	Private goods: food, clothing, automobiles, etc.	Toll goods: theaters, private clubs, daycare centres, etc.

Hardin's tale was first used as an argument for privatisation. If a resource is privatised, the government or private owner can take control of harvesting levels and investments in maintenance. However, collective action is shown to offer a solution as well. Cases are found in which local communities successfully organised themselves around natural CPRs such as fisheries, forestries and irrigation systems. Many of these examples have succeeded to sustainably use their resource for many years (Ostrom 2005).

Through many case studies on successful collective action around CPRs, Elinor Ostrom found 8 design principles leading to robust property-right institutions. Institutions are the prescriptions that humans use to organise all forms of repetitive and structured interactions, such as rules, norms and strategies. The design principles are not blueprints that are applied to all situations in the same way. Rather, they can be described as structural similarities that are found in self-organised systems which have adapted and learnt to be robust to social, economic and ecological disturbances (Ostrom, 2005, 2009a).

The design principles are studied extensively for collective action on CPRs such as forestries, fisheries and irrigation systems, and many of the studies confirmed their importance (Ostrom 2005). However, their relevance for community gardens is unclear. Two main reasons can be appointed to this. Firstly, little research was done on community gardens and design principles. Only one unpublished master thesis was found, in which the necessity of design principles for successful collective action on community gardens was investigated through a comparative case study on seven community gardens in the UK (Butler, 2013). Secondly, it is unclear whether community gardens are similar enough to the traditional CPRs from which the design principles were extracted. On some aspects, community gardens are similar to the resources that are usually investigated in commons research. Like traditional CPRs, the resource on community gardens can be interpreted as a CPR and is vulnerable to free-riding. However, community gardens are also different from traditional CPRs because harvesting a CPR is not the only aim in maintaining of the resource. The motivation of volunteers to contribute to maintaining the garden is not only yielding as much food as possible or only enjoying the garden when it suits them, the motivations differ. They include things such as enjoying social cohesion, improving health, enjoying nature, receiving education or enhancing sustainability (Guitart, Pickering, & Byrne, 2012). Because of these varying motivations, collective action might be harmed only little by free-riding on one aspect. This idea is supported by Butlers study, which concluded that design principles essential to sustainable collective action on community gardens are the ones that are less directly related to the management of the resource: collective choice mechanisms and minimal recognition of rights to organise.

However, these are only speculations. What role the design principles play in the robustness of collective action on community gardens, is not clear yet. This research aims to contribute to filling this research gap.

1.2 Research questions

The goal of this research is to gain insight in the effect of the design principles on the robustness of collective action on community gardens. Our main question therefore is:

'What are influences of institutional design on the robustness of collective action on community gardens, seen from the perspective of the design principles?'

In order to avoid confusion, a clear distinction should be made between robustness, resilience and sustainability. Anderies, Folke, Walker and Ostrom address the meaning of these terms and describe how they can complement each other. *Sustainability* they suggest to define as an analytical framework to guide action, a skeleton to support discourse about the interaction between human societies and the environment. This skeleton implies the recognition that a functioning biosphere is a precondition for economic and social development. Resilience and robustness can be used within this context to characterise important aspects of decision making, especially to have current systems deal with uncertainty and disturbances, to adapt systems to deal with future uncertainties and disturbances and to and to transform systems when current systems become untenable. *Resilience* deals with the 'capacity to cope with changing geometry of basins of attraction and perhaps to influence that geometry'. *Robustness* deals with the fragility of certain outputs of the system to the changes in dynamics of the system (Anderies, Folke, Walker, & Ostrom, 2013). In this research, the angle of robustness was chosen for two reasons. Firstly, we are interested in the capacity of the system to maintain its output of collective action. Secondly, the design principles are collected as principles influencing robustness (Ostrom, 2009a).

In order to find an answer to the main question, we first need insight in our topic of research. We need to know what theoretical basis we can use to address the main research question, and we need to understand how characteristics of collective action specifically on community gardens fit within these theories. Therefore, our first subquestions are:

1. *What theories can be used to model the relationship between design principles and collective action?*
2. *What characteristics of community gardens do we need to operationalise the theoretical concepts described for subquestion 1?*

When we have an overview of the theoretical and practical working of collective action on community gardens and the influences of the design principles, we have insight in the influences of the design principles on individual parts of the system. We don't know yet how these individual parts lead to a lower or higher degree of robustness of collective action. Both collective action and robustness are emergent properties of the system: they grow from interaction between gardeners under a context. Agent-based modelling (ABM) is a method that allows modelling individual agents, using internal rules, decision making and adaptive behaviour and interacting with each other and their environment. With this bottom-up basis, macro-level behaviour emerging from micro-level dynamics can be observed (Nikolic, 2009). In our case, it means that the emergence of collective action resulting from the individual behaviour of actors under varying design principles can be studied. By conducting multiple virtual experiments in which the design principles vary, we can learn about their effect on dynamics of the system and the resulting emergence of robust or not so robust collective action.

To create an agent-based model based on subquestion 1 and 2, we need to find a way to combine the theories and characteristics found. We therefore need to find an answer to subquestion 3:

3. *How can we model the relationship between design principles and the robustness of collective action on community gardens?*

When subquestion 3 is answered, we have a model that can mimic collective action on community gardens under various circumstances. In order to align find results applicable to reality with this model, we need a case study allowing to calibrate the model and compare the results from the model with reality. Therefore, we use Gandhi Tuin as a case study allowing to answer subquestion 4:

4. *How do the design principles influence the robustness of collective action on Gandhi Tuin, according to the model?*

As we have learnt in the introduction already, community gardens differ from traditional common pool resources in the varying motivations that people have to join the community. Therefore, to further understand the influence of the design principles, it is also interesting to learn about their influence on individual motivations:

5. *How do the design principles influence the motivations of volunteers at Gandhi Tuin, according to the model?*

Finally, a model is only a model of reality. Per default it is wrong, although we hope the model is useful. In order to assess the model's usefulness in answering our main research question and its potential for future practical use, we will answer the last subquestion:

6. *To what extent does the model reflect reality, and how can it be used for practical purposes?*

1.3 Results

The answers on subquestions 1 and 2 provide an overview of characteristics of collective action on community gardens applied to a theoretical basis, including the various practical implementations of the design principles. The answer on subquestion 3 provides insight in the way in which we can gain insight in the behaviour emerging from agents interacting under these different institutions. The answers on subquestions 4 and 5 then provide insight in the influence of the design principles on Gandhi Tuin, after which subquestion 6 allows insight in the usefulness of these results. These lessons will allow us to provide insights in our main question on the way in which design principles in general influence collective action on community gardens.

1.4 Thesis structure

Chapter 2 first elaborates on the methodology used in this study. Then, chapter 3 contains a literature review, including definitions and former research on the topic. Chapter 4 provides a theoretical background in which the study can be nestled, after which in chapter 5 the fit of community gardens within this background is discussed. In these two chapters, subquestions 1 and 2 are addressed. The following chapters 6, 7, 8 and 9 address subquestion 3 on modelling. Chapter 6 contains the concept formalisation in which the relevant concepts for the model are collected and ordered. Chapter 7 contains the model formalisation, and chapter 8 the model verification. Chapter 9 then describes the experiments conducted with the model. Then, in chapter 10 the results from these experiments can be analysed, from which subquestions 4 and 5 can be addressed. In chapter 11 these results are validated, addressing subquestion 6. Finally, in chapter 12 we can summarise our conclusions, followed by an elaboration of the relevance of this study, a discussion on the research, reflections, and recommendations for further research.

2. Methodology

In this chapter, I explain the methodology used to address the research questions. This includes desk research, interviews and Agent-Based Modelling. This chapter describes how these three methods are executed, what data is used, and how methods and data relate to the chronological steps taken in this research.

2.1 Desk research

Desk research by means of internet search and extracting information from a dataset was used to compose a literature review, position this work in a theoretical background, and to collect data on community gardens. For the desk research resulting in literature review and theoretical background, literature was collected through internet search. For the literature review, this resulted in defining the main concepts of our research question and an overview of former literature addressing the topic of research. For the part on theoretical background, the search for literature resulted in an overview of theories related to our research question, after which the most suitable ones can be chosen to proceed with in modelling. The data on community gardens, providing insight in how community gardens fit in the theories chosen, was collected through internet search and a recently setup dataset containing detailed information on German community gardens (Rogge, 2017).

2.2 Interviews

Interviews are used for two causes. Firstly, specific data on Gandhi Tuin was collected through structured interviews with gardeners. Secondly, the model was validated through semi-structured interviews with gardeners on Gandhi Tuin and PhD-candidate and expert on community gardens Nicole Rogge.

The interview for collecting data on Gandhi Tuin was a structured interview with the aim of collecting data for the experimenting phase of the modelling. During this meeting, a list of questions was prepared facilitating the garden expert to provide the needed case specific data. These questions were based on the model created with ABM, which will be further explained in section 2.3.

For validation at Gandhi Tuin, a semi-structured interview had the aim of validating the model and discussing the results. First, the model was validated by discussing the results applicable to Gandhi Tuin with gardeners. Then, surprising parts of these results were highlighted, after which together could be thought about the reasons for these surprising results. Validation with garden expert Rogge was done in two ways. During the modelling process, the content of the model and assumptions were discussed in order to assess the model's realism. After the modelling process, the results of the model were shared to reflect on the realism of the outcomes as well.

2.3 Agent-Based Modelling

Van Dam, Nikolic & Lukszo describe a methodology for the Agent-Based Modelling of socio-technical systems (2013). The methodology consists of 10 steps, which were used in this research. It should be noted that the steps were followed iteratively, as often latter steps gave more clarity about what was needed from a former step.

Our first step in the building of the model, was system identification and decomposition. Here we can recognise our desk research. This step resulted in all relevant concepts, actors, objects, behaviours, interactions, flows, states and properties are collected and structured. Our next step after this desk research, was a repeated problem formulation specifying the problem the model addresses. In this step, the lack of insight was identified, the observed emergent pattern of interest and how this can be different from a desired emergent pattern could be formulated, and an initial hypothesis on the emergent patterns was stated. When the problem that needs to be addressed was clear, a concept could be formalised. In this step, it was determined what parts of the information found in subquestion 1 and 2 would be used in the model. The result of this step was a concept model. This concept was given a storyline in the step of model formalisation. This resulted in a model narrative and a pseudo-code showing the structure of the algorithm for the computer. The pseudo-code was then translated to software. Because of easy use and familiarity of the author, NetLogo was used for this. Then, the Netlogo model was verified, which means tests were done to find out whether the model is built right. This was done by testing the behaviour of single agents and interaction between agents. Additionally, in this step the sensitivity of the model to variability in parameters was tested. After verification, the model was almost ready to be used for experimentation. With more insight in the model, first the data needed to calibrate the model to Gandhi Tuin was collected through structured interviews. Then, all combinations of design principles could be tested under circumstances indicated by the case study. When the experiments had yielded results, the data was analysed using R. The following step is model validation, for which we used historic replay and face validation through expert consultation as described in section 2.2 on 'interviews'. For historic replay, gardeners of Gandhi Tuin were asked whether they regard the results as likely. For expert consultation, a both academic and practical expert on community gardens judged whether the results are likely. When this step was completed, the results could be used to formulate conclusions.

Figure 2.1 shows an overview of the methodology of this research including methods, data, products and where parts can be found in this research.

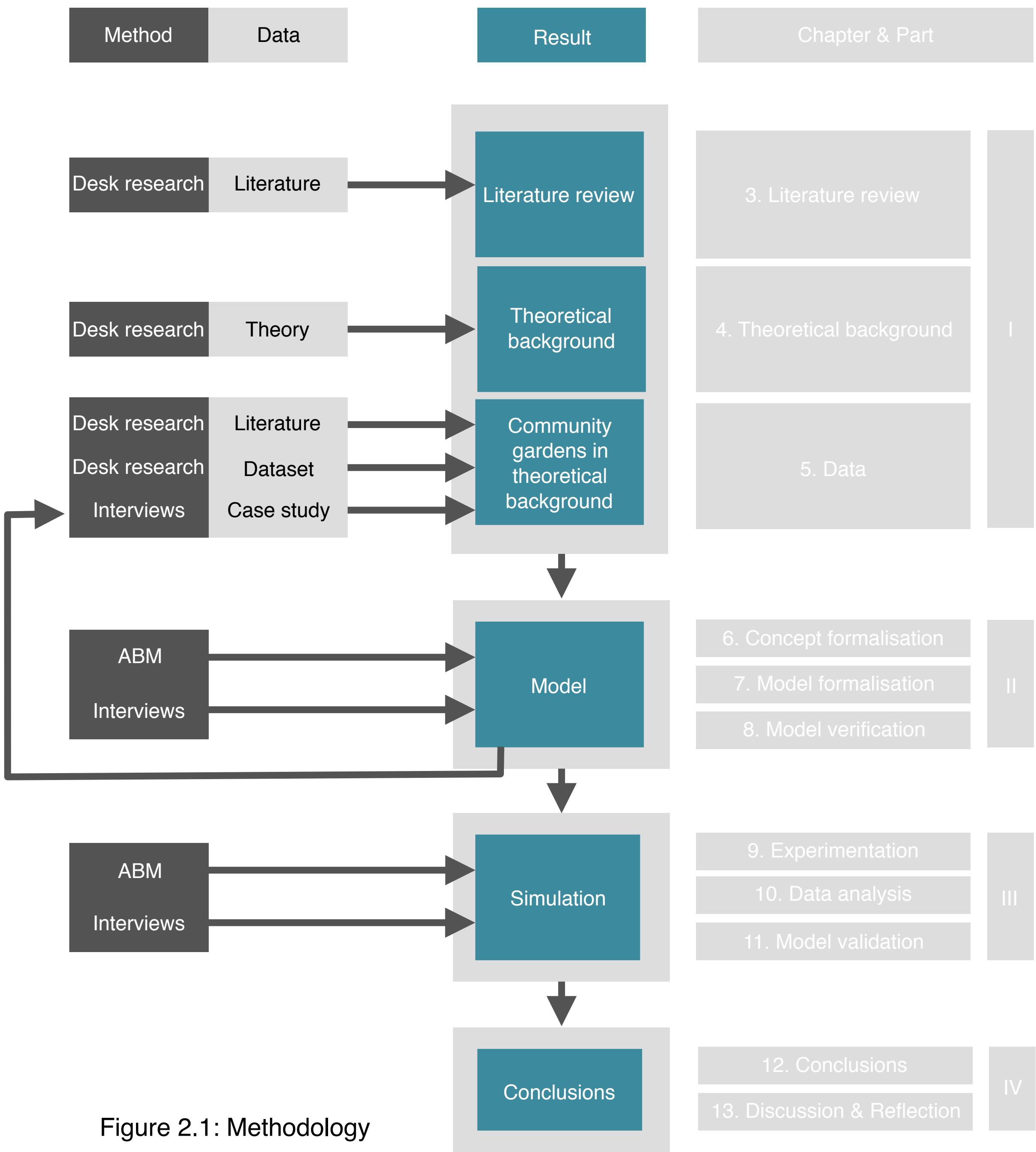


Figure 2.1: Methodology

I

Information collection

3. Literature review

In this chapter, I describe former literature on collective action on community gardens. First, robust collective action on community gardens is further defined. Then, existing literature within this scope is discussed.

3.1 Definitions

In order to further define our topic, we define the parts of our main research question. Two terms will be discussed: ‘community garden’ and ‘robust collective action’. The third concept in the main research question, the design principles, will be elaborated upon in chapter 4 on theoretical background.

3.1.1 Community garden

Definitions of community gardens exist in varying detail. Okvat & Zautra (2011) define community gardens as ‘a plot of land used for growing food by people from different families, typically urban dwellers with limited access to their own land’. Guitart et al. (2012) defines community gardens as ‘open spaces which are managed and operated by members of the local community in which food or flowers are cultivated’. Pudup (2008) describes the many possibilities of defining community gardens, in which he argues that the term ‘community’ is especially problematic because the definition is very broad. He proposes the term ‘organised garden project’, which is characterised by the following three axioms: (Okvat & Zautra, 2011; Pudup, 2007)

1. ‘an organised group of people is involved in cultivation, even if gardening is individualised in its spatial arrangement and practice (e.g. gardens consisting of individual plots worked by individuals)’
2. ‘the group involved in cultivation has espoused a set of goals for its gardening practice’
3. ‘the cultivated space is not typically devoted to third party gardening, i.e., gardening by people other than the owners of and/or custodial employees on the property.’ (Pudup 2008)

The community garden this research investigates is different from this detailed description by Pudup, and we think therefore it is especially wise to specify on these points. The community garden this research investigates differs on the following Pudups first and third axiom:

1. an organised group of people is involved in cultivation of land for which they are not individually responsible
2. the cultivated space is devoted to third party gardening, the space is maintained by people that do not own the land.

Therefore, we define a *‘community garden’* for this research as an ‘*open space on which food or flowers are cultivated, and which is managed and operated by members of the local community who do not individually own the land’.*

3.1.2 Robust collective action

Marshall defines collective action as ‘action taken by a group (either directly or on its behalf through an organisation) in pursuit of members’ perceived shared interests’. Meinzen-Dick et al. note that the definition of collective action depends on the purpose of the study, and that collective action can have many forms. Collective action can be a one-time event, being applied many times, or be a process. It can be seen in for instance the form of developing institutions, mobilising resources, coordinating activities or information sharing. However, Meinzen-Dick et al. also found some characteristics that most definitions of collective action have in common, being the *involvement of a group of people, shared interest within the group* and *common action that works in pursuit of this shared interest.* Additionally, they argue the definition should include the common action to be *voluntary,* so that collective action can be distinguished from hired or corvee labour. (Meinzen-Dick, Digregorio, McCarthy, & Di Gregorio, 2004)

For this research, as all actors enjoying benefits of the garden have a shared interest in maintaining it, we define ‘*collective action on a community garden’* as ‘*action taken voluntarily by a group of people in pursuit of maintaining the garden’.*

Castell defines robustness as 'the capability of performing without failure under a wide range of conditions'. Ostrom defines it as 'the maintenance of some desired system characteristics despite fluctuations in the behaviour of its component parts or its environment' (Castell, 2010; Ostrom, 2005)

Combining these similar definitions with the definition for collective action, we can define '*robust collective action on a community gardens* as '*action taken voluntarily by a group of people in pursuit of maintaining the garden, which continues despite fluctuations in the behaviour of its component parts or its environment'.*

3.2 Former research addressing the problem

There are few studies addressing Ostroms theory on collective action in the context of the success of collective action on community gardens. As mentioned in the introduction, Anna Butler studied the conditions required for sustainable collective action on urban community gardens through a qualitative analysis based on documentation and interviews at 7 cases in the United Kingdom. She measured the sustainability of collective action as the regularity of meetings, the extent to which participants are informed, the extent to which the garden is connected to other similar communities and outside organisations, the availability of financial and material resources and the number of participants. The design principles were part of the conditions she compared among the case studies. According to her findings collective-choice mechanisms and the recognition of the right to organise are important, whilst collective action could sustain without the other design principles present. In Butlers understanding of the recognition of rights to organise, this principle results in extra help and resources from the municipality (Butler, 2013). Aligning with this, Nishesh Chalise found that building partnerships was crucial. Informants of his case studies stressed that it would be difficult to maintain the garden without partnerships (Chalise, 2015). Other findings of Butler are are that trust, knowledge, common understanding and leadership are necessary, whilst reciprocity, group size and homogeneity of the group were not found to be important to sustainability of collective action. (Butler, 2013)

Chalise conducted a second study using Ostroms theory in relation to collective action on community gardens. His PhD research resulted in a system dynamics model to better understand the relationship between behaviour and the structure of a community garden: gardeners, land, activities, quality, rules, trust, social relationships and partners. His model is based on theory and multiple case studies in a low income urban neighbourhood in the United States. He finds that rules are often created to increase the level of effort. These rules are important, but severe sanctions might not work because participants join as a leisure activity and many community gardens have difficulties finding new gardeners. Additionally, he finds that creating rules does not mean anything when there is no foundation of strong relationships. Social relationships affect the level of trust, which allows the rules to be implemented. When people fulfil their commitments the social relationships increase and trust increases, resulting in a positive feedback loop which he calls the 'reciprocity feedback loop'. Related to this, social capital is both a need and an outcome of community gardens. Finally, Chalise argues that the concept of free-riding might be different on community gardens than it is on traditional commons. People who enjoy the garden but do not contribute to maintaining the garden seem to be free riding, but in the case of a garden people enjoying the garden do not really subtract from the garden. The presence of people can even add to the value of the garden from a social point of view. In other words, whether these visitors are free riders depends on the product a community garden is regarded as. (Chalise, 2015)

Rogge, Frey, Strassner & Theesfeld wrote more on these products community gardens offer, and relate it to collective action. They identify different elements which can be shared and divided on community gardens: the resource system, infrastructure, resource units, work and social time. They note that all elements can be divided, except for social time, which can only be shared. They then describe different degrees of collective action on community gardens, as different gardens differently apply sharing, dividing and individual use to the resources of the garden (Rogge, Frey, Strassner, & Theesfeld, 2015). Another article by Rogge and Theesfeld further explores successful collectivity and its causalities. By questionnaires they collected information on German community gardens, of which the article provides an overview. Based on the results, the authors formulate the assumption that size or heterogeneity of the community has no significant impact on the success of collectivity, whilst the share of the core group or leader group relative to the total group size, or aspects of participation and management do have an influence. (Rogge & Theesfeld, 2017)

4. Theoretical background

In this chapter on theoretical background, I will provide an overview of the theoretical concepts in which this study is nestled. First, I will provide information on the design principles. Then, several theoretical frameworks which could be useful to address our main question are explained. the IAD-framework is found most suitable. Because in this framework the decision making of agents is central, theories addressing this are discussed as well. The Theory of Reasoned Action is found most suitable for this research.

4.1 the design principles

The design principles were identified by Ostrom as underlying principles in robust CPR governance systems. They are also described as institutions, which are the prescriptions that humans use to organise all forms of repetitive and structured interactions, such as rules, norms and strategies. The design principles are not blueprints, the institutions differ in varying situations. The design principles can therefore better be described as structural similarities that are found in self-organised systems which have adapted and learnt to be robust to social, economic and ecological disturbances (Ostrom, 2005).

Wilson, Ostrom and Cox describe the cores of the design principles as follows (Wilson et al., 2013):

1. *Clearly defined boundaries.* The boundaries of both the resource system and the individuals or groups with rights to harvest resource units are clearly defined. The clearly defined boundaries are about boundaries for the group and boundaries for the resource. For clarity, both group and plot boundaries will be discussed separately from now on.

2. *Proportional equivalence between benefits and costs.* Members of the group must negotiate a system that rewards members for their contributions. High status or other disproportionate benefits must be earned, as unfair inequality harms collective efforts.

3. *Collective-choice arrangements.* Group members must be able to create at least some of their own rules and make their own decisions by consensus. People don't like being told what to do, but will work hard for group goals that they have agreed upon.

4. *Monitoring.* Managing a commons is inherently vulnerable to free-riding and active exploitation. Unless these undermining strategies can be detected at relatively low cost by norm-abiding members of the group, the tragedy of the commons will occur.

5. *Graduated sanctions.* Rule violations don't need heavy-handed punishment, at least initially. Often gossip or a gentle reminder is sufficient, but more severe forms of punishment must also available for use when necessary.

6. *Conflict-resolution mechanisms*. It must be possible to resolve conflicts quickly and in ways that are perceived as fair by members of the group.

7. *Minimal recognition of rights to organise.* Groups must have the authority to conduct their own affairs. Externally imposed rules are unlikely to be adapted to local circumstances and violate principle 3.

8. *Nestled enterprises* are relevant for groups that are part of larger social systems, as there should be appropriate coordination among relevant groups. Every sphere of activity has an optimal scale. Large scale governance requires finding the optimal scale for each sphere of activity and appropriately coordinating the activities. Because community gardens are quite independent and not part of larger groups that would make nestled enterprises relevant, this design principle is not taken into account in this study.

4.2 the IAD-framework

A framework provides a 'set of assumptions, concepts, values and practices that constitute the way of viewing the specific reality' (Ostrom, 2005). Many studies discuss characteristics of community gardens. In order to know what information is relevant for our study, we need a framework to guide our search for information. CPRs and all other humanly used resources, are embedded in social ecological systems (SES). SES are systems in which subsystems such as resource system, resource units, users and governance systems interact. (Ostrom, 2009b). Binder, Hinkel, Bots and Pahl-Wostl published a comparison of 10 frameworks to analyse social-ecological systems (Binder, Hinkel, Bots, & Pahl-Wostl, 2013). As we are interested in collective action within a SES, the decision making of individuals leading to contributing on the garden is important. Additionally, the framework needs to contain institutions for including the design principles. 4 frameworks stand out by highlighting these topics: the Human Environment Systems Framework (HES), the Management and Transition Framework (MTF), the Institutional Analysis and Development Framework (IAD) and the Social-Ecological Systems Framework (SESF). (Binder et al., 2013)

The HES framework is based on decision making theory. It analyses human actions, learning and feedback processes between different hierarchical levels of a social system. Decisions that humans make are based on goal formation, strategy formation and strategy selection. These three aspects are based in their turn on preferences and different degrees of environmental awareness. (Binder et al., 2013)

The Institutional Analysis and Development (IAD) framework was developed by Ostrom and colleagues with the aim to help understanding the way in which institutions operate and change over time (McGinnis, 2011). It is based on the decisions of actors in actions situations under various conditions, leading to interactions and outcomes influencing the external variables and action situations.

The MTF framework consists of a rational choice framework and social constructivism. It is based on the IAD-framework, but adds concepts of adaptive and integrated water management, social learning processes and regime transition theory (Knüppe, Pahl-Wostl, Knüppe, & Pahl-Wostl, 2011). In comparison with IAD, MTF focuses less on institutions.

The SES framework is a revision of the IAD framework, giving more attention to biophysical and ecological foundations of institutional systems. It contains factor or variables that research have found relevant to dynamic patterns of interaction between human groups and their environment. They are organised in 7 categories: the action situation with interactions and outcomes, resource units, resource system, users, governance system, related ecosystems and social, economic and political settings. (McGinnis, 2011)

Because IAD focuses most on institutions and decision making, and includes interaction between agents and learning of agents, this framework is perceived as most suitable in this research.

As mentioned, the IAD framework was developed to help understanding the way in which institutions operate and change over time. It assigns all factors and variables that explain institutions and their development to categories, and shows how they are linked to each other (McGinnis, 2011). By highlighting the decisions of actors in the action arena, resulting in actors undergoing patterns of interaction and evaluating the outcomes resulting from those interactions, the IAD framework provides a suitable basis for the building of an agent based model in which agent's interactions and adaptions are essential.

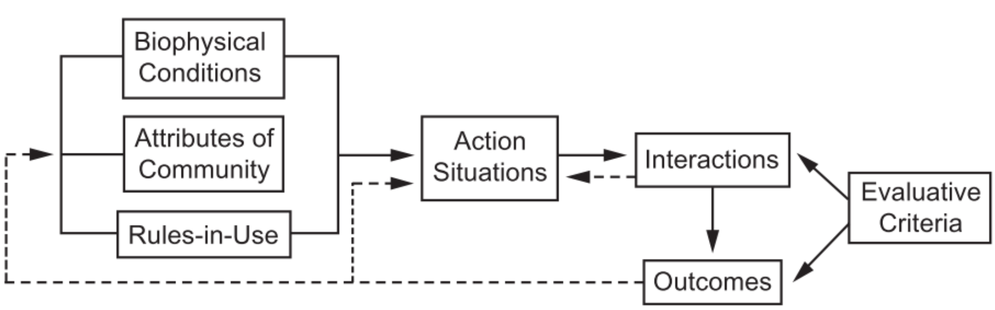


Figure 2.1: The IAD framework (Ostrom 2011)

Figure 2.1 shows the IAD-framework, which consists of the following parts:

1. *Biophysical and material conditions*, in which the relevant physical constraints of action situations are taken into account.

2. *Attributes of the community*, which brings in the relevant social and cultural behaviour of the individuals in the society such as values of behaviour generally accepted in the community, level of common understanding, extent of homogeneity in the preferences of those living in a community, size of the community and the extent of inequality of basic assets among those affected (Ostrom 2005). Additionally, attributes of the community include social and cultural context such as trust, reciprocity, common understanding, social capital and cultural repertoire (McGinnis, 2011).

3. *Rules in use* bring the constraints to the action situations. These rules can be in the form of a *regulation*, which can be enforced and broken, *instruction*, which is more in the form of an effective strategy for solving a problem and won't be enforced, *percept*, which contains moral behaviour and is not enforced, or *principle*, which are physical laws which can not be broken.

4. *Action situations:* box where governance decisions and choices are made by actors (figure 2.2). The actions situation contains the following information:
    1. *participants* are the decision-making entities, which are assigned to positions and can select actions from a set of alternative made available. Participants are present in a number, may represent an individual or a group, and and can have attributes such as age or experience.
    2. *positions* are slots to which participants can move and to which actions are assigned. Positions represent roles such as players, voters or judges.
    3. *potential outcomes of actions*, which has three components: physical results, external results, and the valuation placed on the combination of the first and second components by the participants.
    4. *actions* are assigned to positions and can be chosen by participants. It can be thought of as a selection of a setting, or a value on a control variable that a participant hopes will affect an outcome.
    5. *action-outcome linkages*, which exist when a setting on a control variable can cause a state variable (outcome) to come into being, disappear, or change in degree. In other words, one or multiple actions of an actor can change one or multiple states. These linkages can be certain, in which case available actions are linked directly with one outcome, risky, in which case the probability between actions and outcomes can be known, or uncertain, when the probabilities of specific actions leading to outcomes are not known.
    6. *control that actors exercise over the linkage of the action to outcomes*, which can range from absolute to none.
    7. *type of information generated*, which determines whether the participants of the action situation know all about the previously described characteristics or not.
    8. *costs and benefits assigned to actions and outcomes* can be processed in various ways by the participants. (Ostrom 2005)

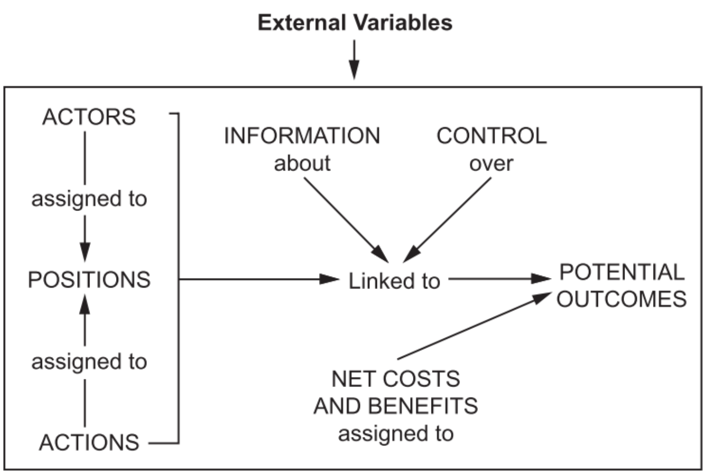


Figure 2.2: The action situation (Ostrom 2011)

5. *Outcomes* result from the outputs of an action situation, the exogenous variables and other closely related action situations.

6. The outcomes are evaluated by actors within or outside of the action situation with *evaluative criteria*, which can for instance be efficiency, effectiveness, economy, or sustainability (Bal, 2015).

The IAD framework can be applied at different nested levels:

1. *Operational choice*: implementation of practical decisions by those individuals who can take these actions as a consequence of collective choice processes
2. *Collective choice*: providing insight in the processes through which institutions are constructed and policy decisions are made
3. *Constitutional choice*: providing insight in the processes through which collective choice procedures are defined
4. *Meta-constitutional*: suitable to study long-lasting and often subtle constraints on the forms of constitutional, collective, or operational choice choices resulting from culture. (McGinnis 2011)

As this research aims to gain insight in the influence of set design principles, without changing them, we will limit ourselves to the first level on operational choice.

4.3 the Theory of Reasoned Action

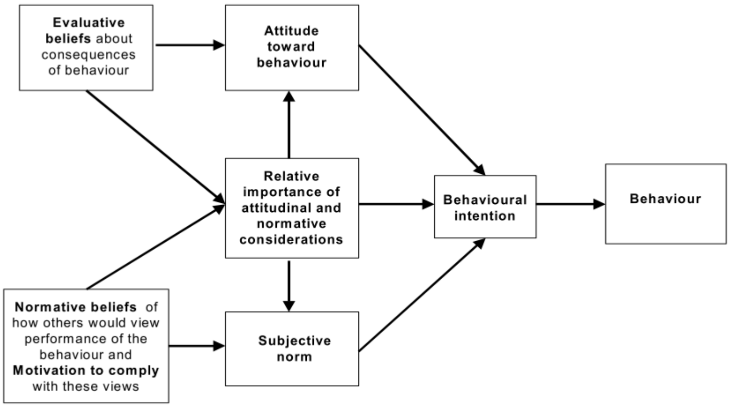
Central in the IAD framework, is the decision making of agents in the action situation, resulting in behaviour of agents. Many theories for predicting and understanding behaviour exist. Andrew Darnton provides a clear overview with over 60 socio-psychological models and theories of behaviour. Because we are interested in the decision making of individual agents, we can already narrow down this large number of models and theories to behaviour at the individual level. Within this section, we need a theory which allows for the incorporation of the broad range of individual motivations as well as the social influence of trust. Few models seem suitable for this task without focusing on habits: the Theory of Reasoned Action, the Theory of Planned Behaviour and the risk as feelings model (Darnton, 2008).

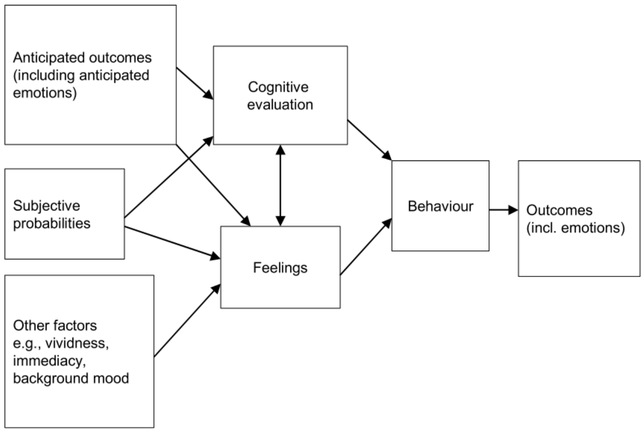
The simplest theory is Fishbein and Ajzen's Theory of Reasoned Action (TRA). It is based on behaviour resulting from intentions, and intentions resulting from attitudes and subjective norms. Attitudes consist of evaluative beliefs accessible in memory about the consequences of behaviour and importance for that belief (Darnton, 2008). Subjective norms consist of normative beliefs and motivations to comply. Normative beliefs are the social pressures perceived by an individual to perform or not perform a certain behaviour, and the motivation to comply is value an individual assigns to comply with this perceived expectation (Fishbein & Ajzen, 2010). The theory of planned behaviour is developed by the same authors as the theory of reasoned action, and adds 'perceived behavioural control'. Perceived behavioural control is defined as 'people's perceptions of the degree to which they are capable of, or have control over, performing a given behaviour'. It includes in the decision making the notions of 'preforming this behaviour is up to me', 'I can perform this behaviour if I really want to', or 'I have the necessary skills and abilities to perform this behaviour' (Fishbein & Ajzen, 2010). The risk as feelings model adds emotions to the decision making, showing how behavioural outcomes can differ from the perceived best course of action because of emotions. Figure 2.3 shows the figures corresponding with the three theories.

The Theory of Reasoned action is perceived as most suitable for our research, because it combines the motivations of interest to us: attitudes and subjective norms. On community gardens we can recognise various attitudes: gardeners can for instance expect to enjoy the gardening or to receive yield. Some gardeners consider the receiving of yield more important, while others join mostly to enjoy the gardening. Lawson & Drake highlight that the importance of certain beliefs largely differs across global area's. Subjective norms consist of normative beliefs and motivations to comply. We can recognise normative beliefs on community gardens as the social expectation resulting from trust and reciprocity as described by

Chalise. He describes that gardeners find it easier to contribute on the garden for the community, when gardeners trust the others in the community to do the same (Chalise, 2015).

Additionally to attitudes and subjective norms, the Theory of Planned Behaviour takes behavioural control into account. However, as the control on ‘going to contribute’ is not mentioned in any of the literature as a factor influencing collective action on community gardens or as something influenced by the design principles, for this research this addition is not necessary. The same argument can made for ‘emotions’ in the risks as feelings model, this concept was also not recognised as dominant in literature on collective action on community gardens or the design principles.





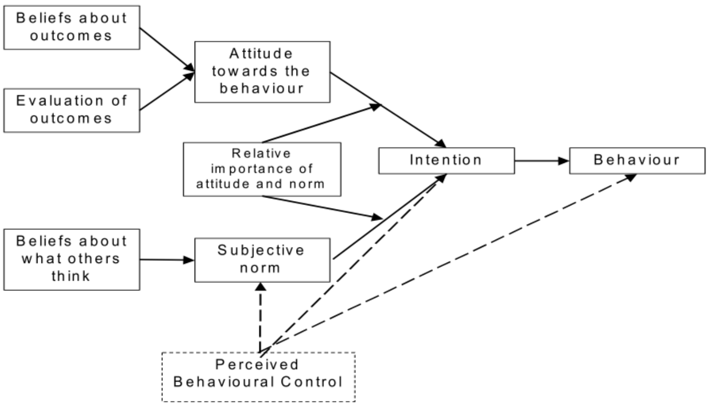


Figure 2.3:
Top left: Theory of Reasoned Action
Bottom left: Theory of Planned Behaviour
Top right: Risk as feelings model
(Darnton, 2008)

5. Data

In this chapter, I will discuss how community gardens relate to the theories discussed in the previous chapter. First the way in which community gardens relate to the design principles is discussed, then community gardens are fit in the Theory of Reasoned Action. These two theories already represent parts of the IAD-framework. Finally, community gardens are related to the parts of the IAD-framework that were not discussed yet. Data was retrieved from three sources: literature, a recently set up dataset, and a structured interview at Gandhi tuin.

5.1 Data from literature

5.1.1 The design principles in the field and their influence

This section will address Butlers findings for the implementation of design principles in the field, and adds the influences of these design principles as described in literature on CPRs (Butler, 2013). Butler describes different degrees of design principle implementation for community gardens within our definition. It should be noted that in her cases often the rules are not clear. She describes that in many cases, interviewees gave varying answers to her questions. Additionally, she used a broader interpretation of community gardens than we do. She also included community gardens with individual plots, which are not taken into account in this research. Therefore, her findings on regulations regarding individual plots are not mentioned in this research.

Clearly defined spatial boundaries

For clearly defined spatial boundaries, two options were found. The plot has fencing or hedges around it, or the plot has no fencing or hedges around it (Butler, 2013). The effects of clear spatial boundaries can be found in both literature on traditional commons and literature on specifically community gardens. The first traditional effect is described by Poteete, Janssen and Ostrom as limiting problems relating to externalities, which we can recognise as on community gardens a a reduction of the risks of yield theft. Additionally, Poteete et al. mention that because rules, rights and obligations applying to the context are more clear, the principle eases rule enforcement (Poteete, Janssen, & Ostrom, 2010; Wilson et al., 2013). Milburn and Vail add to these traditional effects that some gardeners believe that fences block out the community for which a community garden was intended (Milburn & Vail, 2010).

Clearly defined group boundaries

Regarding clearly defined group boundaries, more options were found. Firstly, least in line with this design principle there are gardens on which the group boundaries are not defined at all. On these gardens, anyone can be a volunteer, contribute and receive yield. Secondly, there are gardens on which next to volunteers there are key-holders, members, employees, trustees, and/or committee members. This already seems more in line with Ostroms principle, as some particular group members can be distinguished. On one garden described by Butler, only members paying a small fee are allowed to take yield. Associated members pay only a small fee, their defined 'core members' pay more, are obliged to do a set amount of work and receive a double share of yield. Volunteers are not allowed any yield. Although in practice the volunteers tend to receive a little bit of yield, this garden seems to be the case in which this design principle is implemented most strictly.

The general effect of clearly defined group boundaries is, like the spatial boundaries, described as making it clear who is allowed to appropriate the resource, and making rule enforcement easier (Poteete et al., 2010). Additionally, when a fee is active on the garden, people might sustain their contributions because they want to get their money's worth (Milburn & Vail, 2010).

Proportional equivalence between benefits and costs

Regarding proportional equivalence between benefits and costs, the option least in line with Ostroms design principle seems to be the absence of any rules regarding the amount of contribution and amount of yield for volunteers to take. Butler describes in this light a case in which people can take what they need from the garden. Another option is that volunteers might take yield, but that it is not standard procedure as yield mostly goes to other initiatives or groups. Furthermore, it could be that volunteers which are present during harvesting receive equal shares of yield, or that only members are allowed yield as described with regard to the design principle of group boundaries. In this case, core-members paying a higher fee were allowed to take a double share, needed to invest a minimum of 12 hours a month and be on a committee. Finally, there was a case in which an employee gave out yield based on a volunteers effort in maintaining the garden, in addition to eating the communally cooked produce together.

As perceived inequity may lead to participants to violate rules they perceive as unfair, proportional equivalence between benefits and costs generally leads to proportional rules being accepted easier, (Poteete et al., 2010). The principle also makes participants more willing to keep a resource well maintained and sustainable (Ostrom, 2005).

Collective-choice arrangements
Regarding collective-choice arrangements, Butler describes various layers of decision making. For instance, there is a difference between daily decision making on where to plant seeds, and decision making on an Annual General Meeting about membership fees. For all decision making layers, there are the following options. The option that seems most aligning with Ostroms design principle is the option in which decision making processes are open to anyone interested. There are also gardens on which only members participate in decision making or on which a committee or an unchosen coordinator makes decisions. The unchosen coordinator as a decision maker seems to be least in line with Ostroms design principle.

Collective-choice arrangements increase the likelihood that rules fit local circumstances, change over time to reflect local environmental and social dynamics, and are considered fair by participants (Ostrom, 2005; Poteete et al., 2010). Additionally, Ostrom notes that users who have been engaged in the process of developing, trying out, modifying and experimenting with property rules understand them, agree on why they are using them, and follow their own rules to a greater extent than rules imposed on them (Ostrom, 2005). Wilson explains this notion further, by highlighting that collective decision making provides a safeguard against decisions imposed by some members of the group at the expense of others, since group members will not agree to arrangements that place them at a disadvantage (Wilson et al., 2013).

Monitoring
Regarding monitoring, there can be made a distinction in Butlers findings between monitoring of general rules or behaviour, and monitoring of presence and gardening activities. The monitoring of general rules and behaviour can depend on a coordinator or on peer policing. For the monitoring of presence and gardening activities, there can be a registration book to keep record of the volunteers present. Additionally, on some gardens this registration book is combined with a record on the jobs done, the weight of produce, or how much is sown, potted and planted. As we have seen, the ‘resources’ on the garden entail more than only the plants, and the garden needs more than only ‘maintaining the plants’ to make it a success. Therefore in this study we regard the monitoring of general rules and behaviour, as misbehaving on the garden can be seen as a ‘tragedy of the commons’ as well when it diminishes the joy of other gardeners.

Because violators are likely to be sanctioned, the effect of monitoring is an increased confidence among users that they can cooperate without the fear that others are taking advantage of them (Wilson et al., 2013).

Graduated sanctioning
Regarding graduated sanctioning, Butler found four different options. The first is ‘no sanctioning rules at all’. It is not clear whether ‘no sanctioning rules’ also means that people are never being told off when they violate a rule, or whether it means that there are no rules to sanction. Secondly, some of Butlers interviewees specifically mentioned the sanction of telling off. Furthermore, on some gardens interviewees mention that volunteers can have their entrance right to the garden cancelled when their behaviour harms the interests and objectives of the organisation. Finally, the garden that mostly aligned with this design principle had graduated sanctions in the order of telling off, suspension and cancelling of entrance right.

The effect of graduated sanctions is multiple. Firstly, the first correcting sanction notifies the person who purposely or by error violated a rule about the meaning of the rule and that others notice the behaviour. Thus, the confidence that others would also be caught increases and the individual who broke a rule is encouraged to comply further in order to enjoy ongoing trust (Ostrom, 2005; Poteete et al., 2010). Secondly, an individual who continues to violate rules will have to pay ever higher sanctions and eventually can be expelled from the group so he can do no more harm (Ostrom, 2005).

Conflict-resolution mechanisms
On the Community Garden Conference: promoting sustainability, health and inclusion in the city 2010, conflict was mentioned as a main challenge for community gardens (Community Garden Conference, Turner, Henryks, Pearson, & University of Canberra, 2010). Two types of conflict can be found in literature on community gardens: conflicts externally of the community (often with the municipality or developers, about land) and conflict within the community (Petrescu, Petcou, & Baibarac, 2016). As conflict-resolution mechanisms address conflicts within the community, we leave external conflicts out of our discussion. Internal conflicts on community garden can be about various issues. Literature describes conflict on who should grow what, why certain behaviours are preferred, who belongs and who does not (Okvat & Zautra, 2011), about collective management and who tried to appropriate tools and opportunities for own personal purposes (Petrescu et al., 2016), and about uses of the garden related to different agenda's (Pearson & Firth, 2012).

Regarding conflict-resolution mechanisms, Butler describes gardens which have no conflict-resolution mechanisms at all. On some gardens this was used because participants reasoned that every separate case needed an individual approach. On other gardens, it was a rule that a problem should be addressed to a committee. Furthermore, sometimes people are encouraged to talk informally about their conflict, after which they take it to the weekly meeting if that fails, and then mediation can take place. Finally, an option is for people having a conflict to talk to a member of a committee first, after which the problem it is taken to the chair, after which a third party takes up the matter.

The effect of conflict-resolution mechanisms is reducing the number of conflicts that reduce trust (Ostrom, 2005; Poteete et al., 2010). Wilson et al. explain this further: the mechanisms act as a safeguard against exploitation within a group by a small elite (Wilson et al., 2013).

Recognition of rights to organise
Regarding the recognition of rights to organise, all gardens described by Butler have support from the local council. This often means the council supports the garden by providing resources or help. One garden had little recognition of its right to organise, not because the council did not support the initiative but because the initiative was on the land illegally.

The effect of recognition of rights to organise is described for commons in general as easing the process to change rules. When there is no recognition of rights, participants who do not agree with a rule change can go to external authorities to threaten the organisation. Therefore changing rules needs unanimity, which is difficult and leads to a high price for the search for better rules (Ostrom, 2005; Poteete et al., 2010). Another effect could be connected to time horizons. When the initiative is on the land illegally, it can be forced to leave anytime (Butler, 2013). This leads to short time horizons for decision making of the participants. According to Ostrom, a short time horizon can decrease the likelihood of reciprocity and cooperation (Ostrom, 1997).

Recognition of rights to organise was identified by Butler as an important design principle. However, we doubt whether threatening the garden organisation through external authorities is likely for community gardens, as in contrast to traditional commons no money or businesses are involved. Additionally, the theory on time horizons could not be verified. The community garden expert reviewing our assumptions mentioned that the lack of recognition by the government could lead to decreased reciprocity, but it can also lead to an increased feeling of togetherness within the group, leading to higher reciprocity. As we do not know details of this effect, we can not make a valuable judgement on the effect of this design principle. Therefore, this design principle is not taken further into account in this research.

Other rules

As the IAD-framework highlights rules in general, we also want to elaborate on other rules on community gardens. Additionally to the design principles, Butler describes several of them. They include keeping the kitchen tidy, take no dogs to the garden, all equipment needs to be washed and stored, harvesting happens together or only when you are told to, health and safety rules, roots have to be disposed of correctly, produce needs to to be weighted, weeds need to be disposed of properly, no stepping on the bed, and no pesticides are permitted (Butler, 2013).

5.1.2 Theory of Reasoned Action

Central in the Theory of Reasoned Action are the attitudes and social norms of the agents making decisions and the way in which they are evaluated. We made the choice to use this theory because we recognised motivations for individuals to contribute to collective action on community gardens in those attitudes and social norms. We will now discuss these motivations further.

Many articles describe motivations to join on community gardens, but 3 articles were particularly found to provide an overview. Guitart et al. summarised the different motivations gardeners can have to join a community garden that are described in 73 articles: social development/cohesion, consuming fresh food, saving/making money, improving health, enjoying nature, education, enhancing cultural practices, increasing land accessibility, environmental sustainability and enhancing spiritual practice (Guitart et al., 2012). Additionally, Vercauteren and Drake & Lawson mention uncomfortable conditions on the garden to be a barrier to participating in maintaining the garden (Drake & Lawson, 2015; Vercauteren, 2013). Additionally, Chalise mentions the perception of too much work as a barrier. Regarding social norms, he also mentioned trust as an important driver for collective action (Chalise, 2015). The following section further elaborates on the meaning of those motivations and how they can be evaluated.

Social development/cohesion

Duchemin, Wegmuller and Legault explain how social development can be recognised on urban agriculture projects. They argue social development emerges out of urban agriculture as people mention 'meeting people' as an important part of the gardening, and because interactions involved in the activities of gardening foster a social environment that enhances the activity itself by providing participants with a social network that becomes important particularly when they are feeling isolated (Duchemin, Wegmuller, & Legault, 2008).

Veen et al. studied the influences of community gardens' organisational designs and objectives on the presence of social cohesion. They define social cohesion following De Kam and Needham (2003): people in a society feeling and being connected to each other. In their study, they operationalise the concept of social cohesion as the extent to which community garden participants form relationships with each other and offer each other mutual help. They find that this is the case on all community gardens, even if plots are individually owned and the motivation of the gardeners to visit their plot is not social (Veen, Bock, Van den Berg, Visser, & Wiskerke, 2016).

From the two descriptions above, we can conclude that both social development and cohesion on community gardens is based on the development of a social network connecting gardeners through relationships. Both concepts therefore align well with a notion many investigators have for the concept of social cohesion: that it can be measured by the number of mutual dyadic ties within the group. Many scientists use the density of interpersonal relationships in a group as a group level measure of cohesion: a group is more attractive to an individual when they have friends in it (Friedkin, 2004).

Consuming fresh food

The amount of food an individual can consume as a result of participating on the garden, depends on many things. Firstly, the amount of food a garden produces varies largely and depends on many factors such as crop intensity, the stage of development of the garden, organisational decisions and field decisions on cultivation types (Duchemin et al., 2008). Additionally, the amount of food an individual can consume as a result of visiting the garden depends on institutions active and the behaviour of its fellow-gardeners. As we have seen in section 5.1.1, gardens know various organisational options to divide yield, resulting in equal shares, shares based on amount of work done, shares based on membership, 'free' yield taking or no yield taking at all. When volunteers can choose their share of yield themselves, there is also a risk of volunteers taking too little or too much. Butler describes a garden on which people are encouraged to take yield but often are too modest, while Charles mentions feelings of 'childhood stuff' when people take more yield than others (Butler, 2013; Charles, 2012). Finally, some literature mentions theft of yield as well (Ruggeri, Mazzocchi, & Corsi, 2016).

Saving/making money
Saving or making money can be achieved by eating or selling the received yield produced on the garden (Guitart et al., 2012). Patel describes American gardeners commenting they hardly bought any vegetables since gardening, or planted varieties that they couldn't get at local markets or ones that are too costly (Patel, 1991).

Improving health
Health benefits associated with participating on community gardens are improving a diet, increased exercise and involvement in nature (Guitart et al., 2012). An improved diet can be the direct result of access to fresh food, but studies also suggest that gardening can support healthy eating habits. Additionally, gardening has been found to reduce stress, anger and even blood pressure. The exercise of gardening three to four times a week can have the same health benefits as moderate walking or bicycling. (Urban Agriculture and Community Food Security in the United States: Farming from the City Center to the Urban Fringe, 2003).

Enjoying nature
Nature can be defined as 'the phenomena of the physical world collectively, including plants, animals, the landscape, and other features and products of the earth as opposed to humans or human creations' (Oxford Dictionaries). Because nature was defined as 'opposed to humans or human creations', it is debatable whether plants and animals on a human-made community garden can be called 'nature'. In section 5.2.1 on the dataset developed by Rogge, we will provide more clarity regarding this motivation.

Education
Education on community gardens can take multiple forms. Drake & Lawson list benefits of community gardens, in which respondents mention both education specifically about gardening and education without specification (Drake & Lawson, 2015). Guitart et al. mention that educational benefits of community gardens include benefits for science, nutrition and environmental education (Guitart et al., 2012).

Additionally, there are multiple ways in which participants can be educated. Duchemin, Wegmuller and Legault describe participants learning from participating, as the garden is both the educational context, the subject, the strategy and an approach or goal. Additionally to technical and productive lessons, they highlight the social aspects in this learning process. Participating on a garden can also provide the opportunity to develop social, community and environmental conscience (Duchemin et al., 2008). This is also highlighted by Saldivar-Tanaka & Krasny, who describe gardeners enjoying talking to youth about farming, food and culture. Additionally, gardens can include courses in their activities. An example of this is also described by Saldivar-Tanaka & Krasny, who mention workshops on horticultural techniques, garden organizing, carpentry, and vegetable and herb preserving, processing and marketing (Saldivar-Tanaka & Krasny, 2004).

Enhancing cultural practices
Cultural practices can be defined as 'patterns of social interactions, behaviours, representing the knowledge of 'what to do, when and where', and how to interact within a particular culture' (National Standards for Foreign Language Education Project, 1999). In section 5.2.1 we will describe how the dataset developed by Rogge provides more insight regarding this motivation.

Increasing land accessibility
Karen Schmelzkopf describes community gardens as public spaces that are accessible to all groups and provide freedom of action but also for temporary claim and ownership'. In many cities, there is a lack of

public space. The community gardens are in many cases an attempt to increase green space for citizens. (Schmelzkopf, 2017)

The degree to which the garden is accessible to citizens, is influenced by the plot boundary design principle. Milburn & Vail mention that although a fence can reduce the problem of security and vandalism, the placing of a fence should be considered within community context as some people have the opinion that fences block out the community for which the garden is intended. (Milburn & Vail, 2010)

Environmental sustainability
As we have seen in the introduction, green space can contribute to biodiversity conservation (Colding et al., 2013), to moderating urban summer temperatures by evaporation, shading and transpiration of vegetation, (Kleerekoper et al., 2011; Wolch et al., 2014) and to facilitating the runoff of storm water (Wolch et al., 2014). Additionally, green space can contribute to replenishing ground water, filter air, remove pollution and attenuate noise (Wolch et al., 2014). The way in which a garden is maintained is likely to influence the environmental impact of the garden. Practices that are of influence, are for instance the way in which community gardeners add nutrients to the soil, control pests, and use existing resources. Although many gardens use organic methods or permaculture and are conscious of the environment, the environmental benefit of gardens is demonstrated little in papers. Community gardens are likely to have biodiversity benefits, but there is only a single study on bee population regarding this topic. Despite of this lack of scientific support specifically for community gardens, environmental sustainability is a common motivation to contribute on community gardens, as it is mentioned in at least 10 articles (Guitart et al., 2012).

Enhancing spiritual practice
Townsend, Henderson-Wilson & Kingsley list some descriptions which community gardeners gave on their perception of spirituality on the garden. Members indicate that watching plants grow and being actively involved in the process provided them a connection with the earth and allowed them to be in touch with nature. Other associations made were gardening as a meditation and a way of releasing tension, handling plants being good for the soul, a joy watching the plants grow, or even ‘being nearer to God in the garden than anywhere else on earth’ (Townsend, Henderson-Wilson, & Kingsley, 2009). Okvat & Zautra also describe spiritual benefits resulting from participation in a community garden. Gardeners reported on their relationship with nature as one that involved caring, committed, mutual and intimate connections, both with other people as with nature and past memories. These types of connections can contribute to sense-making and meaning in life (Okvat & Zautra, 2011). In general, spiritual practices on community gardens are associated with gardening and being in nature (Kingsley & Townsend, 2006; Milburn & Vail, 2010)

Social norm: trust in contributing to the community
As we have seen in section 3.2, trust and reciprocity are found to be important to collective action. Gardeners find it easier to contribute on the garden for the community, when gardeners trust the others in the community to do the same (Chalise, 2015). Butler also found that trust was present and perceived as important on all gardens she studied. She additionally found trust to be higher in a small group, which was also noted by Poteete & Ostrom for other communities (Poteete & Ostrom, 2004). Lastly, Butler found that a high amount of in- and outmigration had a negative influence on trust, and that trust was more important to the community when there were no appropriation rules, monitoring or sanctions.

Mui clearly describes and formalises the way in which trust emerges in relation with reciprocity and reputation (Mui, Mohtashemi, & Halberstadt, 2002). Butler found that reciprocity on community gardens was seen as an issue of varying importance on her cases. Many people did not mind when co-gardeners invested less time and effort for the same amount of resource, as they perceived this as inevitable. However, other interviewees did indicate they felt some tension when people said they were going to do something but in practice did not (Butler, 2013). Mui defines reciprocity as ‘the mutual exchange of deeds’, and exists in a direct and indirect form. Direct reciprocity is between two agents, a favour is returned or not by the receiver to the same agent. In the case of indirect reciprocity, the reaction from the recipient is fed back to the group, by which the original giver will be rewarded again as well. As we are looking at the reciprocity of the agent toward the whole group, we will use the perspective of indirect reciprocity. Reciprocity can be measured in two ways: as a norm in the group and as a variable between two agents.

Because we are looking at the relation of an individual with the group, reciprocity as a norm is more applicable. The higher this 'societal reciprocity', the more one expects all agents to reciprocate (Mui et al., 2002).

However, for an individual to reciprocate good behaviour, it needs to see good behaviour and it needs to trust others to answer this reciprocated good behaviour. This is dependent on reputation, which can be defined as the perception that an agent has of another's intentions and norms. Or in this case, the perception that an agent has of the overall intentions and norms in the group. Trust can be defined as 'the subjective expectation an agent has about another's future behaviour' and the conditional expectation of a reputation given a history (Mui et al., 2002). Trust increases with social interaction (Chalise, 2015). Additionally, it can decrease with rule violation and conflict (Ostrom, 2005).

So, when an individual sees others put effort in the community, the group builds the reputation to do so, the individual trusts the group to put this effort in, and the individual gets a higher tendency to put effort in the community too. Alternatively, when the others gain the reputation to harm the trust that they will cooperate, reciprocity causes the value to cooperate of the individual to decrease.

Too much work
Chalise also mentions the evaluation criteria of amount of work. Gardeners leave if maintaining the garden requires more effort than they expected. He determines the amount of work by the amount of activities leading to a desired quality (Chalise, 2015).

Uncomfortable conditions
Although this is not truly a criteria being 'evaluated', it is necessary to mention uncomfortable conditions in this list as it completes the factors taken into account in decision making considering contribution on the garden. Bad weather is mentioned by Vercauteren as a reason not to join gardening, and bad weather and bad bugs are mentioned by Drake & Lawson in the same context (Drake & Lawson, 2015; Vercauteren, 2013).

5.1.3 other parts of the IAD-framework
Although the previous two sections on design principles and the theory of reasoned action covered the parts of the IAD-framework on 'rules' and 'evaluations', the other parts of the framework still need application to community gardens. The following sections describe how biophysical and material conditions and attributes of the community are described for community gardens in literature.

Biophysical and material conditions
From our definition of community gardens, we can already extract three material conditions that are relevant for community gardens: land, flowers and food. The amounts and characteristics of these three material conditions vary largely per community garden. The land can be a few square feet or hundreds of square feet, can be borrowed, leased, squatted or owned and vary largely in spatial design and context (Lawson & Drake, 2013).The food and flowers that are produced vary as well, as it depends largely on the area and management choices. Duchemin, Wegmuller and Legault mention gardens providing between 7 and 87 kg of fresh vegetables per person per year. These amounts depend on crop intensity, the stage of development of the garden, organisational decisions and field decisions on cultivation types (Duchemin et al., 2008).

Drake & Lawson describe that 24% of gardeners interviewed in the United States indicated that materials are a challenge in their organisation. Obtaining materials such as water, tools, seeds and soil are described as problematic Other material problems they describe include funding and land (Drake & Lawson, 2015).

Attributes of the community
The community around community gardens varies largely in size. The community grows when people are invited by existing members of the group. The community shrinks because people choose to stop joining, or because people have to leave due to external reasons such as residential turnover (Chalise, 2015).

Within the group, motivations to join the community often differ. Guitart, Pickering & Byrne (2012) listed the broad range motivations that were found in multiple studies as described in section 5.1.1 (Guitart et al., 2012). Drake & Lawson point out that the relationship between all perceived benefits is not clear. For instance, in some countries social aspects are prioritised, while in other area's food is more important. (Drake & Lawson, 2015)

The IAD framework also brings our attention on common understanding and social capital. Common understanding is described by McGinnis as 'the extent to which members of a community share the same core values or goals' (McGinnis, 2011). Common understanding on community gardens is only mentioned by Butler. She found it to be present on almost all of her case studies and concludes it to be of large importance as informal rules were often more important than strict rules and sanctions in the appropriation process. (Butler, 2013)

Regarding social capital, McGinnis mentions two definitions: (1) resources that an individual can draw upon in terms of relying on others to provide support or assistance in times of need, and (2) a group's aggregate supply of such potential assistance, as generated by stable networks of important interactions among members of that community (McGinnis, 2011). Veen et al. studied the influences of community gardens' organisational designs and objectives on the presence of social cohesion. They operationalise the concept of social cohesion in line with McGinnis' description of social capital: as the extent to which community garden participants form relationships with each other and offer each other mutual help. They find that this is the case on all community gardens, even if plots are individually owned and the motivation of the gardeners to visit their plot is not social (Veen et al., 2016).

Information on the extent of inequality of basic assets among people on community gardens was not found.

5.2 Dataset Rogge

Some information on the operationalisation of the theoretical frameworks on community gardens was not found in literature so far, or needed a more detailed explanation. For this, the dataset by Rogge on German community gardens was used.

5.2.1 Theory of Reasoned Action

Cultural practices

In the previous section, we described the enhancing of cultural practices as the knowledge of 'what to do, when and where', and how to interact within a particular culture. However, this does not give us a clear insight in the way in which this motivation is evaluated. Rogges database sheds more light on this motivation, as she found 'integration' as a motivation. Refugees, for instance, can be common volunteers on the garden (Rogge, 2017). This seems to align with the enhancing of cultural practices, and indicates that this motivation can be evaluated by the presence of other volunteers on the garden.

Enjoying nature

Because nature was defined as 'opposed to humans or human creations', it is debatable whether plants and animals on a human-made community garden can be called 'nature'. However, Rogge also describes the joy of being on the garden gardening and recreating, which seems to align with 'enjoying nature' and no other motivation mentioned by Guitart et al. We therefore assume that this motivation mentioned by Guitart et al. aligns with the joy as described by Rogge. (Guitart et al., 2012; Rogge, 2017)

5.2.2 Other parts of IAD

Attributes of the community

Rogge describes group sizes on German community gardens ranging from 7 to 400 people. Usually within this group, a core group maintaining the garden frequently can be identified. This core group can range from 10 to 82 people. Within the core group, there can be a leader group ranging from 0 to 12 persons (Rogge, 2017).

Interaction
Interaction is a central concept for collective action on community gardens, as collective action implicates working together and thus implicates interaction. Interactive tasks can roughly be divided into gardening, management and social activities. Gardening activities include creating beds, planting, weeding, watering, cleaning up, harvesting, construction work, taking care of animals, repairing activities, maintaining compost, sorting and packaging seeds and dividing yield. Management tasks include organising, documentation, taking care of visitors, contributing to scientific studies, taking care of contact with the neighbourhood, organising conferences, organising exhibitions, planning, and organising parties. Social activities can include parties, workshops, networking, cooking, open days, collaboration with schools, participating on intercultural days, consuming the harvest, cultural events, excursions, bbq'ing, carnival, courses, cooking nights, meeting with other initiatives and club meetings (Rogge, 2017).

5.3 Case study: Gandhi tuin

Differently from previously discussed data, which is used to construct the model in chapter 6, the data on the case study is used in chapter 8. As we have seen in the previous sections, the characteristics of community gardens largely differ. Applying the case of Gandhi Tuin to our model later in chapter 8 on experimentation helps to further define our scope. The case of Gandhi Tuin is used to calibrate the model, leading to results that should be applicable to the garden. Thus, the gardeners can help to validate the results and evaluate the practical use of the model. Gandhi Tuin was chosen because of its geographical proximity to the author and the favourable implementation of the design principles, which matches the design principles investigated in this research. This section first describes the characteristics of Gandhi Tuin as described by Vercauteren, and then describes the specific characteristics that were collected on the garden by a structured interview and used to calibrate the model in chapter 9. Additionally, the characteristics of Vredestuin are very similar to the characteristics of Gandhi Tuin, while Vredestuin has a slightly different institutional structure. Vredestuin is a garden that is initiated by the same people as Gandhi Tuin, and falls under the same organisation. Although Gandhi Tuin remains the main case study, Vredestuin is used as an additional case to compare with Gandhi Tuin. Therefore, data was collected on this garden as well.

Vercauteren describes the history and characteristics of Gandhi Tuin. Gandhi Tuin was a 2000 m2 garden located in Rotterdam since 2011, setup when former school and senior allotment gardens became available. Members from Rotterdam Transition Town and a local neighbourhood community ensured the gardens could stay, and part of these gardens became the Gandhi Tuin. Rotterdam Transition Town is a regional network in which several permaculture garden initiatives are united. Gandhi Tuin was partly set up as an initiative linked to Transition Town, but was also linked to the municipality as Rotterdam wished a garden freely available to the neighbourhood. Therefore, the association Vredestuin received the first 3 years of rent for the land from the municipality. Additionally, participants, friends and family donated many materials to the garden and some social organisations supported the garden financially.

The garden was managed by the Vredestuin Association and was maintained by volunteers, which could participate in gardening 2 times a week. Anyone could be a volunteer, which resulted in a diverse group of gardeners including (temporally) unemployed people, people incapable to work and people with a distance to employment, and participants with and without previous experience in gardening and permaculture. Additionally to gardening and decision-making, participants cooked and ate together when harvest was available. Additionally to gardening sessions, the community hosted educational activities such as lectures, workshops, discussions, documentary nights, yoga and meditation classes in a classroom on the site.

Furthermore, the institutional structure included the following. Anyone was able to to be a volunteer without paying any fee, and besides gardening anyone could participate in the decision-making process regarding future plans, tasks for maintenance, activities, events and other organisational aspects as well. However, the Vredestuin association could intervene if plans do not follow the vision of the Gandhi Tuin. This vision was based on permaculture gardening, Transition Town philosophy and Gandhi's vision of a non-violent and non-exclusive society. Regarding appropriation of benefits and costs, harvested food was spread out on a table after a gardening session, and everyone that helped that day can take some (Vercauteren, 2013) . Although Vercauteren mentions the amount of vegetables coming from the garden being small and available depending on the season because the full potential of the garden could not be exploited yet, in interviews for the research of this thesis it was indicated that there was always yield available. Sometimes, some individuals took too much yield.

The following data on the institutional structure was collected through interviews on the garden as well. The garden used graduated sanctions to in exceptional cases exclude someone from the community which persistently violated a rule. Monitoring was done informally by some leading members of the group, leading to a medium probability of an individual being sanctioned when violating a rule. The garden boundaries were made clear with a fence. It used to be open, but then the garden was harmed by people external of the community. That had not happened since the fence was added. Furthermore, the gardeners' right to organise clearly was recognised by the municipality. Finally, conflict-resolution mechanisms were present. When a conflict arose, it would be first taken to a perceived as suitable group of persons in the group, after which the opinion of the group on the issue would be collected. Then, the issue would be discussed with the group or personally with an individual.

Gandhi tuin existed 6 years when the collective action disappeared during winter 2017. Interviewees indicate that a conflict could not be resolved, which resulted in participants not trusting the community enough anymore to contribute on the garden. Conflict-resolution mechanisms were present, but not executed sufficiently. Therefore, the harm of the conflict became high. The same was described for monitoring, which decreased in the period before the collective action collapsed. The initiators chose to organise a restart for the garden under another name.

Table 5.1 shows the characteristics of Gandhi Tuin which were collected to calibrate the model. The garden was set up by 10 volunteers. New people joined afterwards, the total amount of people that had the potential of joining was perceived as very large, as Rotterdam is a big city. The chance for an individual to leave the garden during a year due to non-motivational reasons such as moving or health issues, was perceived to be 0.1. For a gardening session, around 10 persons were needed to main the garden properly. The maximum amount of tasks was indicated to be 'infinite', as they always managed to think of something to do for a volunteer. The chance that yield was available was 1, as this was always the case. When there were no boundaries, the yield could be stolen once in 10 times. When the fence was installed, this did not happen anymore. Furthermore, during a session, an individual could assess the contribution of around 3 other volunteers. 90% of the volunteers was estimated to be joining the gardening for cohesion reasons, 30% for cultural enhancement/social reasons, 60% for yield reasons, 50% for educational reasons, 80% for enjoying the gardening, 60% for contributing to environmental sustainability, 30% for land availability. 60% of the gardeners was estimated to see uncomfortable conditions as a reason not to go gardening, 20% was estimated to see a too high amount of work as a reason to refrain from contributing. The chance for uncomfortable conditions was estimated to be 25%.The difference in motivations as compared to the description of motivations in this chapter, is explained in the next chapter on concept formalisation.

Vredestuin is a younger garden, which was set up 2 years after Gandhi Tuin by Association Vredestuin as well. The situation on Vredestuin is very similar to Gandhi Tuin. Differences are in the percentage of volunteers with the motivation of cultural enhancement, which is 20% instead of 30%, and the chance for yield to be stolen when no plot boundaries, which is 0 instead of 0.1. Additionally, because the leaders learnt from Gandhi Tuin, they tried to keep the probability of sanctioning high with monitoring and indicated that they expected a conflict to be of much less harm on Vredestuin than it was on Gandhi Tuin.

Table 5.1: Characteristics of Gandhi Tuin and Vredestuin

Question	Gandhi tuin	Vredestuin
Chance for yield to be available	1	1
Chance for yield to be stolen when no plot boundaries	0.1	0
Chance for yield to be stolen when plot boundaries	0	0
Amount of volunteers for an individual to assess fair contribution of	3	3
Chance for conditions to be uncomfortable	0.25	0.25
Minimal amount of volunteers necessary for proper maintenance of garden	10	10
Maximum amount of volunteers that can have a task on the garden	1000	1000
Yearly chance for volunteer to leave community for non-motivational reason	0.1	0.1
Total pool of people from which volunteers can emerge	1000	1000
Amount of volunteers initiating and setting up the garden	10	10
Amount of time initiators are committed to maintaining the garden	52	52
Chance for a session to have a large conflict emerge on it	1/200	1/200
Age of the garden	6 years	4 years
Percentage of volunteers with motivation of cohesion	90%	90%
Percentage of volunteers with motivation of cultural enhancement	30%	20%
Percentage of volunteers with motivation of yield	60%	60%
Percentage of volunteers with motivation of education	50%	50%
Percentage of volunteers with motivation of gardening	80%	80%
Percentage of volunteers with motivation of environmental sustainability	60%	60%
Percentage of volunteers with motivation of land availability	30%	30%
Percentage of volunteers with negative motivation uncomfortable conditions	60%	60%
Percentage of volunteers with negative motivation of too much work	20%	20%
Activeness of plot boundaries	yes	no
The probability of an individual being sanctioned when violating a rule	medium	high
The hight of the fee to be allowed to take harvest when gardening	low (none)	low (none)
The probability of a new volunteer violating a rule	low	low
The multiplications a volunteer can take more yield than its fair share	medium	medium
The activeness of graduated sanctions	yes	yes
The amount of harm a conflict can have to trust	high	low

II

Model development

6. Concept formalisation

In the previous chapter, we have learnt all theories and data used in this research. In this chapter, I will first repeat the problem formulation in light of what we have learnt so far to gain more insight in the aim of our model. Then, I will explain how theory and data are used to create the model that will provide answers to our research questions.

6.1 Modelling problem formulation

Nikolic, van Dam & Luzko describe a procedure for using ABMs to study social systems and propose to answer four questions in order to gain further understanding of the problem (van Dam, Nikolic, & Lukszo, 2013). Because the former analysis of literature provided many insights, we are addressing these questions after the literature review, theoretical analysis and collection of data instead of before.

6.1.1 What is the lack of insight that we are addressing?

As we have learnt already in section 3.2, two previous studies address parts of our problem by investigating the role of design principles on their case studies. Butler investigates the influence of the design principles on the sustainability of collective action by comparing case studies, and Chalise investigates the dynamics of collective action with the use of a system-dynamics model (Butler, 2013; Chalise, 2015). However, Chalise did not model the design principles and Butler did not look into the way underlying dynamics are influenced by the design principles. Neither of them looked at robustness of collective action as an output of the system.

In previous chapters, we have learnt about the various ways in which individual design principles influence individual parts of the system leading to collective action. However, from this information it is not clear yet how these individual influences and individual parts together lead to robust or less robust collective action. The aim of the model is to bring all these individual insights together to provide insight in the way in which the dynamics resulting from the interaction between individual parts leads to the emergence of collective action.

6.1.2 What is the observed emergent pattern of interest to us?

This research and the model that will be developed in this chapter have the aim to provide more insight in the robustness of collective action as a result of the effect of varying design principles on the dynamics that result in our main emergent property: collective action. This emergent collective action is determined by other emergent properties of the system which are of interest to us as well: the evaluations of agents for their personal motivations to join the gardening.

6.1.3 Is there a desired emergent pattern, and if so, how is it different from the observed emergent pattern?

The desired emergent pattern is collective action which is robust and sustains under fluctuating behaviour of parts of the system and the environment. As we have defined collective action as a group of people maintaining the garden, we will call the collective action ‘collapsed’ when there is only 1 person left on the garden. The robustness of collective action is more successful when the collective action does not collapse for a longer time, surviving more fluctuating behaviour.

6.1.4 What is the initial hypothesis on how the emergent patterns emerge?

Van Dam et al. mention two main types of hypothesis:

1. ‘under the specified conditions, a macroscopic regularity of interest emerges from the designed agent-based model
2. ‘a range of clearly identifiable emergent behaviours and regularities can be established from this agent based model of a system.

As we are interested in the emergence of collective action patterns under varying design principles, our hypotheses are of the first type. The hypothesis is falsified if the model does not produce the expected regularity, and is confirmed if the desired regularity emerges. (van Dam et al., 2013)

In our literature review, we have learnt Butlers findings on the influence of design principles on collective action on community gardens. These insights form our initial hypotheses on the emergence of robust collective action:

- Collective choice arrangements are important for robust collective action (Butler, 2013)
- Collective action can sustain without plot boundaries, group boundaries, conflict-resolution mechanisms, appropriation between benefits and costs, monitoring and graduated sanctions being implemented (Butler, 2013)

6.2 System decomposition

According to our definition, collective action depends on the amount of volunteers making the decision to go gardening. Therefore, if we look at the IAD-framework, we need to model the design principles as exogenous variables influencing the evaluative criteria of agents. This section describes how this is done based on the information collected in chapter 4 and 5, following the structure of the IAD-framework.

6.2.1 Action Arena

Action situations in the action arena are where decisions and choices are made by actors. On the community garden, many decisions made by actors. Due to the variety of gardens, activities and actors it is not a realistic task to model all decisions. Luckily this also is not necessary, as our former analysis provides a basis to decide what action situations are of interest. Note that the action situations are about decision making. Not including an action situation for a concept therefore does not mean that an activity is not taken into account in the research at all.

Firstly, from our definition of collective action, we can conclude that the decision of gardeners to go contribute on the garden is essential. Therefore, we will analyse this decision as an action situation. Furthermore, as we are interested in the influence of design principles, we will determine the other action situations to incorporate in the model based on their influence.

The design principle of group boundaries influences the decision of gardeners to go contribute because it indicates membership fees (Butler, 2013). This therefore is an extra reason to take into account the decision of gardeners to go contribute on the garden.

The design principle of spatial boundaries influences the amount of yield available, and the design principle of appropriation between benefits and costs the way in which the yield is shared among gardeners. Additionally, free-riding on community gardens is described mostly in relation to yield taking. The amount of yield gardeners take seems a relevant issue under influence of design principles, and therefore the decision on the amount of yield to take will be analysed as an action situation.

The design principles of monitoring and sanction influence rule violation. As we have learnt in our literature review, rule violation can influence trust. Rule violation during a gardening session therefore will also be analysed as an action situation.

The design principle of collective-choice arrangements regards decision making processes on the garden. As we defined our scope as ‘operational’ in section 4.2, we do not take into account institutional changes resulting from decision making in our analysis. Additionally, the influence of collective-choice arrangements, agents being more likely to follow rules, does not need any insight in the process of decision making. Therefore, process of collective decision making is not analysed as an action situation.

The design principle of conflict-resolution mechanisms regards the amount of conflicts that harm trust (Ostrom, 2005; Poteete et al., 2010; Wilson et al., 2013). We assume conflicts emerge between people, without deliberate decision making. Due to the broad scope of possibilities for the nature of the conflict, it would also be difficult to generally model this concept. Therefore, conflict is not taken into account as an action situation.

Thus, we now have the following three decisions and action situations:

1) Contributing on the garden or not
2) Choosing an amount of yield to take
3) Violating rules or not during contributing on the garden

As described in section 4.2, action situations contain information about participants, positions, potential outcomes of actions, actions, action-outcome linkages, control, type of information and the processing of costs and benefits (Ostrom, 2005). Some aspects of the action situations are determined by other parts of the IAD framework and will be discussed later in this chapter: possible participants and positions become clear from the section on group attributes. Other information was not found in literature or can be reasoned: action-outcome linkages and control that actors exercise over the linkages. Although potential outcomes of actions are mentioned as a separate part of the IAD framework as well, we will discuss them within this chapter because their explanation is closely related to the action situations.

Contributing on the garden or not
Firstly, all agents have to decide whether to go join the gardening and contribute or not. Only one type of participant exists in this action situation: the potential volunteer. This potential volunteer can choose the position of volunteer in this action situation if it decides to join the gardening, and will remain a potential volunteer when it decides not to join. Who can take the position to be a participant for this action situation depends on the design principles for group boundaries and graduated sanctions, which will be further elaborated upon in section 6.2.2 on rules. The potential outcomes of choosing to garden, are described with the evaluative criteria on 6.2.5. For some of these potential outcomes the gardener has full control and the linkage is certain, such as enjoying nature or enhancing spiritual practice. Other outcomes are uncertain, such as access to fresh food, or certain but not under control at all, such as bad conditions.

We have decided in section 4.3 to describe the decision making of agents with the Theory of Reasoned Action (TRA). This theory indicates that agents have evaluative beliefs and strengths for that belief (Darnton, 2008). In our model, all agents are therefore assigned a personal set of strengths for beliefs. A belief is defined as the subjective probability that an object has a certain attribute, which is determined by the information accessible in memory (Ajzen & Fishbein 2000). Therefore, when the agent visits the community garden, it evaluates its beliefs according to its experience. How the beliefs are adapted after an experience is further discussed in section 6.2.5 on evaluative criteria. In this section, we further elaborate on which types of attitudes and social norms influencing the decision of individuals to contribute on community gardens are implemented in the model.

We have learnt in chapter 5.1 that gardeners have multiple motivations to join gardening or not to join gardening (Chalise, 2015; Drake & Lawson, 2015; Guitart et al., 2012), which are the attitudes described in the TRA. They are mentioned in the first column of table 6.2. As we have learnt in chapter 5 as well, is that some of these motivations overlap in their practical need, while the motivation of health has a multiple need. To ease the distinction between overlapping motivations and to ease the evaluation of the motivation with multiple needs, in the model we merge these motivations to their practical need as shown in table 6.1. Both the motivation for consuming fresh food and saving/making money depend on the receiving of yield. Therefore, these motivations are merged under the label of ‘Yield’. When an agent has the motivation of enjoying nature or enhancing spiritual practices, it looks for time spent on the garden. Therefore, these motivations are merged as ‘Enjoying gardening’. Improving health can be satisfied by both yield and being on the garden. Therefore, this motivation is split among those two labels.

Table 6.1: motivations, practical needs and labels

Motivations	Practical need from definitions	Label
Social cohesion/development	Social ties	Cohesion
Enhancing cultural practices	Interaction	Social
Consuming fresh food	Yield	Yield
Saving/making money	Yield	Yield
Enjoying nature	Time on the garden	Enjoying gardening
Enhancing spiritual practices	Time on the garden	Enjoying gardening
Environmental sustainability	Contributing to the garden	Environmental sustainability
Education	New knowledge	Education
Land accessibility	Ideal of garden being accessible	Land accessibility
Improving health	Time on the garden or yield	Yield / Enjoying gardening
Uncomfortable conditions (negative)	Bad weather or bad conditions	Uncomfortable conditions
Too much work (negative)	Too many tasks	Too much work

Next to the attitudes mentioned in table 6.1, TRA describes that subjective norms play a role in making a decision. Ajzen and Fishbein state that ‘when people believe that most respected others would expect them to perform the behaviour or are themselves performing the behaviour, the subjective norm will exert pressure to engage in the behaviour’. In the belief that others perform a certain behaviour, we can recognise trust as defined by Mui: ‘a subjective expectation an agent has about another’s future behaviour based on the history of their encounters’. This trust is fuelled by reputation: the ‘perception that an agent creates through past actions about its intentions and norms’ (Mui, 2002). So, by perceiving a reputation, an individual forms an image of the norms active in a group and trusts others to comply to this norm, and therefore feels pressure to comply to this norm as well.

Therefore, we use the confirmed assumption that when an individual perceives a reputation resulting in a trust that volunteers of the community contribute to maintain the garden, the individual interpret this as the norm and will feel pressure to contribute as well. Whether a person reciprocates the norm of contributing to the garden, depends on the individual’s norm of reciprocity (Mui, 2002). We therefore assume reciprocity determines the strength for this normative belief.

Mathematically, the TRA can be expressed as the following function:

$$BI = (A_B)W_1 + (SN)W_2$$

with

BI	Behavioural Intention

A_b	Attitude towards performing the behaviour

W_1	Empirically derived weight

SN	Subjective norm related to performing the behaviour

W_2	Empirically derived weight

The attitude can be calculated by the sum of the belief strength and belief evaluation:

$$A_B = \Sigma b_i e_i$$

with

b_i	Belief strength, or the certainty to which the belief is held.

e_i	Belief evaluation, the extent to which the attribute is judged to be positive or negative.

and social norm is calculated in a similar way:

$$SN = \Sigma b_i m_i$$

with
b_i Belief strength or perceived expectation of salient others.
m_i The motivation to comply with the perceived expectation of others.
(Hale, Householder & Greene, 2003)

We can then bring together these functions in the following function resulting in a intention to join gardening:

$$Intention = ((b_{cohesion} * e_{cohesion}) + (b_{social} * e_{social}) + (b_{yield} * e_{yield}) + (b_{education} * e_{education}) + (b_{landavailability} * e_{landavailability}) + (b_{enjoyinggarden} * e_{enjoyinggarden}) + (b_{envsustainability} * e_{envsustainability}) - (b_{conditions} * e_{conditions}) - (b_{toomuchwork} * e_{toomuchwork})) * W_1 + (b_{needcontribution} * m_{needcontribution}) * W_2$$

with

$b_{cohesion}$	Belief strength for cohesion.
$e_{cohesion}$	Belief evaluation for cohesion
b_{social}	Belief strength for social time
e_{social}	Belief evaluation for social time
b_{yield}	Belief strength for yield
e_{yield}	Belief evaluation for yield
$b_{education}$	Belief strength for education
$e_{education}$	Belief evaluation strength for education
$b_{landavailability}$	Belief strength for land availability
$e_{landavailability}$	Belief evaluation for land availability
$b_{enjoyinggarden}$	Belief strength for enjoying the garden
$e_{enjoyinggarden}$	Belief evaluation for enjoying the garden
$b_{envsustainability}$	Belief strength for environmental sustainability
$e_{envsustainability}$	Belief evaluation for environmental sustainability
$b_{conditions}$	Belief strength for the ease of conditions
$e_{conditions}$	Belief evaluation for the ease of conditions
$b_{toomuchwork}$	Belief strength for too much work
$e_{toomuchwork}$	Belief evaluation for too much work
$b_{needcontribution}$	Belief strength for the need for contribution
$m_{needcontribution}$	Belief evaluation for the need for contribution
W_1	The weight of the attitude
W_2	The weight of the social norm

The belief strengths are characteristics of the agents, and range between 0 and 1. The evaluations also range between 0 and 1. An agent decides to go gardening when the intention is higher than a set decision threshold called 'ContributingThreshold'. When an agent decides to go gardening, it gets assigned the role of 'volunteer'. When it does not join the gardening, it gets assigned the role of 'potential volunteer'. Only volunteers proceed in the process, potential volunteers can make the choice to volunteer again next opportunity. This is depicted later in figure 6.1 & figure 7.1.

As we don't know W_1 or W_2, these values are a range in the model determined as follows. In literature, we find that for engaging in (team)sports, the maximum value for the social norm compared to the attitudes is a value around 4 for social norm and 3 for attitude. The article actually describes the values as 6.05 and 4.92, but as the maximum total value of our formula is 7 without implementation of W_1 or W_2, we prefer the values to sum to 7 (Eves, Hoppéa, & McLaren, 2007). When W is not included, the attitude automatically has a max weight of 6 because of the amount of attitudes, against a weight of 1 for social norm. We assume scenario represents the minimum weight of the social norm. We do not want the maximum outcome of the formula to chance with regard to the set ContributingThreshold. Therefore, when we range the weight of the social norm W_2 between 1 and 4, we calculate W_1 as follows:

$$W_1 = (7 - W_2) / 6$$

This formula resulted from the following steps based on the amount of attitudes and social norms summing up to 7 together:

$$6 * W_1 + 1 * W_2 = 7 \rightarrow 6 * W_1 = 7 - W_2 \rightarrow W_1 = (7 - W_2) / 6$$

Choosing an amount of yield to take
Regarding the action arena in which agents choose an amount of yield to take, a lot of information became clear from the former literature study already too. Who can take the position to take yield, depends on the design principles for group boundaries and appropriation between benefits and costs. The potential outcomes of taking yield can be having a fair amount, having more than a fair amount or having less than a fair amount. In the action situation of yield taking, only volunteers participate. Whether this action situation happens, depends on the design principle for appropriation of benefits and costs. When this design principle is active, volunteers get assigned a fair share of yield instead of taking it themselves. The choices and implementation regarding the design principles is explained more elaborately in section 6.2.2 on rules.

When the design principle for appropriation of benefits and costs is not active, volunteers are free to take their desired amount of yield. In literature it was found that people can be taking too little yield, or too much. Many gardens indicate to have a surplus of yield, which they bring to charity or additionally give to the volunteers, but it is also indicated that people sometimes take too much leaving others disappointed (Butler, 2013; Charles, 2012). Reasons for this behaviour are not described. Therefore, we assume the following. The yield is divided in equal shares; one share for each volunteer. The minimum amount a volunteer can take is 0, the maximum amount a volunteer might take is a variable set for an experiment, the fair amount is 1. The volunteers randomly choose to wish for an amount of yield higher than 0 and lower than the maximum amount. When volunteers take their randomly chosen share, the amount of yield decreases. When the amount of yield decreases too far and volunteers can not take their chosen share anymore, they evaluate the yield taking of that session negatively. This results in a decrease of $e_{yield.}$

Violating a rule during contribution
The final decision volunteers can make, is to contribute fairly or violate a rule. As we have seen in theory, rule violation can happen because of a mistake, or deliberately (Ostrom, 2005). However, the exact meanings of the rules differ per garden and are not important for our model testing the influences of design principles. Therefore, the ‘decision’ for violating a rule or making a mistake is made very abstract. Volunteers have a probability for rule violation during the contributing on the garden between 0.01 and 0.9, which decreases and increases under influence of design principles and experiences with other volunteers.

6.2.2 Rules
As we have seen in section 5.1, there are many practical implementations for the design principles found on community gardens (Butler, 2013). These implementations influence the experiences that volunteers have on the garden. Incorporating all implementations in the model would be too elaborate for this master thesis. Therefore, the institutions that address the design principles most precisely are chosen to be evaluated in this study, by comparing them to the institutions that address the design principles the least. Like this, we can learn whether the design principles in their essence are useful to collective action on community gardens. In this section, it is explained in which way the design principles are incorporated in the model.

Plot boundaries
There are two options for plot boundaries: a closed fence/hedge around the garden, or no fence/hedge around the garden (Butler, 2013). Therefore, this design principle is incorporated in the model as a boolean: it can be active or not active. Having a boundary around the garden compared to no boundaries has three effects:

1) the chance that yield gets stolen decreases (personal communication)
2) rule enforcement is easier, leading to an increased probability of sanctioning (Poteete et al., 2010)
3) the evaluation for the motivation of ‘land availability’ to join on the garden worsens (Milburn & Vail, 2010)

The chance for yield getting stolen is assumed to depend on the location of the garden. Therefore, both the chance for yield getting stolen when there are boundaries and the chance yield getting stolen when there are no boundaries are added to the model as garden characteristics.

The way in which rule enforcements gets easier with plot boundaries is unclear, just as the probability of rule violation being sanctioned is unclear. Therefore, we'd like to vary the probability of sanctioning in our model across a range and test this separately from the plot boundaries boolean.

The impact of a worse evaluation for motivation 'land availability' on the amount of people contributing is clear: a lower motivation leads to less people contributing on the garden, leading to a higher chance for the collective action to collapse. The decrease of this motivation does only influence individuals, and not any interaction among agents. Therefore, as it does not lead to new patterns, the impact is neglected. It could be argued that a smaller group resulting from lower motivations could lead to a change in interaction among agents. However, the impact of this will be tested already by varying the ContributingThreshold.

Group boundaries
The design principle of group boundaries can be not implemented at all when everyone is allowed to join gardening and take yield, or most precisely implemented in the form of a membership which allows yield while other volunteers are not allowed yield (Butler, 2013). This design principle is incorporated in the model as follows. When the design principle for group boundaries is active, only members are allowed yield. Volunteers make the decision to become a member or not based on the benefits of receiving yield against the cost of paying the fee. As we don't know the impact of the fee, it is beneficial to learn about this impact by varying this value. Therefore, this design principle is incorporated in the model as a range. The so called 'MemberIntention' is defined as follows:

$$MemberIntention = Intention - fee$$

with

Intention	the behavioural intention to go volunteer on the garden, based on the evaluations and importance of separate motivations
fee	a range between 0 and 0.9, which practically means 'no fee for yield' and 'a fee for yield which is only worth paying for people that regard yield very important'.

While the Intention for volunteering without taking yield is defined as follows:

$$IntentionWithoutYield = Intention - (b_{yield} * e_{yield})$$

When the MemberIntention is higher than the regular Intention and higher than the ContributingThreshold, the agent becomes an active member. The membership is active for a set amount of sessions, after these sessions the agent can make the choice for membership again.

Monitoring
The only effect of monitoring is a higher probability of sanctioning (Wilson et al., 2013). As we have already discussed with plot boundaries, all values around this probability of sanctioning are unclear. Therefore, monitoring is viewed as a range determining the probability of sanctioning to allow assessing its affect.

Graduated sanctions
When there is no regulation for graduated sanctions, we assume sanctioning implies telling off. Butler described 'no sanctioning rules at all', but it is perceived to be unlikely that people do not correct each other at all. When there is regulation for graduated sanctions, a first set amount of times of rule violation the agent is told off, then the agent is suspended for a set amount of time. When it comes back and violates again, the agent is denied further access to the garden. (Butler, 2013)

Appropriation of benefits and costs
Regarding the design principle for appropriation of benefits and costs, we found two options in line with Ostroms design principle: the membership and the employee giving out yield. However, they have the same practical influence: contributors receive a (aimed to be) fair amount of yield according to rules. Therefore,

we don’t need to make a distinction between the two options and can implement the ‘best principle’ by taking the decision making for an amount of yield out of the experiment. The option least in line with Ostroms design principle seems to be the case on which volunteers could take the yield they needed, which for some meant taking a lot and for some taking a little. On the case study, a similar procedure was described. However, there were boundaries. When an individual took way too much yield, something would be said about it. As it seems unlikely that free-riding is completely permitted, the scenario of the case study is used in the model: people can choose their own amount of yield, but when this exceeds a set amount they violate a norm and can be told off or sanctioned.

Collective choice arrangements
When there are collective choice arrangements, the probability of an individual violating a rule decreases according to literature (Ostrom, 2005; Wilson et al., 2013). Similarly to the probability of sanctioning, we don’t know any values for the probability of rule violation. Therefore, to assess the influence of this design principle, the initial probability an agent violates a rule is also incorporated in the model as a range.

Another influence of collective choice arrangements found, was a set of rules that is better aligned with local circumstances (Ostrom, 2005). However, as we only take into account an operational scope of rules, this influence is not taken into account.

Conflict resolution mechanisms
Conflict resolution mechanisms have the effect of decreasing the harm of a conflict (Ostrom, 2005; Poteete et al., 2010; Wilson et al., 2013). The initial and adapted value for conflict harm are unknown. Therefore this design principle is also incorporated in the model as a range determining the harm of a conflict.

We can conclude from this section, that some design principles overlap in influences. Because often the extent to which the design principles exert their influence is not clear, influences are modelled separately. Table 6.2 summarises the resulting implementation in the model.

Table 6.2: the way in which design principles are implemented in the model

Design principle	Implementation in model	Type variable	Description implementation
plot boundaries*	DPplotboundaries	true/false	boundaries around garden influence the probability for yield to be stolen, probabilities are indicated by garden
monitoring	DPprobabilitysanctioning	floating point >= 0.01, <= 0.9	determines the probability rule violation is sanctioned
group boundaries	DPfee	floating point >= 0, <= 0.9	determines the height of the fee to receive yield
collective-choice arrangements	DPglobalprobabilityruleviolation	floating point >= 0.01, <= 0.9	determines the initial probability of rule violation of a volunteer
proportional equivalence benefits&costs	DPMaxTakingMoreThanShare	floating point >= 1, <= 5	determines the max value of the range from which volunteers randomly choose their desired amount of yield
graduated sanctions	DPgraduatedsanctions	true/false	determines whether graduated sanctions are active or not
conflict-resolution mechanisms	DPconflictharm	floating point >= 0, <= 100	determines the extend to which a conflict harms trust

* the potential effect of fences diminishing belief in land availability is not taken into account

6.2.3 Interactions
The IAD framework also highlights interactions. Interactions between agents take place during the gardening. The outcomes resulting from these interactions influence the beliefs of the agents. The various outcomes that interactions can have are described in the next section, and how these are evaluated is described in the section after that.

6.2.4 Outcomes
Outcomes result from moments of interactions: gardening, potentially yield taking and potentially conflict. In section 6.2.2 we have determined the outcomes of these interactions. During the gardening, volunteers work together and socialise, see each other contribute and perhaps see someone violate a rule and being sanctioned or not. After yield taking, outcomes for a volunteer can be to have a fair amount of yield, too much yield when it chose so, or no yield at all when another volunteer took their yield or the yield was stolen by an outsider. The outcomes of conflict can be that it harms trust, or that it does not harm trust of an individual.

6.2.5 Evaluative Criteria
After a gardening session, agents evaluate their beliefs based on their experiences according to evaluative criteria. The outcomes that we have seen in the previous section influence these experiences. This section describes how motivations of agents are evaluated for each session. The final beliefs that are used in the intention formula, are calculated as follows:

$$e_{motivation} = \Sigma\, e_{motivation,gardening\ session} / Amountofvisits$$

with

$e_{motivation,gardening\ session}$	The evaluation of a motivation on all individual gardening sessions experienced
Amountofvisits	The amount of times that an agent chose to volunteer and visited the garden

Social development/cohesion
As we have seen in section 5.1, social development and cohesion can be assessed by the density of interpersonal relationships in a group (Friedkin, 2004). Therefore, the evaluation of this belief is formulated as follows:

$$CurrentCohesion = PresentTies / count\ volunteers$$

with

PresentTies	Amount of relationships an individual has with the other present volunteers
Count volunteers	The amount of volunteers that are present

Yield
Regarding yield, we assume that volunteers adapt their desires to the restraints and possibilities regarding the amount of yield available. Thus, there are four options: there is no yield available, there is yield available and the volunteer receives a fair share, there is yield available and the volunteer takes too much yield, or there is yield available and the volunteer receives no (or too little) yield because it was taken by another volunteer or stolen by an outsider. When the volunteer receives a fair share of yield, the motivation is evaluated positively. When the volunteer does not receive a fair share of yield while it should, the motivation is evaluated negatively.

Enjoying gardening
Enjoying gardening and being in nature is something that we assume to be encapsulated in the activity of gardening. Therefore this criteria is always evaluated positively.

Environmental sustainability
The motivation of environmental sustainability, as we have seen in section 5.1, seems to be independent of scientifically proven environmental sustainability. Therefore, this criteria is always evaluated positively too.

Education
Education takes place on community gardens in many forms. As we have seen in section 5.2, there can be workshops and classes. These educational activities are not organised on all gardens though, and because they are not influenced by the design principles we do not take them into account. However, literature also indicates that learning happens by being on the garden (Duchemin et al., 2008; Saldivar-Tanaka & Krasny, 2004). The extent to which an individual gains new knowledge on the garden, we can learn from learning curves. Typically, people first learn things relatively quickly. The more an individual learns, the more time and effort it takes to gain more expertise (Thalheimer, 2006). Therefore, we assume the belief for education to start at 1, and then exponentially decays until it's zero. The amount of learning that's possible is assumed to depend on the type of garden and the characteristics of the individual. Therefore the maximum amount of visits after which an individuals belief for education is 0, is an input parameter. Each individual randomly gets assigned a value between 0 and that input parameter.

Cultural practices
The motivation regarding enhancement of cultural practices involves the learning about social interaction and behaviour (National Standards for Foreign Language Education, 1999), and therefore requires social interaction on the garden. As this is always possible when there is more than 1 person, we assume this motivation would be evaluated positive when the amount of volunteers is larger than 1.

Land accessibility
The degree in which the garden is accessible to citizens, is influenced by the design principles for plot boundaries. Milburn and Vail mention that people didn't like that there were fences around a garden. Therefore, this design principle influences this motivation (Milburn & Vail, 2010). However, as the design principles are stable, this motivation is also stable during the run. This makes it very easy to predict its effect: it will cause motivations to decrease in any scenario. As we can predict this already, it is not useful to take it into account in the model. Therefore, land accessibility is always evaluated positively.

Too much work
Chalise determines the amount of work by the amount of desired activities: a higher amount of desired activities leads to a higher amount of work, which can lead to a gap in the actual level of effort and the level of effort needed to reach the desired quality of the garden (Chalise, 2015). In our model, the amount of work is indicated by a garden characteristic in the form of 'amount of people necessary on a session to sufficiently maintain the garden'. When the amount of people on a gardening session is lower than this number, there is too much work. When the amount of people on a garden session is higher than this number, there is not too much work.

Uncomfortable conditions
The amount of this discomfort due to weather and bugs (Drake & Lawson, 2015; Vercauteren, 2013), naturally depends on the area. Therefore, the percentage of days with 'uncomfortable conditions' is a garden specific input parameter. As people are assumed to be able to predict conditions regarding weather and insects, this is the only value in the decision formula which is not evaluated according to past experiences, but accurately predicted every session separately.

Social Norm
As we have learnt in section 6.2.2, the motivation of complying to the social norm to go contribute on the garden is influenced by trust, reputation and reciprocity. When an individual sees that other volunteers take good care of the garden, the community builds the reputation to take good care of the garden and forms the norm like that too. The evaluation of the social norm is therefore based on trust.

In section 6.2.2 we discussed Mui's formalisation of the relations between reciprocity, trust and reputation (Mui, 2002). 2 other concepts he describes become relevant when implementing this formalisation in a model: action and encounter. An action can be either to cooperate or to defect during an encounter. When a volunteer is on the garden, it has encounters with multiple other volunteers, on which it bases its verdict about the trustworthiness of the group. We define cooperative actions as actions of contribution to the whole community, and non-cooperative actions as actions that do not contribute to the community.

Cooperative and non-cooperative actions are modelled as follows. When an individual interacts with another volunteer and it does not see that volunteer make a mistake or violating a rule, his is a cooperative action. This aligns with Chalise's insight that social interaction improves trust (Chalise, 2015). When an individual interacts with a volunteer that violates a rule or when a conflict escalates, this can be seen as behaviour counterproductive to the garden. Therefore, this is seen as defecting.Violation of rules happens in several ways. People can take too much yield, or people can make mistakes such as not tidying the kitchen or bringing a dog. Although literature mentions rule violations to harm the trust in a group (Ostrom, 2005), within our definitions it harms the reputation of the group (which has the same effect as reputation is directly linked to trust).

We assume that the reputation of the group directly affects the individual's trust, which means the individual believes that the group in the future behaves the same way as in the past (Mui, 2002). When evaluating the trustworthiness of the group based on reputation, the agent relies on all its former encounters. Mui formalizes this as follows:

$$Reputation = p / n$$

With

p number of cooperative actions (which we see as an encounter with someone who does not violate a rule or is in a bad conflict)

n the number of encounters with others in total.

Figure 6.1 shows an overview of the evaluations of motivations agents make.

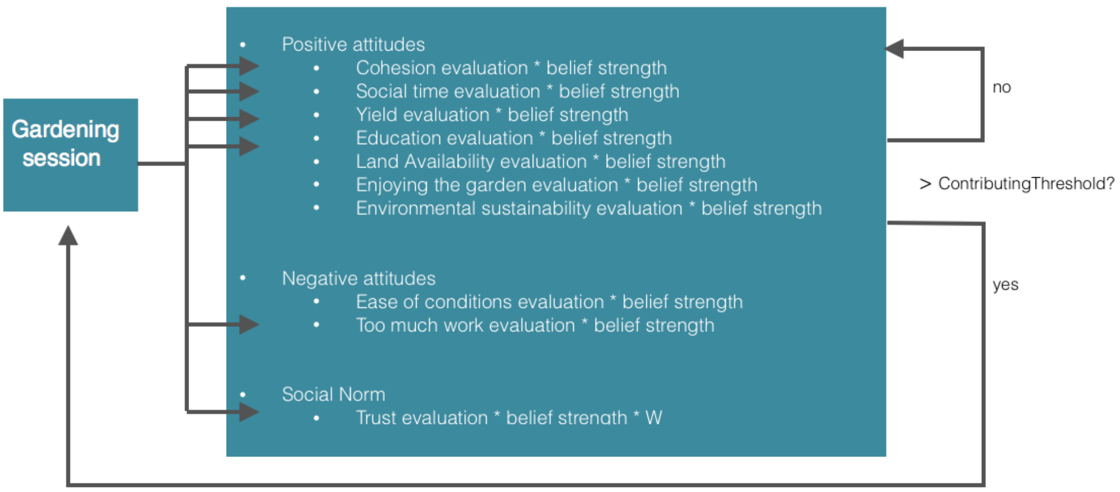


Figure 6.1: evaluations of motivations

Probability of rule violation

Next to motivations, agents update their probability of rule violation. The seeing of someone violating a rule increases the chance that the viewer violates a rule, as unsanctioned errors or unfair situations makes viewers less willing to follow rules, and because the viewer might think the rule violation is normal behaviour (Anderies & Janssen, 2013; Ostrom, 2005). The probability of an individual violating a rule during a gardening session is therefore formalised as:

$$ProbabilityRuleviolation = AmountOfSeenViolationsWithoutSanctions / TotalEncounters$$

With

ProbabilityRuleviolation	the probability of an individual agent to violate a rule during gardening
AmountOfSeenViolationsWithoutSanctions	The amount of violations without sanctions an individual agent saw
TotalEncounters	The total amount of encounters an individual agent experienced

The initial probability of rule violation that an agent has, depends on DPglobalprobabilityruleviolation, for which the value ranges between 0.01 and 0.9. The chance that a rule-violator gets punished when it is seen, depends on DPprobabilitysanctioning, of which the value also ranges between 0.01 and 0.9.

6.2.6 Biophysical/material conditions

Relevant biophysical/material conditions regard the amount of yield and the weather/bugs conditions. During the action situation of taking yield, the amount of yield equals the amount of volunteers plus a maximum percentage of surplus which can be indicated garden-specifically. The amount of times that the yield is available is a garden-specific characteristic as well. Finally, the yield can get stolen by outsiders.

6.2.7 Attributes of community

A new community first consists of initiators. These initiators have the characteristic that they visit the garden regardless of their motivation for a set amount of gardening sessions, as they have accepted the responsibility to set up the garden. The community grows as new volunteers are invited. This is formalised following Chalise: each member of the group speaks to a set amount of individuals about the garden, of which a set percentage decides to give gardening a try. After this first try, the new volunteer becomes a potential-volunteer. The amount of potential-volunteers shrinks with a set rate as well, as they leave due to external reasons. The network in which agents interact is a random network.

6.3 Assumptions

Some formalisations of our model description could not be based on literature. Table 6.3 contains the assumptions that were made and validated by an expert on community gardens.

Table 6.3: assumptions

Assumption	Validated?
when individuals build up the trust that its fellow-volunteers contribute to the quality of the garden, this normative belief that help of an individual is needed on the garden becomes an increasingly important motivation for an individual to go contribute as well	yes
Initiators usually stay committed to maintaining the garden longer than regular volunteers	yes
volunteers only negatively evaluate yield taking when their fair share of yield is unavailable	yes
Enjoying gardening is always evaluated positively	yes
Environmental sustainability is always evaluated positively	yes
Cultural enhancement is evaluated positively when there is more than 1 person	yes
Amount of sessions after which an individual does join the garden for educational purposes anymore is 100-400	yes
Minimum amount someone can be told off before being suspended is 2 to 10 times	yes
Maximum amount someone can be told off before being suspended is 10 to 40 times	yes
When someone is suspended, the individual can not access the garden 5 to 20 gardening sessions	no*
The amount of times someone can be told off after suspension before being denied access to the garden permanently, is between 2 and 10.	yes
A conflict can harm trust up to a 100 times worse than seeing someone violate a rule	yes
Volunteers taking too much yield, can take up to 5 times the fair amount	yes**
The probability for a volunteer to violate a rule during gardening, can be between 0.01 and 0.9	yes
The probability for a volunteer violating a rule to be sanctioned, can be between 0.01 and 0.9	yes
A membership can last between 13 and 52 weeks	no

*The expert did not know any cases in which suspension happens. ** 5 might be too much

6.4 Concept formalisation

According to Van Dam et al. (2013), concept formalisation can be done in two ways: by making a non-structured list of software data structures, or by making a formal ontology. Because a software data structure works sufficiently for our model and is easier to make than a formal ontology, software data structure is chosen as our method.

To make the concepts described in the system identification understandable for the computer, we need to translate them into a language that Netlogo understands. Computer languages can deal with a set list of concepts, which are called primitive types. On this website, all Netlogo primitives are described: https://ccl.northwestern.edu/netlogo/docs/dictionary.html.

How the concepts of the system are formalised in Netlogo is shown in the list below. Concepts in black are calculated from the model as discussed before or based on values found in literature when citation is added. Concepts in grey are assumed and validated. Concepts in blue are garden characteristics for which a value was provided by the case study.

Agents have:

- AmountOfGoodEncounters: integer >= 0. Represents the total amount of good encounters that an agent has had.
- AmountOfSeenViolationsWithoutSanctions: integer >=0. Represents the total amount of times an agent saw another volunteer violate a rule without being sanctioned.
- Amountofvisits: integer >= 0. Represents the amount of times that an agent volunteered on the garden.
- BeingMember: boolean. Indicates whether the agent chose to be a member or not.
- BeliefCohesion: floating point >= 0, <= 1. Represents the belief evaluation for cohesion.
- BeliefConditions: integer 0 (good conditions), 1 (bad conditions). Represents the belief evaluation for comfortable conditions.
- BeliefEducation: floating point >= 0, <= 1. Represents the belief evaluation for education.
- BeliefEnjoyingGarden: integer 1. Represents the belief evaluation for enjoying the garden.
- BeliefEnvsustainability: integer 1. Represents the belief evaluation for environmental sustainability.
- BeliefLandavailability: integer 1. Represents the belief evaluation for land accessibility.
- BeliefSocial: floating point >= 0, <= 1. Represents the belief evaluation for social interaction.
- BeliefToomuchwork: floating point >= 0, <= 1. Represents the belief evaluation for too much work.
- BeliefYield: floating point >= 0, <= 1. Represents the belief evaluation for yield.
- CohesionList: list with length ‘number of visits’. Each gardening session, volunteers extend the list with a new evaluation regarding cohesion.
- CommittedTime: integer >= InitiatorCommittedTime. Represents the amount of time that an initiator is committed to the garden, meaning it contributes even if it is not motivated.
- Conflict?: boolean. Indicates whether there has been a conflict or not.
- ContactTime?: boolean. Indicates whether it is time for a volunteer to invite a new volunteer.
- CurrentCohesion: floating point >= 0, <= 1. Represents the current cohesion as experienced by the volunteer.
- Membermotivation: floating point >= 0, <= 7. Represents the MemberIntention of an agent.
- Membertimer: integer >= 0, <= CommittedTime. Represents how long an agents’ membership lasts.
- MomentOfSuspension: integer > 0. Remembers the tick in which an agent was suspended.
- Motivation: floating point >= 0, <= 7. Represents the Intention of an agent.
- MyAmountofSanctions: integer >= 0. Represents the amount of sanctions an agent received.
- NoAccess: integer >= 0, <= 10000. Represent the amount of sessions an agent can not access the garden due to a sanction.

- PersonalEducationDecay: floating point >= 0, <= EducationDecay. Represents the rate with which the education belief for an agent decays, which is determined as a random number for each agent.
- PresentTies: integer <= 0. Indicating the amount of volunteers in the group an agent has a tie with.
- ProbabilityRuleviolation: floating point >= 0, <= 1. Represents the probability of an agent to violate a rule during gardening.
- Reciprocity: integer 1. Represents the belief strength for trust.
- SocialList: list with length 'number of visits'. Each gardening session, volunteers extend the list with a new evaluation regarding social interaction.
- suspended?: boolean. Indicates whether a volunteer is suspended or not.
- TooMuchWorkList: list with length 'number of visits'. Each gardening session, volunteers extend the list with a new evaluation regarding too much work.
- TotalConflicts integer > 0. Indicates the amount of conflicts an agent has experienced.
- TotalEncounters: integer >= 0. Indicates the amount of encounters an agent has experienced.
- Trust: floating point >= 0, <= 1. Represents the trust an agent has in the community.
- TrustList: list with length 'number of visits'. Each gardening session, volunteers extend the list with a new evaluation regarding trust.
- ValueCohesion: floating point >= 0, <= 1. Represents the belief strength of an agent regarding cohesion.
- ValueConditions: floating point >= 0, <= 1. Represents the belief strength of an agent regarding comfortable conditions.
- ValueEducation: floating point >= 0, <= 1. Represents the belief strength of an agent regarding education.
- ValueEnjoyingGarden: floating point >= 0, <= 1. Represents the belief strength of an agent regarding enjoying the garden.
- ValueEnvsustainability: floating point >= 0, <= 1. . Represents the belief strength of an agent regarding environmental sustainability.
- ValueLandavailability: floating point >= 0, <= 1. Represents the belief strength of an agent regarding land accessibiltiy.
- ValueSocial: floating point >= 0, <= 1. Represents the belief strength of an agent regarding social interaction.
- ValueToomuchwork: floating point >= 0, <= 1. Represents the belief strength of an agent regarding too much work.
- ValueYield: floating point >= 0, <= 1. Represents the belief strength of an agent regarding yield.
- YieldAccess: boolean. Indicates whether a volunteer receives yield, when group boundaries are active.
- YieldList: list with length 'number of visits'. Each gardening session, volunteers extend the list with a new evaluation regarding yield.
- YourYieldTaken?: boolean. Indicates whether the volunteer received its desired share of yield or not.

Volunteers have:

- MyRuleViolationsThisRound: integer >= 0, <= 1. Indicates the amount of rules a volunteer violated during a single gardening session.
- MySanctionsThisRound: integer >= 0, <= 1. Indicates the amount of sanctions a volunteer received during a single gardening session.
- RuleViolated?: boolean. Indicates whether a volunteer violated a rule.
- Sanctioned?: boolean. Indicates whether a volunteer was sanctioned.
- YieldWish: floating point >= 0, <= DPMaxTakingMoreThanShare. Represents the amount of yield a volunteer desires.

The environment has:

- %HighCohesionValue: floating point >= 0, <= 1. Indicates the percentage of gardeners with a high belief strength for cohesion.

- %HighConditionsValue: floating point >= 0, <= 1. Indicates the percentage of gardeners with a high belief strength for comfortable conditions.
- %HighEducationValue: floating point >= 0, <= 1. Indicates the percentage of gardeners with a high belief strength for education.
- %HighEnjoyingGardenValue: floating point >= 0, <= 1. Indicates the percentage of gardeners with a high belief strength for enjoying gardening.
- %HighEnvSustainabilityValue: floating point >= 0, <= 1. Indicates the percentage of gardeners with a high belief strength for environmental sustainability.
- %HighLandavailabilityValue: floating point >= 0, <= 1. Indicates the percentage of gardeners with a high belief strength for land accessibility.
- %HighSocialValue: floating point >= 0, <= 1. Indicates the percentage of gardeners with a high belief strength for social interaction.
- %HighTooMuchWorkValue: floating point >= 0, <= 1. Indicates the percentage of gardeners with a high belief strength for too much work.
- %HighYieldValue: floating point >= 0, <= 1. Indicates the percentage of gardeners with a high belief strength for yield.
- AmountOfTasks: integer >= 1. Represents the amount of tasks necessary to properly maintain the garden.
- AmountOfYield: integer >= 0. Represents the amount of yield that is in stock for a volunteer.
- AvailabilityYield: boolean. Indicates whether yield is available on a particular gardening session.
- AverageTrust: floating point >= 0, <= 1. Indicates the average trust on a particular gardening session.
- BalanceAttitudeSocialNorm: floating point >= 0.5, <= 4. Represents weight of social norm ‘W_2’ in the intention formula.
- ChanceContactTriesGardening: floating point >= 0.05, <= 0.15. Represents the probability that a new person contacted about the garden participates on a gardening session. (Chalise, 2015)
- ChanceUncomfortableConditions: floating point >= 0, <= 1. Represents the probability that there are uncomfortable conditions on a gardening session.
- ChanceYieldAvailability: floating point >= 0, <= 1. Indicates the probability that yield is available on a gardening session.
- ChanceYieldStolen: floating point >= 0, <= 1. Indicates the probability that yield gets stolen.
- ChanceYieldStolenWhenBoundaries: floating point >= 0, <= 1. Indicates the probability that yield gets stolen when it is available, when there are boundaries around the garden.
- ChanceYieldStolenWhenNoBoundaries: floating point >= 0, <= 1. Indicates the probability that yield gets stolen when it is available, when there are no boundaries around the garden.
- ChoosingYield?: boolean. Indicates whether a volunteer can take yield itself or gets assigned a fair share of yield.
- CollectiveActionFailed: integer >= 0, <= 600. Indicates the tick during which collective action collapsed.
- CollectiveActionFailed?: boolean. Indicates whether collective action failed or not.
- Contactrate: integer >= 1, <= 3. Represents the amount of people a volunteer contacts to join gardening when it is time for the volunteer to reach out. (Chalise, 2015)
- ContributingTreshold: floating point >= 1, <= 6. Represents the threshold above which the intention formula should be for the potential volunteer to become a volunteer and join gardening.
- died: integer <= 0. Representing the amount of agents that left due to external reasons.
- DPconflictharm: floating point >= 0, <= 100. Representing the harm of a conflict as the amount of ‘bad encounters’ it equals.
- DPfee: floating point >= 0, <= 0.9. Representing the height of the fee for receiving yield.
- DPglobalprobabilityruleviolation: floating point >= 0.01, <= 0.9. Representing the initial probability a new volunteer has to violate a rule.
- DPgraduatedsanctions: boolean. Indicating whether there are graduated sanctions or not.

- DPMaxTakingMoreThanShare: integer >= 1, <= 5. Indicating the maximum amount of yield a volunteer can choose to take more than their fair share.
- DPplotboundaries: boolean. Indicating whether there are plot boundaries or not.
- DPprobabilitysanctioning: floating point >= 0.01, <= 0.9. Indicating the probability that a volunteer violating a rule is sanctioned.
- DropOutAYear: floating point >= 0, <= 1. Indicating the rate of the community dropping out each year due to external reasons. 0 is none, 1 is all.
- GardenAge: integer >= 1. Indicating the age of the garden to simulate (in gardening sessions) and the amount of ticks after which the simulation can stop.
- Generalrange: List [0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9]. Indicating the range with which some probabilities can be executed.
- GlobalAmountOfVisits: integer >= 0. Indicating the total amount of visits volunteers brought to the garden.
- Highrange: List [0.5 0.6 0.7 0.8 0.9 1]. Indicating the range from which volunteers with a high motivation can take their value for that motivation.
- InitiatorCommittedTime: integer >=16, <= 104. Indicating the amount of time initiators commit.
- Initiators: integer >= 1. Indicating the amount of initiators the garden started with.
- Interactionrate: integer >= 1, <= 6. Indicating the amount of other volunteers an individual potentially forms a relationship with during a gardening session. (Chalise, 2015)
- Lowrange: List [0 0.1 0.2 0.3 0.4 0.5]. Indicating the range from which volunteers with a low motivation can take their value for that motivation.
- MaxAmountOfTasks: integer >= 1. Representing the amount of maximum tasks that can be done on the garden.
- MaxAmountOfTellingOff: floating point >= 10, <= 40. Representing the maximum amount a volunteer can get told off before being suspended.
- MaxAmountTellingOffAfterSuspension: floating point >= 2, <= 10. Representing the maximum amount a volunteer is told off after being suspended, before having denied access to the garden permanently.
- MaxEducationdecay: floating point >= 0, <= 0.1. Indicating the maximum value for education decay an individual can have.
- Membershipduration: floating point >= 26, <= 104. Indicating the amount of gardening sessions a membership lasts.
- MinAmountOfTellingOff: floating point >= 2, <= 10. Indicating the minimum amount of times a volunteer is told off before being suspended.
- NoAccessSessions: floating point >= 5, <= 20. Indicating the amount of sessions an agent can not join gardening when suspended.
- ProbabilityConflict: integer >= 1. Indicating the amount of conflicts during a model run.
- RandomSeed: integer >= 0. Representing the current seed for random numbers used in a model run.
- Relationrate: floating point >= 0.15, <= 0.45. Indicating the probability for an individual to form a relation with the volunteer interacting with. (Chalise, 2015)
- teststop: boolean. Variable used to stop the run during verification when a value appears.
- TimeAlone: integer <= 1. Indicates the amount of sessions in a row that a volunteer has been maintaining the garden alone.
- TimeAloneWithoutCAfail: 1. Indicates the amount of sessions a volunteer can be maintaining the garden alone before collective action is called ‘collapsed’
- TotalBeliefCohesionAllTicks: floating point >= 0. Indicating the total belief of cohesion among all ticks among all volunteers.
- TotalBeliefCohesionAllTicks/GlobalAmountOfVisits: floating point >= 0, <= 1. Indicating the average belief for cohesion among all ticks among all volunteers.
- TotalBeliefCohesionThisTick floating point >= 0. Indicating the total belief of cohesion among all volunteers in the current tick.

- TotalBeliefTooMuchWorkAllTicks: floating point >= 0. Indicating the total belief for too much work among all volunteers among all ticks.
- TotalBeliefTooMuchWorkAllTicks/GlobalAmountOfVisits: floating point >= 0, <= 1. Indicating the average belief for too much work among all volunteers among all ticks.
- TotalBeliefTooMuchWorkThisTick floating point >= 0. Indicating the total belief for too much work among all volunteers in the current tick.
- TotalBeliefYieldAllTicks: floating point >= 0. Indicating the total belief for too much work among all volunteers among all ticks.
- TotalBeliefYieldAllTicks/GlobalAmountOfVisits: floating point >= 0, <= 1. Indicating the average belief for yield among all volunteers among all ticks.
- TotalBeliefYieldThisTick: floating point >= 0, <= 1 Indicating the total belief for yield among all volunteers in the current tick.
- Totalpool: integer >= 1. Indicating the total amount of agents that can be grown.
- TotalRuleViolations: integer >= 0. Indicating the total amount of rule violations among all volunteers and all ticks.
- TotalRuleviolations/GlobalAmountOfVisits: floating point >= 0, <= 1. Indicating the average amount of rule violations among all ticks among all volunteers.
- TotalRuleViolationsCount: integer >= 0. Indicating the total amount of rule violations among all volunteers in the current tick.
- Totaltrust: floating point >= 0, <= 1. Indicating the total amount of trust among volunteers in the current tick.
- TotalTrust/Volunteer: floating point >= 0, <= 1. Indicating the average amount of trust among volunteers among ticks.
- Totaltrustoverruns: floating point >= 0. Indicating the total amount of trust among ticks.
- TotalViolatedAndSanctioned: integer >= 0. Indicating the total amount sanctions among ticks.
- TotalViolatedWithoutSanctioned: integer >= 0. Indicating the total amount of rule violations among ticks.
- VolunteersToFullySeeThisRound: integer >= 0, <= VolunteersToFullySee. Indicating the amount of other volunteers an individual can assess of whether they violated a rule, during contribution on a garden session, adapted to current group size.
- VolunteerToFullySee: integer >= 1. Indicating the amount of other volunteers an individual can assess of whether they violated a rule, during contribution on a gardening session.

7. Model formalisation

In this chapter, the model formalisation is described. This process consists of two tasks: the creation of a model narrative and the expression of this narrative in pseudo-code.

7.1 Model narrative

As we have seen in the system identification, the activities of agents we are interested in include making the decision to go to the garden, contributing to the garden, conflict, taking yield and evaluating the gardening. Figure 7.1 shows the main narrative of the model, this subchapter explains the narrative more elaborately.

The model run starts with the initialisation of characteristics. The first agents are grown and given their characteristics, and the environment is set accordingly to input parameters. The first agents are called 'initiators'. Regardless of their motivations, the initiators contribute a set amount of times on the garden.

When the model is set up and the amount of ticks has not reached its limit, the procedure with the activities of interest follows. Every tick, an agent first makes the decision to go to the garden or not. Based on this decision, which depends on the beliefs and values as discussed in chapter 6, the agent becomes a volunteer or a potential-volunteer. Depending on the design principle of group boundaries, an agent might need to make the choice to become a member or not. Additionally, agents that are suspended or are denied access permanently, can not become a volunteer. Potential-volunteers do not proceed in the activities of gardening and can decide to become a volunteer again in this procedure during the next tick. If the agent chose to be a volunteer, it continues to the gardening activities.

During the activity of contributing to the garden, volunteers either contribute in a way that is beneficial for the community, or violate a rule. When a volunteer violates a rule, it can be sanctioned. When the design principle of monitoring is active, the chance that a volunteer is sanctioned increases. When the design principle of graduated sanctions is not active, the only sanction available is telling off. When this design principle is active, after a set amounts of sanctions the agent gets suspended. Then, when it comes back and gets caught violates a rule again, it can be permanently denied access to being a volunteer. During this procedure of contributing to the garden, the amounts of rule violations and sanctions are counted.

A set amount of times, conflict happens. When conflict happens, the effect of this depends on the design principle of conflict-resolution mechanisms. When this design principle is implemented well and conflictharm is low, the conflict represents a low amount of bad encounters. When the design principle is implemented not so well and conflictharm is high, the conflict represents a high amount of bad encounters.

Whether the procedure of taking yield happens, depends on whether yield is available. Yield is available a set amount of ticks as indicated by the characteristics of the case study. When the design principle of spatial boundaries is not active, there is also a set chance that the yield gets stolen. All agents then find their yield taken by someone else. During the yield taking procedure, agents take an amount of yield. When agents take too much yield, a chance exists that another agents finds an unfair amount of yield or even nothing left in stock.

In the last procedure, volunteers evaluate their time on the garden and update their beliefs. Whether a belief is stable or unstable and when it increases or decreases, is described in chapter 6.

7.2 Pseudo-code

The pseudo-code can be found in appendix A.

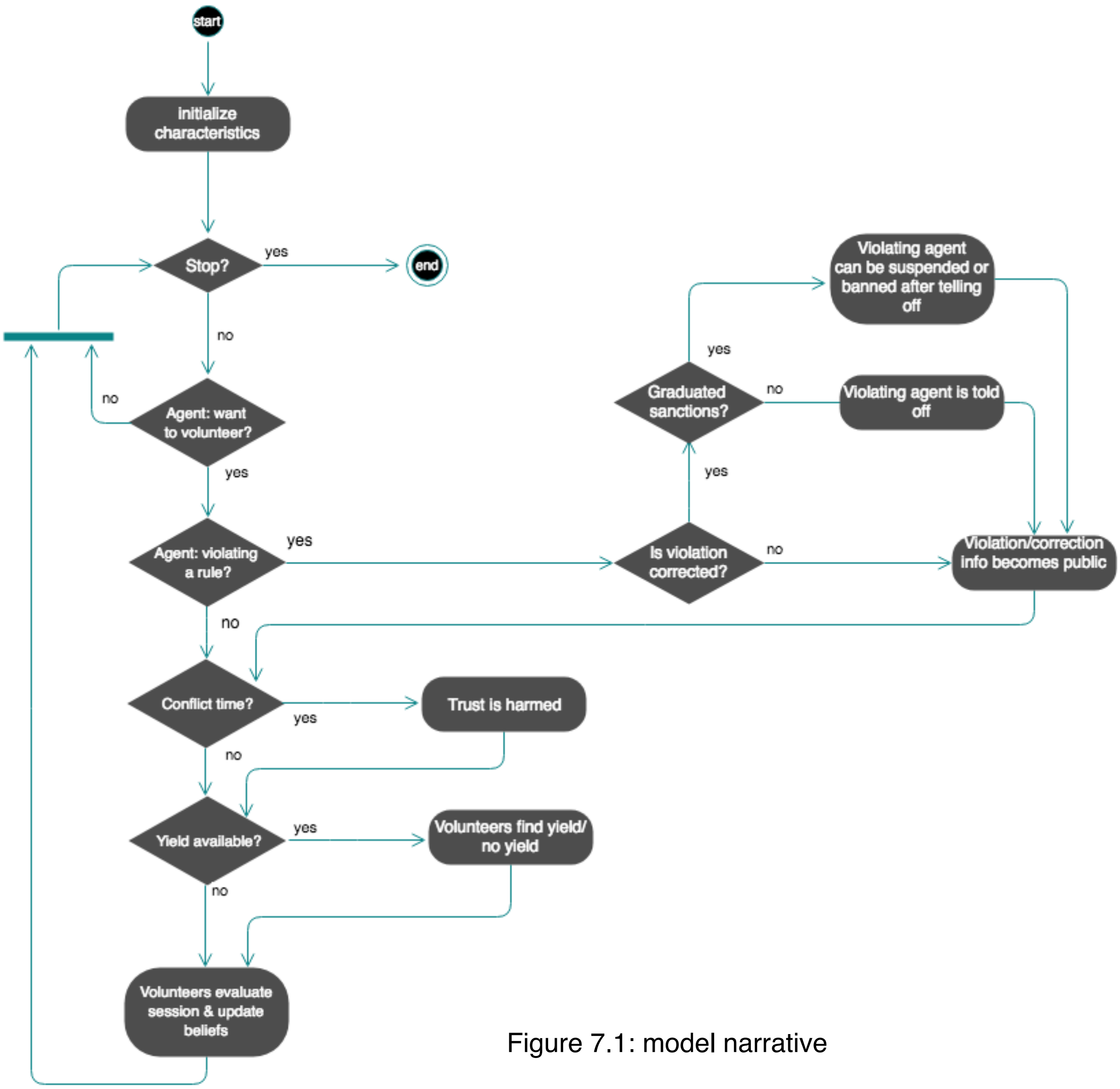


Figure 7.1: model narrative

8. Model verification

In this chapter, the model described in the previous chapter is verified. This means that tests are conducted in order to find out whether the model does what we want it to do.

According to van Dam et al. 2013, verification consists of four main parts: recording and tracking agent behaviour, single agent testing, interaction testing limited to minimal model and multi-agent testing.

1 .Recording and tracking agent behaviour

Recording and tracking agent behaviour can be done by recording and logging inputs, states and outputs of agents and internal processes (van Dam et al., 2013). To record the inputs and outputs, several 'print' procedures are added to the Netlogo model. The Netlogo model can be found in appendix B.

2. Single-agent testing

Additionally, we test the behaviour of single agents by formulating inputs which should lead to a certain output. There are two tests that can be done this way:

1) theoretical prediction and sanity checks: testing whether an agent behaves normally under normal conditions.
2) breaking the agent: testing how an agent behaves under extreme conditions.

Theoretical prediction and sanity: check whether an agent behaves normally under normal conditions

setBeingVolunteer

- *agent becomes volunteer when intention is above or on contributingThreshold.* ***Confirmed***
- *agent becomes potential-volunteer when intention is below contributingThreshold.* ***Confirmed***
- *when membership is active, the agent becomes prefers to become a member when the motivation to become a member is higher than the motivation to volunteer* ***Confirmed***
- *an agent only has a Membertimer value above 0 when it is a member*
  - ***Not confirmed:*** *non-members also had a positive Membertimer value. Fixed: start the Membertimer at 0.* ***Confirmed***
- *when graduated sanctions are active and an agent has NoAccess > 0, it is not allowed to volunteer and NoAccess is set NoAccess - 1.* ***Confirmed***

contributing

- *if a rule is violated, TotalRuleViolations and MyRuleViolationsThisRound increase 1.* ***Confirmed***
- *when the volunteer is sanctioned, AmountofSanctions, MySanctionsThisRound and TotalViolatedAndSanctioned increase with 1.* ***Confirmed***

conflict

- *there is conflict when the general range falls within the probability of conflict.* ***Confirmed***
- *when there is conflict, trust is harmed when the general range falls within the probability of conflict.* ***Confirmed***
- *when there is conflict, no trust is harmed when probability conflict harming trust is 0.*
  - ***Not confirmed****: when probability conflict harming trust was 0 and general range was 0 too, Evaluationconflict was set 0 (meaning the conflict harmed trust). "<=" in the formula had to be "<".* ***Confirmed***

TakingYield

- *when a random number from the general range is lower than the probability of yield being available, the yield taking procedure happens during that tick.* ***Confirmed***
- *when a volunteer finds an empty stock of yield, it remembers that its yield was taken.* ***Confirmed***

updateBeliefs
- *when there are no other volunteers, community reputation and probability of sanctioning and rule violation of a volunteer do not change.* ***Confirmed***
- *when there are no other volunteers on the garden, BeliefSocial of a volunteer decreases.* ***Confirmed***
- *when there are other volunteers on the garden, BeliefSocial of a volunteer increases.* ***Confirmed***
- *when a volunteer receives yield, BeliefFood of a volunteer increases.* ***Confirmed***
- *when a volunteer could have received yield but didn't, BeliefFood of a volunteer decreases.* ***Confirmed***

Break the agent: check how an agent behaves under abnormal conditions
setup-turtles/setup valueadaption
- *all agents have high values when the %highvalues are set 1* ***Confirmed***
- *no agents have high values when the %highvalues are set 0* ***Confirmed***

setBeingVolunteer
- *no agents become volunteers without being committed when the threshold is 10.* ***Not confirmed.*** *Fixed: Newbies set CommittedTime 0 when hatched ->* **Confirmed**
- *No potential volunteers exist when the threshold is 0 and graduated sanctions are not active.* **Confirmed**

updateBeliefs
- *total trust becomes 1 when DP global probability of rule violation is 0.01* ***Confirmed***

3. interaction testing in a minimal model: take 2 agents
setup-valueadaption
- *Values are adapted to the percentages asked for.* ***Confirmed***

addNewbies
- *Newbies adjust their values to the percentages asked for.* ***Confirmed***

contributing
- *agent can not get punished when there are no agents to punish him.*
  - ***Not confirmed,*** *'AND' condition is added to rule out punishing when there are no other agents ->* ***Confirmed***

TakingYield
- *agent finds an empty stock when other agents took all yield from the stock.* ***Confirmed***

updateBeliefs
- *when a volunteers sees someone violating but not being sanctioned, the probability of rule violation increases.* ***Confirmed***
- *the trust of an agent decreases when it sees rule violation.* ***Confirmed***

4. Multi-agent testing
For multi-agent testing we use variability testing. This means we explore variability of the output in different regions of the parameter space (van Dam et al., 2013). There are two results of this analysis: firstly, we will have insight in the sensitivity of the outcomes to estimated parameters, indicating the importance of these parameters for our outcome. Secondly, we can gain insight in the range of values for these parameters for which the outcomes are sensitive. We can use this information in the next chapter to define the parameter space in which the experiments will be done.

A common way to find the variability of output resulting from model parameters is a sensitivity analysis. This sensitivity analysis can be done in various ways. As it is very unlikely to get a complete picture of the model behaviour, the one-factor-at-a-time (OFAT) methodology is used to gain insight in the sensitivity of the model to uncertain parameters and define the parameter space in which the experiments will be conducted. OFAT is executed by setting a baseline of parameter values for all parameters, and varying each uncertain parameter individually across a wide range. (ten Broeke, van Voorn, & Ligtenberg, 2016)

Before we start testing the other parameters, we need to find the ContributingThreshold under which results emerge. The ContributingThreshold represents the threshold above which the intention formula of potential volunteers should be to become a volunteer, as was explained in section 6.2.1. Because this parameter is expected to have a very large effect on the outcomes and can not be estimated empirically, meaning we can not guess it like we can for the other parameters, it needs to be explored first. During the experiments for this sensitivity analysis the other parameters are set on their base value, and design principles estimated as not active and active. Table 8.1 shows the estimations for the values of the design principles, table 8.2 shows the estimations for the values of the uncertain parameters. Figure 8.1 shows the results for CollectiveActionFailed for several ContributingThreshold values. CollectiveActionFailed is our main output of interest, as it represents the robustness of collective action by marking the moment that only 1 person maintained the garden, as was explained in section 6.1.3. When the value for this CollectiveActionFailed is 600, the collective action did not fail at all in that particular experiment. Figure 8.1 shows that results for CollectiveActionFailed vary for all scenarios when the value for ContributingThreshold is 3,5 or 4. Therefore, we will use value 4 as a base in further variability tests, and use values between 3,5 and 4 in our experiments next chapter to retrieve results for all circumstances.

Table 8.1: DP initial behaviour space

Name	Not Active	Active
DPplotboundaries	Off	On
DPfee	0	5
DPMaxTakingMoreThanShare	2	1
DPglobalprobabilityruleviolation	0.61	0.31
DPconflictharm	70	30
DPprobabilitysanctioning	0.31	0.61
DPgraduatedsanctions	Off	On

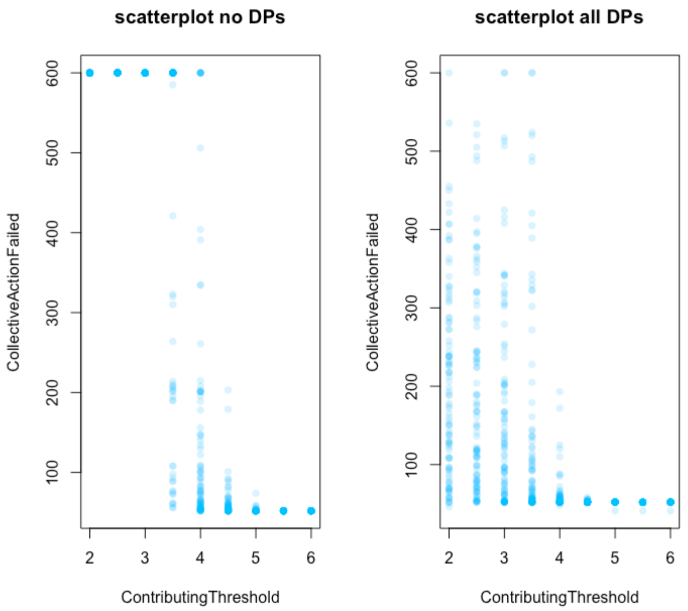


Figure 8.1: moment of CollectiveActionFailed for different ContributingThresholds

Table 8.2 shows the other estimated parameters with their ranges and their sensitivity. A few parameters were left out of the analysis: ProbabilityConflict, ContactRate, ChanceContactTriesGardening, MaxEducationdecay, Totalpool, DropOutAYear, Interactionrate, Relationrate and the distributions of motivations. These parameters directly influence a motivation or the presence of a volunteer without interplay of interaction, and therefore they are not expected to give us surprising results in the experiments. One could argue that their influence is in the increased or decreased group size, but about this can be learnt with the varying ContributingTreshold already. Finally, ChanceYieldStolenWhenNoBoundaries was left out as this would have the same effect as ChanceYieldStolenWhenBoundaries.

Furthermore, as it is interesting to know the importance of the precision on garden characteristics, the sensitivity of the model to interesting garden characteristics is tested as well (table 8.2, italics). However, as the experiments are based on our case study and therefore stay within the parameters indicated by the case study, they are not taken into account in the experiments

For each parameter, a base, a higher value and a lower value were tested for 100 repetitions. An exception is when the base variable is a maximum or minimum value, then two values above or below the base value were tested. Also in the case of BalanceAttitudeSocialNorm, more values were chosen to better learn the effect as it is expected to be influential. Table 8.2 shows values for the tested parameters, the Spearman correlations including Kruskal-Wallis p-values with CollectiveActionFailed. Spearman and Kruskal-Wallis were chosen as our independent variables are categorical and the dependent variable continuous and not normally distributed (we can state this without a test as we know all 'left over' successful values are 600).

Table 8.2: uncertain parameters

Name	Option A (base)	Option B	Option C	CollectiveAction Failed Sensitive? (No DPs)	CollectiveAction Failed Sensitive? (DPs)
ContributingTreshold	2	2.5, 3.5, 4, 4.5, 5, 5.5	6	-0.45***	-0.32***
NoAccessSessions	10	5	20	0.00	0.00
MaxAmountTellingOffAfterSuspension	5	2, 8	10	0.00	0.12
Membershipduration	52	26	104	0.00	0.00
MinAmountOfTellingOff	5	2	10	0.00	0.00
MaxAmountOfTellingOff	20	10	40	0.00	0.00
BalanceAttitudeSocialNorm	1	2, 3	4	0.15***	0.28***
ChanceYieldAvailability	*1*	*0.8*	*0.6*	*-0.03*	*0.03***
ChanceYieldStolenWhenBoundaries	*0*	*0.20*	*0.5*	*-0.01*	*-0.02***
VolunteersToFullySee	*3*	*1*	*6*	*0.09***	*0.06*
AmountOfTasks	*10*	*5*	*20*	*-0.05***	*-0.03*
Initiators	*10*	*5*	*20*	*0.14****	*0.12**
InitiatorCommittedTime	*52*	*104*	*26*	*0.20****	*0.33****

Italics: garden characteristic, *** $p < .001$, ** $p < .01$, * $p < .05$

First of all, we learn from table 8.2 that the fluctuations in NoAccesSessions, Membershipduration, MinAmountOfTellingOff and MaxAmountOfTellingOff do not have any impact on the end results in our tests. MaxAmountTellingOffAfterSuspension only has a very weak influence when design principles are active, but this correlation is not statistically significant. Only the values for the ContributingTreshold and BalanceAttitudeSocialNorm show significant impact, and allow us to specify their range for the experiments. For the ContributingTreshold we already did that. The scatterplot for BalanceAttitudeSocialNorm and MaxAmountTellingOffAfterSuspension (Figure 8.2 and 8.3) show that the output changes over all values of these parameters. Therefore we have to take into account the whole range in our experiments. This will also be done for the parameters that did not show to have an impact and for which we therefore were not able to specify a range either. The independent variables in table 10.1 show the ranges of parameters as they are in the experiments.

Regarding garden characteristics, the very weak impacts of ChanceYieldStolenWhenBoundaries and ChanceYieldAvailability were only found significant when design principles are active, while the very weak impacts of VolunteersToFullySee and AmountOfTasks only are significant when no design principles were active. The amount of Initiators and InitiatorCommittedTime had respectively very weak and weak impact in both scenarios.

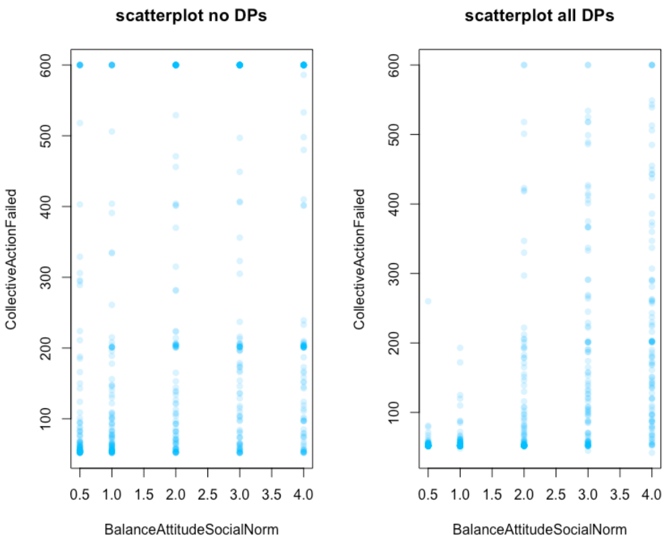


Figure 8.2: moment of CollectiveActionFailed for range BalanceAttitudeSocialNorm

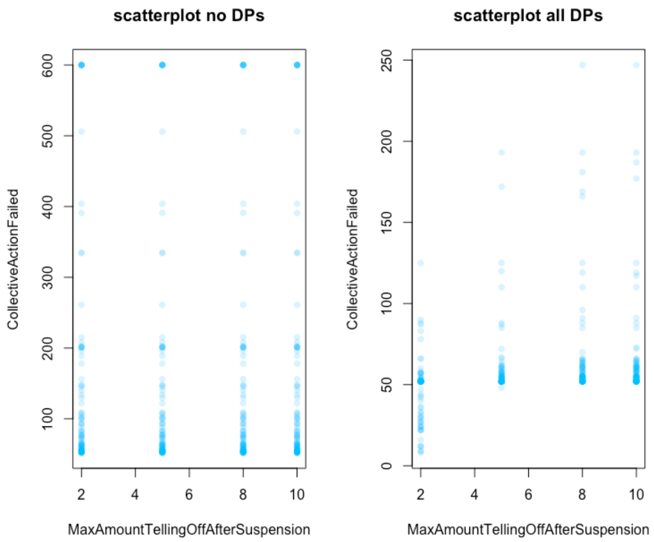


Figure 8.3: moment of CollectiveActionFailed for range MaxAmountTellingOffAfterSuspension

III

Model Simulation

9. Experimentation

In this chapter, we describe the experiments conducted with the model we described in the previous sections. This means we will describe characteristics of the experiments: the scenarios chosen, the time and the experiment setup including parameter space, amount of repetitions and randomseed.

9.1 Scenarios

The model as described so far, has many parameters that vary among gardens. In order provide context, we use Gandhi tuin as a case study. The data was collected by means of interviews, which is described in section 5.3. The information resulted in the case-specific formalisation of the model as described in table 9.1.

9.2 Time

The time the model runs is based on Gandhi Tuin, which was 6 years old when it collapsed. Therefore, as the gardeners of Gandhi Tuin will understand this time range, 6 years was also used for our model. Gandhi tuin had 2 gardening sessions a week. Excluding a 2-week christmas break, this results in 100 gardening sessions a year and thus 600 in six years. Therefore, unless they collapse earlier, our experiments run 600 ticks.

9.3 Experiment setup

9.3.1 Parameter space

van Dam et al. mention 4 ways to conduct experiments across a parameter space: full factorial, random parameter, Latin Hypercube Sampling (LHS) and Monte Carlo. Because we have many parameters, a full factorial approach testing all possible combinations among parameters is not feasible. The method of random parameter is only recommended for preliminary experiments or experiment with few wide ranging parameters. Monte Carlo generates random points for each parameter separately. LHS adds the advantage to Monte Carlo that it can find where in the parameter space we should perform a predetermined number of experiments. This allows to get the most representative subset of the space, and a more evenly spread of sample points. (van Dam et al., 2013) Therefore we choose to use LHS. Within this method we choose the optimum LHS package because it spreads the values as broadly as possible, which is beneficial as we have no indication where our uncertain parameters lie in reality.

9.3.2 Amount of repetitions and randomseed

Additionally, we have to choose an amount of repetitions and a random seed. Regarding repetitions, an important rule in agent based experiments is to ‘never trust the outcome of a single run of an agent-based model’. Every single run could be an unrepresentative outlier, and therefore a standard is to do 100 repetitions per experiment. This amount of repetitions is implemented in the Netlogo behaviourspace by varying a randomseed, so that each experiment can be reproduced.

Table 9.1: Characteristics of case studies

Parameter	Gandhi tuin	Vredestuin
ChanceYieldAvailability	1	1
ChanceYieldStolenWhenNoPlotBoundaries	0.1	0
ChanceYieldStolenWhenPlotBoundaries	0	0
VolunteersToFullySee	3	3
ChanceUncomfortableConditions	0.25	0.25
AmountOfTasks	10	10
MaxAmountOfTasks	1000	1000
DropOutAYear	0.1	0.1
Totalpool	1000	1000
Initiators	10	10
%HighCohesionValue	0.9	0.9
%HighSocialValue	0.3	0.2
%HighYieldValue	0.6	0.6
%HighEducationValue	0.5	0.5
%HighEnjoyingGardenValue	0.8	0.8
%HighEnvSustainabilityValue	0.6	0.6
%HighLandavailabilityValue	0.3	0.3
%HighConditionsValue	0.6	0.6
%HighTooMuchWorkValue	0.2	0.2

10. Data analysis

In this chapter, we analyse the data that resulted from the experiments described in the previous chapter. We analyse the influence of the design principles on the robustness of collective action and additionally the influence of independent variables on the motivations of trust, cohesion, belief for yield and belief for too much work. These motivations are interesting because they can change as a result of the design principles.

Table 10.1 provides an overview of the names of independent variables and dependent variables in the experiments, and shows the origin of the values for these variables. To analyse the way in which the dependent variables are influenced by independent variables, we use correlation tables and decision trees. The correlation tables show the correlation of the individual design principles with an output. Because our independent and dependent variables are measured both categorical and continuous, we need to use different statistical tests for the correlation tables. As the data is not normally distributed, correlations are calculated following the Spearmans method and p-values are calculated following the Kruskal-Wallis method. Figure 10.1 shows the data is not normally distributed. When data is normally distributed, the line in the Q-Q plot should be a straight line.

Table 10.1: independent and dependent variables

Variable	Dependent/ independent	Value origin
CollectiveActionFailed	dependent	first moment there is 1 or no volunteer on the garden
Trust	dependent	sum of volunteers' trust after every tick / total visits. Trust is defined as good encounters / total encounters.
Cohesion	dependent	sum of volunteers' cohesion belief after every tick / total visits. Cohesion is defined by the rate of volunteers in the group with which an individual has a tie.
Yield	dependent	sum of volunteers' yield belief after every tick / total visits. Yield is evaluated positively if the wished amount of yield is received.
Too much work	dependent	sum of volunteers' belief for too much work after every tick / total visits. Too much work evaluated positively if the amount of volunteers is lower than the amount of tasks.
DPfee	independent	LHS: >= 0, <= 0.9
DPMaxTakingMoreThanShare	independent	LHS: >= 1, <= 5
DPglobalprobabilityruleviolation	independent	LHS: >= 0.01, <= 0.9
DPconflictharm	independent	LHS: >= 0, <= 100
DPprobabilitysanctioning	independent	LHS: >= 0.01, <= 0.9
DPgraduatedsanctions	independent	LHS: true / false
DPplotboundaries	independent	LHS: true / false
NoAccessSessions	independent	LHS: >= 5, <= 20
MaxAmountTellingOffAfterSuspension	independent	LHS: >= 2, <= 8
Membershipduration	independent	LHS: >= 26, <= 104
MinAmountOfTellingOff	independent	LHS: >= 2, <= 10
MaxAmountOfTellingOff	independent	LHS: >= 10, <= 40
BalanceAttitudeSocialNorm	independent	LHS: >= 0.5, <= 4
ContributingThreshold	independent	LHS: : >= 3.5, <= 4

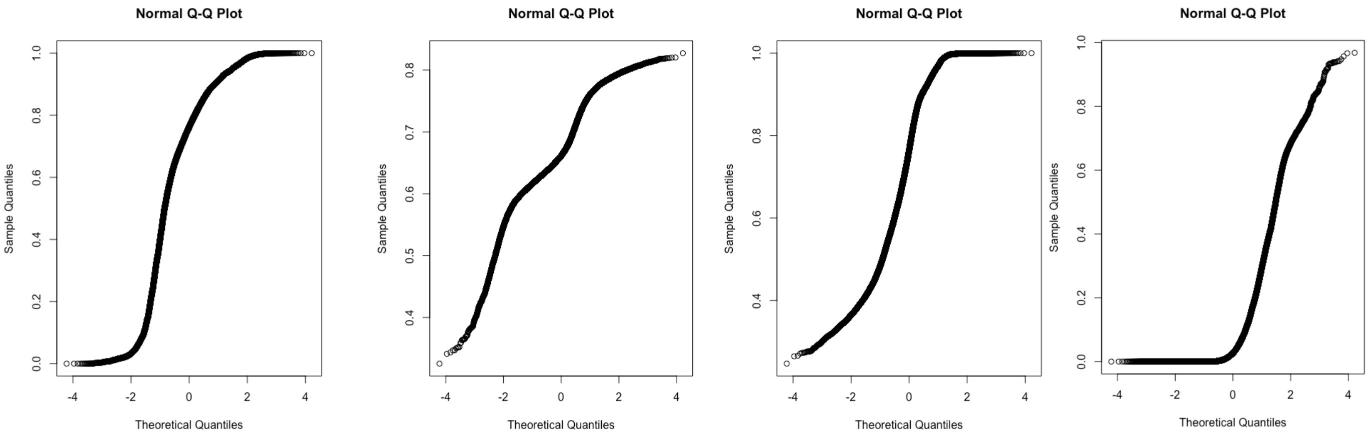


Figure 10.1: left to right Q-Q plots for the distributions of total amount of beliefs of trust, cohesion, yield and too much work

When we have learnt the general correlations in our model from the correlation tables, we can proceed to more detailed insights. When many agents act and react to each other, this is likely to cause non-linear emergent behaviour: a small change in conditions can lead to a large change in results. It is therefore likely that the our found influences of the design principles are not simply linear, and that combining them differently yields different results. A conditional inference tree is a useful way to solve and visualise how the design principles differ in impact when they are combined with each other various ways. The algorithm roughly works as follows: first, it tests the global null hypothesis of independence between any of the input variables and the response. When the hypothesis can not be rejected, the algorithm stops. Otherwise, the input variable with the strongest association to the response is selected. Then, the split is implemented in the selected input variable, after which the process repeats until the hypothesis can not be rejected anymore (Hothorn, n.d.). We use the ctree function of the R 'party' package. Because the trees tend to get very large, only predictions with a p-value < 0.01 were taken into account. Furthermore, continuous variables were divided in three parts categorised as 'low', 'med' and 'high' to ease comparing results. Making choices on the design principles results for the tree on CollectiveActionFailed in amounts of experiments that succeeded to sustain their collective action for 6 years for a scenario, compared to amounts of experiments in which collective action failed for that same scenario. The trees on other dependent variables show boxplots including all values resulting within a scenario.

Decision trees have the risk of overfitting, meaning that the model is made too specific for the dataset it was trained with. To test this, we split our dataset in two parts before making the tree. The first part functions as a training set, and the second as a testing set. With the training set, the tree is built. After this, the model is tested with the testing set. This test resulted in a p-value < 2.2 e-16 for all the trees discussed, which means that the accuracy of which the tree predicts the output of an experiment is significantly better than predicting the output based on chance resulting from the distribution of outputs.

10.1 The robustness of collective action

First, we look into our main dependent variable of interest: CollectiveActionFailed. Figure 10.2 shows how the values for this variable are distributed among the experiments. Four peaks appear in this graph. The first peak emerges because the initiators can leave the garden, resulting in a drop in volunteers which can cause the collective action to collapse. The next two peaks when CollectiveActionFailed is 200 and 400 appear because of conflict. The final peak at 600 is the amount of cases that did not collapse. As the most successful cases can not have a higher value than 600, we have categorised CollectiveActionFailed for further analysis into four ordinal categories: 0 - 199, 200 - 399, 400 - 599 and 600.

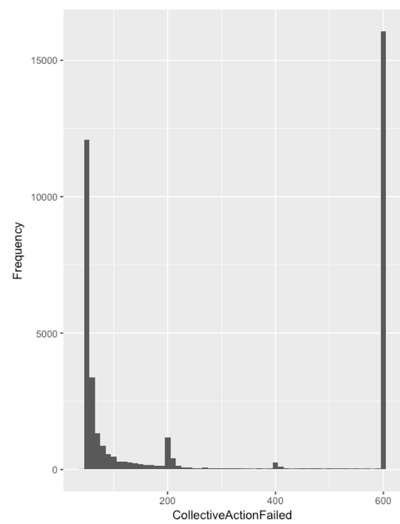


Figure 10.2: frequency of experiments for values of CollectiveActionFailed

Table 10.1 shows the correlations of the independent variables with CollectiveActionFailed. From this table, we can formulate several conclusions. Regarding the influences of design principles, DPprobabilitysanctioning is strongly positively correlated with a higher robustness of collective action. Furthermore, DPglobalprobabilityruleviolation has a weak negative correlation, and DPfee and DPMaxTakingMoreThanShare a very weak negative correlation with the success of collective action. Also DPgraduatedsanctions has a weak negative correlation. However, because DPgraduatedsanctions has a value of true or false, the direction of this correlation does not give us information. Figure 10.3 shows that DPgraduatedsanctions being false has a small negative effect.

Regarding the influences of other independent variables, the BalanceAttitudeSocialNorm has a weak positive correlation with the sustaining of collective action. Membershipduration and MaxAmountTellingOffAfterSuspension have a very weak positive correlation, and NoAccessSessions, MinAmountOfTelingOff, MaxAmountOfTellingOff and ContributingThreshold a very weak negative correlation.

Table 10.1: Correlations and p-values CollectiveActionFailed

Independent variable	Correlation
DPfee	-0.12***
DPMaxTakingMoreThanShare	-0.08***
DPglobalprobabilityruleviolation	-0.24***
DPconflictharm	0.00***
DPprobabilitysanctioning	0.60***
DPgraduatedsanctions	-0.02***
DPplotboundaries	0.01
NoAccessSessions	-0.03***
MaxAmountTellingOffAfterSuspension	0.03***
Membershipduration	0.03***
MinAmountOfTellingOff	-0.03***
MaxAmountOfTellingOff	-0.02***
BalanceAttitudeSocialNorm	0.35***
ContributingThreshold	-0.14***

*** p < .001, ** p < .01, * p < .05

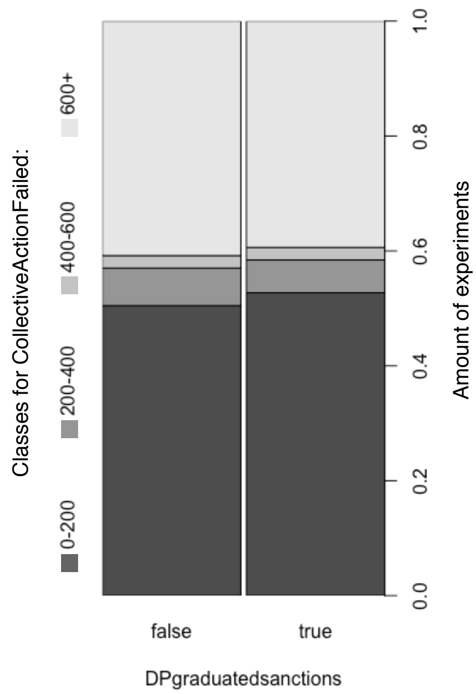


Figure 10.3: CollectiveActionFailed for DPgraduatedsanctions true/false

The complete decision tree in which design principles predict the robustness of collective action can be found in Appendix B. CollectiveActionFailed is in this tree divided in 2 categories, making comparison easier. The 'successful case' sustained for 6 years or more, the 'collapsed' case collapsed before that time. From the tree we can learn that the influences of design principles are not always the same. 6 combinations of design principles lead to exceptionally high chances on robust collective action, they are shown in table 10.2. For these scenarios, almost all experiments sustained collective action for 6 years. 5 combinations lead to an exceptionally low chance for robust collective action, they are shown in table 10.3. For these scenarios, almost all experiments failed to sustain their collective action for 6 years. No value for a design principle in the table means that this design principle could not predict a statistically significant enough distinction in this scenario. We can learn from the tables that we did not find an institutional 'silver bullet' for robust collective action. For most design principles, low, medium and high values can predict both a high chance for robust collective action and a high chance for fragile collective action. An exception is DPprobabilitysanctioning, for which a high value seems to allow a high chance for robust collective action. However, as figure 10.4 shows, a high value for DPprobabilitysanctioning does not exclude the risk for fragile collective action.

Table 10.2: scenario's predicting highest chance for robust collective action

	DPprobabiltiysanctioning	DPglobalprobabiltiyruleviolation	DPconflictharm	DPMaxTakingMoreThanShare	DPfee	DPgraduatedsanctions	DPplotboundaries
Scenario 1	high	med/ high	low	med	-	-	-
Scenario 2	high	high	med/ high	med	med	-	-
Scenario 3	high	low	low/ high	low/ high	low/ high	-	-
Scenario 4	high	med	low/ high	high	low/ high	-	-
Scenario 5	high	high	med/ high	low	med	-	-
Scenario 6	med	low	low/ med	med	low/ med	-	-

Table 10.3: scenario's predicting highest chances for fragile collective action

	DPprobabiltiysanctioning	DPglobalprobabiltiyruleviolation	DPconflictharm	DPMaxTakingMoreThanShare	DPfee	DPgraduatedsanctions	DPplotboundaries
Scenario 1	low	low	-	med	high	-	-
Scenario 2	low	high	med	-	low/ high	-	-
Scenario 3	med	high	low	low/ med	high	-	-
Scenario 4	med	med/ high	-	-	med/ high	-	-
Scenario 5	med	high	med/ high	-	low	-	-

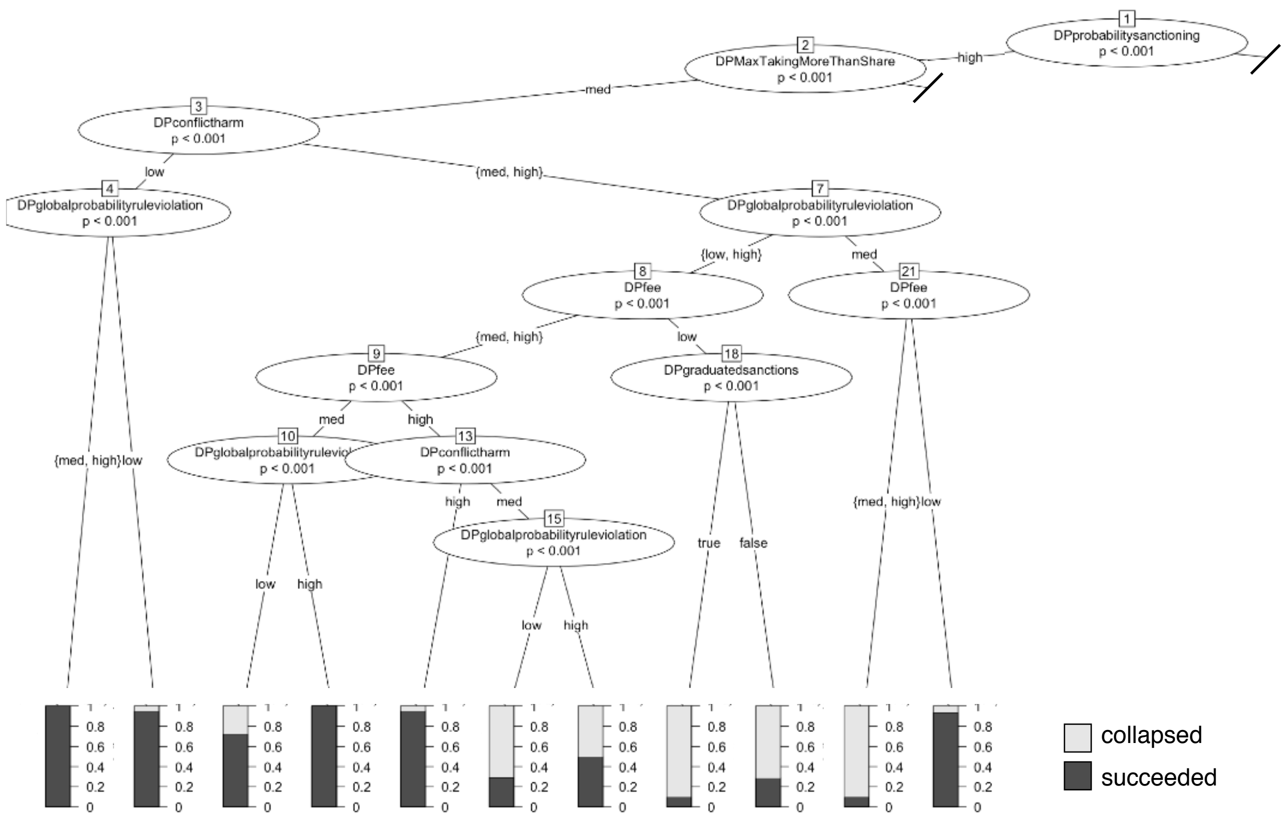


Figure 10.4: part of decision tree for CollectiveActionFailed

10.2 Correlations among output variables

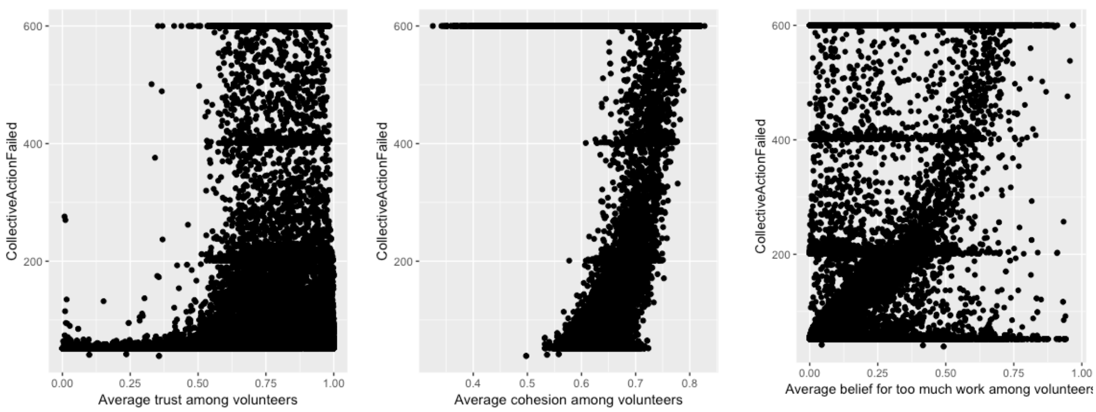
Table 10.4 shows the correlations among all output variables and their significance. We can conclude from this table that a high chance for sustained collective action is correlated positively strongly average belief for cohesion. This seems logical, as the belief for cohesion not only causes people to be motivated, but also is likely to be higher when collective action sustains because volunteers stay longer and keep their social ties. Furthermore, a higher value for CollectiveActionFailed is moderately positively correlated with average trust and average belief for yield. It is weakly negatively correlated with the belief for too much work. This indicates that collective action is a little more likely to sustain when there are enough volunteers to do all the tasks.

Trust shows also a weak positive correlation with with average beliefs for cohesion and yield. It is very weakly negatively correlated with the belief for too much work. The belief for yield is weakly positively correlated with trust and cohesion. It is weakly negatively correlated with the belief for too much work, indicating that a smaller group goes together with a smaller belief for yield. The only variable weakly positively correlated with the belief for too much work is the belief for cohesion. This makes sense, as in a large group it takes more time for a volunteer to build a high rate of relationships among group members. Figure 10.4 shows the scatterplots with CollectiveActionFailed for ranging motivation variables. We can conclude from these plots that collective action can sustain longer when trust is higher than 0.5, and that cohesion varies along all values when collective action sustains 6 years, but ranges between 0.5 and 0.8 when collective action does not sustain for 6 years.

Table 10.4: Correlations and significance among output variables

	Trust	Belief for cohesion	Belief for yield	Belief for too much work
CollectiveActionFailed	0.49***	0.60***	0.45**	-0.12***
Trust		0.25***	0.25***	-0.03***
Belief for cohesion			0.23*	0.18***
Belief for yield				-0.15***

*** p < .001, ** p < .01, * p < .05



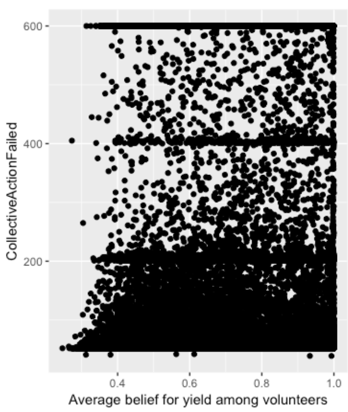


Figure 10.4: scatterplots CollectiveActionFailed for ranging trust, cohesion, belief for yield and belief for too much work

10.3 Trust

Figure 10.5 shows how the values for this average amount of trust among volunteers are distributed among the experiments. From table 10.5, we can formulate various conclusions regarding the influences of independent variables on trust. DPprobabilitysanctioning has a strong positive correlation with trust. This seems logical, as trust is harmed by volunteers violating rules without being sanctioned and DPprobabilitysanctioning directly reduces the probability for this to happen. DPglobalprobabilityruleviolation has a moderate negative correlation with trust. This is logical for a similar reason: this design principle increases the probability for a volunteer to violate a rule. DPfee and DPMaxTakingMoreThanShare show a very weak positive correlation. DPconflictharm shows a weak negative correlation. It is interesting that this correlation is only weak, as this design principle directly influences the trust of volunteers in case of conflict.

Regarding other independent variables, the BalanceAttitudeSocialNorm has the highest, but still a weak negative correlation value. This is interesting, as it indicates that trust is likely to be slightly lower when trust is a more important motivation to go gardening. Furthermore, MaxAmountTellingOffAfterSuspension, MinAmountOfTellingOff, MaxAmountOfTelingOff, Membershipduration and ContributingThreshold are all weakly positively correlated with trust, while NoAccessSessions is weakly negatively correlated. It is interesting that MinAmountOfTellingOff and MaxAmountOfTellingOff are positively correlated, as one would expect trust to be higher when these values are lower and violating agents can be excluded from the group earlier. It could be explained by the tendency for new volunteers to violate rules being higher than older volunteers. When older volunteers get excluded from the group, the chance for an individual to see a new volunteer violating a rule is higher.

Appendix B contains the decision tree for trust. We can learn from this tree that indeed most high values for trust emerge when DPprobabilitysanctioning is high, but just as high values for trust can emerge as well when DPprobabilitysanctioning is medium or low. A higher value for DPfee tends to lead to lower trust. However, when DPprobabilitysanctioning is high, higher values for DPfee are also observed to lead to higher trust. Also DPMaxTakingMoreThanShare and DPconflict have varying effects, and sometimes a medium value also has a different effect while low and high values result in the same.

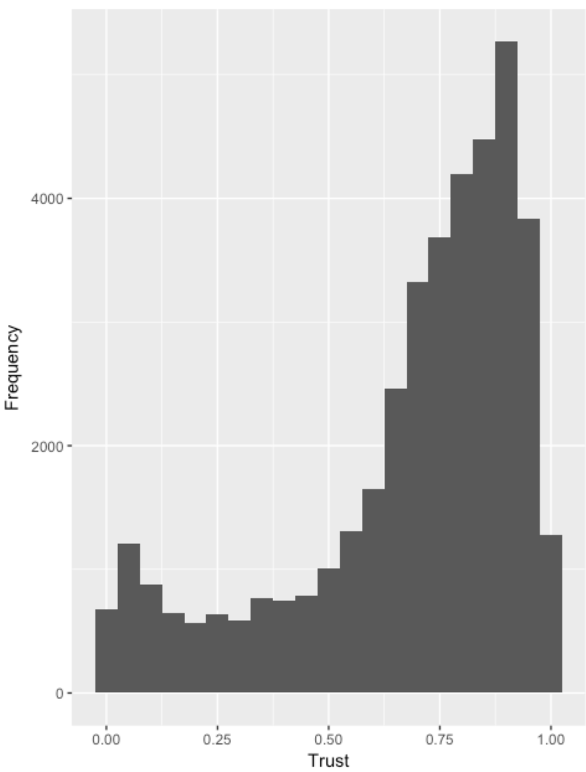


Figure 10.5: frequency of experiments for values of average trust among volunteers

Table 10.5: Correlations and p-values Trust

Independent variable	Correlation
DPfee	0.03***
DPMaxTakingMoreThanShare	0.04***
DPglobalprobabilityruleviolation	−0.43***
DPconflictharm	−0.03***
DPprobabilitysanctioning	0.71***
DPgraduatedsanctions	0.00
DPplotboundaries	−0.01
NoAccessSessions	−0.03***
MaxAmountTellingOffAfterSuspension	0.04***
Membershipduration	0.01***
MinAmountOfTellingOff	0.03***
MaxAmountOfTellingOff	0.03***
BalanceAttitudeSocialNorm	−0.16***
ContributingThreshold	0.11***

*** p < .001, ** p < .01, * p < .05

10.4 Cohesion

Figure 10.6 shows the distributions for average values of cohesion among volunteers. We can learn from table 10.6, that for this variable all correlations are weak. DPprobabilitysanctioning has the highest, but still weak positive impact. All other design principles have a weak negative correlation with cohesion. DPgraduatedsanctions shows a weak negative correlation, meaning when this design principle is not implemented cohesion is more likely to be higher (figure 10.7). This is logical as graduated sanctioning allows people to be suspended or denied access, and therefore social ties can be broken

Regarding other independent variables, the only weak positive correlation is with BalanceAttitudeSocialNorm. NoAccessSessions, MinAmountOfTellingOff, MaxAmountOfTellingOff and ContributingThreshold have a weak negative impact. The negative impact of MinAmountOfTellingOff and MaxAmountOfTellingOff is interesting, as this implies that faster excluding of people leads to a higher rate of cohesion.

Appendix B contains the decision tree related to cohesion. We can conclude from this tree that although DPprobabiltiysanctioning has most impact, both high, medium and low DPprobabilitysanctioning can lead to fairly high values for cohesion. DPfee, DPMaxTakingMoreThanShare, DPglobalprobabilityruleviolation and DPconflict have varying impacts. For DPfee sometimes low and high values have the same impact while medium differs. DPgraduatedsanctioning appears twice in the tree and it being true has a negative effect on cohesion. This is logical as graduated sanctioning allows people to be suspended or denied access, and therefore social ties can be broken.

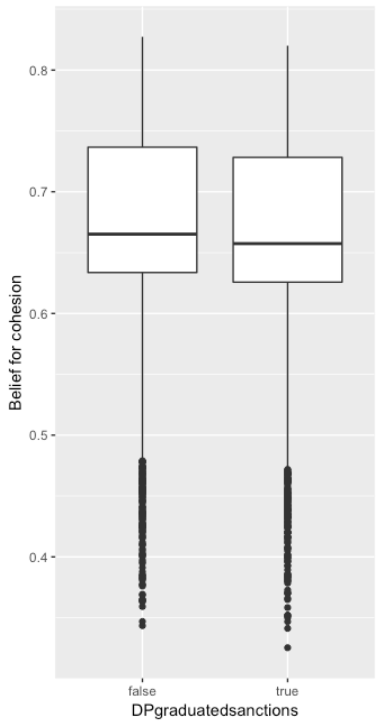


Figure 10.7: Cohesion for DPgraduatedsanctions true/false

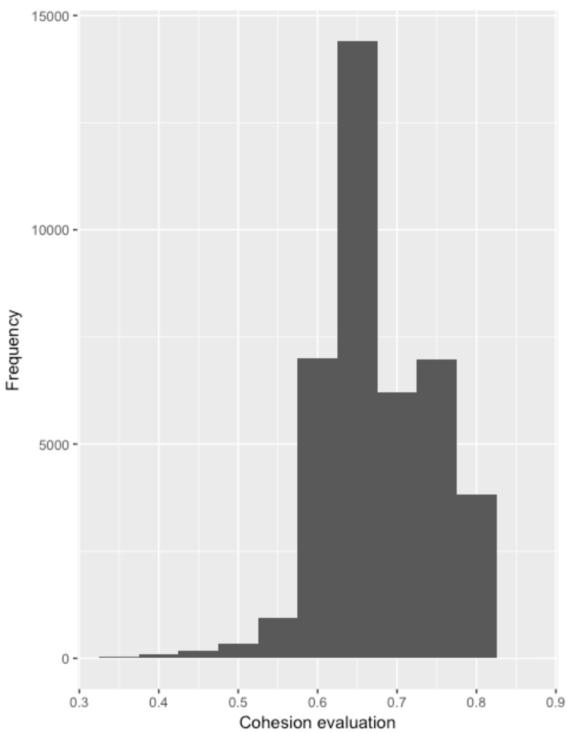


Figure 10.6: frequency of experiments for values of average cohesion among volunteers

Table 10.6: Correlations and p-values Cohesion

Independent variable	Correlation
DPfee	-0.12***
DPMaxTakingMoreThanShare	-0.12***
DPglobalprobabilityruleviolation	-0.04***
DPconflictharm	-0.01***
DPprobabilitysanctioning	0.34***
DPgraduatedsanctions	-0.07***
DPplotboundaries	0.01
NoAccessSessions	-0.04***
MaxAmountTellingOffAfterSuspension	0.00***
Membershipduration	0.00***
MinAmountOfTellingOff	-0.05***
MaxAmountOfTellingOff	-0.04***
BalanceAttitudeSocialNorm	0.08***
ContributingThreshold	-0.09***

*** p < .001, ** p < .01, * p < .05

10.5 Yield

Figure 10.8 shows the distribution of values for the average belief for yield among volunteers. From table 10.7 we can conclude the following. The strongest correlation is strongly negative for DPMaxTakingMoreThanShare, which makes sense as this makes people take the yield of others. Because of the same reason, the weak positive correlation with DPplotboundaries can also be explained; plot boundaries decrease the taking of yield by external people (figure 10.8). Furthermore, DPprobabilitysanctioning and DPfee are weakly positively correlated with the belief for yield. The positive impact of DPfee makes sense, as it limits the amount of people that can take yield and therefore the probability that someone takes too much is less. DPconflictharm and DPglobalprobabilityruleviolation are very weakly negatively correlated.

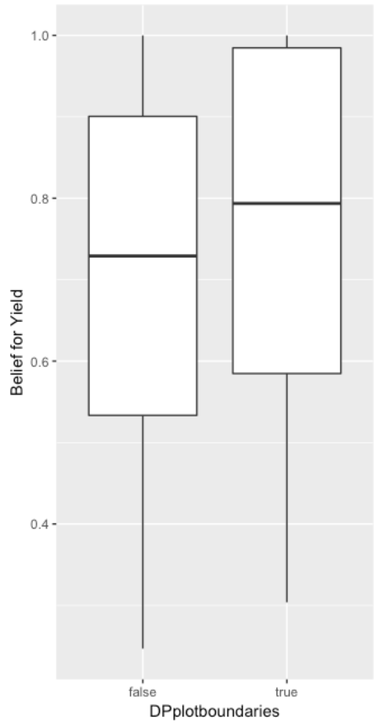


Figure 10.9: Belief for Yield for DPplotboundaries true/false

Regarding the other dependent variables, BalanceAttitudeSocialNorm has a the strongest but still weak positive correlation with the belief for yield. MaxAmountTellingOffAfterSuspension shows a very weak positive correlation and NoAccessSessions, MaxAmountTellinOff and ContributinThreshold show a very weak negative correlation.

Appendix B contains decision tree related to the belief for yield. DPMaxTakingMoreThanShare indeed is the strongest predictor, but both low, medium and high values can lead to high outcomes for yield belief. The impact of a higher DPfee is generally positive. The impact of DPplotboundaries is often very small, but in some cases shows a clearly positive effect. The impacts of DPglobalprobabilityruleviolation and DPconflictharm differ; they can be clearly positive or clearly negative. The most high values are found in the area where DPMaxTakingMoreThanShare is low and DPplotboundaries is true, which is logical as these two design principles secure a fair amount of yield. However, surprisingly high values for yield belief are also found when values for DPMaxTakingMoreThanShare, DPfee and DPprobabilitysanctioning are all high.

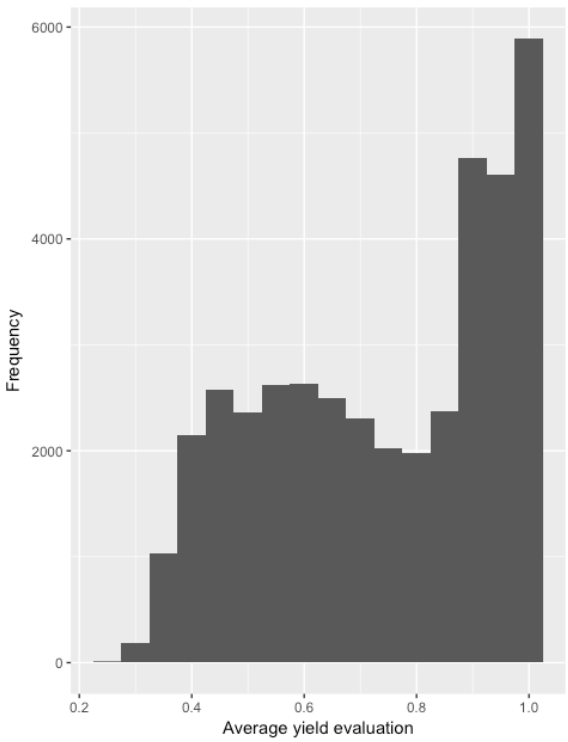


Figure 10.8: frequency of experiments for values of average belief for yield among volunteers

Table 10.7: Correlations and p-values Yield

Independent variable	Correlation
DPfee	0.19***
DPMaxTakingMoreThanShare	-0.76***
DPglobalprobabilityruleviolation	-0.14***
DPconflictharm	-0.02***
DPprobabilitysanctioning	0.25***
DPgraduatedsanctions	0.00
DPplotboundaries	0.20***
NoAccessSessions	-0.03***
MaxAmountTellingOffAfterSuspension	0.04***
Membershipduration	0.00***
MinAmountOfTellingOff	0.00***
MaxAmountOfTellingOff	-0.03***
BalanceAttitudeSocialNorm	0.22***
ContributingThreshold	-0.08***

*** p < .001, ** p < .01, * p < .05

10.6 Too much work

Figure 10.10 shows the distribution of values for the average belief of too much work among volunteers. Table 10.7 results in the following conclusions. The design principles have little influence on this output; DPglobalprobabilityruleviolation, DPconflictharm and DPgraduatedsanctions show a very weak positive correlation. The positive correlation for DPgraduatedsanctions means that DPgraduatedsanctions being true leads to higher values for too much work, as can be seen in figure 10.11. Furthermore DPfee and DPprobabilitysanctioning show a very weak negative correlation with the belief of too much work. Because the amount of tasks is a stable value, the small correlations indicate that the design principles do not influence the average group size strongly. As we know correlations with the sustaining of collective action are much larger, it indicates that collective action sustains because people don't mind the amount of work, rather than the group being larger.

Regarding the other independent variables, BalanceAttitudeSocialNorm shows the strongest, although still weak negative correlation. This indicates that the group size is likely to be larger when the social norm is important, which makes sense as the social norm drives people to go contribute when they do not necessarily feel like it. In this sense it is interesting that the ContributingThreshold does not have a strongly negative correlation, as it would be logical if a higher threshold to go gardening leads to a smaller group.

In Appendix B, the decision tree in which design principles predict the average value for too much work among volunteers can be found. We can learn that DPfee and DPconflictharm have varying impacts. For DPfee and DPconflictharm sometimes low and high values have the same impact while medium differs. There are two scenarios in which the belief for too much work is remarkably low, indicating a large group size:

1) When DPfee is low, DPconflictharm is low, DPglobalprobabilityruleviolation is low and DPprobabilitysanctioning is medium
2) When DPconflictharm is low, DPglobalprobabilityruleviolation is low or high, DPprobabilitysanctioning is high, DPfee is low or high and DPMaxTakingMoreThanShare is low or high.

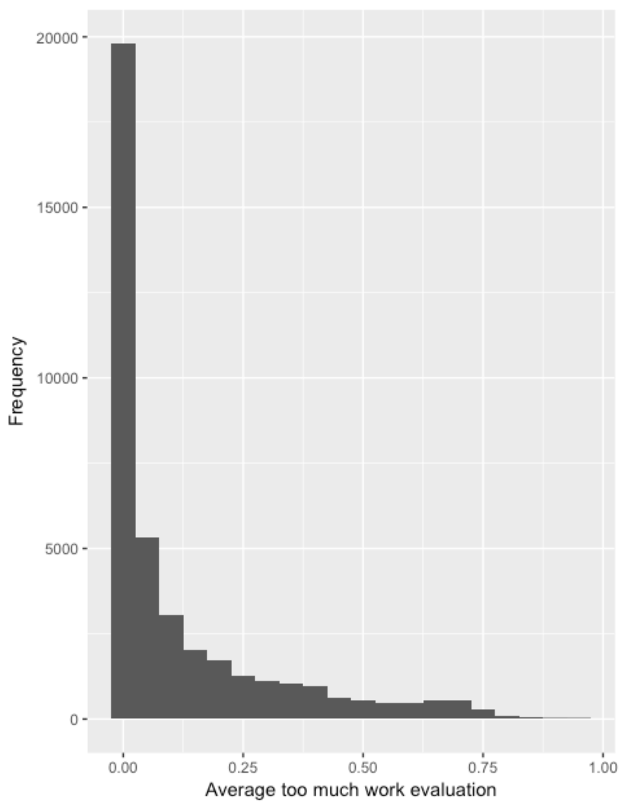


Figure 10.10: frequency of experiments for values of average belief for too much work among volunteers

Table 10.7: Correlations and p-values Too much work

Independent variable	Correlation
DPfee	−0.03***
DPMaxTakingMoreThanShare	0.00***
DPglobalprobabilityruleviolation	0.05***
DPconflictharm	0.04***
DPprobabilitysanctioning	−0.05***
DPgraduatedsanctions	0.09***
DPplotboundaries	−0.01
NoAccessSessions	−0.02***
MaxAmountTellingOffAfterSuspension	0.03***
Membershipduration	−0.04***
MinAmountOfTellingOff	−0.04***
MaxAmountOfTellingOff	−0.04***
BalanceAttitudeSocialNorm	−0.22***
ContributingThreshold	0.01***

*** p < .001, ** p < .01, * p < .05

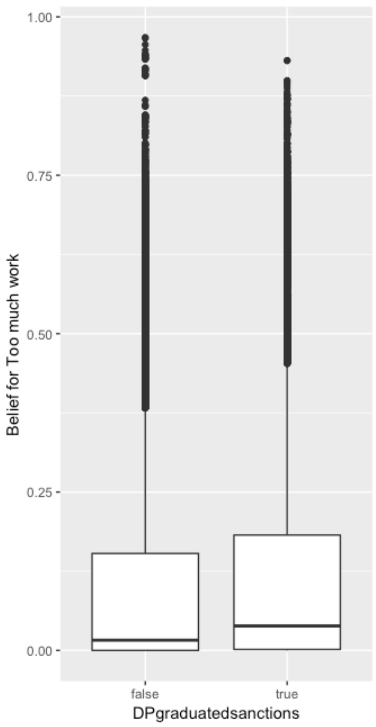


Figure 10.11: Belief for Too much work for DPgraduatedsanctions true/false

IV

Conclusions & Discussion

11. Model validation

Model validation is meant to check whether the model has become what we needed and answers our questions (van Dam et al., 2013). In this chapter, we discuss the validation done by historic replay and expert validation. For Historic we compare the outcomes of the model regarding robustness of collective action with the experiences from gardeners on Gandhi Tuin. Additionally to validating the model, this also offers the opportunity to assess the usefulness of the model for practical recommendations. Expert validation is done with the help of Nicole Rogge, she indicated whether she recognised the results we found from the gardens she studied.

11.1 Historic replay

Historic replay can be done by translating real-life scenario characteristics to the model and evaluate whether the emergent properties of the experiments are also recognised in the real situation. When this evaluation is negative, we have to conclude that we miss something in our model. When this evaluation is positive, we can have increased confidence in the model. (van Dam et al., 2013)

The historic replay was anticipated in the experiments by using the characteristics of Gandhi tuin as input for the model. A leader on the garden provided the information on design principles to find the place of this garden in the decision tree. The paths are shown in figure 11.1. As described in section 5.3, it was concluded that Gandhi tuin had a medium probability of sanctioning because of a lack in guidance on the garden, and started with a low probability of rule violation. There was no fee and there were no clear appropriation rights so sometimes people took too much yield. In general people didn't take too much yield, but exceptionally some people showed up late only to take a lot of yield (including that of others) at the end of the gardening session. DPMaxTakingMoreThanShare is therefore medium. We can see that these characteristics result in a very good chance for collective action to sustain when conflict harm is low or medium, the tree shows that in this scenario all experiments resulted in sustained collective action. However, when conflict harm is high, the tree shows that only half of the experiments sustained their collective action. The gardener that was interviewed, recognised this vulnerability. In the real-life case of Gandhi tuin, indeed the collective action collapsed because of an escalated conflict. Although the garden had conflict-resolution mechanisms, they failed to protect trust from the conflicts harm.

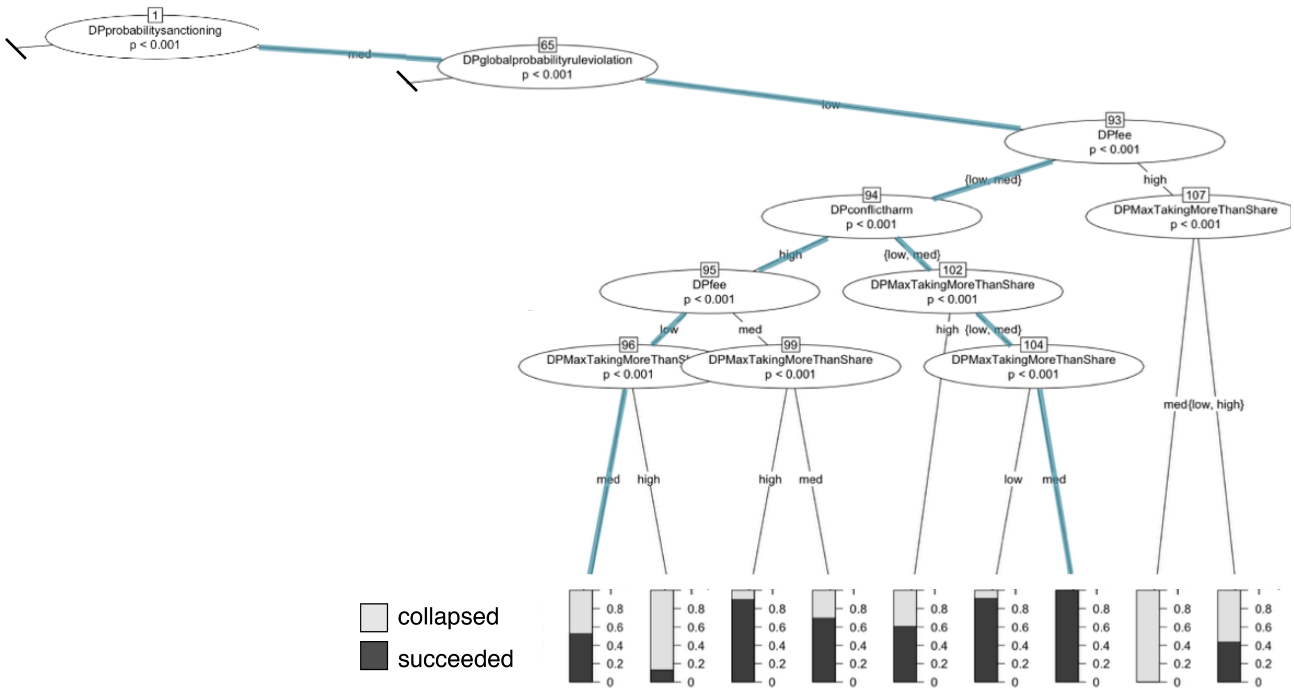


Figure 11.1: part of decision tree for CollectiveActionFailed
blue line = scenario Gandhi Tuin

Additionally to the Gandhi tuin, we had the opportunity to evaluate the model with Vredestuin. This garden was set up more recently by the same initiators that set up Gandhi tuin. The Vredestuin is very similar to the Gandhi tuin with regards to the input of the model, and therefore the decision tree can be applied to this garden as well. When we apply the institutions of Vredestuin in the model, we start in a different way. As the initiators learnt from Gandhi tuin that peoples behaviour can harm trust when monitoring and correction happens little, they try to guide more strictly on Vredestuin. DPprobabilitysanctioning is high, DPMaxTakingMoreThanShare is medium, DPglobalprobilityruleviolation is low, there is no fee and conflict was said to be unlikely to harm as well. We can see in figure 11.2 that this results in a very high chance for collective action to sustain, and the garden expert agreed that he felt very sure about this group of people. However, when we assume DPconflictharm medium or high for this scenario, this also results in a high risk for collective action to collapse. Apparently this scenario is also very dependent on high trust among volunteers so that conflict remains a threat for the Vredestuin. As we can see in figure 11.3, the already present high probability of sanctioning and a low (including none) or high fee would, in combination with making sure that people do not take too much yield, would bring the garden in an area of the decision tree where conflict has less impact. This seems logical, as a guaranteed fair distribution of yield could make the intention of volunteers to join gardening less dependent on trust as the belief for yield is also high.

Furthermore, the Gandhi tuin leader had an interesting explanation for the fluctuating effect of a high fee. In the trees we have seen that a higher value for trust sometimes leads to a higher probability of sustained collective action, and sometimes to a lower probability for sustained collective action. This was described in chapter 10.1, but also can be seen when comparing figure 11.1 (node 95) and 11.2 (node 21). When trust is low in a scenario, people need another strong motivation to join the gardening: this can be yield, which is more secure when there are less people taking it due to the membership fee. However, in scenarios where trust is higher, the fee is likely to have a negative impact because it takes away the motivation of yield from many others.

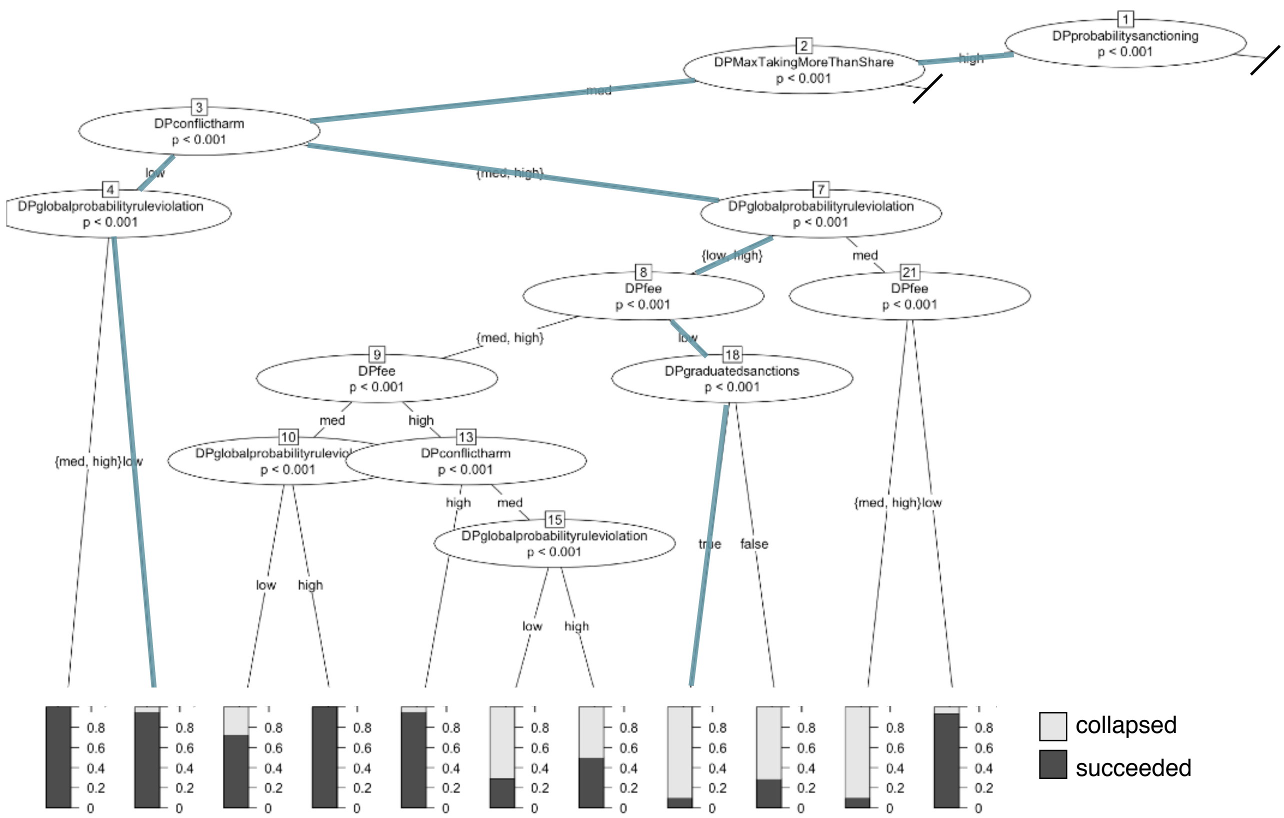


Figure 11.2: part of decision tree for CollectiveActionFailed
blue line = scenario Vredestuin

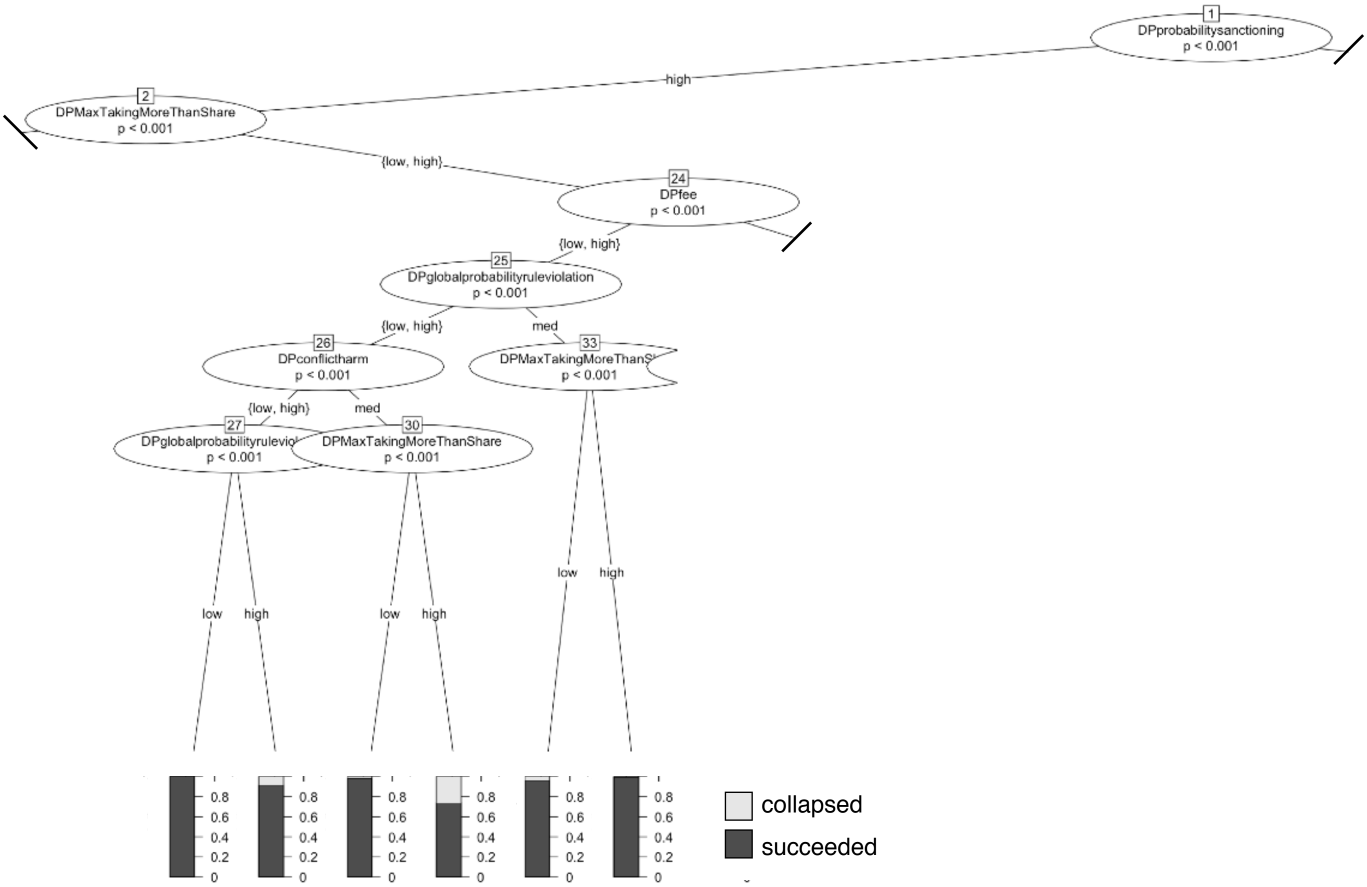


Figure 11.3: part of decision tree for CollectiveActionFailed

11.2 Expert validation

This section discusses whether academic expert Nicole Rogge recognised the results of the model from her knowledge on case studies. The information was collected with the use of a structured interview. Below, statements and reactions are listed. Remarkable findings are reflected upon by the author in blue.

11.2.1 effect of design principles on the robustness of collective action

- DPprobabilitysanctioning shows a strong positive correlation: **recognised**
    - The positive effect of sanctioning is not a surprise, but the extent to which it correlates is. Results from case studies across gardens show that sanctioning happens on less than 50% of the gardens, probably because socialising is the main aim of the volunteers. However, as sanctioning includes ‘correcting mistakes’ as well, the correlation seems not too unlikely.
    - Although sanctioning might not happen formally, it might happen informally by for instance gossip too on the gardens that seem not to have sanctions. This would count as a (perhaps weaker form of) ’sanction’ in the model as well, as it gives off the signal that a behaviour is not appropriate to both violator and the group

- DPglobalprobabilityruleviolation shows a weak negative correlation: **recognised**

- Other design principles, DPgraduatedsanctions, DPconflictharm, DPMaxTakingMoreThanFood, DPfee and DPplotboundaries only very weak correlations: **recognised**

- A specific combination of design principles can reverse the effect of a single design principle. Their eventual effect therefore depends not he total package of principles: **recognised**

11.2.2 effect of design principles on trust

- DPprobabilitysanctioning has a strong positive correlation with trust: **not recognised**
    - Wouldn't trust be higher if no sanctioning is necessary because every one complies to the rules?
    - Such a scenario of everyone complying to the rules 'themselves without help' was not modelled, we assumed people always make mistakes/violate rules and that this probability can be diminished by correction and sanctioning.

- DPprobabilityruleviolation shows a moderate negative correlation with trust: **recognised**

- Other design principles, DPgraduatedsanctions, DPconflictharm, DPMaxTakingMoreThanFood, DPfee and DPplotboundaries only very weak correlations: **recognised**

11.2.3 effect of design principles on cohesion

- Only very weak correlations were found for all design principles: **recognised**

- The highest (positive) correlation was found with DPprobabilitysanctioning: **surprised**
    - A higher correlation with DPglobalprobabilityruleviolation was expected.
    - This surprise can be explained by the way in which DPglobalprobabiltiyruleviolation and DPprobabilitysanctioning were implemented in the model. DPprobabilitysanctioning (influencing probability of rule violation throughout all times a volunteer visits the garden) leads to a lower amount of rule violation than DPglobalprobabilityruleviolation (influencing probability of rule violation only when a volunteer is new).

11.2.4 effect of design principles on belief for yield availability

- A strong negative correlation was found with DPMaxTakingMoreThanShare can take: **doubt**
    - Rogges did not experience set expectations for yield, as yield is not a important part of the motivation of gardeners she spoke with.

- A weak positive correlation was found with DPplotboundaries: **recognised**

- A weak positive correlation was found with DPfee: **recognised**

- A weak positive correlation was found with DPprobabilitysanctioning: **recognised**

- Only very weak correlations were found with DPgraduatedsanctions, DPconflictharm and DPprobabilityruleviolation: **recognised**

11.2.5 effect of design principles on belief for too much work

- Only very weak correlations were found for all design principles: **recognised**
    - May confirm Rogges thoughts on group size and its weak effect on collective action

- There are two scenario's in which the belief for too much work is exceptionally low, indicating a large group size. 1) When the fee for taking is low or none, conflict harm is low, the global probability of rule violation is low and the probability of sanctioning is medium, and 2) when conflict harm is low, global probability of rule violation is low or high, then probability of sanctioning is high, when the fee for taking is low, none or high and the amount people can take too much yield is low or high: **recognised**

12. Conclusions

In this chapter, the conclusions are described. We start with the main conclusions: the answers on our research questions. Then, a discussion including limitations of the research follows. We end with a reflection on the choices made in this research and recommendations for further research.

12.1 Conclusions

The answers on our subquestions provide the information used to answer the main questions. We will therefore first discuss the results regarding the subquestion, and then discuss the insights gained regarding the main question.

12.1.1 What theories do we need to model the relationship between design principles and collective action?

Chapter 4 contains the discussion on theory. Firstly, we clearly needed the theory on design principles. This theory provides 8 underlying principles of robust CPR governance systems: clearly defined boundaries, proportional equivalence between benefits and costs, collective-choice arrangements, monitoring, graduated sanctions, conflict-resolution mechanisms, minimal recognition of rights to organise and nestled enterprises. Because nestled enterprises are only relevant for groups within larger social systems, this design principle was not taken into account in this research. Minimal recognition of rights to organise were not taken into account due to a lack of data.

Additionally to the design principles, we needed a framework to guide our search for information and to help structuring that information, and therefore a variety frameworks including individual decision making and institutions was discussed. The Institutional Analysis and Development (IAD) framework was chosen as a basis to address our main research question. The IAD framework is suitable as it focuses on institutions and decision making, and includes interaction between agents and learning of agents. This aligns with our understanding of collective action, for which individuals make the choice to contribute on the garden voluntarily, which means they can adapt their preferences depending on their experiences on the garden. Within the IAD framework, the decision making of agents leading to their behaviour is central. Therefore, we needed a theory to understand and predict behaviour. Several theories were discussed. The Theory of Reasoned Action, was chosen because it combines the motivations of interest to us: *attitudes*, within which individual motivations to go gardening can be implemented, and *subjective norms*, being the influence of the norm to contribute to the garden if one is a part of the community.

12.1.2 What characteristics of community gardens do we need to operationalise the theoretical concepts described for subquestion 1?

Chapter 5 contains an overview of the characteristics of collective action on community gardens within the theories found in subquestion 1. The overview is based on literature, a recently developed database on community gardens in Germany, and interviews. Chapter 6.2 describes how these characteristics are used in the model.

To operationalise the design principles, we use the research of Butler (2013). She collected the various ways in which design principles are practically implemented on community gardens in the UK, which are described in chapter 5.1.1. It would drive too far in this research to assess the impact of all varieties she describes. Therefore, after the reviewing of all practical implementations, the implementations most and least in line with Ostroms design principles were assessed in this research as described in section 6.2.2. The influences of the design principles were retrieved from both literature on community gardens and literature on common pool resources.

Secondly, to operationalise the Theory of Reasoned Action, we found various motivations for volunteers to participate or not to participate on a community garden. As in literature the motivations showed overlap, they were clustered according to their practical need on the garden, resulting in labels of cohesion, social, yield, enjoying gardening, environmental sustainability, education, land accessibility, uncomfortable conditions and too much work. These practical needs were understood from literature and Rogges database on community gardens. Finally, the moral obligation to contribute to maintaining the garden plays a role, which is influenced by the trust that others would do the same. The various motivations make collective action on community gardens differ from collective action on traditional commons. Not only food, which decreases when others take from it, is a resource. Resources that do not decrease when more people join, such as social cohesion and enhancing spiritual practice, play a role too. Table 6.1 shows these clustered motivations and the way they are evaluated.

Thirdly, to finalise the operationalisation of the IAD-framework, biophysical/material conditions and attributes of the community needed to be added. Most of them were used to calibrate the model to Gandhi Tuin, our case study. Table 5.1 shows the conditions and attributes as found through structured interviews.

12.1.3 How can we model the relationship between design principles and the robustness of collective action on community gardens?

The dynamics leading to the emergence of collective action on community gardens were modelled using Agent-Based Modelling (ABM). ABM is a suitable tool to study collective action because it allows to model individual agents and interaction between those agents, resulting in the emergent behaviour of collective action. In the model, agents have a set of values for the motivations that were found to influence the choice go join gardening. When an agent chooses to join the gardening, it interacts during the gardening with the other agent that chose to volunteer. After the gardening session, the agent evaluates for its attitude its perceived level of cohesion, whether it gained its fair share of yield, whether it was able to interact with another agent and whether there were enough agents for the amount of work. To evaluate the social norm, the agent evaluates the amount of rule violation that it saw in a set amount of encounters with other volunteers. Other volunteers contributing fairly results in a higher trust in the community. When an individual violates a rule, there is a chance that this volunteer gets caught and sanctioned. When not sanctioned, the chance for further rule violation increases for both the violating agent and perceiving agent. When sanctioned, this leads for both the violating agent and perceiving agent in a lower probability to violate a rule later on, as sanctioning leads to both the content of the rules and the risk for getting an uncomfortable sanction get more clear. Based on the evaluations of the gardening session, the agent updates its expectations or beliefs for the way in which the garden fulfils its motivations. It then takes this into account in the next decision to intend to join the gardening. This results in the emergence of groups maintaining the garden.

The design principles influence this emergence of collective action, and they are incorporated in the model based on their influence. This was done because some influences overlap and have unclear values. To learn the impact of varying values for these influences, it was necessary to isolate them. This resulted in 7 implementations of design principle-influences.
DPplotboundaries represents an effect of the design principle for plot boundaries only. This parameter can be true or false. When true, the probability of yield getting stolen when there are boundaries is active. When false, the probability of yield getting stolen when there are no boundaries is active. These probabilities are estimated by gardeners of Gandhi Tuin to calibrate the model to their case.

DPprobabilitysanctioning represents the probability that an agent violating a rule or making a mistake is sanctioned. This was found as the influence of three design principles: plot boundaries, monitoring and group boundaries.

DPfee represents the other effect of the design principle for group boundaries. It was found that the practical implementation of group boundaries most in line with Ostroms design principle, was a fee for receiving yield from the garden. DPfee is a ranging parameter, allowing a higher value to represent a higher fee. When DPfee is very low, all agents will pay the fee. This leads to alignment with the reality least in line with Ostroms design principle: any volunteer can receive yield.

DPglobalprobabilityruleviolation represents the effect of the design principle for collective-choice arrangements. It was found that this design principle decreases the probability that volunteers violate rules. As DPprobabiltiysanctioning already influences the probability to violate rules, DPglobalprobabilityruleviolation determines the initial probability of a new volunteer to violate a rule.

DPMaxTakingMoreThanShare represents the design principle for proportional equivalence between benefits and costs. It was found that the implementation most in line with Ostroms design principle was contributing volunteers receiving a fair share of yield by an employee or as a share connected to membership. Both have the same effect: contributors receive an (aimed to be) fair amount of yield. It is assumed that visions about a fair amount do not differ among volunteers in this scenario. The option least in line, seemed to be volunteers taking any yield they needed. This could be too much, but the extent to which this happens and how much yield is taken, we don't know. Therefore, DPMaxTakingMoreThanShare is a range indicating the maximum amount from which volunteers randomly choose a desired amount of yield. A low value for DPMaxTakingMoreThanShare results in people receiving a fair amount. A high value results in the risk that people take too much.

DPgraduatedsanctions represents the design principle for graduated sanctions. It was found that the most precise implementation of this design principle indicated people first being told off, then being suspended, and then restricted access from the garden permanently. It was found that the least precise implementation of this design principle was telling off being the only sanctioned (as it was assumed that not telling off would not be a realistic scenario). Therefore, DPgraduatedsanctions can be true or false, with true indicating the availability of suspension and permanent access restriction additionally to telling off as a sanction.

Finally, DPconflictharm represents the design principle for conflict-resolution mechanisms. Many types of conflict-resolution mechanisms were found. The effect of these mechanisms is a decreased harm of conflict regrading trust. As the effectiveness of specific conflict-resolution mechanisms is difficult to assess, DPconflictharm is a ranging value indicating the eventual extend to which a conflict harms trust.

12.1.4 How do the design principles influence the robustness of collective action on Gandhi Tuin, according to the model?

The model indicated that for the conditions of Gandhi Tuin, the amount of sanctioning has the strongest correlation with the robustness of collective action. This indicates that monitoring, plot boundaries, and group boundaries are beneficial. The global probability of rule violation shows a weak negative correlation. This indicates that collective choice arrangements are beneficial for the robustness of collective action too. Other design principles show only very weak correlations. However, the decision tree shows that the impact of a single design principle depends largely on the other regulations in place. Although design principles can have a tendency for a positive or negative impact, the decision trees showed that combinations of design principles can lead to surprisingly robust or vulnerable collective action. A high amount of sanctioning therefore still can result in a high chance for collective action to collapse within 6 years. We therefore conclude that it is more useful to look at influences of combined design principles in specific situations than at influences of design principles in general. More about this is discussed in section 12.1.6.

12.1.5 How do the design principles influence the motivations of volunteers at Gandhi Tuin, according to the model?

The model indicated several conclusions for the influence of design principles on motivations for the conditions of Gandhi Tuin, which are discussed in chapter 10. In this section we will discuss the stronger and most interesting correlations only.

With trust, the probability of sanctioning has a strong positive correlation. This seems logical, as trust is harmed by volunteers violating rules without being sanctioned. This means that trust is positively correlated with the design principles of plot boundaries, monitoring and group boundaries. Additionally, the global probability of rule violation shows a moderate negative correlation with trust. This is logical for a similar reason, as an increase in the probability for a volunteer to violate a rule increases the probability for an individual to see another volunteer violating a rule unsanctioned. The global probability of rule violation represents the design principle of collective-choice arrangements.

Regarding the belief for yield, stronger correlations were found. A strong correlation is with the maximum amount of yield that volunteers can take, which is connected to the principle for proportional equivalence between benefits and costs. This makes sense, as a higher value for this variable leads to a higher probability for volunteers to take the yield of someone else, leading to a lower chance that a volunteer finds the fair amount of yield available. Similarly, a weak positive correlation with plot boundaries can be explained. Furthermore, the probability of sanctioning and a fee are weakly positively correlated with the belief for yield. We can explain the positive impact of the fee, representing group boundaries, as it limits the amount of people that can take yield and therefore the probability that someone takes too much is lower. The reason for the positive correlation with the probability of sanctioning is that a higher value leads to more people being excluded from the community, leading to more yield for the people that are left.

With cohesion and the belief for too much work, only weak correlations were found. There are two scenarios in which the belief for too much work is exceptionally low, indicating a large group size:
1) When DPfee is low, DPconflictharm is low, DPglobalprobabilityruleviolation is low and DPprobabilitysanctioning is medium
2) When DPconflictharm is low, DPglobalprobabilityruleviolation is low or high, DPprobabilitysanctioning is high, DPfee is low or high and DPMaxTakingMoreThanShare is low or high.

12.1.6 To what extent does the model reflect reality, and how can it be used for practical purposes?

Chapter 11 discusses the validating of the model. This validation was done in two ways: by communicating the general results in the form of correlations with an academic expert on community gardens, and by discussing the specific results for Gandhi Tuin and Vredestuin in the form of the decision tree with gardeners from these gardens.

The academic expert indicated to recognise most of the correlations resulting from the model. Three findings she did not recognise. Firstly, she did not recognise the strong positive correlation of DPprobabilitysanctioning with trust. She expected trust to be higher if sanctioning was not necessary at all because volunteers comply to the rule. We did not model such a scenario of everyone complying to the rules ‘without help’, we assumed people always make mistakes or violate rules. Secondly, she was surprised that DPprobabilitysanctioning had the highest (although still very weak) positive correlation with cohesion. She would have expected a higher correlation with DPglobalprobabilityruleviolation. This surprise can be explained by the way in which DPglobalprobabiltiyruleviolation and DPprobabilitysanctioning were implemented in the model. DPprobabilitysanctioning (influencing probability of rule violation throughout all times a volunteer visits the garden) leads to a lower amount of rule violation than DPglobalprobabilityruleviolation (influencing probability of rule violation only when a volunteer is new). Thirdly, she was not sure about the strong negative correlation of DPMaxTakingMoreThanShare with the belief for yield availability, mostly because she did not experience set expectations for yield. Different from the gardeners on Gandhi Tuin, for most of the gardeners she spoke with yield was not an important motivation.

Specific results for Gandhi Tuin and Vredestuin were discussed with gardeners of these cases. A decision tree showed the likeliness of collective action sustaining for 6 years as a result of choices made regarding design principles. It was assessed in which ‘path’ of design principles these gardens belong and what chance for sustained collective action results from that according to the model. It was concluded that Gandhi Tuin had a very high probability for collective action to sustain when conflict harm was low or medium. However, when conflict harm is high, the tree shows that only half of the experiments sustained their collective action. The gardener that was interviewed, recognised this vulnerability. In the real-life case of Gandhi tuin, indeed the collective action collapsed because of an escalated conflict. Although the garden had conflict-resolution mechanisms, they failed to protect trust from the conflicts harm.

Additionally to Gandhi Tuin, we could explore the decision tree with Vredestuin as this garden has very similar characteristics. The initiators of Gandhi Tuin recognised the probability of sanctioning as an important factor leading to robust collective action on this garden earlier. Therefore, they tried to monitor more strictly on Vredestuin. The design principles on Vredestuin result in a very high chance for collective action to sustain, and the gardener agreed that he felt very sure about the group of people on Vredestuin. However, the model shows that when conflict harm gets medium or high from the current position of Vredestuin, this also results in a very high risk for collective action to collapse.

Based on the findings from our model, we would recommend a combination of good monitoring, making sure every one gets a fair share of yield and either a low or no fee for taking yield, or a very high fee. With these institutions, several further combinations of design principles are possible, but all of them end in a high possibility for sustained collective action. A main advantage of the combination of design principles described, is that both low, medium and high conflict harm does not harm the robustness of collective action. This is beneficial, as it seems difficult to predict the success of conflict-resolution mechanisms.

The use of a decision tree to visualise the results has been experienced as a helpful intuitive way to communicate with interviewees.

12.1.7 Answering the main question: how do the 8 design principles influence the robustness of collective action on community gardens?

In our literature search and conceptualisation, we found that the design principles and dynamics on the garden affect the motivations of cohesion, yield and too much work and trust. Through these motivations, they influence the collective action. Robust collective action was defined as '*action taken voluntarily by a group of people in pursuit of maintaining the garden, which continues despite fluctuations in the behaviour of its component parts or its environment'.* As the notion of a group is central in this definition, we measured the moment of collapse of collective action as the moment on which there is only a single person contributing on the garden. By investigating Gandhi Tuin with the model, our main finding was that the robustness of collective action mainly depends on *combinations* of design principles rather than on design principles on their own.

Based on our findings from the model, we can confirm and reject our earlier discussed hypotheses based on Butlers work (Butler, 2013):

- Collective choice arrangements are important for robust collective action
    - **partly confirmed.** A low DPglobalprobabilityruleviolation generally is correlated with a higher chance for robust collective action. However, the model also shows cases in which DPglobalprobabilityruleviolation has the opposite effect.
- Collective action can sustain without plot boundaries, group boundaries, conflict-resolution mechanisms, appropriation between benefits and costs, monitoring and graduated sanctions being implemented
    - **partly confirmed.** Figure 12.1 shows the decision tree for the scenario described in this hypotheses. Although the model shows that most experiments collapsed, there are few experiments in which Gandhi Tuin would have managed to sustain over 6 years in this scenario.

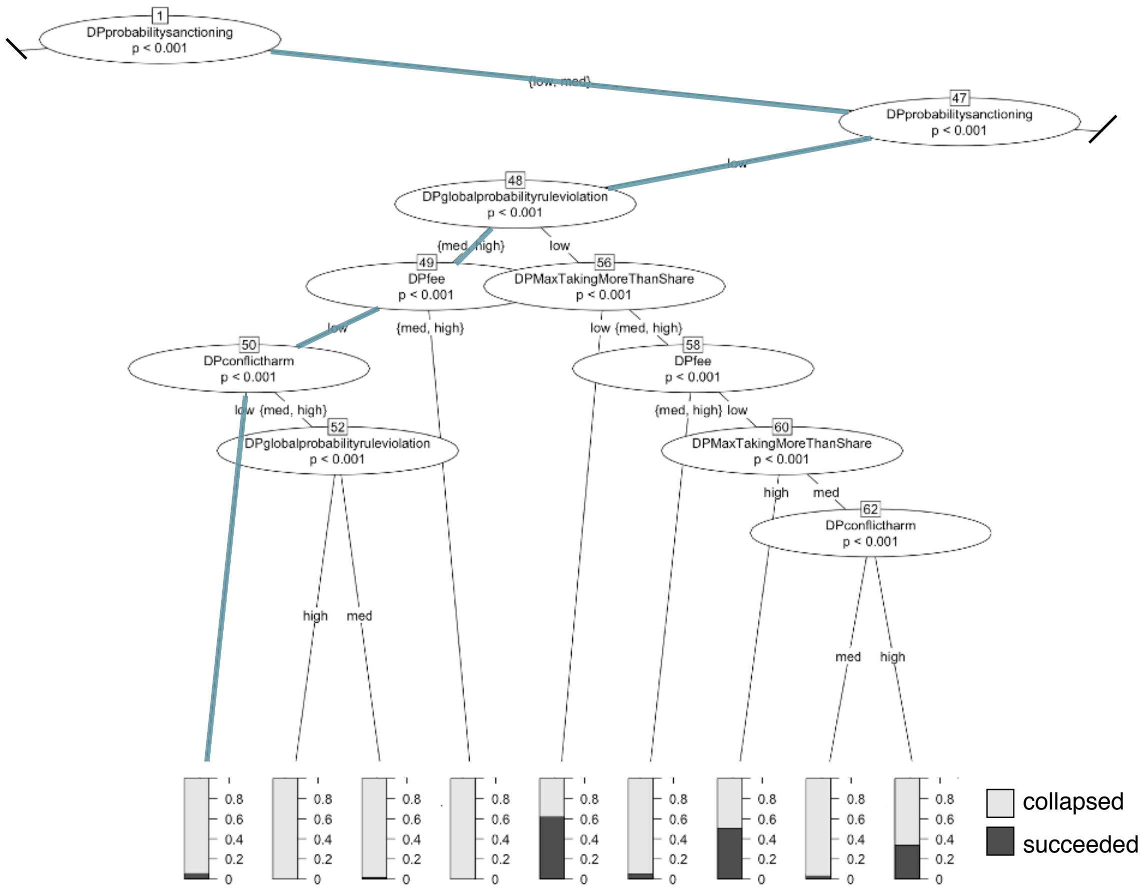


Figure 12.1: part of decision tree for CollectiveActionFailed
blue line = hypothesis scenario

12.2 Scientific relevance

The scientific relevance of this research involves two types: the providing of insights in the influence of design principles on community gardens, and the example of a method to study such problems.

Regarding the insights in the influence of design principles, the influence of the design principles on collective action on community gardens has been studied before only to a limited extend. Butler (2013) compared conditions and the characteristics of resulting collective action through case studies. Additionally, some authors have formulated hypotheses about the influence of some design principles based on their model or case study which was designed to address another question. This research provides both a more detailed view on the influence of the design principles on collective action on community garden, as a more specific view on the robustness of collective action.

Additionally, the research provides a first example on the agent-based modelling of collective action on community gardens and the agent-based modelling of design principles. The model can be used as a basis to study more influences on collective action, or more effects of the implementation of design principles. While the modelling of collective action on community gardens might be of interest for a very specific community of researchers, the modelling and visualisation of the impact of design principles might be of use for researchers interested in the commons in general.

12.3 Societal relevance

The outcomes of this research can be useful in practice in different ways. Firstly, the results facilitate insight in the likeliness of collective action on a garden to sustain under certain institutional conditions. Additionally, the results provide a practical insight of risks and opportunities under institutional conditions. For instance, it was found that high conflict harm can severely decrease the probability for sustained collective action in under certain institutional conditions. The case study expert noted that they could use the result to show the municipality what they had been trying to explain them: that strict monitoring is an important factor for sustained collective action, and that therefore guidance and funds should be provided for their garden. Ideally, the results from the model would be used by municipalities too, in order to gain trust in bottom-up initiatives by understanding their strengths and weaknesses, their opportunities and threats.

12.4 Discussion

Although we have been able to formulate conclusions in the previous section, some limitations of this study must be mentioned.

First of all, it should be kept in mind that the model was based on both literature and assumptions. Some important assumptions will be described, although more exist. Rule violation is simplified to an individual's fluctuating chance, only influenced by the design principles initially and then influenced by the amount of uncorrected rule violation seen. Yield taking is simplified to 'taking a fair share or X times more' by chance, not taking into account a high or low real amount of yield. Although for the case study it was mentioned that there was always enough yield, this might not be the case on other gardens. Also, the motivations of environmental sustainability, enjoying nature, cultural practices and land accessibility have a stable value while this might not be the case in reality. Additionally, it was assumed that the network in which people interact is random while this might be not the case. Finally, the 'feeling of constraints' when there are more rules, which Chalise (2015) found to lead to less volunteers, is not included in the model. We expect that the model including all these assumptions resulted in a useful model, as results were validated positively by historical validation and expert validation. However, the validation method of someone else independently rebuilding the model was not executed as this is not likely within the scope of a thesis.

Secondly, although we have been able to model the practical influences of design principles, it is not completely clear whether these are the only influences the design principles have. The influences of design principles as implemented on community gardens was largely based on influences of design principles on traditional common pool resources. The author for instance can imagine that collective-choice mechanisms have a different and more diverse impact than only decreasing the probability for rule violation of volunteers.

Thirdly, it was found plot boundaries and graduated sanctions have little impact. Regarding plot boundaries an interviewed gardener agreed with their small impact, but graduated sanctions were important according to him. He perceived the possibility deny access to an individual as important because some individuals do not learn to follow the rules. Individuals like this are not incorporated in the model, and this might be of influence to the result. Another explanation for the small influence of graduated sanctions, is that its impact is dependent on multiple uncertain parameters. We have seen in table 10.1 and 10.5 that these uncertain parameters (MinAmountTellingOff, MaxAmountTellingoff and MaxAmountTellingOffAfterSustpension) can have a larger impact than DPgraduatedsanctions.

Finally, the scope used in this research was that of the operational level. Thus, rules could not be changed during an experiment. Although this was useful for a clear view on the influence of all design principles, in reality rules can be changed. The way rules are changed is also influenced by the design principles, especially the design principle of collective choice mechanisms.

12.5 Reflections

During the process resulting in this thesis, some decisions have been of influence on the end result. Some of them lead to limitations mentioned in the discussion. This section contains a reflection on choices and important parts of the process.

12.5.1 Information collection

Firstly, as mentioned in the discussion, the influences of design principles might not be complete. For this research, they were collected from literature on traditional common pool resources. However, the image might have been more complete if additional interviews were conducted with experts in order to learn more effects.

12.5.2 Model development

Regarding the influences of design principles, collective-choice mechanisms should especially be mentioned. This design principle was implemented in the model as ‘describing the initial probability of volunteers to violate a rule’. However, this means that the probability only is adapted in the beginning. Looking at reality, this is not entirely logical as it means that the collective choice arrangements have their effect when the volunteer has not been participating in collective choice arrangements at all yet. Although the current implementation might lead to a lower global probability to violate a rule and yield the same results, it might have been better to implement this design principle as describing the range in which the probability of rule violation can vary. Another alternative would have been to deeper investigate the influence of this design principle in other literature in order to specify it’s effect further. The same could have been done for the other design principles.

12.5.3 Model simulation

It was noticed during the interview session to find Gandhi Tuin and Vredestuin in the decision tree, that it was difficult to estimate the values for the design principles. Multiple people could give different answers on the same question, influencing the verdict of the model. When the author had known this in advance, she would have better prepared the interview to indicate the differences between ‘low’, ‘medium’ and ‘high’ for a design principle. Another option could be to only split the design principles in two levels, making it easier to choose. However, this would also eliminate the interesting insight that sometimes a high or low value of a design principle have a similar effect, while the medium value has a very different effect.

12.6 Further research

This research showed a way in which design principles and collective action on community gardens can be modelled, resulting in the conclusion that robustness of collective action on community gardens strongly depends on specific combinations of design principles. This section provides recommendations for further research within this field. Further research could improve the knowledge on which models can be based, it could build on the model developed in this research, or could be dedicated to a new model.

12.6.1 Further research on knowledge regarding design principles and community gardens

For the developing of the model in this research, many assumptions had to be made because knowledge was not available. Thus, the influence of the design principles as implemented on the community gardens was extracted from knowledge on the influence of design principles on traditional common pool resources.

Although the model was validated quite successfully, we might have missed influences or modelled influences that are not that important. Additionally, the design principle of recognition of rights to organise was not studied in this research due to a lack of information on its influence. Further empirical research could contribute to knowledge on the influences of design principles on community gardens.

12.6.2 Further research regarding the model developed in this research

Extending the model

Graduated sanctions and plot boundaries have been implemented as booleans in this research. However, ranges were used for other design principles, allowing for a more dramatic implementation and therefore more insight in their effect. It might be interesting to implement graduated sanctions and plot boundaries in a similar way in the model, as it could increase the small influence they seem to have now.

This research was conducted at the operational level of the IAD framework. As rules often are changed in reality, it is interesting to take this into account by also looking at the collective choice and constitutional choice level. For instance the influence of collective choice arrangements, a set of rules that is better aligned with local circumstances (Ostrom, 2005), then also can be modelled. Related to this scope, are the notions of robustness and resilience. Anderies et al. explain these terms. While robustness focuses on systems that do not fail within a defined range of uncertainty, resilience focuses on systems capable of learning, self organising and adapting to change (Anderies et al., 2013). Therefore, while this research robustness was used, for further research taking the adaption of rules into account it might be interesting to use the perspective of resilience as well.

Finally, the design principles are not the only principles known to influence the likeliness of sustained collective action regarding the commons. Agrawal collected 33 variables mentioned in literature (Agrawal, 2014). Extending the model with those influences could make it more insightful and increase its predictive value .

Using the model

This research indicates that the effect of design principles on robustness of collective action is dependent on the way they are combined. More research can be dedicated to finding the ways in which the model can help to find successful combinations, by testing the model on other gardens like we did in this research with Gandhi Tuin. This would give insight in the value of the model, and additionally allow to compare the effect of design principles on community gardens with different characteristics.

12.6.3 Further research regarding new models on the design principles

As mentioned in the discussion, it would be interesting to independently of this research develop a new model addressing the same research question. This would allow insight in the sensitivity of the results to the modeller.

It also would be interesting to experiment with the modelling of design principles regarding other (traditional) common pool resources.

Bibliography

Agrawal, A. (2014). Studying the commons, governing common-pool resource outcomes: Some concluding thoughts. doi: 10.1016/j.envsci.2013.08.012

Anderies, J. M., Folke, C., Walker, B., & Ostrom, E. (2013). Aligning key concepts for global change policy: Robustness, resilience, and sustainability. *Ecology and Society, 18*(2). doi: 10.5751/ES-05178-180208

Anderies, J. M., & Janssen, M. A. (2013). *Sustaining the Commons*.

Bal, M. (2015). Social-Ecological System Framework: Understanding urban lake governance and sustainability in India. Erasmus University Rotterdam.

Binder, C. R., Hinkel, J., Bots, P. W. G., & Pahl-Wostl, C. (2013). Comparison of frameworks for analyzing social-ecological systems. *Ecology and Society, 18*(4). doi: 10.5751/ES-05551-180426

Butler, A. (2013). Collective Action in UK Urban Community Growing Projects: A Comparative Analysis.

Castell, P. (2010). Sustainable development and social robustness 1.

Chalise, N. (2015). Collective Action Dynamics in Urban Neighborhoods : A Study of Urban Community Gardens.

Charles, D. (2012). [At The Community Garden, It's Community That's The Hard Part : The Salt : NPR].

Colding, J., Barthel, S., Bendt, P., Snep, R., Van Der Knaap, W., & Ernstson, H. (2013). Urban green commons: Insights on urban common property systems. *Global Environmental Change, 23*, 1039-1051. doi: 10.1016/j.gloenvcha.2013.05.006

Community Garden Conference, Turner, B., Henryks, J., Pearson, D., & University of Canberra. (2010). Community Garden Conference : promoting sustainability, health and inclusion in the city, University of Canberra, 7-8 October 2010 : proceedings. [Belconnen, A.C.T.]: University of Canberra.

Darnton, A. (2008). GSR Behaviour Change Knowledge Review Reference Report: An overview of behaviour change models and their uses.

Drake, L., & Lawson, L. J. (2015). Results of a US and Canada community garden survey: shared challenges in garden management amid diverse geographical and organizational contexts. *Agric Hum Values*. doi: 10.1007/s10460-014-9558-7

Duchemin, E., Wegmuller, F., & Legault, a. M. (2008). Urban agriculture: multi-dimensional tools for social development in poor neighbourhoods. *Field Actions Science Reports, 1*(October 2012), 42-52. doi: 10.5194/facts-2-1-2009

Eves, F., Hoppéa, R., & McLaren, L. (2007). Prediction of Specific Types of Physical Activity Using the Theory of Planned Behavior. *Journal of Applied Biobehavioral Research, 8*(2), 77-95. doi: 10.1111/j.1751-9861.2003.tb00086.x

Fishbein, M., & Ajzen, I. (2010). Predicting and Changing Behavior: The Reasoned Action Approach - Martin Fishbein, Icek Ajzen - Google Boeken. New York: Taylor and Francis Group.

Fors, H., Molin, J. F., Murphy, M. A., & Bosch, C. K. v. d. (2015a). User participation in urban green spaces– for the people or the parks? *Urban Forestry Urban Greening, 14*(3), 722-734. doi: 10.1016/j.ufug.2015.05.007

Fors, H., Molin, J. F., Murphy, M. A., & Bosch, C. K. v. d. (2015b). User participation in urban green spaces– for the people or the parks? *Urban Forestry & Urban Greening, 14*(3), 722-734. doi: 10.1016/j.ufug.2015.05.007

Foster, S. R. (2011). COLLECTIVE ACTION AND THE URBAN COMMONS.

Friedkin, N. E. (2004). Social Cohesion. *Annual Review of Sociology, 30*, 409-425. doi: 10.1146/annurev.soc.30.012703.110625

Gemeente Amsterdam. (2013). Agenda Groen, Gemeenste Amsterdam (pp. 1-45).

Gemeente Rotterdam). [Rotterdam.nl | Zelfbeheer, er kan meer dan u denkt].

Gemeente Utrecht. (2017). Actualisatie Groenstructuurplan 2017 -2030.

Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). ADAPTING CITIES FOR CLIMATE CHANGE: THE ROLE OF THE GREEN INFRASTRUCTURE.

Guitart, D., Pickering, C., & Byrne, J. (2012). Past results and future directions in urban community gardens research. *Urban Forestry & Urban Greening, 11*, 364-373. doi: 10.1016/j.ufug.2012.06.007

Hothorn, T.). [Conditional Inference Trees function | R Documentation].

Kingsley, J., & Townsend, M. (2006). 'Dig In' to Social Capital: Community Gardens as Mechanisms for Growing Urban Social Connectedness. *Urban Policy and Research, 24*(4), 525-537. doi: 10.1080/08111140601035200

Kleerekoper, L., van Escha, M., & Salcedo, T. B. (2011). How to make a city climate-proof, addressing the urban heat island effect. *Resources, conservation and recycling*.
Knüppe, K., Pahl-Wostl, C., Knüppe, K., & Pahl-Wostl, C. (2011). A Framework for the Analysis of Governance Structures Applying to Groundwater Resources and the Requirements for the Sustainable Management of Associated Ecosystem Services. *Water Resour Manage, 25*, 3387-3411. doi: 10.1007/s11269-011-9861-7
Lawson, L., & Drake, L. (2013). Community gardening organization survey 2011-2012. *Community Greening Review*, 20-47.
McGinnis, M. D. (2011). An introduction to IAD and the language of the Ostrom workshop: a simple guide to a complex framework. *The policy studies journal, 39*(1).
Meinzen-Dick, R., Digregorio, M., McCarthy, N., & Di Gregorio, M. (2004). Methods for studying collective action in rural development. *Agricultural Systems, 82*, 1-202. doi: 10.1016/j.agsy.2004.07.006
Milburn, L.-A. S., & Vail, B. A. (2010). Sowing the Seeds of Success Cultivating a Future for Community Gardens.
Moreira, J. a., Pacheco, J. M., & Santos, F. C. (2013). Evolution of collective action in adaptive social structures. *Scientific reports, 3*, 1521-1521. doi: 10.1038/srep01521
Mui, L. (2002). Computational Models of Trust and Reputation: Agents, Evolutionary Games, and Social Networks. *Department of Electrical Engineering and Computer Science, Doctor of*, 139-139. doi: 10.1109/HICSS.2002.994181
Mui, L., Mohtashemi, M., & Halberstadt, A. (2002). A computational model of trust and reputation. *System Sciences, 2002. …, 00*(c), 1-9. doi: 10.1109/HICSS.2002.994181
National Standards for Foreign Language Education, P. (1999). *Standards for foreign language learning in the 21st century*. Lawrence, KS: Allen Press, Inc.
Nikolic, I. (2009). Co-Evolutionary Method For Modelling Large Scale Socio-Technical Systems Evolution.
Okvat, H. A., & Zautra, A. J. (2011). Community Gardening: A Parsimonious Path to Individual, Community, and Environmental Resilience. *Am J Community Psychol, 47*, 374-378. doi: 10.1007/s10464-010-9404-z
Openbaar Groen Rotterdam (2016). [Beheeraanpak].
Ostrom, E. (1997). A Behavioral Approach to the Rational Choice Theory of Collective Action. *The American Political Science Review, 92*(1), 1-22.
Ostrom, E. (2005). Understanding institutional diversity: Princeton University Press.
Ostrom, E. (2009a). Design principles of robust property-rights institutions: What have we learned?
Ostrom, E. (2009b). A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science, 325*(5939).
Oxford Dictionaries. nature | Definition of nature in English by Oxford Dictionaries. Retrieved 2018-02-27, from https://en.oxforddictionaries.com/definition/nature
Patel, I. C. (1991). Gardening's socioeconomic impacts. *Journal of Extension, 29*(4).
PBL Netherlands Environmental Assessment Agency. (2012). Effect of climate changes on waterborne disease in The Netherlands.
Pearson, D. H., & Firth, C. (2012). Diversity in community gardens: Evidence from one region in the United Kingdom. *Biological Agriculture & Horticulture, 28*(3), 147-155.
Petrescu, D., Petcou, C., & Baibarac, C. (2016). Co-producing commons-based resilience: lessons from R-Urban. *Building Research & Information, 44*(7), 717-736. doi: 10.1080/09613218.2016.1214891
Poteete, A. R., Janssen, M. A., & Ostrom, E. (2010). *Working together*. Princeton: Princeton University Press.
Poteete, A. R., & Ostrom, E. (2004). In pursuit of comparable concepts and data about collective action. doi: 10.1016/j.agsy.2004.07.002
Pudup, M. B. (2007). It takes a garden: Cultivating citizen-subjects in organized garden projects. *Geoforum, 39*. doi: 10.1016/j.geoforum.2007.06.012
Rogge, N. (2017). Community garden survey throughout Germany [Data file and code book] [Unpublished raw data].
Rogge, N., Frey, U., Strassner, C., & Theesfeld, I. (2015). Categorizing Urban Commons – Collective Action in Urban Gardens.
Rogge, N., & Theesfeld, I. (2017). Title: Community Gardens as Commons -A Typology for Self-Governed Food Production Networks.

Ruggeri, G., Mazzocchi, C., & Corsi, S. (2016). Urban gardeners' motivations in a Metropolitan city: The case of Milan. *Sustainability (Switzerland), 8*(11). doi: 10.3390/su8111099
Saldivar-Tanaka, L., & Krasny, M. E. (2004). Culturing community development, neighborhood open space, and civic agriculture: The case of Latino community gardens in New York City. *Agriculture and human values, 21*.
Schmelzkopf, K. (2017). Incommensurability, Land Use, and the Right to Space: Community Gardens in New York City. *Urban Geography, 23*(4), 323-343. doi: 10.2747/0272-3638.23.4.323
ten Broeke, G., van Voorn, G., & Ligtenberg, A. (2016). Which Sensitivity Analysis Method Should I Use for My Agent-Based Model? *Journal of Artificial Societies and Social Simulation, 19*(1), 1-35. doi: 10.18564/jasss.2857
Thalheimer, W. (2006). Spacing learning events over time: What the research says. *Retrieved March*(February), 54-54.
Townsend, M., Henderson-Wilson, C., & Kingsley, J. (2009). Cultivating health and wellbeing: members' perceptions of the health benefits of a Port Melbourne community garden. *Leisure Studies, 28*(2), 207-219. doi: 10.1080/02614360902769894
van Dam, K. H., Nikolic, I., & Lukszo, Z. (2013). *Agent-Based Social Systems*. Dordrecht: Springer.
Veen, E. J., Bock, B. B., Van den Berg, W., Visser, A. J., & Wiskerke, J. S. C. (2016). Community gardening and social cohesion: different designs, different motivations. *Local Environment, 21*(10). doi: 10.1080/13549839.2015.1101433
Vercauteren, C. (2013). Urban Agriulture and Innovative food provisioning practices: Evaluating community gardens as learning environment for sustainable food provisioning practices.
Wilson, D. S., Ostrom, E., & Cox, M. E. (2013). Generalizing the core design principles for the efficacy of groups. *Journal of Economic Behavior and Organization, 90*, S21-S32. doi: 10.1016/j.jebo.2012.12.010
Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. *Landscape and Urban Planning*. doi: 10.1016/j.landurbplan.2014.01.017

Appendices

Appendix A: pseudo code

Setup procedure

1. Clear all information from previous experiments
2. Set random-seed the input value Randomseed to make the run reproducable

3. Setup patches
4. Set one half of the environment black, and one half of the environment green (representing the garden)

5. Setup globals
   5.1. Set Generalrange a list containing [0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9]
   5.2. Set Highrange a list containing [0.5 0.6 0.7 0.8 0.9 1]
   5.3. Set Lowrange a list containing [0 0.1 0.2 0.3 0.4 0.5]
   5.4. Set CollectiveActionFailed? “no”

6. Setup constitutional structure
   6.1. If DP plot boundaries is true, set the chance that yield gets stolen the chance that yield gets stolen when there are plot boundaries as indicated by the garden expert. If DP plot boundaries is false, set the chance that yield gets stolen the chance that yield gets stolen when there are no plot boundaries as indicated by the garden expert.

7. Create the initiators
   7.1. Create number potential volunteers as initiators, number indicated by garden expert
   7.2. Set the initial variables of the first potential volunteers
      7.2.1. Set shape to person and color blue
      7.2.2. Set amount of good encounters 0
      7.2.3. Set total amount of encounters 0
      7.2.4. Set community reputation 0
      7.2.5. Set amount of visits 0
      7.2.6. Set amount of sanctions 0
      7.2.7. Set the probability of rule violation the DP indicated initial probability of rule violation
      7.2.8. Set being member “no”
      7.2.9. Set membertimer 0
      7.2.10. Set CommittedTime InitiatorCommittedTime as indicated by slider
      7.2.11. Set YieldList empty list
      7.2.12. If DP for fee is larger than 0, set BeliefYield 1
      7.2.13. Set BeliefEducation 1
      7.2.14. Set BeliefLandavailability 1
      7.2.15. Set BeliefEnjoyingGarden 1
      7.2.16. Set BeliefEnvsustainability 1
      7.2.17. Set SocialList empty list
      7.2.18. Set BeliefCohesion 0
      7.2.19. Set Reciprocity 1
      7.2.20. Set TooMuchWorkList empty list
      7.2.21. Place the initiators in rows in the environment
   7.3. Set the characteristics of the potential volunteers
      7.3.1. First set values for Yield, Education, LandAvailability, EnjoyingGarden, Envsustainability, Social, Cohesion, Toomuchwork and Conditions one of the low range. Then for each value, give a percentage of potential volunteers a value from the high range.
      7.3.2. The percentage with high value for a motivation type is indicated by the garden expert.

Go procedure

8. Stop if ticks reach the GardenAge (600) or if collective action failed
9. Set the value for CollectiveActionFailed 600 if the GardenAge is reached and the collective action has not failed yet

10. Reset numbers
    10.1. Reset numbers used to measure characteristics of a run: TotalViolatedAndSanctioned, TotalViolatedWithoutSanctioned, Totaltrust, TotalRuleViolations, TotalBeliefCohesionThisTick, TotalBeliefYieldThisTick, TotalBeliefTooMuchWorkThisTick

11. Add newbies
    11.1. Every 9th session a volunteer visits the garden, it contacts an amount of people of which a percentage might try the gardening (Chalise, 2015).
        11.1.1. The amount of people contacted is between 1 and 3 (Chalise, 2015)
        11.1.2. The ratio of them trying gardening can be between 0.05 and 0.15.(Chalise, 2015)
    11.2. When a contacted person tries gardening, it becomes a volunteer following the procedure 7.2 & 7.3. The growing of a new volunteer is only possible if the amount of agents has not exceeded the total pool.

12. Set being volunteer
    12.1. Check whether there are uncomfortable conditions on the garden. When a random number within 100 falls within the ChanceUncomfortableConditions * 100, conditions are bad. Turtles then set their BeliefConditions 1. Else, they set their BeliefConditions 0.
    12.2. Check whether DPfee, the design principle for group boundaries, resulting in membership, is active. If not and the fee is 0, membership does not need to be taken into account.

When membership is not active

12.3. When amount of visits is 0 or CommittedTime is larger than 0,
    12.3.1. the agent becomes a volunteer as newbies always try the garden and committed agents must volunteer too
    12.3.2. the agent sets its CommittedTime CommittedTime -1
    12.3.3. the agent sets its YieldAccess “yes”, as everyone in this scenario is allowed yield

12.4. When the amount of visits is not 0 and CommittedTime is not larger than 0, the agent needs to decide itself whether to become a volunteer or not.
    12.4.1. Motivation of the agent is set (BeliefCohesion * ValueCohesion) + (BeliefSocial * ValueSocial) + (BeliefYield * ValueYield) + (BeliefEducation * ValueEducation) + (BeliefLandavailability * ValueLandavailability) + (BeliefEnjoyingGarden * ValueEnjoyingGarden) + (BeliefEnvsustainability * ValueEnvsustainability) + (Trust * Reciprocity) - (BeliefConditions * ValueConditions) - (BeliefToomuchwork * ValueToomuchwork)
    12.4.2. When the motivation is higher than the contributingthreshold, the agent becomes a volunteer and YieldAccess is set “yes” as everyone in this scenario is allowed yield.
    12.4.3. When the motivation is lower than the contributingthreshold, the agent becomes a potential-volunteer.

When membership is active

12.5. The agent sets membertimer membertimer -1

12.6. If its membertimer = 0,
    12.6.1. the agent sets its BeingMember “no” and its YieldAccess “no”

12.7. When the agents amount of visits is 0 or the committedtime is larger than 0,
    12.7.1. the agent becomes a volunteer as newbies always try the garden and committed agents must volunteer too
    12.7.2. the agent sets its CommittedTime CommittedTime -1 and its YieldAccess “yes”

12.8. When the agents amount of visits is not 0 and committedtime is not larger than 0,
    12.8.1. The agent sets its motivation (BeliefCohesion * ValueCohesion) + (BeliefSocial * ValueSocial) + (0 * ValueYield) + (BeliefEducation * ValueEducation) + (BeliefLandavailability *

ValueLandavailability) + (BeliefEnjoyingGarden * ValueEnjoyingGarden) + (BeliefEnvsustainability * ValueEnvsustainability) + (Trust * Reciprocity) - ((BeliefConditions * ValueConditions) - (BeliefToomuchwork * ValueToomuchwork)

12.8.2. The agent sets its membermotivation (BeliefCohesion * ValueCohesion) + (BeliefSocial * ValueSocial) + (BeliefYield * ValueYield) + (BeliefEducation * ValueEducation) + (BeliefLandavailability * ValueLandavailability) + (BeliefEnjoyingGarden * ValueEnjoyingGarden) + (BeliefEnvsustainability * ValueEnvsustainability) + (Trust * Reciprocity) - (BeliefConditions * ValueConditions) - (BeliefToomuchwork * ValueToomuchwork) – DPfee

12.8.3. When the Motivation < Membermotivation or BeingMember = "yes"

12.8.3.1. If BeingMember is not "yes", the agent becomes a member by setting its BeingMember "yes", its YieldAccess "yes" and its Membertimer the current amount of ticks + Membershipduration (which can be 26 to 104 sessions)

12.8.3.2. If the agent is already a member by BeingMember is "yes", and Membermotivation or regular motivation is higher than the contributingthreshold, the agent becomes a volunteer

12.8.4. When the agents Motivation is higher than the Membermotivation and higher than the ContributingThreshold, the agent wants to be a volunteer without being a member. YieldAccess is then set "no".

12.8.5. If neither the membermotivation and the regular motivation are higher than the contributingthreshold, the agent becomes a potential volunteer.

Checking Access

12.9. When graduated sanctions are active, it could happen that the agent has no access to the garden for a set amount of sessions. It NoAccess > 0, the agents sets NoAccess NoAccess – 1 and becomes a potential volunteer.

Finding a place

12.10. When all agents became a volunteer or a potential volunteer, the potential volunteers form rows in the black part of the environment, and the volunteers form rows in the green part of the environment.

Checking whether collective action failed

12.11. When the number of volunteers has been lower than 2 for a set amount of time, the collective action has failed. When this is the case, CollectiveActionFailed is set the amount of ticks to register the moment of collapse, and CollectiveActionFailed? Is set "yes".

Contributing

12.12. When volunteers contribute on the garden, they might violate a rule. The chance that this happens is determined by an agents probability of ruleviolation. When the agent violates a rule, its Ruleviolated? Is set "yes".

12.13. When an agent violated a rule and Ruleviolated? = "yes",

12.13.1. it sets the global value for TotalRuleviolations TotalRuleViolations + 1.

12.13.2. the agent sets its private value for MyRuleViolations MyRuleViolations + 1.

12.13.3. when there are other volunteers on the garden, there is a probability that the agent also gets sanctioned. This probability is determined by DPprobabilitysanctioning.

12.13.3.1. When the agent is sanctioned, it sets its private AmountOfSeenViolationsWithSanctions + 1, MyAmountofSanctions + 1 and MySanctionsThisRound + 1, and global TotalViolatedAndSanctioned + 1.

12.13.3.2. When DP graduated sanctions is true, the amount the agent is told off is checked. When an agent has not been suspended yet and his amount of telling off is too high and falls within a random value in the range between a set minimum and maximum amount of being told off, the agent is suspended. The amount of sanctions for the suspension is saved in MomentOfSuspension.

12.13.3.3. When the agent has been suspended already a set number of rules again when back, it does not get access anymore to the garden at all. NoAccess therefore is set 10000.

12.13.4. When the agent is not told off, his AmountOfSeenViolationsWithoutSanctions increases with 1. Also, the global TotalViolatedWithoutSanctioned increases with 1.

Conflict

13. How often conflict arises, is determined by the probability of conflict. When there is conflict, volunteers set their private value of Conflict? 1.

YieldTaking

14. Only if a random number under 100 is within the range of ChanceYieldAvailability * 100, yieldavailability is set "yes" and the yieldTaking procedure continues
    14.1. If yield is available, there is a chance that it gets stolen. This chance is determined by the ChanceYieldStolen, which was determined earlier by the design principle of plot boundaries. When the yield was stolen, AmountOfYield is set 0. If the yield is not stolen, AmountOfYield is set 100.
    14.2. Then, volunteers with YieldAccess = "yes" can set a YieldWish. The amount they can wish, depends on the design principle for appropriation of benefits and costs, in the form of 'DPMaxTakingMoreThanShare'. When the design principle for appropriation of benefits and costs is active, DPMaxTakingMoreThanShare is 1 and the amount of yield volunteers can wish is a random amount of max 100% of the yield / amount of volunteers. This means everyone receives their fair share and can not take too much yield. When DPMaxTakingMoreThanShare > 1, it means that volunteers can take more than their fair share. DPMaxTakingMoreThanShare results in the amount they can wish for to be 1, 2, 3, 4 or 5 times their fair share.
    14.3. When a volunteer has set its YieldWish, it checks whether its wish is available. If the YieldWish < AmountOfYield, it is available and the agent sets YourYieldTaken? "no" and the AmountOfYield AmountOfYield – YieldWish. When YieldWish > AmountOfYield, the agent sets the AmountOfYield 0 and YourYieldTaken? "yes".

UpdateBeliefs

15. When agents update their beliefs, they first increase their private amount of visits with 1, and then increase the global amount of visits with 1.
16. Then, agents update their trust in the community. They do that by looking at an amount of volunteers determined by 'VolunteersToFullySeeThisRound', which determines how often 16.1 and 16.2 are executed by every agent. VolunteersToFullySeeThisRound is VolunteersToFullySee, except when there are not enough agents, then the value decreases to (count volunteers - 1)
    16.1. If random 100 >= ((TotalRuleViolations - MyRuleViolationsThisRound) / (count volunteers - 1)) * 100 is true, the agent saw no one violate a rule and sets AmountOfGoodEncounters AmountOfGoodEncounters + 1.
    16.2. If the 16.1 statement is false, the agent saw someone violate a rule. It then checks whether the rule was violated by checking if random 100 < (((TotalViolatedAndSanctioned - MySanctionsThisRound) / (TotalRuleViolations - MyRuleViolationsThisRound)) * 100). If this statement is true, it saw someone who violated unsanctioned and increases AmountOfSeenViolationsWithoutSanctions with 1.
    16.3. When 16.1 and 16.2 are repeated the set amount of times, the amount of TotalEncounters is updated. The encounters with volunteers during contributing and conflict with a certain impact are taken into account: the agent sets TotalEncounters TotalEncounters + VolunteersToFullySee + (Conflict? * DPconflictharm). Additionally, the amount of conflict impact on the TotalEncounters is saved, as TotalConflicts is set TotalConflicts + (Conflict? * DPconflictharm)
    16.4. The agent then updates its ProbabilityRuleViolation by the following formula: AmountOfSeenViolationsWithoutSanctions / (TotalEncounters - TotalConflicts)
    16.5. The agent updates its trust with the following formula: AmountOfGoodEncounters / TotalEncounters
17. Then, the agent updates its belief for cohesion.
    17.1. First, the agent tries to form relationships with the other volunteers that are present. The chance that a relation is formed is set by the Relationrate [1 - 5]. The amount of times that an agent can try is set by the Interactionrate [0.15 - 0.45]. When a relationship is formed, a link is created. To find the value for cohesion, the agent counts the amount of volunteers present that he has a link with. It counts them under PresentTies. The CurrentCohesion is calculated with the PresentTies / (count

volunteers), and then added to the CohesionList. The BeliefCohesion calculated as sum CohesionList / AmountofVisits. After the procedure, PresentTies is set to 0 again.

18. The agent evaluates BeliefSocial by checking whether count volunteers > 1. When this is true, 1 is added to SocialList. When this is not true, 0 is added to SocialList. BeliefSocial is set as (sum SocialList) / AmountofVisits
19. To evaluate yield, the agent checks whether its yield was taken or not by evaluating the value for YourYieldTaken?. If this value is not “yes”, the agents yield was not taken and it evaluates yield positively by adding 1 to Yieldlist. When its yield was taken it adds 0 to yieldlist. BeliefYield is defined as (sum YieldList) / AmountofVisits.
20. The agent evaluates TooMuchWork by checking whether the necessary AmountOfTasks was larger than count volunteers. When it was, 1 is added to TooMuchWorkList. When it was not, 0 is added to TooMuchWorkList. BeliefTooMuchWork is the (sum TooMuchWOrkList) / AmountOfVisits
21. The agent evaluates Education by decreasing its BeliefEducation exponentially. BeliefEducation is set (BeliefEducation - (BeliefEducation * Educationdecay))
22. Finally, some agents can not come back to the garden due to external reasons. An agent drops out and dies if a random number under 10000 <= (DropOutAYear / 104) * 10000 is true. DropOutAYear is a garden characteristic between 0 and 1.

adjustValues

23. Finally, the values to evaluate are determined and session-specific values for agents are set to 0:
24. TotalRuleViolationsCount is set TotalRuleViolationsCount + TotalRuleViolations
25. Volunteers
    25.1. set YourYieldTaken? 0
    25.2. set RuleViolated? 0
    25.3. set YieldWish 0
    25.4. set Conflict? 0
    25.5. set Totaltrust Totaltrust + Trust
    25.6. set TotalBeliefYieldThisTick TotalBeliefYieldThisTick + BeliefYield
    25.7. set TotalBeliefCohesionThisTick TotalBeliefCohesionThisTick + BeliefCohesion
    25.8. set TotalBeliefTooMuchWorkThisTick TotalBeliefTooMuchWorkThisTick + BeliefTooMuchWork
    25.9. set MyRuleViolationsThisRound 0
    25.10. set MySanctionsThisRound 0

26. TotalBeliefYieldAllTicks is set TotalBeliefYieldAllTicks + TotalBeliefYieldThisTick
27. TotalBeliefCohesionAllTicks is set TotalBeliefCohesionAllTicks + TotalBeliefCohesionThisTick
28. TotalBeliefTooMuchWorkAllTicks is set TotalBeliefTooMuchWorkAllTicks + TotalBeliefTooMuchWorkThisTick
29. Totaltrustoverruns is set Totaltrustoverruns + Totaltrust
30. TotalBeliefYieldAllTicks/GlobalAmountOfVisits is set TotalBeliefYieldAllTicks / GlobalAmountOfVisits
31. TotalBeliefCohesionAllTicks/GlobalAmountOfVisits is set TotalBeliefCohesionAllTicks / GlobalAmountOfVisits
32. TotalBeliefTooMuchWorkAllTicks/GlobalAmountOfVisits is set TotalBeliefTooMuchWorkAllTicks / GlobalAmountOfVisits
33. TotalTrust/Volunteer is set Totaltrustoverruns / GlobalAmountOfVisits
34. TotalRuleviolations/GlobalAmountOfVisits is set TotalRuleViolationsCount / GlobalAmountOfVisits
35. if count volunteers > 0, AverageTrust is set Totaltrust / count volunteers

Appendix B: link to Netlogo and R files

The Netlogo file, R files and full decision trees can be found following [this link].