Preference based decision support system for Waelpolder

Master Construction Management and Engineering

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Preference based decision support system for Waelpolder

An a priori design optimization approach (PDOA) as decision support system, applied to the urban development of Waelpolder

by

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Cover image: Illustrative imagine of Waelpolder Fullhouse vastgoed (2022).

TU Delft

Summary

Negotiations in urban development projects can take a long time, going back and forward to the designer many times, even leading to stalemate situations. Requirements can be set intuitively, without knowing what the side effects of the constraints will be for the urban development. On top of that, approval of all stakeholders is needed to be able to implement the design. An integral process of decision-making, with cooperation, open communication and considering everyone's opinion, seems to be challenging when it comes to urban development projects.

Current decision-making methods, such as Linear Programming, are lacking in terms of cooperation between parties, only finding a feasible design for a group of stakeholders and satisfying one party. Considering preferences helps overcome this problem. In this thesis, an a priori design optimization approach (PDOA) has been developed as decision support system, applied and tested on a real-life urban planning case, Waelpolder.

The PDOA returns a quantitative design (Program of Requirements) for the to be developed area which is considering preferences and wishes of stakeholders a priori, before a design is generated. By basing the design on preferences of stakeholders, intuitively determined requirements are avoided and designs will be more compliant to stakeholders' needs. The PDOA generates a design by optimizing on overall preference. So, finding a feasible solution is guaranteed, on top of that the approach is able to find a most desired group solution.

The Preferendus (based on Tetra) method, where stakeholders do not make the same amount of compromises in a design, is preferred to use in the PDOA rather than the goal attainment method, where stakeholders do the same amount of compromises. This is mainly because the Preferendus returns more extreme designs and can better show the impact of adjustments in requirements in comparison to the more moderate designs generated with goal attainment. In addition, the stakeholders of Waelpolder indicate that it is realistic that one party should do more compromises than another party within a project. Therefore, the Preferendus is better able to support decision-making and open up discussions.

The PDOA allows a new direction in decision-making, where negotiations become an open glass box rather than a black box. Openness & transparency, which is one of the fundamentals of the PDOA, takes away strategic play between stakeholders. Stakeholders are forced to express what they want upfront, before any design is created.

The approach supports negotiations in decision-making as it provides insights in a rapid and simple manner. The tool allows requirement modification, thereby showing the impact of certain requirements and presenting alternative possibilities. In addition, long negotiation processes where stakeholders need to get aligned are avoided because of the required openness and adaptability of the tool.

One of the stakeholders within Waelpolder is willing to implement the PDOA within its organization as slip school model in urban development projects, to investigate the effects of adjusting requirements. Due to the iterative value of the approach, the stakeholders are positive about using the approach in other area developments, in an early stage.

Preface

This thesis was written for the completion of the master Construction Management and Engineering at the faculty of Civil Engineering & Geosciences (CEG), conducted with the help of Planmaat, a company specialized in optimization techniques. The focus of this thesis is on a development where preference measurement is incorporated in urban development projects.

During this period, we learned many things. Not only did we develop knowledge about the details of urban development projects and the possibilities of decision-making processes, but also did we learn how to apply the decision-making models to a real-life area development case. This included a new aspect stakeholder engagement, which seemed to be a challenging aspect. Luckily, we had some great feedback, related to this topic, along the way.

Furthermore, we would like to thank our supervisors at the TU Delft, Rogier Wolfert and Ruud Binnekamp, for their supervision, feedback and guidance during our thesis. We feel honored that we were given the opportunity to conduct this thesis together. Moreover, Dmitry Zhilyaev (PhD student at the TU Delft), helped us in the construction of the preference-based model, for which we would like to thank him. His ideas and insights provided us with interesting information. Last but not least, we would like to thank Patrick Nan, for his enthusiasm on the subject, critical remarks based on his knowledge of model creation and stakeholder involvement, and encouragement to dive into urban development projects. His connection to urban development projects that are suitable to apply the development to, and the insights he gave during our meetings, were very helpful. We would also like to express our thanks to the employees of Planmaat, who participated in the testcase, and the involved stakeholders in the application to Waelpolder.

Both of us want to thank other people as well. I (Sabine) would like to thank my family and friends for supporting me along the way in this thesis. With full joy and interest, you listened to stories about my thesis even though some topics were entirely new to you.

In this way, I (Roel) would like to thank all people that were somehow involved and being supportive throughout the process. A special thanks to a dear friend of mine, Stijn, who gave the courage to keep going. Of course, I would like to express my appreciation towards Sabine for the collaboration during this period.

In front of you of the final product of this graduation project: "*Preference based decision support system for Waelpolder*". We sincerely hope you enjoy reading this thesis report.

Roel Nannes
Sabine van Eijck

Delft, August 2022

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1 Introduction

The municipality of Westland is willing to implement the a priori design optimization approach (PDOA) as decision-support system in their urban development projects, such as in the Waelpolder project. The PDOA allows a new direction in decision-making, where negotiations become an open glass box rather than a black box.

Requirements are set top-down for urban development projects within governmental organizations, without the policy makers knowing what the impact of certain standards will be on the possibilities for the urban development. On top of that, wishes and requirements of other stakeholders within the project must be considered. This can lead to situations where negotiations can take a long time, going back and forward to the designer many times, even leading to stalemate situations. An integral process of designing, considering everyone's opinion, seems to be challenging when it comes to urban development projects.

The developed PDOA is taking on another approach, where the quantitative design (Program of Requirements) for an area will be based on preferences and wishes of stakeholders. A design will be based on deep thoughts rather than top-down intuitively determined requirements of which the impact is unknown. Such designs will be more compliant to stakeholders' needs. In addition, the tool can instantly show the consequences of requirements in the design.

Stakeholders within the development of Waelpolder see added value in the iterative aspect of the tool. Being able to make modifications to requirements & preferences easily and getting insights into the consequences for the design directly, is experienced as an advantage of the tool by the stakeholders. In Waelpolder, the PDOA showed that more was possible than the stakeholders thought beforehand. The municipality of Westland wants to use the PDOA as slip school model to see how far they can go with adjusting requirements.

Applying the tool to a project in an early phase makes sure that all the facets of the tool can be used to its full capacity, resulting in concrete discussions. For this reason, the stakeholders of Waelpolder are willing to use the approach in other area developments. In addition, they want to use the obtained PoR with accompanied preferences to evaluate tenders.

This thesis substantiates the above-mentioned conclusions. It will provide a concise story in which all the key elements of the PDOA development will be discussed. A more elaborated version on the emergence of the PDOA can be found in the appendices of this document.

First, the thesis will dive into concepts such as negotiating and decision-making (instruments) and what is already known related to that aspect in chapter 2. From this literature research, a development gap followed in which a development goal was identified and the importance of developing the PDOA is addressed (chapter 3).

The working, usability, and acceptance of the invented approach is tested in two urban development cases. Based on these applications, conclusions can be drawn regarding the developed tool. The first two elements (the working and usability) are addressed in a test-case called Bloemendalerpolder (BDP) and is meant to improve the tool. The appliance to BDP will be discussed in chapter 5. The latter element (the acceptance of the tool among stakeholders) is tested in a real-life area development case called Waelpolder and is elaborated in chapters 6, 7 and 8.

The thesis ends with the key positive elements of the PDOA according to the stakeholders of Waelpolder (chapter 9) and the main conclusions regarding this development. Lastly, it will discuss recommendations for future research of the tool (chapter 11).

2 Analysis on current decision-making

In decision-making, two sides can be identified: a social side and a technical side. The social side is focusing on the social processes that take place during decision-making. The technical side is elaborating on decision-making methods that are used to accommodate decision-making. Both sides will be discussed in section 2.1. Preference modeling will be introduced in section 2.2. An elaboration on the literature can be found in appendix A.

2.1 Social & technical side

An important element of decision-making is the negotiations between stakeholders. During negotiations, stakeholders try to come to a joint solution. Fisher et al. (1993) describe in their book 'Excellent onderhandelen' the method of negotiating and important aspects in negotiating in order to come to this joint solution, five of these aspects are described in more detail in appendix A.3.

The main idea of Fisher et al. (1993) is to involve the stakeholders early in the process of negotiating. The feeling of involvement is perhaps the most important factor for a negotiator to accept a result since the stakeholder will consider the new idea as something of his own. Furthermore, it is key to find the reason behind the goal of a stakeholder. Reasoning the stakes can lead to insights and similarities within the stakes, even though they seem conflicting at first sight. If stakeholders find more stakes that they share, they could be more willing to make compromises in the agreement and to come to good terms. Being open and communicative about the reasoning behind a goal, makes it able to find mutual interests between the involved stakeholders. Such, they are more likely to settle with a more favorable option for parties involved. The other way around, not sharing their thoughts and holding their cards behind the table (black box), the solution is likely to be less favorable than making it open box such that they find a solution in mutual interest.

Finding a solution in mutual interest is of importance in urban development projects where a group solution needs to be found. If everyone is asked individually to choose a design, everyone would choose a different design. Parties need to cooperate with each other in order to come to a group solution that is in mutual interest.

The importance of looking further than only the obvious goals of parties during negotiations can be linked to what Kahneman (2013) is stating in his book 'Thinking Fast and Slow'. Kahneman (2013) constructed a theory in decision-making which is based on two ways of thinking. System 1 is referred to as the 'fast' thinking and is based on intuition and emotions. It is guided by instinct and experience. It happens automatically, like navigating to a friends' house. System 2, referred to as 'slow' thinking, is more deliberate, effortful, and analytical. System 2 is, for example, activated when solving a mathematical calculation.

Stakeholders that are in the negotiating phase of an urban development project could be using System 1 instead of System 2. They could only express their obvious goals without sharing the reason behind it or act out of emotion. It could become 'intuition' that a stakeholder wants something for an area, based on his experience. This could, among others, lead to miscommunications, long negotiations and stalemate situations in projects.

System 2 should be the foundation for decision-making rather than the intuitive, emotional thinking in System 1, Kahneman (2013). Opportunities can arise when reasons behind a goal are elaborated and communicated to other stakeholders.

There are several decision-making methods that can be used to select or design alternatives based on a thorough analysis, these are discussed in appendix A.1. An investigation into these methods show that they all have downsides. The CBA, MCDA and LP method are not able to incorporate cooperation between parties since they assume a focus on only one aspect, only satisfying one party instead of the entire group. In addition, the mathematical operations that are applied in these methods are incorrect following Barzilai (2010).

2.2 Preference modeling

A way to deal with the downsides of the described analyzing methods is to incorporate preferences. By incorporating preferences, the underlying thoughts are considered, and decision-making can easily be based on System 2. In addition, preferences allow cooperation and open communication between parties. Last, asking for preferences of stakeholders gives a feeling of involvement, such that understanding for a design will be created.

A method that incorporates preferences is PFM, invented by Barzilai (2010) and considers preferences a posteriori. For this method, the alternatives need to be created before the scoring can start which makes it time-consuming. It would be better to consider preferences a priori, before all alternatives are created, and create alternatives based on preferences. This is done in the PBD method of Binnekamp (2010). However, also the PBD has a pitfall. A 'brute force' approach is used to search for the alternative with the highest total preference since a large number of alternatives is generated and evaluated manually. Both the PFM and PBD are not able to cope with the many alternatives, therefore there is a chance of finding a feasible solution rather than the most desired solution which is most compliant to stakeholders' wishes.

Opportunities lay in further investigations on the PBD method, where alternatives can be generated and scored by the method itself automatically (a priori), rather than rate them manually.

In addition, it is interesting to investigate how stakeholders in real-world urban planning projects respond to a preference-based approach. A preference-based method is currently (at the start of this thesis) under development, for that development it would be interesting to test it in a real-life case with multiple stakeholders, Zhilyaev et al. (2022). Are those stakeholders will to accept the approach since it requires openness, transparency, and another way of thinking & expressing thoughts? Before testing this, the added value of the advanced method should be demonstrated by showing that the method can find a group solution which is more compliant to the stakeholders' wishes (the most desired solution) involved in an urban development project.

3 Development goal

The development goal of this thesis was:

To develop a non-linear preference model that enables support for urban development decisions, where the approach used in the model is accepted by the stakeholders and generates the most desired solution in group decision making.

On the one hand, the statement addresses the model that is developed, which returns the most desired solution when making a group decision. On the other hand, the statement focuses on the acceptance of the approach used in the model among the stakeholders. The development is referred to as PDOA, an a priori design optimization approach.

The PDOA is developed and tested by means of two cases. In the first case, the PDOA is applied to a test-case, a re-enacted urban development project (Bloemendalerpolder), to test the usability and the added value of the tool as decision support system. Besides that, improvements could be made during the test case before the model was applied to a real-life case.

Usability of the approach considers the ability of stakeholders to give input for the model, and an interpretation of the stakeholders related to the complexity of giving input based on their preferences.
The added value relates to the difference in overall preference score between the design generated with the PDOA and the design obtained with LP. Added value is achieved when the PDOA returns a higher overall preference score than the LP design. This implies that the design created with the PDOA is more compliant to the stakeholders' needs and the approach is able to find the most desired group solution.

The second case is focusing on the acceptance of the approach in a real-life case (Waelpolder). Since the stakeholders have a real stake within the project, they can empathize well on the situation rather than if a case would be re-enacted. In addition, the real-life case enables testing if the required openness, which is one of the 'pillars' of the approach, is accepted by the stakeholders that are in a negotiating phase of the design process. The approach is assumed to be accepted if stakeholders are positive about the approach and establish the benefit of using the approach in certain phases of a project.

4 The approach: elements & working

The PDOA is a decision-making support tool, that is based on the preferences of the involved stakeholders in a project and can support negotiation processes by showing an outcome based on the preferences of stakeholders. Getting stuck in long negotiations can be avoided by letting the tool decide and show the possibilities. The final design is the most desired quantitative program of requirements among all involved stakeholders. The approach has a specified way to search for a design and needs several input elements, both will be discussed in this chapter. A further (detailed) explanation of the working of the model and the method is given in appendix C.

4.1 Working of the approach

Figure 4.1 shows how the model tries to find the most desired group solution, going from preferences and constraints to a solution space. And within the solution space, finding the most desired solution based on the preferences. To make the working of the model comprehensible, it is explained by the means of a market example where one has to choose between apples and oranges. A more elaborate explanation is given in appendix G.4.
One person has a preference over the number of oranges and apples, which can be translated to the curves shown on the left, in fig. 4.1. He prefers seven oranges, as his preference is increasing to the highest number of oranges possible (100 preference), and he does not prefer zero oranges, as this results in a preference of zero. He has an ideal number of apples (two), and after two it slowly decreases again to a preference of zero at ten apples.

In the example two constraints are added, a budget and a weight one can carry in the bag. This results in a solution space, shown in the middle of fig. 4.1.

To find the most preferred solution in the solution space, in this example, the preferences of one person are put in a raster to be able to search for the square with the highest score. It optimizes on overall preference with the use of the Preferendus[1] (Zhilyaev et al. (2022)) in combination with Tetra SDM version 3.5.2., which results in the most preferred solution.

The example in fig. 4.1 only considers the preferences of one person, over two objectives, as it can be displayed in a 2D figure. When more preferences are considered, it would result in a multidimensional figure, this is the case for the model, but it cannot be visualized on paper.

[1]To enable convergence of the optimization algorithm (Genetic Algorithm) results within Matlab two extreme alternatives were added to each scale (0 and 100) which, compared to the current enhanced approach, is suboptimal. The enhanced approach is to make changes to the GA solver itself to enable proper convergence. However, this requires a change of programming language and conversion of all decision models to Python. At the time of executing the graduation project it was no longer feasible to make this change. Most important, when verifying the results obtained by the Matlab approach to the state-of-the-art Python approach with a modified GA algorithm, it was concluded that although the result differ, they can be considered an approximation.

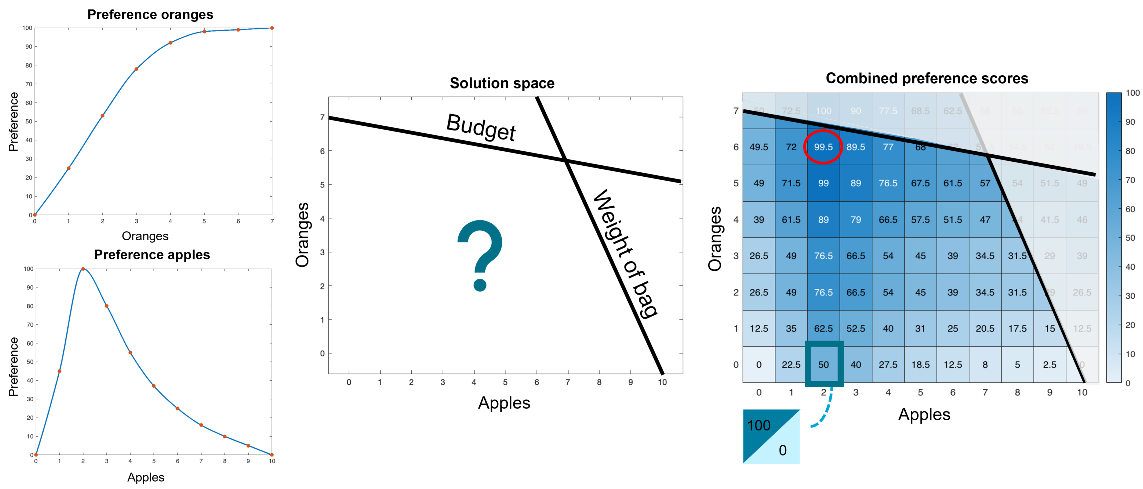


Figure 4.1: Visualization of the PDOA

4.2 Input elements

For the model behind the PDOA seven input elements are needed to be able to generate a design, these elements are listed below. Some of these elements are created and gathered by the System Engineers, other elements are input of the stakeholders themselves.

Design variables: Independent variable in the model that makes up the final design. The variables change during the optimization process to find the most desired design. With the data and relations, the design variables are connected to the objectives and constraints.
Constraints: The constraints enable the model to identify and exclude unacceptable designs and are defined by agreements made between the parties, legislation & policy or physical limitations.
Objectives: Objectives are based on the goals of the stakeholders within the project, are measurable and have a unit.
Preferences: Stakeholders express a preference between zero (not preferred) and hundred (preferred) over values of each of their objectives. These preferences are based on the wishes and perspectives of the stakeholders. The preferences are the main element of the model, the design will be based on the preferences, by calculating the overall preference.
Weights: Stakeholders assign a weight to each of their objectives, to indicate which objective is (more) important. Those weights will be used in the final calculation to come to a design.
Relations: Are the elements in the model that connect the other input elements and are created by the System Engineer.
Data: Is based on information, about properties of certain elements, such as the selling prices for housing types, or the parking norm for an area. This information is gathered by the System Engineer. The data makes it possible to create design variables, relations and objectives.

A further explanation on the input elements will be given in appendix F.2 and G.2, where there is touched upon the model development for both application cases.

5 Test-case BDP

Bloemendalerpolder (BDP) is an urban development project that took place 15 years ago. The project was in a stalemate position where a trade-off between result, greenery and housing had to be made. Planmaat created a LP model which was only optimized on one aspect: result. However, optimizing on one aspect does not show cooperation between parties and will not fulfill everyone's needs. In addition, the LP model of Planmaat did not come to a solution without having a major result deficit even though it was optimized on result. This shows that the problem was mostly related to the defined constraints.

Therefore, it can be investigated if there is added value when preferences would be involved in the model and cooperation between parties is established, such that a solution can be found that does satisfy the group of stakeholders. Besides, in this test-case it is investigated whether stakeholders are able to give preferences (input) for the approach.
For the application to the PDOA, the case is re-enacted with three stakeholders: the municipality, developers and a green party. The roles of the stakeholders were fulfilled by employees from Planmaat. From their work within Planmaat, they understand (mostly) the working of LP, however working with a nonlinear preference model is new to them. The model development for application of the PDOA to BDP can be found in appendix F.2.

During the application to BDP, three stakeholder sessions took place. Starting with a workshop (with all stakeholders) after which an individual session followed to gather the preferences of the stakeholders. It ended with a final workshop to discuss the results and reflect on the approach.

5.1 Goal A: added value

In table 5.1 the outcome of the LP method and the PDOA is shown. It can be concluded that the design that does not consider preferences (the LP solution) is different from the design where preferences are considered. It shows a delta in overall preference, in which the preference score is higher in the design considering preferences. This means that this design is more compliant (more responsive to the needs of the stakeholders).
The PDOA is always able to find a feasible solution. Besides that, it can be concluded that the PDOA looks for a most desired group solution (most fitted for purpose), compared to LP which is only able to find a feasible solution (fit for purpose) when optimizing on one aspect rather than preference. From these findings, it can be concluded that the PDOA has added value.

Table 5.1: PoR LP and PDOA optimized on preference

PoR	Unit	Optimization	
		LP model	Preference
Preference	-	48	74
Result	Million €	-11	35
Total area	ha	435	435
Costs	Million €	206	268
Revenues	Million €	196	303
Total amount of green	ha	336	292
Gemeenschapspolder	ha	196	198
Plas	ha	104	73
Sport/Zorglandgoed	ha	20	4
Stadspark Weesp	ha	15	18
Total area housing	ha	99	143
Total number of houses	Houses	1859	3000
Vechtstad	Houses	257	900
Weesp	Houses	565	650
Tuinbuurt	Houses	641	1000
Lint nat	Houses	310	350
Landgoed	Houses	86	100

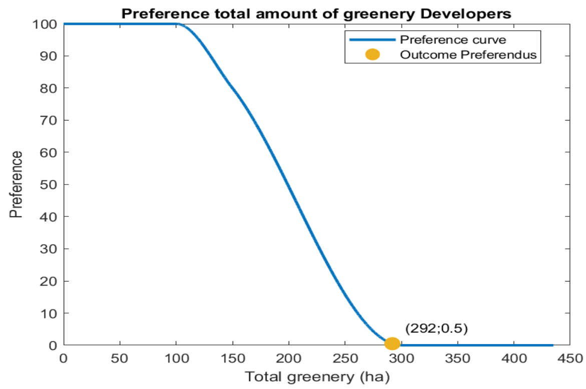
5.2 Goal B: usability

The PDOA can also be considered as usable for the stakeholders, since the BDP case shows that stakeholders are able to give input based on their needs and wishes. All the preference curves of the stakeholders, with the plotted design outcome, can be found in appendix H.5. However, stakeholders still find it difficult to give input without seeing a possible design first. This shows they find it hard to step away from the regular design process, determining what they really want after seeing a design first. The fact that the model should be an iterative process can help overcome this problem, as stakeholders are able to adjust their preference curves between each iteration such that they fully reflect their wishes.

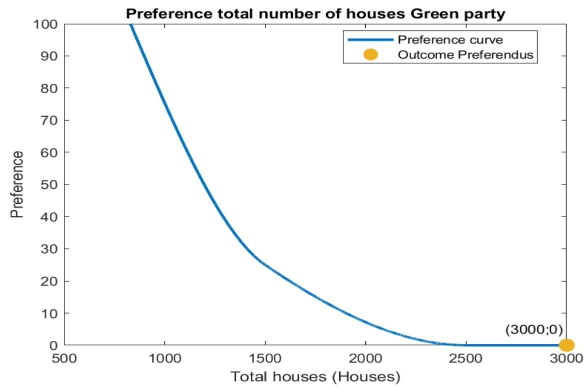
Besides that, stakeholders are willing to be transparent during the process, when it comes to expressing goals, needs & wishes, and preferences. Being transparent undermines the possibility for strategic play and holding the cards behind the table in such a process. It is advised to gather the preferences in individual sessions rather than in a group session, as a preference is something personal of the individual stakeholder. This avoids transparency issues and strategic influence of stakeholders on each other's preferences.

5.3 Improvements

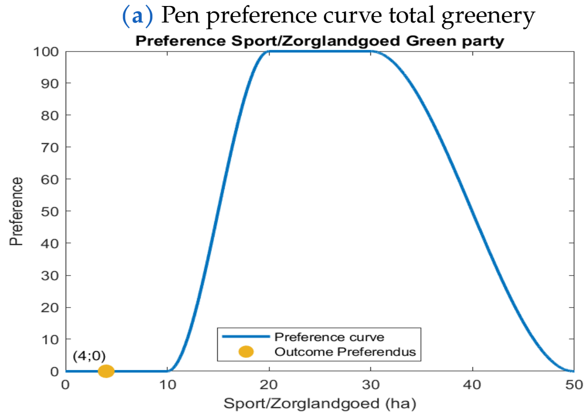
The personal preference scores of zero harmed the stakeholders in the belief of the Preferendus method, three examples are shown in fig. 5.1. The Preferendus method tries to search for a group solution, where it could be that one stakeholder has to do more compromises than another.
The observation of zero preferences raises the question if the stakeholders are willing to accept the outcome that is generated with a method that does not consider the amount of compromises each stakeholder makes.
Therefore, another method has been introduced to take into account in the second application. This new method is called goal attainment and is looking for a group solution where the amount of compromises that each stakeholder makes are considered. It tries to balance the compromises of the stakeholders by looking for a solution where every stakeholder is making about the same amount of compromises. A more detailed explanation on the goal attainment method is given in appendix E. It is interesting to investigate in the second application what method the stakeholders support the most, the Preferendus method or the goal attainment method, which is also suggested by Zhilyaev et al. (2022). This can have its influence on the total acceptance for the PDOA.



(a) Pen preference curve total greenery



(b) Pen preference curve total houses



(c) Pen preference curve Sport- en Zorglandgoed

Figure 5.1: Examples of zero preference scores

6 Real-life case Waelpolder

In Waelpolder subarea 5 a trade-off should be made between finances, area usage and quality. Three stakeholders were involved in the decision-making process, a financial director of the Ontwikkelingsmaatschappij (Development Company) 'Het Nieuwe Westland' (ONW), an urban planner and a representative of the municipality of Westland (referred to as the municipality). These stakeholders all have different goals in the project related to the trade-off that should be made.

During the application of the PDOA to Waelpolder, it was investigated, with the help of decision criteria, which method was preferred to come to a solution (goal attainment or Preferendus). Secondly, the focus was on the acceptance of the PDOA by the stakeholders and if they establish a benefit using the approach in a phase of a project. The outcome of both goals will be discussed in chapter 7 and 8.

The application to Waelpolder consisted of two stakeholder sessions per stakeholder, to go from goals of the stakeholders to measurable criteria to preference curves. Besides the two stakeholder sessions, a final workshop with all stakeholders took place.
The first stakeholder session focused on gathering the goals of the stakeholders, with the use of a speaking sheet. The speaking sheet, shown in fig. 6.2, elaborated on the four main problems in subarea 5.
The goals of the stakeholders were translated to objectives, in between the sessions by the System Engineers. The second stakeholder session started with a small summary where the stakeholders could reflect on their goals and their objectives. With the use the PAS webtool created by Arkesteijn (2019), preferences over the objectives were gathered.
Besides the preferences, weights for the objectives, to let stakeholders express the importance of the different objectives, were gathered using the same PAS tool. More information on the usage of the PAS tool is given in appendix D.2.

An example of a goal, translated into measurable criteria over which preferences were expressed is shown in fig. 6.1, and the relating preference curves in fig. 6.3. In the example, the stakeholder aims for diversity in housing types. Diving into this goal shows that he wants an attractive area by building diverse housing types. The diversity is translated into measurable criteria, several housing types that can be expressed in number of houses. The stakeholders' preference curves show that he aims for the maximum of expensive houses. Since it is already known that there will be social and affordable houses in the area, the stakeholder wants to have the minimum number of these types to preserve diversity in the area.

Goal ↑	Problems	Criteria	Unit
1. Diversity in housing	An attractive area can be achieved with diversity in housing. The subarea should not become a uniform area with the same kind of houses.	1.1 Affordable houses	Houses
		1.2 Social housing	Houses
		1.3 Expensive houses	Houses

Figure 6.1: Example of a goal translated into a criteria using PAS

During the workshop, the output of the PDOA and the working of the approach was discussed with all the stakeholders, as elaborated in appendix G.4. Besides that, the workshop gave the stakeholders a possibility to reflect on the entire process.

The model development for application of the PDOA to Waelpolder can be found in appendix G.2.

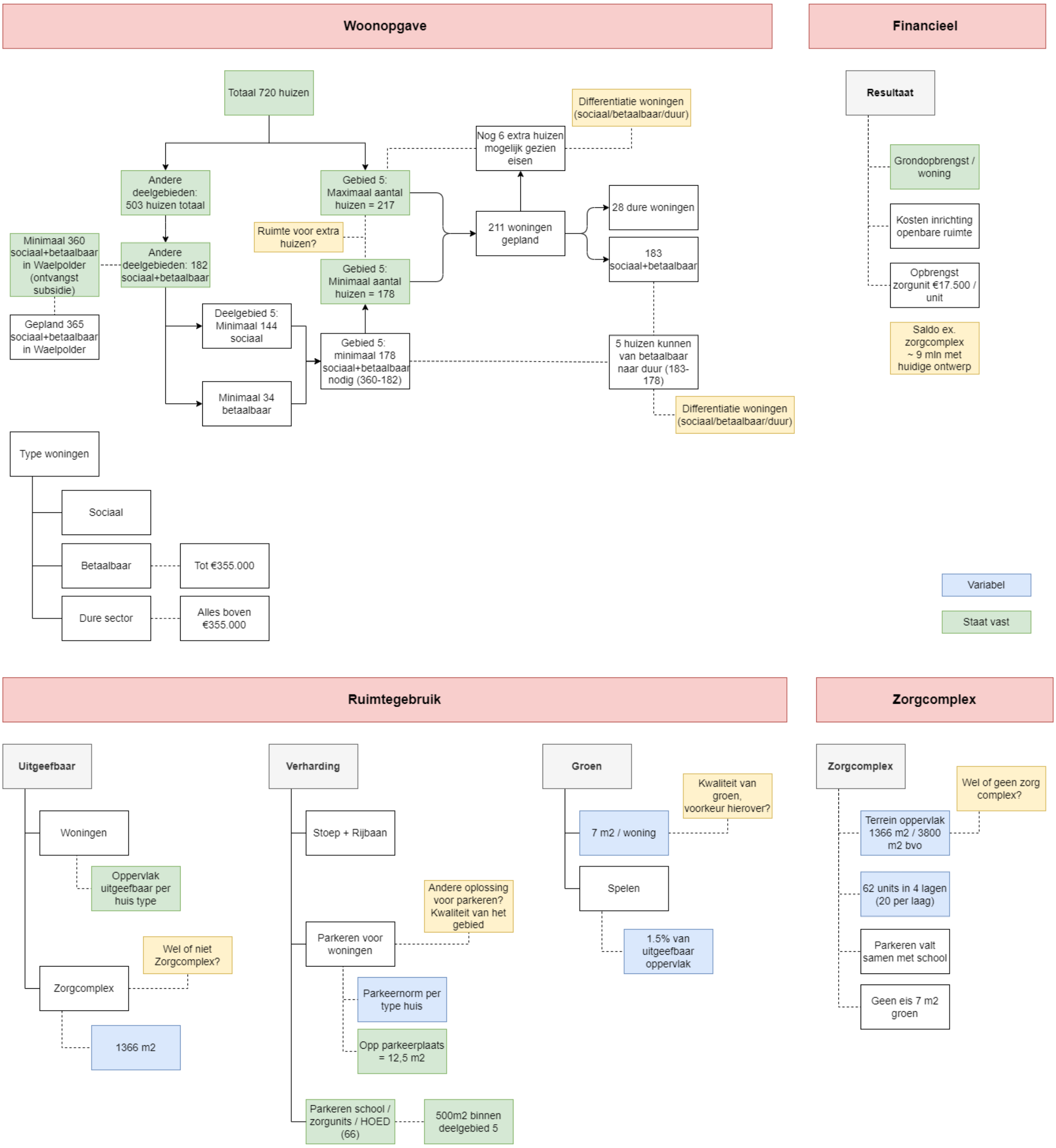
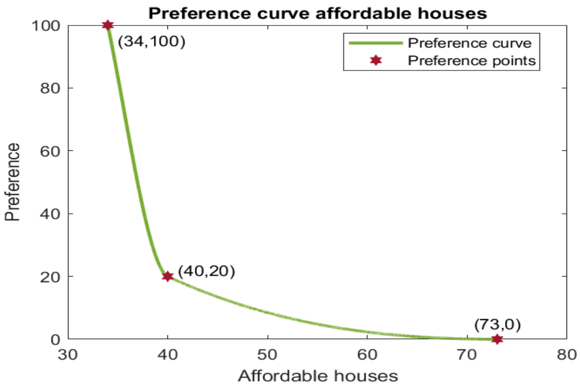
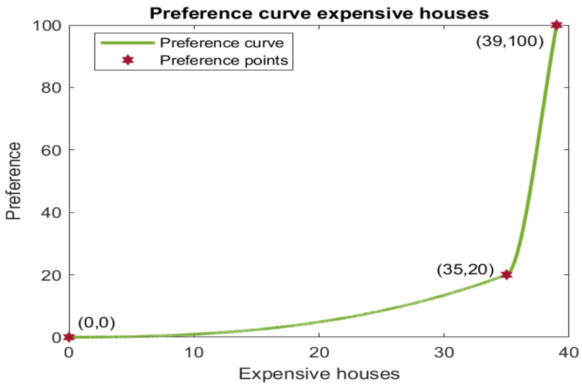


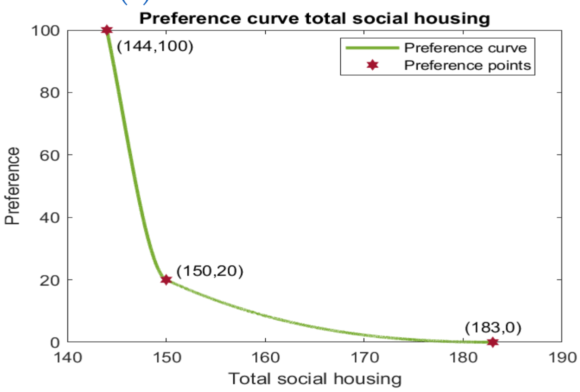
Figure 6.2: Speaking sheet Waelpolder, as showed to the stakeholders



(a) Preference curve affordable houses



(b) Preference curve expensive houses



(c) Preference curve total social housing

Figure 6.3: Examples preference curves

7 Goal A: Preferendus vs. goal attainment

The first goal of the application to Waelpolder was to investigate which method, Preferendus or goal attainment, is suited to use to support a decision-making process. The differences between the Preferendus and goal attainment will first be explained, after which the decision criteria will evaluate which method is preferred to use. Following from this is an analysis on these criteria and a conclusion regarding the first goal in this application.

7.1 Differences in method

The Preferendus and the goal attainment method differ in the amount of compromises each stakeholder makes on the group design. Using the Preferendus method, where the overall preference score is maximized to find the most desired group solution, the amount of compromises per stakeholder on the solution can be far apart. The goal attainment method is minimizing the total distance to each stakeholders' goal over different objectives, where the compromises of each stakeholder on the group solution is more equal.

The difference between the methods is shown in fig. 7.1, where the design outcomes per method are plotted per stakeholder in comparison to his personal best outcome. The distance to the personal goals is almost equal for the goal attainment group design. This is different for the Preferendus group design, where the distances between each stakeholders' personal goal vary and the stakeholders do not make the same amount of compromises related to the design.

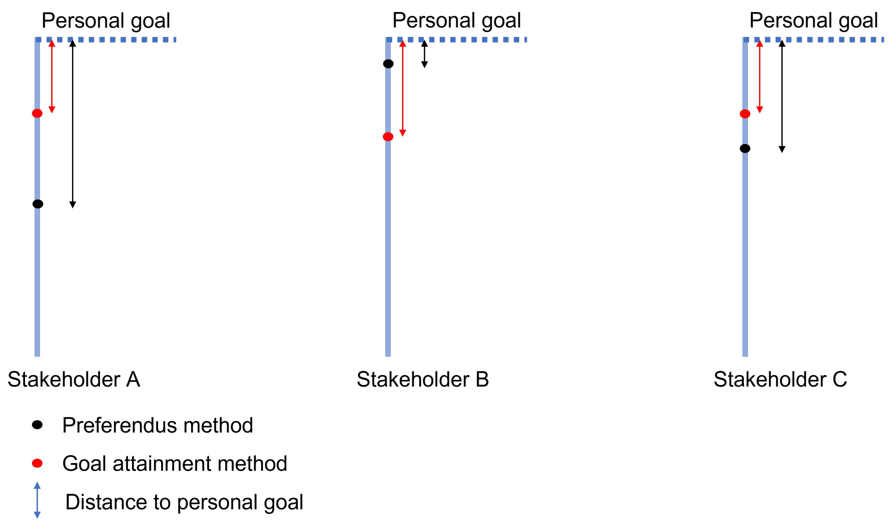


Figure 7.1: Difference Preferendus and goal attainment

7.2 Decision criteria

To get an answer which method is most suitable for the purpose of finding the group solution, several criteria are determined on which a conclusion can be drawn.

7.2.1 Type of solution

The type of design refers to what kind of design the stakeholders are looking for, a design where one stakeholder makes more compromises than another or a design where this is approximately equal. This question could be answered by the stakeholder and was asked before the outcome was shown to them, so the answer would only be based on the storyline of the working of both methods and not on a design outcome.

Outcome

The stakeholders chose the Preferendus method unanimously, to come to a design. They think it is realistic to that one stakeholder should make more compromises than the other. They are looking for a unique design which is in their opinion more likely to be obtained with the Preferendus method, rather than a moderate design with goal attainment.

7.2.2 Amount of compromises in designs

The actual amount of compromises that every stakeholder makes in the design was analyzed to verify (before the workshop started) if the assumptions about the amount of compromises in both methods are correct. Both designs were analyzed by looking at the overall outcome first, comparing the designs, overall preferences and distances. Next to that, the overall distance to the personal goal of each stakeholder was analyzed and the designs of both methods were plotted on interesting preference curves. These findings also indicate an expected design choice for each stakeholder, based on the design.

Outcome

The following designs are generated, as shown in table 7.1, with the Preferendus and the goal attainment method.

Table 7.1: PoR for Preferendus and goal attainment

		Unit	Optimization with Preferendus	Optimization with goal attainment
	Preference	**-**	**73.6393**	72.3
	Distance to goal	**-**	37.9741	**27.9082**
Finances	Revenues	Million €	11.7971	12.5167
Green	Greenery per house	m^2 / house	50	49.0253
Parking	Deviation parking norm	-	0.8	0.8
	Houses with built-in parking	%	8.2949	13.0188
	Parking spaces with a roof	m^2	2500	2375
Category houses	Total number of houses	Houses	217	217
	Affordable housing	Houses	43	34
	Total social housing	Houses	144	144
	Social rental	Houses	112	104
	Social owner-occupied	Houses	32	40
	Expensive housing	Houses	30	39
	Single-family housing	Houses	54	11
	Multi-family housing	Houses	163	206
Quiet neighborhood	Quiet neighborhood	-	0.2	0.2
Healthcare center	Healthcare center	Units	62	62
Housing differentiation	EG soc kp <€194.000	Houses	21	-
	EG sociale huur	Houses	-	-
	EG bereikb kp <€231.500	Houses	1	-
	EG betaalb kp <€310.000	Houses	4	-
	EG rijwoning €375.000	Houses	9	-
	EG 2/1kap €542.500	Houses	3	-
	EG vrijstaand klein €585.900	Houses	7	11
	EG vrijstaand groot €672.300	Houses	-	-
	EG verandawoning €328.000	Houses	-	-
	EG drive-in €355.000+€25.000	Houses	9	-
	MG sociale huur	Houses	112	104
	MG sociale kp <€194.000	Houses	4	40
	MG kp €291.000	Houses	29	34
	MG duur geb P	Houses	2	28
	MG sociale kp <€194.000 geb P	Houses	7	-
	MG kp betaalbaar, geb P onder dek	Houses	9	-
	MG kp €290.000+€20.000 alles geb P	Houses	-	-

Overall outcome
The outcome shows that the goal attainment design is more connected to revenues, as it shows a higher revenue and a design with the more profitable housing types. This can be justified since the goal attainment calculates the distances considering the weight distribution and the financial director gave such a high weight to this objective (revenues). As the amount of compromises among the stakeholders should be around equal with goal attainment, the revenues are heavily considered in the design. In addition, there is a significant difference in distribution of the housing types, where the goal attainment design shows a more moderate distribution than the Preferendus design.

Calculating the related overall preference for the goal attainment design shows that the overall preferences lay close to each other in the Preferendus and goal attainment design (respectively 73,6 to 72,3). This small difference can be related to the fact that the solution space is small in the Waelpolder case, so differences between the methods are less visible. However, the Preferendus design shows the highest preference score (as expected).
The distance to the goal for both designs is not relevant to compare with each other since the distance shows a maximum distance for one stakeholder to one objective and is not an overall distance.

Personal outcomes
Figure 7.2[1] shows that the distances of the stakeholders are closer to each other for the goal attainment design than for the Preferendus design. So, the amount of compromises each stakeholder makes is around equal in the goal attainment design and less equal in the Preferendus design. Hereby, the expectations are verified. The financial director makes the most compromises in the Preferendus design so he would benefit most from when choosing the goal attainment design.

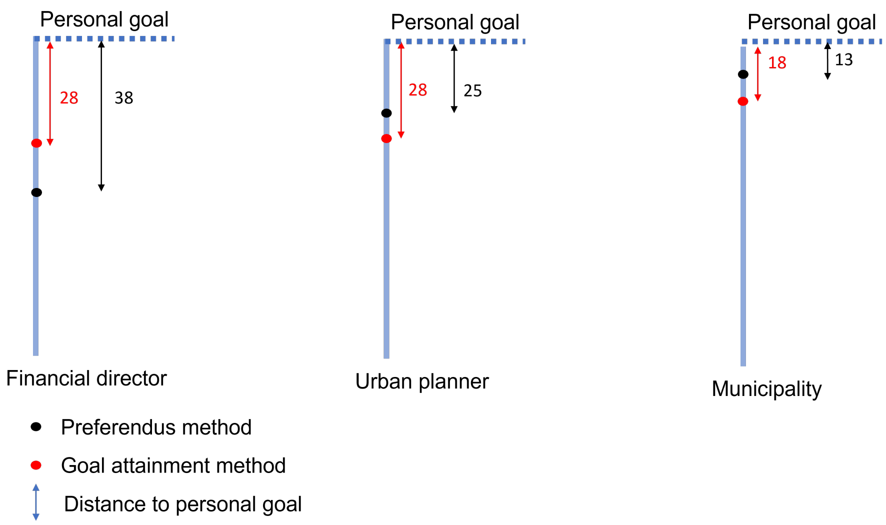


Figure 7.2: Difference Preferendus and goal attainment for Waelpolder

The interesting outcomes per stakeholder are discussed in the next sections. An elaboration on the outcomes and the plotted designs on all preference curves can be found in appendix I.4.

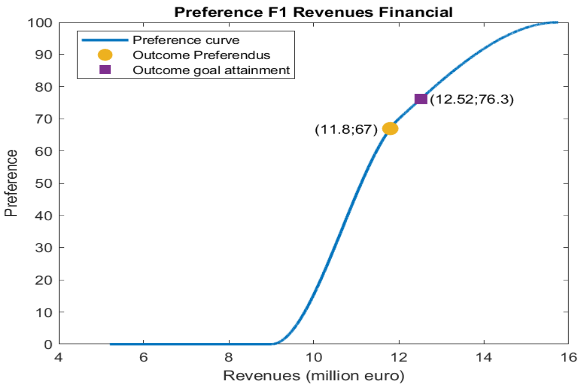
Financial director
As stated earlier, the financial director scores better on the design obtained with goal attainment method. The distance from his personal goal, considering all his objectives and weights, is smaller in the goal attainment design (28) than in the design with the Preferendus (38). This outcome is expected since the revenues are highly important for the financial director (he assigned a weight of 90% to this objective) and the goal attainment design generates the highest revenue.

Plotting both designs on the most interesting preference curves for the financial director (where there is a large difference in outcome between both methods) shows indeed that he has higher preferences on objectives with the goal attainment design.

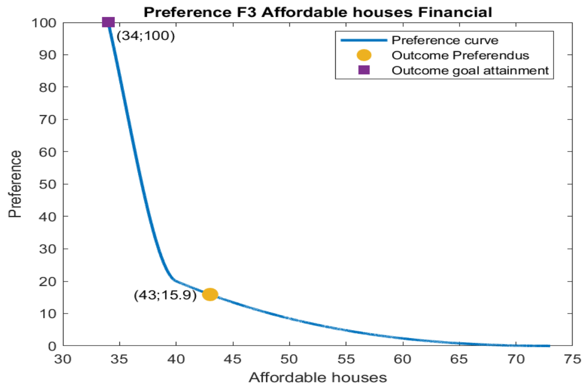
[1]Figure 7.2 is not on scale, the length of the arrows is an approximation and are only to give an idea of distances.

The financial director scores a preference of 76.3 on the revenue objective in the goal attainment design in comparison to 67 in the Preferendus design, as shown in fig. 7.3a.

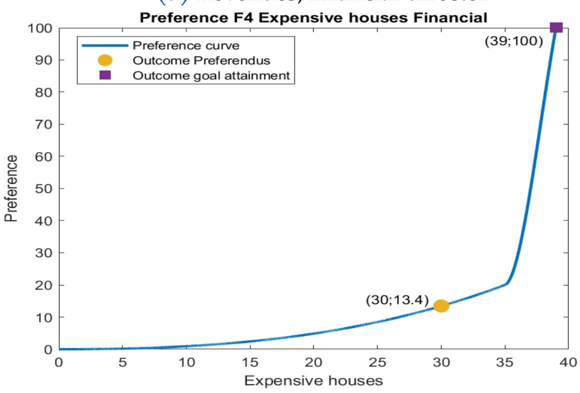
The outcomes for affordable houses and expensive houses go hand in hand, those are almost the direct opposite in both designs. The financial director scores significantly better for both types of housing with the goal attainment design, as can be seen in fig. 7.3b and fig. 7.3c.



(**a**) Revenues, financial director



(**b**) Affordable houses, financial director



(**c**) Expensive houses, financial director

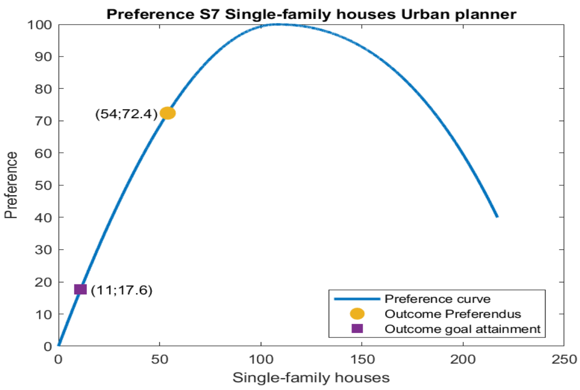
Figure 7.3: Interesting preference curves for the financial director ONW

Urban planner

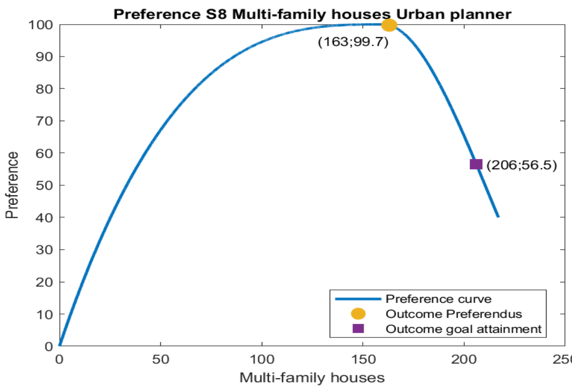
For the urban planner, the distance from his personal goal is smaller in the Preferendus design (25) than in the design with goal attainment (28). Based on this, it would be likely that the urban planner chooses the design created with the Preferendus method. However, the designs are close to each other, which can also be seen in the scoring of both designs on several objectives, that can be found in appendix I.4.

The Preferendus design shows a better mixture between single-family and multi-family houses, which is an important objective for the urban planner, than the goal attainment design. This is shown in fig. 7.4a and fig. 7.4b where the total number of single-family and multi-family houses have a significant higher preference score with the Preferendus design.

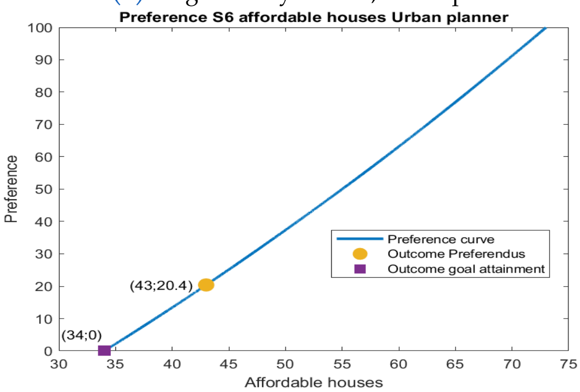
The outcomes for affordable houses and expensive houses go hand in hand, those are the opposite between the two designs, made with the Preferendus and the goal attainment. For the goal attainment method, the urban planner scores way better on expensive houses (shown in fig. 7.4d) than on affordable houses (fig. 7.4c). For the Preferendus method the exact opposite holds, a high preference score for affordable houses and a low score for expensive houses. Leading to a large difference between the two designs related to this objective.



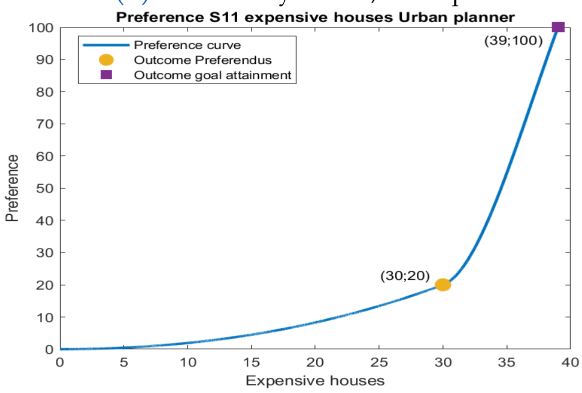
(a) Single-family houses, urban planner



(b) Multi-family houses, urban planner



(c) Affordable houses, urban planner

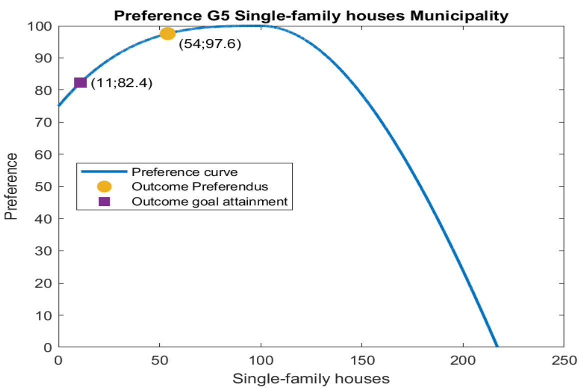


(d) Expensive houses, urban planner

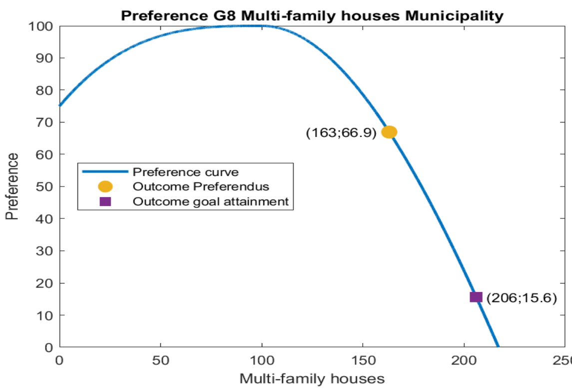
Figure 7.4: Interesting preference curves for the urban planner

Municipality
Taking into account all the objectives from the municipality, the Preferendus creates a smaller distance to her personal goal than the goal attainment design. The distance from her personal goal is 13 in the Preferendus design compared to 18 in the goal attainment design. Based on this, it would be likely that the municipality chooses the design created with the Preferendus. This choice is substantiated by looking at several preference curves of the municipality.

For example, the Preferendus design has a better mixture between single-family and multi-family houses than the goal attainment design. This is shown in fig. 7.5b where the total number of multi-family houses has a higher preference.



(a) Single-family houses, municipality



(b) Multi-family houses, municipality

Figure 7.5: Interesting preference curves for the municipality

Conclusive, it can be stated that in the designs for Waelpolder subarea 5 the total amount of compromises per stakeholder in the goal attainment method is more equal among the stakeholders than in the Preferendus method, as expected. In addition, the expected choice for a method differs per stakeholder.

7.2.3 Design choice

Next to the first and second criterion, the actual design choice by the stakeholders is a criterion as well. Would the stakeholders still make the same choice for a design, as argued in criterion one and two, if they did not know which design was generated with which method? This question was asked to each stakeholder individually when showing both designs next to each other without indicating which design is generated with which method.

Outcome

The stakeholders chose the design that suited them most, regardless from the method that is used. The preferred design was the design which was most compliant to the personal wishes. This is for the municipality and the urban planner the design generated with the Preferendus and for the financial director the design generated with the goal attainment method, so never leads to an unanimously answer related to a method.
Conclusive, the stakeholders will always choose a design that suits him best, even though it may hurt other stakeholders. With respect to the third criterion, no conclusions can be drawn regarding a preferred method.

7.2.4 Sensitivity for a power game

It can be idealistic to assume equal weights between stakeholders. Because, in practice, a power game between the stakeholders can occur. Overconfidence – where one thinks his contribution is more important than it is – is one of the most significant decision-making biases according to Kahneman (2013). Therefore, both methods and the sensibility for a power game are tested.

Three cases were analyzed, in which each stakeholder gets significantly more weight than the others (respectively 80%, 10%, 10%). The new designs for the Preferendus as well as for the goal attainment can be compared to the design in which the stakeholders are assumed to be equal. By looking at the amount and the scale of differences in the design values, conclusions were drawn which method is most sensitive for a power game. These conclusions gave insights in which method to use in a negotiation process. The criterion can be seen as a verification step for both methods.

Outcome

Table 7.2 and table 7.3 show, for both methods, a comparison between the regular design and the designs with a different weight distribution between the stakeholders. Some numbers that differ significantly with the regular design are colored red to be able to compare the designs easily.

Preferendus
Comparing the designs shows that all designs differ a lot with the regular design created with the Preferendus. Especially the designs where the municipality and the urban planner have more weight differ from the regular design, there is a larger differentiation in housing types when those two stakeholders are given more weight.

All three designs generate a higher overall preference and show a design in line with expectations, looking at the weights of the stakeholders' goals and objectives. The design focusing on the financial director shows higher revenues. The design of the municipality shows a high green norm and a housing distribution according to her wishes (low total number of houses and high number of social houses). The urban planner's design shows a high green norm, and the parking related subjects (deviation in parking norm and houses with built-in parking spaces) have values as expected.

The differences in the designs show that the Preferendus is sensitive for changes in weight distribution between the stakeholders. It shows differences related to all subjects in the PoR, which indicates extreme outcomes.

Table 7.2: Sensitivity to powergame Preferendus

		Unit	Preferendus	Preferendus Financial 80%	Preferendus Municipality 80%	Preferendus Urban planner 80%
	Optimization value	**-**	**73.6393**	**82.2108**	**80.4368**	**77.1306**
Finances	Revenues	Million €	11.80	14.35	8.40	6.76
Green	Greenery per house	m^2 / house	50	5.01	49.98	50
Parking	Deviation parking norm	-	0.8	0.85	0.8	0.81
	Houses with built-in parking	%	8.29	6.91	22.43	50.23
	Parking spaces with a roof	m^2	2500	0	400	75
Category houses	Total number of houses	Houses	217	217	214	217
	Affordable housing	Houses	43	44	45	38
	Total social housing	Houses	144	144	169	179
	Social rental	Houses	112	122	130	104
	Social owner-occupied	Houses	32	22	39	75
	Expensive housing	Houses	30	29	-	-
	Single-family housing	Houses	54	52	82	106
	Multi-family housing	Houses	163	165	132	111
Quiet neighborhood	Quiet neighborhood	-	0.2	0.0	0.2	0.5
Healthcare center	Healthcare center	Units	62	93	62	-
Housing differentiation	EG soc kp <€194.000	Houses	21	3	24	-
	EG sociale huur	Houses	-	16	57	103
	EG bereikb kp <€231.500	Houses	1	-	-	-
	EG betaalb kp <€310.000	Houses	4	-	1	2
	EG rijwoning €375.000	Houses	9	-	-	-
	EG 2/1kap €542.500	Houses	3	6	-	-
	EG vrijstaand klein €585.900	Houses	7	16	-	-
	EG vrijstaand groot €672.300	Houses	-	7	-	-
	EG verandawoning €328.000	Houses	-	4	-	1
	EG drive-in €355.000+€25.000	Houses	9	-	-	-
	MG sociale huur	Houses	112	106	73	1
	MG sociale kp <€194.000	Houses	4	16	11	-
	MG kp €291.000	Houses	29	28	-	1
	MG duur geb P	Houses	2	-	-	-
	MG sociale kp <€194.000 geb P	Houses	7	3	4	75
	MG kp betaalbaar, geb P onder dek	Houses	9	11	23	11
	MG kp €290.000+€20.000 alles geb P	Houses	-	1	21	23

Goal attainment

For the goal attainment design, the design mostly changes when the municipality gets more weight, especially in the category of houses that are generated. The design is least sensitive to a heavy weight for the financial director. This is as expected since the financial director has a high weight on his objective for revenue (90%) which means the regular goal attainment design already takes this into account strongly.

All three designs generate a smaller distance and show a design in line with expectations, looking at the weights of their goals and objectives. The design focusing on the financial director shows higher revenues. The design of the municipality shows a high green norm and a housing distribution according to the wishes (low number of expensive houses and a high number of social houses). The urban planner's design also shows a high green norm, and the parking related subjects (deviation in parking norm and houses with built-in parking spaces) have values as expected.

Besides the changes in goals when a stakeholder gets more weight, the designs also show a shift in housing types. The designs show that when the urban planner gets more weight, there is more differentiation in housing types compared to when the other stakeholders get more weight. The housing differentiation where the financial director gets more weight comes closest to the housing differentiation in the regular design with goal attainment. This can again be explained by the fact that the regular design considers the financial director strongly.

Overall, there are more differences between the designs and the regular design generated with the Preferendus than with the designs and the regular design generated with goal attainment. The Preferendus shows more extreme outcomes rather than the goal attainment method showing moderate outcomes. For a model supporting negotiations, the Preferendus method is assumed to be a better fit since it can show extreme outcomes and consequences of changes in values and requirements. The impact of changing values becomes more apparent when using the Preferendus rather than using goal attainment with moderate outcomes. Therefore, the Preferendus is better able to support negotiations and discussions than the goal attainment where changes in the requirements return moderate outcomes.

Table 7.3: Sensitivity to powergame goal attainment

		Unit	Goal attainment equal weights	Goal attainment Financial 80%	Goal attainment Preference Municipality 80%	Goal attainment Preference Urban planner 80%
	Optimization value	**-**	**27.9082**	**5.0787**	**5.4901**	**9.6478**
Finances	Revenues	Million €	12.52	14.36	11.07	8.15
Green	Greenery per house	m^2 / house	49.03	5	50	49.99
Parking	Deviation parking norm	-	0.8	0.8	0.8	0.8
	Houses with built-in parking	%	12.9	22.6	0	46.5
	Parking spaces with a roof	m^2	2375	0	2637.5	725
Category houses	Total number of houses	Houses	217	217	217	217
	Affordable housing	Houses	34	34	66	34
	Total social housing	Houses	144	144	150	144
	Social rental	Houses	104	104	144	104
	Social owner-occupied	Houses	40	40	6	40
	Expensive housing	Houses	39	39	1	39
	Single-family housing	Houses	11	32	38	79
	Multi-family housing	Houses	206	185	179	138
Quiet neighborhood	Quiet neighborhood	-	0.2	0.2	0.0	0.5
Healthcare center	Healthcare center	Units	62	62	93	-
Housing differentiation	EG soc kp <€194.000	Houses	-	-	1	2
	EG sociale huur	Houses	-	-	12	67
	EG bereikb kp <€231.500	Houses	-	-	-	1
	EG betaalb kp <€310.000	Houses	-	-	24	-
	EG rijwoning €375.000	Houses	-	-	-	1
	EG 2/1kap €542.500	Houses	-	-	-	-
	EG vrijstaand klein €585.900	Houses	11	32	1	-
	EG vrijstaand groot €672.300	Houses	-	-	-	-
	EG verandawoning €328.000	Houses	-	-	-	3
	EG drive-in €355.000+€25.000	Houses	-	-	-	5
	MG sociale huur	Houses	104	104	132	37
	MG sociale kp <€194.000	Houses	40	-	5	-
	MG kp €291.000	Houses	34	32	42	-
	MG duur geb P	Houses	28	7	-	33
	MG sociale kp <€194.000 geb P	Houses	-	40	-	38
	MG kp betaalbaar, geb P onder dek	Houses	-	2	-	3
	MG kp €290.000+€20.000 alles geb P	Houses	-	-	-	27

7.3 Conclusions regarding goal A

Based on the results of the decision criteria it can be stated that the Preferendus is best fit for purpose as supporting negotiations tool. Stakeholders think it is realistic that one party should do more compromises than another party within a project. In addition, the Preferendus returns more extreme designs and can show the impact of adjustments in requirements better in comparison to the more moderate designs generated with goal attainment.

8 Goal B: Acceptance of PDOA

The second goal for Waelpolder was to test the acceptance of the PDOA. Investigating the acceptance is linked to the entire process of the PDOA, starting with the input and ending with a PoR. The approach is accepted if the stakeholders establish added value to use the approach and are able to give input related to their preferences. Acceptation is not linked to the acceptance of the outcome of the model, which the stakeholders could not answer in this case. Since, in this project, the stakeholders are the not the ones that create such a detailed design. They are the ones that define the outlines for a tender. Within the boundaries of the tender, they want to see what a company will create as a detailed design. Therefore, the stakeholders are not in a position that they would or would not accept the PoR of the model. So, the outcome of the model is only used to give them answers on the considerations that the stakeholders had to make for this project, taking into account everyone's preferences.

8.1 Input

During the application to Waelpolder, the stakeholders were able to give input for the model. But there are three struggles for the stakeholders regarding the construction of the preference curves. They all relate to the fact that the impact of their preferences curves is unknown as the input is gathered before the outcome is shown.

8.1.1 Proxy curves

It occurred, when creating a preference curve, other criteria than purely the single criterion itself were kept in mind by the stakeholders. The preference curve over the criterion then becomes a so-called 'proxy' curve: a curve where the stakeholder shapes the curve in such a way that it will be beneficial for another objective. For example, the municipality used the green standard as the basis for the definition of her preference curve for the total number of houses, this curve is shown in fig. 8.1. She wants the minimum number of houses, so it will leave enough space for greenery. However, greenery is already another objective for this stakeholder. It is difficult for the stakeholders to look purely at one criterion without thinking how this objective can help in reaching another objective.

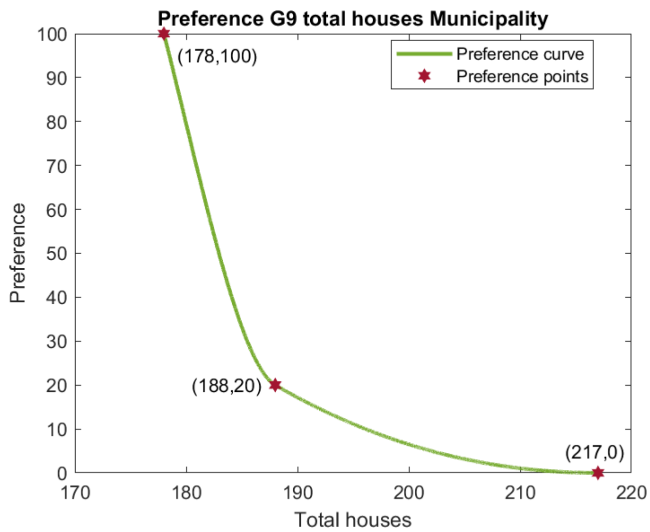
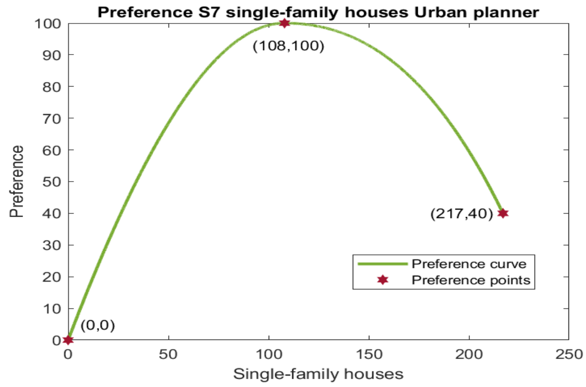


Figure 8.1: Example proxy curve

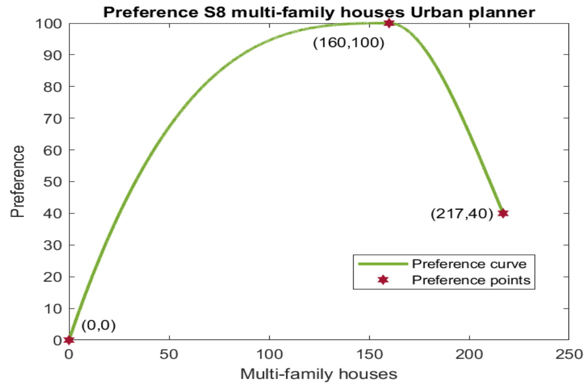
8.1.2 Parabolic curves

The fact that stakeholders find it hard to only focus on one objective alone is the reason for some parabolic preference curves. This does not mean that every parabolic curve is based on more than one objective, like the curves for single-family and multi-family houses of the urban planner, the urban planner just wants to have a mixture between the two, as can be seen in fig. 8.2a and fig. 8.2b.

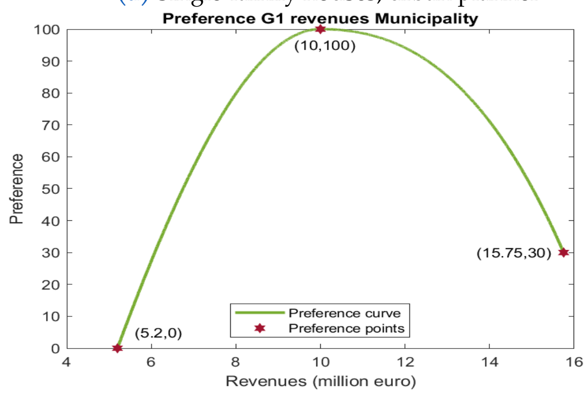
The municipality's preference curve for revenues (fig. 8.2c) has a parabolic shape. One could argue that it is odd that a stakeholder would not be happy with more revenues if the focus would be solely on the financial aspect. However, the municipality already thinks one step ahead and knows that the high revenues can only be reached when expensive houses are built. She lets the curve raise up to 10 million since that is the point from where she will be satisfied (one objective). She lets the curve drop after 10 million revenues because she does not want expensive houses in the area (another objective). In this way, a parabolic curve appears. It seems difficult for the stakeholders to only think about one objective, and not let two or more objectives define one curve.



(a) Single-family houses, urban planner



(b) Multi-family houses, urban planner



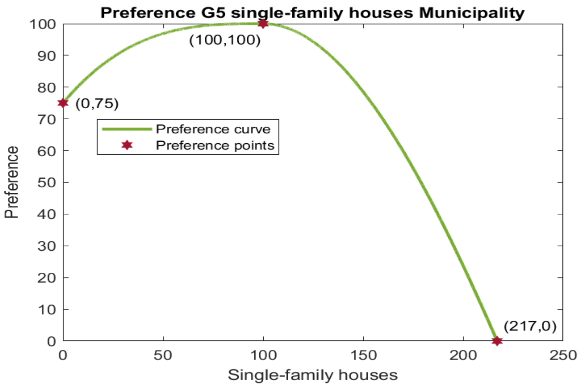
(c) Revenues, municipality

Figure 8.2: Examples of parabolic curves

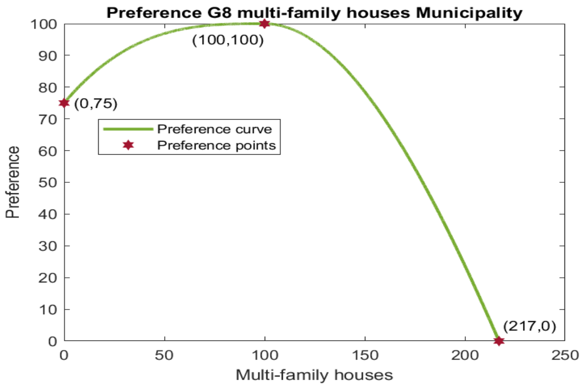
8.1.3 Intermediate point on the curve

It was observed by the System Engineer that the stakeholders find it a technical challenge to determine their preference curve because they do not know what the impact will be on the outcome. They find it difficult that they do not know what the outcome would look like. The issue that the stakeholders do not have a clue what the impact on the outcome will be, has an impact on the determination of the intermediate preference point on the curve. Stakeholders find it difficult to determine an intermediate point that defines the shape of their curve. The impact of their curve is not known yet, so they are 'guessing' on the intermediate point. Statements as *"Just set the number of houses around 100 houses"* are common, as shown in fig. 8.3. Here, the System Engineer plays an important role, helping the stakeholder to identify the intermediate point because a stakeholder finds it difficult to identify this by himself. The System Engineer translates the statements about an objective of a stakeholder into a certain shaped preference curve, after which the stakeholder confirms if this shape reflects what he is thinking.

The fact that the System Engineer takes on a helping role could mix up the roles between a stakeholder and a System Engineer. It can let the stakeholders give the feeling as if the System Engineers generates an outcome. This is in contrast with the approach, where the model outputs the best design based on the input of the stakeholders.



(a) Single-family houses, municipality



(b) Multi-family houses, municipality

Figure 8.3: Examples of curves with guessed intermediate point(s)

8.2 System 2 thinking

The PDOA is able to show the stakeholders what happens when intuition is left behind and the design would be based on the rational thinking and preferences of the stakeholders. The PDOA enables this, two-folded shift between intuition and rationality.

On the one hand, stakeholders often do not know exactly what they want specifically, but they have an idealistic thought which relates to one aspect only. For example, the urban planner wants to have as much quality in the area as possible. Quick thinking would say the urban planner only focuses on quality. However, what does quality mean exactly? By thinking through and let the urban planner express what he wants in multiple preferences, System 2 will be activated. The PDOA ensures that System 2 can be activated in an easy way, which will help in the negotiations in the design phase in urban development projects.

On the other hand, the tool tackles decision-making based on intuition (System 1 thinking). If stakeholders think fast (System 1), they could immediately draw the conclusion that something is not possible. For example, intuition was leading to a discussion about the minimal green norm and seemed to be a big issue during the negotiations within Waelpolder. The intuition of the stakeholders let the discussions go about this minimal value. However, the confidence to trust those intuitions, even when that intuition is wrong, is a problem according to Kahneman (2013). The model showed that the amount of greenery was not a problem at all, since almost every design showed that the minimal green norm was easily met. So, the model showed there was more possible than thought of beforehand and the intuition related to this aspect was not accurate.

One of the strategies that Kahneman (2013) suggests for better decision-making is to not trust people, but trust algorithms. Algorithms tend to be significantly more accurate than human beings, as it takes away intuition, acting out of emotion and fast thinking, and should be used when possible. The PDOA is an example of a model that takes on that approach, including algorithms.

8.3 Transparency

The stakeholders in Waelpolder were willing to be transparent and open during the entire process. This transparency made the stakeholders accept one of the fundamental elements in the PDOA. The transparency avoids strategic play during negotiations, as stakeholders should be clear and open about their goals and preferences in the project. This made the approach usable as preferences were gathered without any problems.

With the change in thinking (from System 1 to System 2) and accepting to be transparent when giving preferences over their objectives, stakeholders are able to give input for the approach. However, the problems described in section 8.1 could occur. Two suggested ways to cope with these problems that the stakeholders experienced while giving input for the approach, are that it should be used as an iterative tool and (start) in an early phase of a project.

8.4 Iterative and early phase usage

For the stakeholders within Waelpolder, the PDOA has added value if it is used at the beginning of the process where a group of stakeholders comes together and wants to develop an area. Urban design processes are iterative, so the model should be iterative as well. It should be used continuously throughout the process, with additions and adjustments in requirement and constraints. The urban planner stated during the workshop: "*I find the method interesting to use at the beginning of a project, with the agreement to repeat and update the process and model from time to time*". Since the input is concrete, as System 2 of Kahneman is stimulated when stakeholders are giving input, the output is concrete as well. The concrete outcome (PoR) makes it easier for the stakeholders to define their expectations on certain aspects within the project.
The urban planner mentioned that normally, a design process can be 'floaty' and unclear as a masterplan for an area will be elaborated which contains vague terms as 'develop in line with the market' (*marktconform uitwerken*). There may be several interpretations on these vague terms. As the outcome of the PDOA is concrete, stakeholders are able to see whether their expectations are taken into account in the design.

Stakeholders accept the approach when it is iterative. The construction of preference curves before seeing a design is experienced as difficult. The stakeholders are still slightly attached to the regular process of designing, in which a design will be assessed after it is being created and stakeholders will start to think what they wish for from that moment on. This makes it even more important for the process to be iterative so the preference curves can be changed after seeing the outcome of the first iteration. Stakeholders see the approach as an iterative process where it is important to still adjust preference curves later on in the process such that they fully reflect the stakeholders' wishes.

In addition, an iterative process makes sure that the model can be updated and consider external changes (for example rising housing prices), leading to a design that is aligned to the current conditions.

8.5 Insights into consequences

The stakeholders appreciate that the model can give insights into the consequences of certain choices considering requirements, in an effortless and quick manner. The model gives insights in the possibilities when the fixed, hard standards in the cooperation agreement would be loosened. These insights let the stakeholder doubt about some of the values of the standards that are set in the agreement because the stakeholders saw that more is possible than thought of beforehand. Examples of the values that the stakeholders have doubts about are the parking norm and the maximum number of houses, that are set in the cooperation agreement and zoning plan. The model showed that a lower parking norm could lead to more greenery, this opened the discussion among the stakeholders, how to lower the parking norm. That discussion leaded to some creative solutions, like sharing cars. Increasing the number of houses would be interesting but cannot be done in this phase of the project, due current zoning plans.

Another example where the model showed that it can give insights easily is the healthcare center. Stakeholders had long negotiations with each other, about the effects of a healthcare center, before the stakeholders agreed on building one. In contrast with the PDOA, which showed a design related to this consideration in an easy and quick manner.

Being able to play with the model (with other words: play with the constraints in the model) is therefore seen as important added value for the stakeholders. The financial director stated during workshop: "*The possibilities to turn the knobs and the (added) information value of seeing the consequences of those changes, makes it a good tool to come to a decision together*".

9 Key positive elements of the PDOA

The key positive aspects that substantiate the conclusions are listed below.

- The stakeholders are positive about the ability to play with the constraints within the model. This ability gives the stakeholders insights into the consequences of adjustments in needs and constraints, in an effortless and quick manner, so that long negotiations about the considerations and thereafter fitting those adjustments into a design are no longer needed. This ability to play with the model, and rapidly generating a design related to those changes, is one of the elements that adds value to the use of the PDOA for stakeholders.

- The representative of the municipality Westland wants to use the PDOA within her organization to show what possibilities arise when certain norms are adjusted. She wants to use it as slip school model to be able to see how far the different departments within the municipality can go with adjusting the norms. The tool can be able to shift the static way of thinking within governmental organizations to an open and deliberate way of thinking, where they think in opportunities rather than impossibilities. The idea behind using the PDOA within governmental organizations is to get all different departments of the municipality in line with each other.

- The stakeholders of Waelpolder want to explore opportunities to use the PDOA for other subareas in Waelpolder. Especially since negotiations in other subareas did not start yet, so the PDOA can be used in an early stage of the project. In this early phase the stakeholders see added value for the PDOA as requirements still need to be set since the tool enables to define specific expectations. Because the outcome of the approach is concrete, it makes it easier for stakeholders to set clear expectations at the beginning of a project. Since the tool can be used in an iterative way, it would be a good fit to use it at the early phase of a project.

- The stakeholders would like to use the PoR, created with the PDOA during the tender phase, to evaluate the received tenders. As subarea 5 of Waelpolder is currently in the tender phase. Stakeholders are investigating the possibilities to use the PoR and/or the generated preference curves, that are supplied by the stakeholders, to evaluate the tenders.

10 Conclusions

The PDOA is considered to be useful as decision support system during negotiations in urban development projects. It makes the negotiations an open glass box rather than a black box where all stakeholders got something in reserve. The tool allows to leave intuition behind in decision-making and base choices on deep thoughts and preferences of stakeholders in an easy manner.

With the PDOA, finding a feasible solution is guaranteed, on top of that it is able to find the most desired group solution. A design optimized on preference (using the PDOA) shows a higher overall preference score than a design optimized on rather one objective with the use of LP modeling. This implies that a design optimized on overall preference, considering multiple objectives, is more compliant (more responsive to the overall needs of the stakeholders).

The Preferendus method is preferred to use in the PDOA rather than the goal attainment method. This is mainly because the Preferendus returns more extreme designs and can better show the impact of adjustments in requirements in comparison to the more moderate designs generated with goal attainment. So, the Preferendus is better able to support negotiations and open up discussions, since the impact on the design becomes more apparent than with goal attainment. As the Preferendus generates more extreme outcomes, this method is a good fit when the PDOA is used as a slip school model. In addition, stakeholders think it is realistic that one party should do more compromises than another party within a project.

As established by the stakeholders of Waelpolder, a key component of the PDOA is that it provides insights in a rapid and simple manner. The tool allows requirement modification thereby showing the impact of certain requirements and presenting alternative possibilities. The possibility to make adjustments shows the iterative value of the tool, especially when using it in an early phase of a project.

The stakeholders of Waelpolder accept the PDOA and are willing to use it in the future. Not only for future development projects of other subareas in Waelpolder. The municipality wants to use the PDOA (as slip school model) within governmental organizations to open up the discussions about norms and requirements that are set.

The PDOA ensures openness & transparency which avoids strategic play among stakeholders during negotiations. Openness & transparency, which is seen as one of the pillars of the PDOA, is accepted by the stakeholders. The stakeholders were willing to share their ideas and thoughts by giving up preference curves and start discussions about the design in a workshop. In addition, the PDOA enables thinking in System 2 rather than in System 1. The model of Waelpolder showed the stakeholders that more was possible than thought of beforehand, based on their intuitions.

However, to let the stakeholders give input successfully, the approach should be iterative. An iterative process helps the stakeholders to give input for the model as they (possibly) see the changes in designs in the different rounds. Due to the difficulties stakeholders experienced in constructing preference curves before seeing a design, parabolic curves and proxy curves were created by the stakeholders, this could be avoided when the process is more iterative. Besides that, an iterative process helps the stakeholders since they are used to a regular design process of assessing a design after creation. Last, making the process iterative, gives the opportunity to be able to adapt to external circumstances within the long process of an urban development project.

11 Recommendations

There are several recommendations for future research regarding the PDOA.

The approach used in this thesis should be applied to more urban development projects, that are larger in size but also have more stakeholders. It should be investigated if the stakeholders are willing to use this approach, because there is more at stake and there are more 'enemies' to share knowledge with when transparency is needed. By applying the PDOA to a larger project, it can be tested once again if one of the foundations (openness & transparency) with a larger group of stakeholders is accepted.

It is recommended to apply the PDOA to a project that is in an early phase, such as subareas in Waelpolder that still need to be developed, to test the iterative element within the PDOA. Appliance of the PDOA to a project where the involved stakeholders did not come to a cooperation agreement yet, allows to use one of the key components of the tool, the easy requirement modification. When using the tool as decision support system in an early phase, it can be investigated how stakeholders experience the approach.

The tool should be tested during higher level negotiations in organizations where the tool can operate as slip school model, considering the input of the municipality of Westland. The tool can provide insights which helps in establishing standards and reaching compromises between different departments.

To be able to draw harder conclusions between the preferred method (goal attainment or the Preferendus), it is recommended to test both methods again in a case where the solution space is more open. A larger solution space could cause a bigger difference in designs between the two methods, in which the working of the methods and the differences in design will more visible.
Besides testing the goal attainment and Preferendus on a case where the solution space is larger, both methods should also be tested on a project with more stakeholders (10-20). As with a few stakeholders not that many compromises need to be made, but when there are many stakeholders more compromises should be made to come to a group solution with both methods. It should be further investigated if the designs between the two methods differs, when they are applied to a project with more stakeholders.

Another recommendation is regarding the input of the preference curves and determining the boundary values of an objective. In this thesis, the minimal and maximal value were established by the model, minimizing and maximizing on each objective. However, another method can be used to establish the boundaries for the objectives. By letting the stakeholders decide what (idealistic) the minimum and maximum should be based on their needs. This is another approach as it is suggesting that stakeholders should set the boundaries from an idealistic point of view, rather than let the model decide what the boundaries could be considering all constraints (realistically).

Within the mathematical models, options are used to get the optimization solvers running. During this thesis these options are chosen after a search for the best combination of running time and ability to find a 'global' optimum. It could be the case that an even better global optimum could be found with another set of options. More extensive research should be carried out to state that the (real) global optimum is found. On the other hand, changing those options such that they will search more extensively, will probably mean that the running time of the model (where the Preferendus is used) will exceed two hours. These two hours were the time limit that was set during this thesis, to keep everything within a reasonable time limit.
Due to the longer running time it was not possible to run the model during the stakeholder meetings, but the stakeholders would like to see what happens to the design as input changes. It would be interesting to investigate if the model could be changed in such way, or with more advanced hardware, to decrease the running time of the model.

For the second application the Surrogate optimization solver was used, as the Generic Algorithm was not able to find the global optimum for this optimization problem. Due to that, the Preferendus was only used after the search for an optimum was done, as the Preferendus can only optimize in combination with the Generic Algorithm. To be able to use the Preferendus for optimization in any case in the future, it is advised to use the Python version of the Preferendus as it gives a better result, where the MATLAB version only gives an approximation.

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A Literature study

The literature study will focus on several decision-making methods that can be used to select or design alternatives based on a thorough analysis, which does not consider preferences. Following from that, special attention will be paid to methods that incorporate preference modeling into decision-making. The methods all have a connection to negotiating since this plays a role in the selection of a design for an urban development. Section Negotiating of the literature study is discussing the most important aspects and difficulties in negotiating. The last section is elaborating on a development gap and will address opportunities for a new development.

A.1 Methods to accommodate decision-making

A way to evaluate alternatives is doing a cost-benefit analysis. During such an analysis, all criteria are defined on a monetary basis. A limitation to this method is that in reality one criterion can be more difficult to monetize than other criteria. Besides that, it is depending on who performs the analysis and if the analysis is performed by one or more parties (Pearce, 1983). Different people have different understandings for monetary value of different aspects, like for the ecological value of one square meter of greenery. It starts to get difficult when the values of different parties need to be combined to an overall value. In addition, the design is chosen based on the best result (Boardman et al., 2018). This choice is only based on one aspect, money. However, more aspects can play a role during the decision making. These other important aspects are expressed in terms of money, but this does not mean they are expressed in a right way.

A method that is not based on monetizing all criteria is Multi Criteria Decision Analysis (MCDA). In a MCDA, every alternative gets a score, instead of expressing all alternatives in terms of money. In this method, as well as in the cost-benefit analysis, all alternatives need to be generated upfront, and after creating the alternatives they get scored. The alternative with the highest score is chosen (Stewart, 1992). When there are many alternatives, the process of scoring the alternatives can be time consuming. Next to that, the overall score in the MCDA is based on weights and a weighted average is calculated and compared between the alternatives. The weights are often assigned randomly, without a proper foundation (Binnekamp, 2010). Furthermore, the weights that are defined are reflecting one party, however they should be reflecting the preference of a group.

The most important drawback of MCDA is that the algorithm for aggregating is not correct. Mathematical operations (summation and multiplication) are applied where they are not defined, this leads to an infinite number of non-equivalent outcomes (Barzilai, 2010).

Another method that is used to look and choose for an alternative is Linear Programming (LP). LP is a method that searches for feasible alternatives in a solution space. A solution space is a space filled with all feasible solutions, considering the requirements that are set (constraints). LP uses optimization to look for a feasible solution in the space by optimizing on a criterion, such as revenues. The method can only optimize on one criterion, which means that the solution is always at the extremes of the solution space. This can lead to a solution that does not satisfy all parties. So, LP is struggling with the multi-objectives in group decision making. Therefore, it is not suited for group decision making. Optimizing on one criterion would mean that there is a zero-sum game within the group, one stakeholder gets what he wants (the criterion on which is optimized) and all other stakeholders get 'nothing'. The result is an advantage for one party, where on the other side the result is an equivalent loss for another other party since he needs to make concessions on the result and cannot optimize on his preferred criterion. The multi-objective problem is also addressed by Arkesteijn (2019), who is stating that a selection of the best alternative is not dependent on only one aspect. She suggests that all stakeholders should be involved in the process and more than one criterion should be addressed.

There is lack of cooperation in LP models, by optimizing on only one aspect and satisfying only party. This issue is currently solved is by doing many iterations and optimizations on different criteria to find a solution that, in the end, satisfies the group (Van Loon et al., 2008). But this takes time and is rather arbitrary as trial and error is used, to find a feasible solution for the group, but not the most desired solution since there is a chance of 'missing' the most desired one.

Another malfunction of a LP method is that constraints divide the solution space into a feasible or infeasible part (Binnekamp, 2010). Solutions that lay a little outside the solution space, the so called 'gray' solutions, will not be considered. It is, however, not stated that the decision makers would not accept such decisions. For example, a solution that is one euro over budget will not be considered as a feasible solution with LP. However, this may be a solution that the stakeholder will accept. This feasibility problem makes it hard to look for compromising solutions (Arkesteijn et al., 2015).

In addition, sometimes, no solution with LP modeling will be found at all since the solution space is too small if all constraints are considered.

A.2 Preference modeling

The step from going from a or no feasible solution to a most desired solution for the group can be done by considering preferences of the parties in the model. This way of thinking/method is investigated by, among others, Barzilai (2010) and Binnekamp (2010). Preferences can be used to enable cooperation between parties. This section elaborates on considering preferences. First, it is dived into what a preference means. After that, it will be discussed how preferences are considered (a posteriori and a priori) in several methods.

A.2.1 Preference

In order to further discuss preferences, first the definition of a preference must be elaborated. Barzilai (2010) describes preferences as a non-physical, subjective variable. 'Physical properties', such as money, can be converted into 'non-physical properties' that are subjective, such as preferences. Someone's preferences are attached to the person, not to an object. Preferences are therefore subjective per definition (Barzilai, 2010). Choosing things that one prefers makes a preference similar to a choice (Arkesteijn, 2019). According to Binnekamp (2010), preferences come back in a design process since choices need to be made when a design is created. He states that the choice between certain designs in a design process is dependent on preference. Considering preferences should therefore be incorporated in a design process (Arkesteijn, 2019).

Barzilai created a methodology for the 'measurement of subjective variables' such as a preference, in a mathematically proper manner. Following Barzilai, the mathematical foundation of socio-scientific disciplines should not lack in application of mathematical operations to subjective properties (Barzilai, 2010). He investigated decent preference scales for these variables to be able to apply mathematical operations to, like multiplication and addition, which was lacking in the other value function methods (like MCDA) (Binnekamp, 2010). Barzilai rebuilt the foundation for measuring preference by creating proper preference scales – always including zero (not preferred) and hundred (preferred) – and called this methodology Preference Function Modeling (PFM). He developed a software tool Tetra that is able to apply this new methodology.

A.2.2 Considering preferences a posteriori

PFM is based on adding a preference to design alternatives that are created after which the most desired design alternative, based on the preference scores, can be selected. With the use of Tetra software, the alternatives can be evaluated according to these preferences (Binnekamp, 2010). For this method, the alternatives need to be created before the scoring can start (a posteriori).

Problems can arise when too many alternatives are created (Arkesteijn et al., 2015). The manual search for an optimal solution in a combinatorial explosion of alternatives is time-consuming. When there are too many options, it can be hard to choose the best alternative since all alternatives need to get an overall preference score of the stakeholders.

A method to deal with the large amount of alternatives could be the 'satisfying' principal of Simon (1979, 1996), this only looks at the alternatives that each individual stakeholder prefers the most. In a group decision process, this could mean that the best alternative for the group is left out, since it is not the most preferred one by the stakeholders individually. The satisfying principal has a problem; the chance of leaving the most desired solution untouched.

A.2.3 Considering preferences a priori

A better method would be investigating the preferences of the stakeholders before starting the optimization process and use the preferences to create an alternative (a priori). By integrating preferences early in the design process, the alternatives can be created considering these preferences. Preference Based Design (PBD) is a method suggested by Binnekamp (2010) where the design alternatives are based on a preference and could save a lot of time.

PBD combines PFM and the earlier discussed optimization method LP. The problems related to LP can be overcome by incorporating PFM. On the one hand, the feasibility problem can be overcome by incorporating PFM methodology in LP models since it will only look for the 'grey' solutions if a preference is considered (Binnekamp, 2010). By considering preferences, it can open the solution space.

Constraints are limitations on the values of some aspects in the design of the project, which define the solution space. In most cases they are clearly defined by the stakeholders, before creating a model of the problem (Arkesteijn, 2019). There are two types of constraints are hard and negotiable constraints. The hard constraints enable the model to identify and exclude unacceptable designs and are defined by legislation and policy or physical limitations. The gray solutions, that lay a little out of the solution space refer to the negotiable constraints, as stakeholders still could accept a solution that is over this constraint. So, negotiable constraints are constraints that can be redefined and adjusted during the design process and are imposed by a stakeholder.

On the other hand, preference modeling can help in looking for the most desired group solution since the model can be optimized on preference rather than one objective. All objectives can be expressed in a preference, so it can consider multiple objectives. The design represents a group solution and not a solution in the favor of only one party.

Within the PBD method, a preference curve is created for each decision variable. The preference is measured over a scale from 0 to 100 and cannot exceed this scale in both directions. There are different methods to shape a preference curve. Some curve fitting techniques will return a function that exceeds 100 or drops below 0, like the Lagrange polynomial or Cubic spline (Moler, 2012). For this reason, Binnekamp uses Bézier curves (Binnekamp, 2010). The shape of the curve will be determined by four predefined points. Each preference point is linked to a value of the variable:

- The value of the decision variable that is least preferred is given a preference of 0.
- The value of the decision variable that is most preferred is given a preference of 100.
- Two control points with values between the least and most preferred values, to give the curve a shape.

The downside of this Bézier curve is that the data points are not on the curve itself, but only used for the shape of the curve. The preference curve in this case is not a function of the variable, and therefore the curve is not precise. Binnekamp used only a limited amount of Bézier curve shapes, due to the complexity, which does not fully reflect the preference of a decision maker (Arkesteijn, 2019). Suggestions are made for the future to investigate a user-friendly interface so preference curves can be shaped directly according to the stakeholders' wishes.

A second drawback of the PBD method of Binnekamp relates to the method to search for the alternative with the highest total preference score. It is still the same as in the PFM method a 'brute force' approach, in which the number of possible alternatives equals the number of decision variable values to the power of the number of decision variables. This gives a large number of alternatives. Evaluate and score each alternative in a manually proper way, will then take too much time to complete.

A preference-based method that incorporates preferences a priori and searches for a solution automatically, the Preferendus, is currently (at the start of this thesis) under development, for that development it would be interesting to test it in a real-life case with multiple stakeholders, Zhilyaev et al. (2022).

A.3 Negotiating

One of the goals of this thesis is to investigate how to convince the stakeholders of the new approach and what needs to be taken into account in order to increase the chance they will accept the approach. The described analyzing methods can take away the negotiations by implementing important aspects of negotiating into the method. Therefore, it is interesting to investigate what is important to come to a joint solution and what they expect when sitting around the table together.

Fisher et al. (1993) describe in their book 'Excellent onderhandelen' the method of negotiating. There are a few things that they describe that are important to take into account during a negotiation process:

- **Discuss each other's point of view**
  A way to deal with different viewpoints of parties is to tackle them by addressing and discussing the viewpoints. Conversations can bring understanding and insights to take other parties seriously. Something unimportant for one party can be really important for the other party.

- **Get a party involved in the outcome by making sure the party participates in its creation**
  Fisher et al. (1993) state that if people are not involved in the realization of the result, they are less willing to agree on the result. If you want a stakeholder to agree to an unpleasant conclusion, it is of vital importance that he is involved in the realization of that conclusion. If a stakeholder has the feeling, he is involved in the realization process, he will be more willing to agree on the unpleasant conclusion. A stakeholder will consider the new idea as something of his own. In the end, the result consists of so many suggestions of all parties that they have the feeling the design is theirs.
  If you want to involve another party in the process, it is good to do it in an early stage. Fisher et al. (1993) state that the feeling of involvement in decision-making is perhaps the most important factor in if a negotiator accepts a result.

- **For a sensible/prudent solution you need to reconcile interests, not positions**
  Conversations during negotiations are often about a conflict over the positions (hierarchy) and getting into agreement on the positions rather than on the issue. This can also happen in area development projects. For example, the parties that are paying for the project could consider their position and aspects as more important than the other parties (such as finance over quality). The parties should try to stay away from the conflict regarding the positions they have in hierarchy and try to focus on the conflict there is in interests.

- **Behind conflicting positions are not only conflicting interests, but also shared and compatible interests**
  That the positions of parties differ during negotiations does not mean that the stakes are conflicting as well. Further elaboration on the stakes can lead to insights and similarities within the stakes.
  For example, at first sight, a tenant and landlord can seem to have conflicting stakes; a rent as low as possible and as high as possible. However, the two could have a deeper common stake: the tenant wants stability to get a house and the landlord wants stability to have a permanent tenant. If they find more stakes that they share, the parties could be more willing to make compromises in the agreement and to come to good terms. This example emphasizes the importance of looking further than only the obvious goals of parties during negotiations. Also, parties could have more than one goal. Finding the reason behind the goal is seen as important since it makes the interests and goal of a party clearer.

- **Finding a solution in mutual interest**
  Fisher et al. (1993) describes that solving a solution can be hindered by the quantity assumption: the less you get, the more I get (zero-sum game). This assumption is claimed to be incorrect by Fisher. The identification of common interests can help solving problems in a creative way. This can be done by identifying common goals or by intertwining different interests. A common example that is used to demonstrate the importance of intertwining different interests is the example of the orange. Two people can be fighting for an orange which will most of the time end up in a situation where the orange is cut in two and split among both people. However, if both interests for the orange would have been identified, it could become clear that one party wants the peal of the orange to bake a cake with and the other party is looking for the orange fruit that is inside of the peal. If both parties do not communicate with each other what their interest is, they will not find a solution that is in mutual interest since they will settle for half an orange (feasible solution). The example shows that they also could have gotten what they wanted (most desired solution) if they elaborated on the common goal: getting the orange.

The viewpoints of Fisher et al. (1993) show that cooperation between the parties is important. It seems important during negotiations to get to know each other's viewpoints, to gain understanding for other parties' viewpoints. In this way, parties are taken seriously and will respect each other during the negotiations. Furthermore, all stakeholders should be involved in the process of designing the solution. Then they will have more understanding for the solution since they get the feeling that they delivered input for the final design which will increase the chance of accepting the process to come to a solution.

It is important to see the other parties as colleagues to collaborate with and not as opponents, since the group of stakeholders want to achieve something together. The parties should try to stay away from the conflict regarding the positions they have in hierarchy and try to focus on the conflict there is in interests. Identifying interests turns out to be an important aspect of negotiating in order to understand each other well and to come to a compromising solution. This should be provided by an analyzing method. Finding the reason behind the interest of a party is also key. When interests are revealed, the problem becomes clear, and a solution can be sought. The focus should be on a group solution rather than on only one objective of one stakeholder.

A.4 Development gap

The methods described in the literature study are lacking on important aspects which lead to several development gaps. The first point is related to the MCDA and CBA method. Both methods are fully dependent on who completes the analysis and assigns the values to an aspect, since everyone can have a different interpretation. Besides that, it is hard to quantify certain elements in terms of money or a score. Those two methods are mathematically not correct, as mathematical operations that are used are not defined.

It seems that cooperation between parties and being able to find out each other's interests and viewpoints to gain understanding needs to be considered in the analyzing methods in order for the stakeholders to support a decision. Thinking further than obvious goals during negotiating is also encouraged by Kahneman (2013). Decision-making should, according to him, be based on System 2 rather than System 1. Not the intuition, emotion and experience but the more deliberate, analytical way of thinking should be the foundation in decision-making.

Cooperation and activating System 2 thinking during decision-making can be accommodated by considering preferences in the analyzing method. By incorporating preferences, the underlying thoughts are considered, and decision-making can easily be based on System 2. LP is not considered as suitable technique for a decision-making method. As LP is lacking in cooperation in group decision making since it only optimizes on one aspect, pleasing one stakeholder. In addition, the method needs trial & error to find a feasible solution that suits the group, instead of finding the most desired solution for the group.

All methods in the literature study that are considering preference measurement are rather time consuming. All alternatives are created after which they should be scored, like the PFM method. Here, the problem of trial & error to find a feasible and not the most desired solution occurs again. It would be better to have a scoring system before all the alternatives are generated, making it possible to generate alternatives based on the scores (like PBD).

It is interesting to investigate if a new advanced approach lays in considering preference modeling early in the decision process. By letting stakeholders express their preference over objectives to create alternatives, the time to come to a solution can be reduced and methods like brute force approaches can be avoided. As the alternatives will be directly based on the preference (a priori) instead of giving the alternatives a preference score after they are created (a posteriori). Besides that, when all stakeholders give their preference and include cooperation in the method, finding the most desired solution for the group would not be a process of trial & error. Using preference modeling avoids the problems described by for the CBA and MCDA, as all physical and non-physical criteria can be expressed in preference. Also, the criteria related to money, profit and cost are expressed in preference. By expressing every criterion in preference, the mathematical operation problems are avoided as well.

To summarize, there is a development gap for a more advanced method than PBD, where alternatives can be generated and scored by the method itself (a priori), rather than rate them manually. A method that can cope with nonlinear preference curves which better reflects the wishes of stakeholders so cooperation and negotiating between them is considered in the method. Therefore, the Preferendus (Zhilyaev et al. (2022)) can be tested in a real-life case that includes multiple stakeholders.

B Method

A new, advanced approach that builds upon PBD is created in this development. The new approach is an a priori design optimization approach and will be referred to as PDOA in the thesis. The approach considers preference measurement, as the PBD method from Binnekamp. However, it is a more advanced approach than the PBD since the model that is using this approach is able to generate alternatives in by itself way rather than generating alternatives manually (as with PBD).

B.1 Design method

The method according to which a design is created follows the line of reasoning of the Open Design Methodology. Open design is based on the idea of the output being a reflection of the input, where the input is considered as a stakeholders' interests (Binnekamp, 2010). The stakeholders' interests are translated into preferences on which mathematical operations can be applied so the output is a reflection of the input. The entire design process is open and transparent, which is seen as one the fundamentals of the open design approach (Van Loon, 1998). The black box is taken away by incorporating the interests (preferences) of stakeholders. Based on their input, an output will be generated which reflects their wishes.

The development of the PDOA will be a preference optimization in which the model that is created will be tested and evaluated. The model will be optimizing a design process for urban development projects.

B.2 Respondents

The model that is needed to test this approach, will be constructed with the help of experts. The acceptance and working of the approach are investigated among experts and tested and evaluated in two cases.

The PDOA will be applied to two cases: BDP and Waelpolder. Both cases concern an area development in the Netherlands. BDP concerns an area development of 15 years ago, so the case will be re-enacted. The PDOA is tested in this case on a group of employees of Planmaat, a company specialized in solving urban planning problems mathematically. All the knowledge and feedback that was gathered on the BDP case is taken into account in the second application. The PDOA is tested in Waelpolder on three stakeholders, which are looking for consensus in the area development project. Here, the approach will be evaluated by stakeholders from a real-life project.

B.3 Instruments

For the development of the model that supports this approach two mathematical programs are used. First, a mathematical model that supports the PDOA is created in a software called MATLAB which enables to model in a non-linear way. MATLAB is a mathematical coding program which is be able to code in a non-linear way, the model has an optimization solver package that can calculate the most desired outcome.

Second, the MATLAB model is linked to an Excel file which consists of all the input data for the model. The input data consisted of multiple tabs and holds the values for the constraints and preference values.

The preference values (input data) are gathered from the stakeholders. In order to make it more user-friendly and understandable for them, two methods of visualizing the preferences are tested, one in each case.

B.4 Phasing

The development of the PDOA consists of a social and a technical cycle that go hand in hand. The steps that are followed in the thesis can be explained according to the flowchart in fig. B.1.

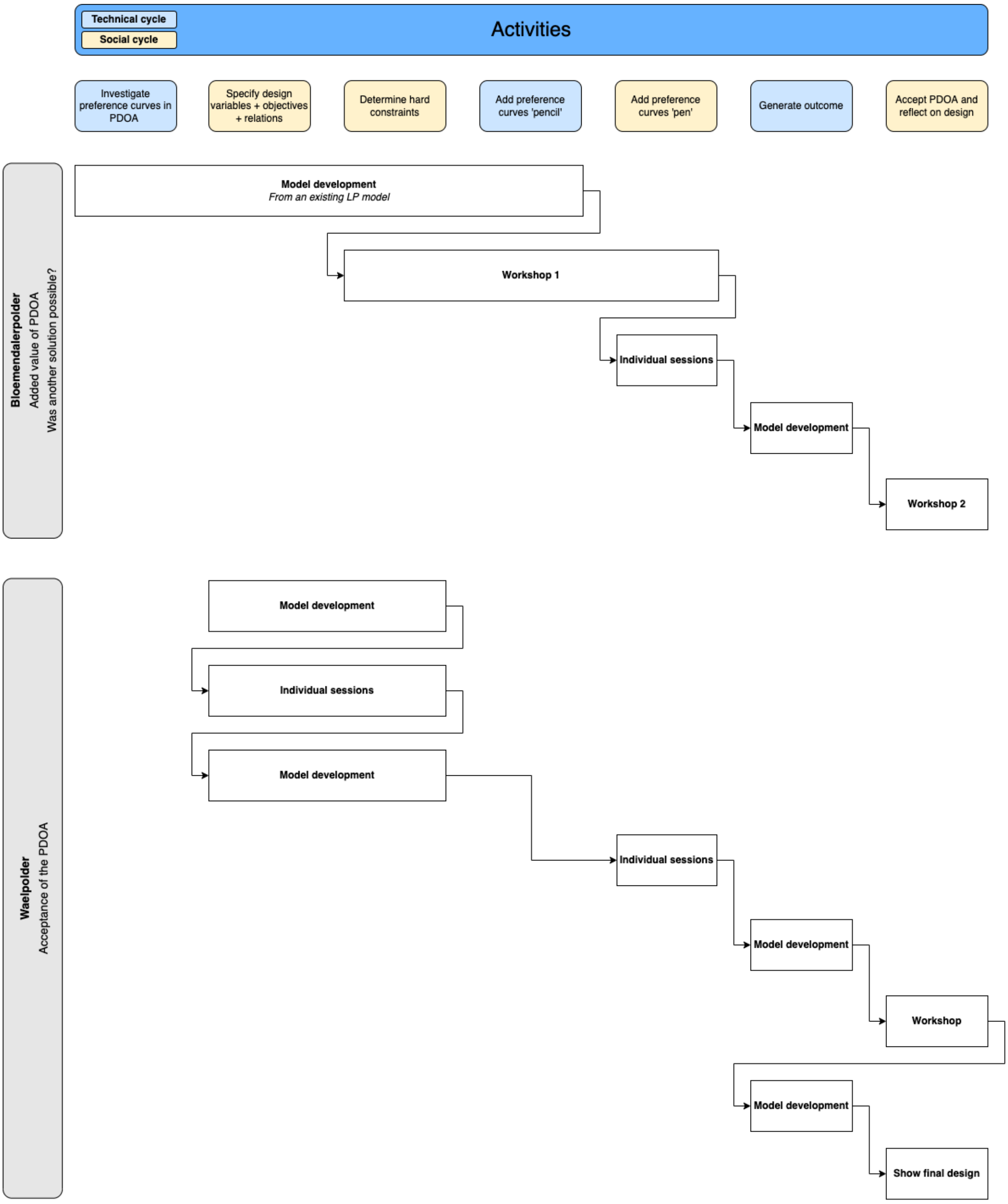


Figure B.1: Flowchart activities thesis

The flowchart shows an overview of activities that together ensured the construction of the PDOA model and the testing of the mathematical model in area development projects. The activities that are blue consider the activities from the technical cycle; the yellow blocks represent the activities from the social cycle.

Before any of the shown activities started, other supportive decision-making instruments and their downsides were investigated. This included an investigation into the problems with LP models. Literature has been used for the investigation into other techniques.

The first activity in the BDP case considers an investigation into preference curves and how they are constructed. Following from this is the specification of the variables, relations, and constraints for BDP in the model. After the basic elements of the model were constructed, the preferences of the stakeholders could be added. The preferences needed to be gathered during a workshop with the group of stakeholders and an individual session with each stakeholder.

The gathering of preferences consisted of two steps. It was chosen to already conduct pencil preferences before talking to the stakeholders. Pencil preferences are fictive preference curves that could represent a stakeholders' wish and goal, based on information about the case that is known in advance. Constructing the pencil preferences was done for two reasons: to test the working of the model when adding preferences and to help the stakeholders get an idea how a goal (or a wish) could be translated into a preference curve. During the workshop and individual session, the pencil preferences were converted into a pen preference: a preference curve which truly represents the objective of a stakeholder, based on statements the stakeholder made during these sessions.

When the preferences were known, the model could run in order to generate an output. The output was discussed during a second workshop, from which the added value of the PDOA can be tested.

In the BDP case, the development of the model for the approach started from scratch as nothing related to the model and the approach was defined. BDP was used to test the approach and test if this approach has added values. Besides that, the convincing story towards stakeholders about the PDOA is practiced and improved. There was no need to talk to the stakeholders about which variables, constraints or relations were present within the BDP case since the model was based on an old LP model. So, all these model elements were already known beforehand. The first workshop in this case covered the activities from collecting the preferences and changing some constraints. After the first session, it turned out to be more useful to gather all preferences in an extra individual session. The model was further developed after information was added. Lastly, the outcome was discussed in a second workshop in order to get extensive feedback on the entire process, the convincing story regarding the PDOA and the gathering of the preference curves, to test the usability. This can be seen as the validation part within BDP. Showing the added value of the PDOA refers to the verification part within BDP.

In Waelpolder, the model development considered less activities since the basis of the model was already set. In this case, it was needed to talk to the stakeholders to set up variables, relations, objectives and constraints for the model. This was done with individual sessions where the goals and constraints of the stakeholders were discussed. The model was constructed based on these individual sessions and information documents that were available from the municipality Westland about the project. After the model construction, the preferences over objectives were gathered from the stakeholders. These preferences were added to the model such that the outcome could be discussed with them in a workshop. Since it is an iterative process, especially in this real-life case, some adjustments were made on the discussed outcome, and this design was sent to the stakeholders afterwards. Waelpolder is considered as a validation of the approach since the PDOA will be tested on the stakeholders.

C Model development

A mathematical nonlinear programming model was created to meet the development statement. This model includes preference measurement. Following (Ragsdale, 2008), there are different types of mathematical models; prescriptive, predictive and descriptive. The type of model that is used in this thesis is a prescriptive model, as the functions between the (design) variables, relations and objectives are well known, and the value of the variables are known or controlled by constraints. These constraints are setup or known by the decision makers as they relate to physical limitations, policy or legislation.

C.1 What is needed for a PDOA model?

The PDOA model is created in two different ways for both cases. For BDP, a LP model in Excel is translated to a model in MATLAB, using coding. MATLAB is a program that is based on self-written codes. Where LP models suffice with the use of Excel, which is a user-friendly mathematical tool. To go from a LP model to a PDOA model, nonlinear preference curves are needed. The preferences of the stakeholders will be gathered during a workshop and individual sessions. The goal of the model is to create a solution with the highest overall preference, the most desired solution for the groups. This also should result which results in a solution with the largest support among the stakeholders. The ability to be able to optimize on (overall) preference and include all preference curves, is the main difference between a LP model and the PDOA model. Besides that, the model enables to see what the preference score of each stakeholder is. Due to that, it is among others possible to see on which objective the stakeholders do not agree on with each other.

Another approach was used in the Waelpolder case to create a PDOA model. There was no LP model to continue from in Waelpolder, which means that there were no variables or relations to start from. Goals were translated into objectives by the stakeholders and that formed the basis for the model.

C.2 Preference curves

Preferences are expressed over the measurable goals of stakeholders, the objectives. Preferences of stakeholders over their objectives within a project are gathered and then transformed into a curve. A preference is expressed over objectives in a scale from 0 to 100, where 0 is the least preferred value of that objective and 100 is the most preferred value of the objective. To create a curve with a nonlinear shape, extra preference points (that are positioned on a nonlinear line) can be added to other values of the objective. The idea behind a nonlinear curve is that it can fully represents the wishes of a stakeholder rather than estimating it on a linear line. After the preferences are gathered, a curve can be fitted through the datapoints. A datapoint is formed by an objective value (x-axis) and a preference value (y-axis).
The different preference curves need to be merged in order for the model to create a design. The preference curves of different objectives are to be summed based on weighting.

C.2.1 From datapoints to a curve

A curve must be fitted through the preference datapoints (x,y), to be able to generate the values in-between the given datapoints. The curve fitting technique that is chosen is Piecewise Cubic Hermite Interpolating Polynomial (PCHIP) (Mathsworks, nde). The PCHIP method is chosen in this development because the curve fits smoothly through the given data points and does not exceed 0 and 100 (overshoot), within a given range of the objective values, as argued by Zhilyaev et al. (2022).

The PCHIP function returns a vector of interpolated values between a range that is given. This range is defined by the minimum and maximum value of an objective, that is given in the datapoints. So, PCHIP generates more datapoints between the existing datapoints. The PCHIP function uses the given datapoint values as 'query points', which are coordinate values. PCHIP can interpolate for the corresponding y value with an x value generated in the optimization, so with the use of PCHIP a preference can be linked to a variable value (Mathsworks, nde). This is done by means of the number of datapoints that were given by the stakeholders.

C.2.2 Aggregated preferences for all objectives and stakeholders

The total preference score is based on the summation of the separate preference scores for all objectives of different stakeholders multiplied by the corresponding weights. There are two methods of aggregating preference curves with different units.

First of all, the simplest method: taking the weighted average. In this method, the preference scores are summed up by multiplying the preference score with the weight, of the objective for a stakeholder, combination. The formula for the weighted average is shown below. This function will be used as optimization function (in MATLAB called objective function) in optimization algorithm in MATLAB to maximize on the total preference, by maximizing $P_a^{\text{Weighted average}}$.

For any alternative *a* the aggregated weighted mean preference $P_a^{\text{Weighted average}}$ can be defined as follows:

$$P_a^{Weighted\ average} = \sum_{i=1}^{n} (w_i * P_{ai}) \tag{C.1}$$

Where:

i is the index of an objective

w_i is the weight of the objective i

P_{ai} is the preference score for the alternative a on the objective i

This method is however seen as an approximation by Binnekamp (2010). It is not correct the way of summation, as mathematical operations are applied where they are not defined and it generates an infinite number of non-equivalent outcomes (Barzilai, 2010).

The second method refers to the Preferendus, developed by Zhilyaev et al. (2022), where the Tetra tool is used that Barzilai created. The main difference between the weighted average method and this method is the applicability of mathematical operations that are needed to come to the overall preference. According to Barzilai (2010), preference does not have an absolute zero point as it is subjective, so it is a 1D affine space. In order to apply mathematical operations such as addition and multiplication, an objective must have an absolute zero point. Since the mathematical rules of addition and multiplication only apply in a 1D vector space, these operations cannot be applied to preference without interference of Tetra. To apply mathematical operations to preferences it needs to be measured on a scale between 0 and 100. Tetra is a tool that can scale preference between 0 and 100 when preferences are aggregated and make it a 1D vector space.

Within this thesis and the models, Tetra is used within the Preferendus method, to generate alternatives based on the preference curves that are given by the stakeholders. In the Preferendus method, the alternatives are generated after the preference is given, a priori.

C.2.3 Weights

The weights that are used in the Preferendus method to calculate the total preference are explained in the application parts of this thesis. The sum of the weights per objective per stakeholder, should be equal to 1 to be able to use them in the Preferendus. In both applications the stakeholders are assumed to be equal to avoid discussions about weight distributions between the stakeholders.

Van Loon (1998) states that for the type of design methodology that is used in this thesis, the fundamental should be transparency and openness. Stakeholders should be open in the design process as much as what is achievable. Tempering and misuse of 'knowledge power' should be prevented. Therefore, he claims that stakeholders should have equal weights in a design process. Based on the statements of van Loon, it is decided that the weights between the stakeholders are equal. Further investigations into different weight distributions between stakeholders are outside the scope of this thesis.

C.2.4 Use of Preferendus in the model

The tetra solver, the Preferendus, in combination with the Generic Algorithm (Mathsworks, ndb) is used as optimization solver within the MATLAB model to optimize on overall preference, Zhilyaev et al. (2022). Due to some technical issues with the Preferendus, as it was still under construction, there were three ways of using it in this thesis; directly as the only optimization function, in a loop combination with another method, and one solution as input for the Preferendus.

Directly as the only optimization function

In the first case, the Preferendus is used as optimization function with the use of the Generic Algorithm as optimization solver in MATLAB. It searches like a normal optimization function would do, slightly increasing the overall preference (of a design) while searching for the most desired solution, with the highest overall preference.

In a loop

Due to some technical difficulties with the newer version of the Tetra solver, the Preferendus was not able to search in a proper way, as it did before, like a normal optimization solver in MATLAB would do. To help the Preferendus in the searching process, a loop was created in combination with the weighted average. In the first part of the loop, the weighted average is used for the optimization. This gives an optimized solution, which is then sent to the Preferendus as initial point to start the search in the second part of the loop. So, the weighted average is helping the Preferendus to start looking in a certain direction in the solution space where the most desired solution will probably be. In this second optimization, the Preferendus optimizes on overall preference score, and after several iterations the Preferendus comes with a final design. This final design is created with the correct mathematical operations as the Preferendus is used.

It was noticed that this final design, created with the Preferendus, did not deviate from the solution that was generated with the weighted average, the only thing that differed was the preference score of both outcomes. The Preferendus method gave a slightly lower preference score than the weighted average (a delta of maximum 2).

Because of this observation, it was tested more intensively (around a hundred times for the BDP case) if the design would change between the two methods or that there was only a difference in preference. During these tests it became clear that the design did not change at all, only the preference score changed between the weighted average and Preferendus.

In parallel , it was tested what would happen if only the optimized solution of the weighted average was send to the Preferendus (one time), without using the Preferendus for further optimizations (in a loop). This led to the conclusion that both ways, using the Preferendus in a loop with many iterations and using the Preferendus only once, resulted in the same overall preference.

One solution as input for Preferendus

Therefore, it was decided to not use Preferendus within the optimization of MATLAB but only send the optimized solution to the Preferendus to get the final overall preference in the second application. In addition, doing the optimization in this way helped in running time of the model since the webserver of the Preferendus got really slow at this point.

Besides that, in the second application it was even harder for the Generic Algorithm to find the global optimum. Due to that, it was chosen to use the Surrogate optimization solver for the second case instead of the Generic Algorithm, appendix G.2.3 a more detailed explanation for this decision is given. However, using Surrogate optimization (Mathsworks, ndd) as a solver came with the problem of not being able to use the Preferendus as optimization function, as it only works with the Generic Algorithm. So, in the second application, the optimized solution was run with Preferendus only once.

D Stakeholder engagement

The stakeholders are giving the input for the model and are the ones that will or will not support the approach that is developed. Therefore, the social cycle focuses on getting the stakeholders on board regarding the design approach, meaning they understand which input is required, and they see the advantage in the way of working in this approach to come to a design.

Obtaining and documenting the right information of the stakeholders should happen in a structured way. In addition, giving input, such as preferences, should be user-friendly for them. It needs to be clear for the stakeholders what is expected of them in terms of input for the model. The stakeholders must give the right input, in order for the model to fully return the most desired group outcome based on all the stakeholders' wishes. Visualization of the input can help stakeholders in this process and is discussed in appendix D.1. The process until acceptance of the design by all stakeholders is an iterative process. Arkesteijn (2019) states that since the outcome reflects the stakeholders' input, the input need to be changed when stakeholders do not support the outcome. When the process of determining stakeholders' preferences is done again, after looking at the outcome, the stakeholders understands the effect of their input on the design better.

Arkesteijn (2019) conducted a study which is focusing on obtaining and documenting the right information this led to the development of PAS (Preference-based Accommodation Strategy), which will be discussed in section PAS (D.2).

Last, the outcome needs to be showed in such a way, that is it understandable for a stakeholder that does not have a background in a preference-based optimization approach. This will be discussed in appendix D.3.

D.1 Visualizing the input

It is important that the stakeholders at least understand the basic principles of the approach in order to give the right information and accept the approach. Clear diagrams, where information can be entered, and visualizations can contribute to the right input for the model. Next to that, showing results of the model in a simple, understandable manner can contribute to the acceptance of the approach. Both the gathering of information for the preference curves and showing the design outcome need to be accompanied by a clear explanation to the stakeholders before and during the consultation.

For the BDP case, the model was built upon an existing LP model so the variables in this case were already set. The model for the Waelpolder case is built without knowing the goals of the stakeholders in advance. This means that extra attention has to be paid to the collection of information about the problems, goals and objectives in Waelpolder.

In addition, the stakeholders in BDP were already known with concepts as LP modeling. Since the prior knowledge of stakeholders and the information known beforehand differ in both cases, the visualizations and explanations differ for both cases. More information on the visualization of the input for BDP can be found in appendix F.2.3. The visualizations for Waelpolder will be discussed in the next section (D.2).

D.2 PAS

All the stakeholders have different interests, goals and preferences within the project. These different perspectives need to be identified to use them properly as input for the decision support model. PAS, invented by Arkesteijn (2019), helps in transforming goals and ambitions of stakeholders into measurable criteria on which a preference can be expressed in a structured and in a user-friendly way. PAS, the Preference-based Accommodation Strategy, is a design and decision approach in corporate real estate alignment. PAS helps in creating and choosing the right portfolio that has the most added value for an organization and focuses among others, on gathering preferences from the stakeholders. The 'stakeholder & activities' element of PAS will be elaborated and is from here on referred to in the thesis as PAS.

Since a model needed to be built from scratch in Waelpolder, where nothing of the stakeholders was known yet, it is chosen to use PAS in Waelpolder to gather information of the stakeholders in a structured way. PAS has not been used in BDP.

The preferences are gathered following a certain structure which will be discussed in the subsections of this paragraph. First, the goal and subgoals of the stakeholders are gathered. From this, measurable objectives or criteria are defined that the stakeholder would like to achieve. Following are the preference curves that could be defined over the objectives. Last, weights are identified between the goals and objectives.

When using the PAS tool, two roles can be identified. There is a facilitator, called the System Engineer, that is responsible for facilitating the process to come to decent preference curves. This person manages the system during conversations with the stakeholders and helps the stakeholders when needed. Next to that, there are decision-makers, represented by the stakeholders of a project. Arkesteijn (2019) states that in PAS, the stakeholders can choose, among others, their own criteria (objectives), preference curves and weights. Since the alternative with the highest overall preference score is chosen based on these aspects, she argues that the stakeholders determine the chosen solution and can therefore be called decision-makers.

D.2.1 Overview

In PAS, each stakeholder has his own page in which all the information per stakeholder is gathered. The overview of the selection of a stakeholder is shown in fig. D.1. The information per stakeholder consists of three elements: Goals & Criteria, Preferences and Weights (fig. D.2). All elements will be discussed in the following subsections.

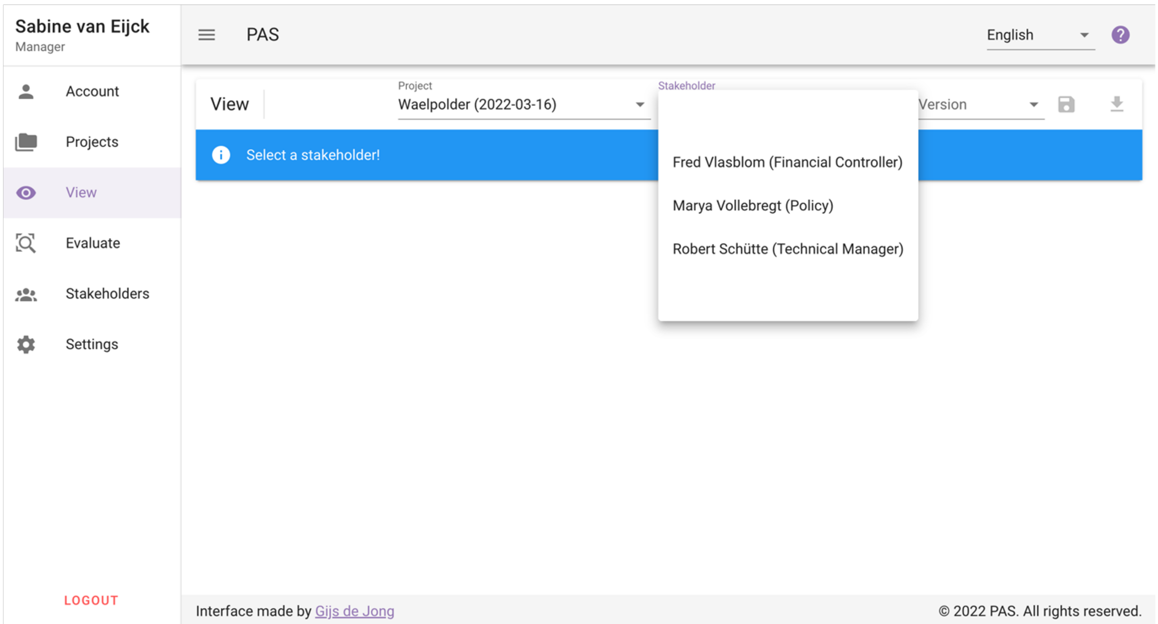


Figure D.1: Selection stakeholder in PAS

Figure D.2: Steps in PAS

D.2.2 Goals & Criteria

The first step is to collect information about the goals for a stakeholder within the project. The goals are briefly described in one word. If the goals are hard to establish, there can be touched upon problems that the stakeholder has in the current situation, according to Arkesteijn (2019). An explanation of the goal follows under the problem tab, where the problem that is experienced related to the goal, is described if applicable. Otherwise, a more detailed explanation of the goal is given.

Following from the goals are criteria (or objectives) that represent that goal. The criteria are expressed in units, which makes them measurable and gives the possibility to assess the goals. Figure D.3 shows an example of the Goals & Criteria sheet in PAS, where two goals and their corresponding criteria are shown.


Goals & Criteria

NEW

Goal ↓	Problems	Criteria	Unit	Formula	Actions
1. Zorgcomplex	Het zorgcomplex neemt afhankelijk van het aantal units ruimte in beslag, die ook gebruikt kunnen worden voor lucratievere woningen. Daarnaast heeft het zorgcomplex een neutrale kwaliteit voor het gebied.	1.1 Opties voor zorgcomplex	Preference		
2. Wonen	Gemengd wonen draagt bij aan kwaliteit. Een mix van woningen is essentieel voor de kwaliteit van het gebied. Alleen maar appartementen zonder tuin doet de kwaliteit niet ten goede.	2.1 Woningen in betaalbaar	Stuks		
		2.2 Woningen MG	Stuks		
		2.3 Woningen in sociaal (koop + huur)	Stuks		
		2.4 Woningen EG	Stuks		
		2.5 Totaal aantal woningen	Stuks		
		2.6 Woningen in Vrije sector	Stuks		

Figure D.3: Goals & Criteria in PAS

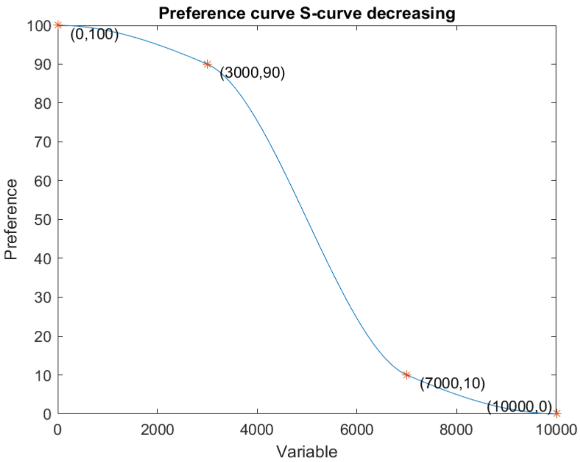
D.2.3 Preferences

In the second step, preference curves are defined for each criterion. Arkesteijn states that the number of defined datapoints of the curve should be around three (or as low as possible), to make it simple and understandable for the stakeholder (M. Arkesteijn, personal communication, March 10, 2022).

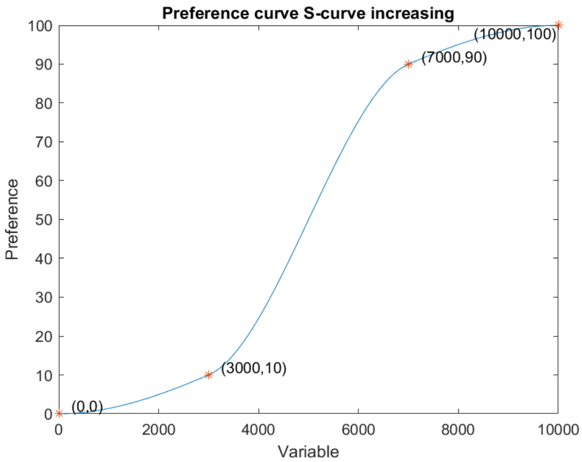
An explanation of PAS and a preference curve should be given to the stakeholders before they can be gathered. This is explained as follows to the stakeholders:

- *A preference is defined over a criterion that is related to a goal. A preference curve is a line that represents which values of an objective are preferred and which are not preferred. A preference of 100 means that someone becomes very satisfied when that value of a criterion is obtained, and 0 means that someone becomes very dissatisfied.*
- *A preference curve can be shown in a graph on which the y-axis always represents the preference, and the x-axis represents the value of the objective. The objectives on the x-axis can change per objective, the preference on the y-axis with a range from 0 to 100 can never change into something else than preference. A graph will be shown in the PAS tool as soon as a criterion is selected.*
- *3-6 datapoints on the curve need to be assigned in order to give a shape to the curve. A preference curve should at least have values where the preference is 0 and 100.*
  - *First, the value where the stakeholders' preference is 100 is determined. This is the top preference.*
  - *After that, the bottom preference is determined, which is the value that the stakeholder links to a preference of 0.*
  - *To get a minimum of three datapoints, the stakeholder can identify an intermediate preference, a value that is linked to a preference value between 0 and 100. While doing this, a curve appears, and the stakeholders can play with the shape of the curve until he is satisfied. More intermediate preference points can be added if desired by the stakeholder. This process is repeated for all the criteria with all stakeholders.*

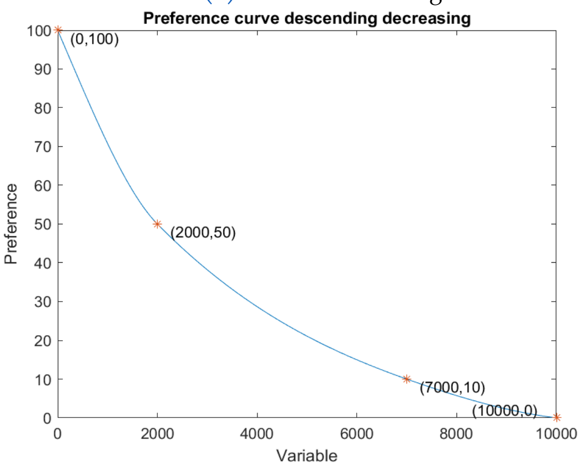
- *There are multiple shapes for the curves possible for a preference. Arkesteijn (2019) states that preference curves can have several shapes, such as a parabola or a concave/convex form.*
  The examples of shapes that were presented to the stakeholders in this development are shown in fig. D.4 and fig. D.5. The stakeholders were free to shape their own curve.
- *In some situations, the stakeholder cannot create a curve for a criterion because there are several predefined alternatives within the criteria (so-called discrete choices). In that case, a preference is given over a choice. An example of a criterion that has a preference over a choice in Waelpolder is the healthcare center. The healthcare center could only be generated in certain amounts of units. Therefore, the preference curves are expressed in a different way (fig. D.7).*



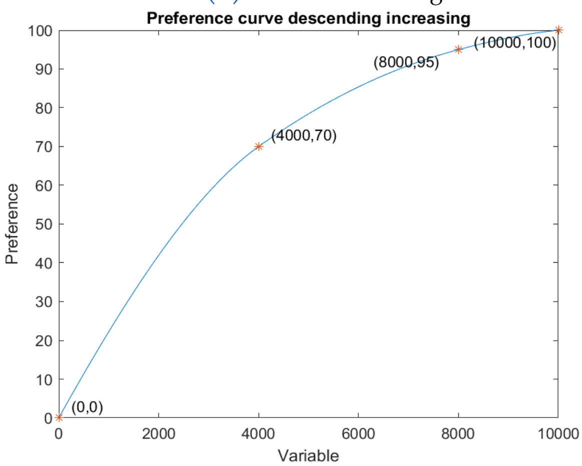
(a) S-curve decreasing



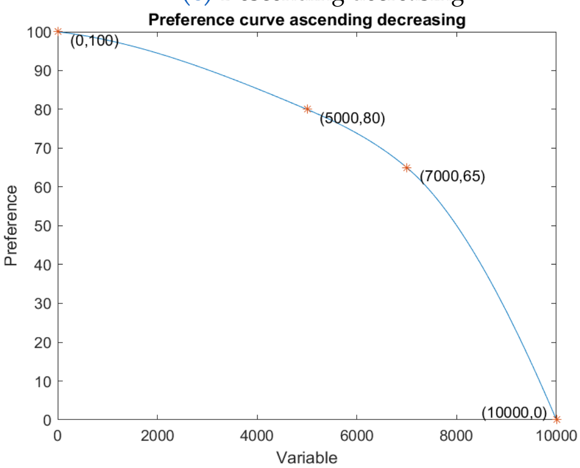
(b) S-curve increasing



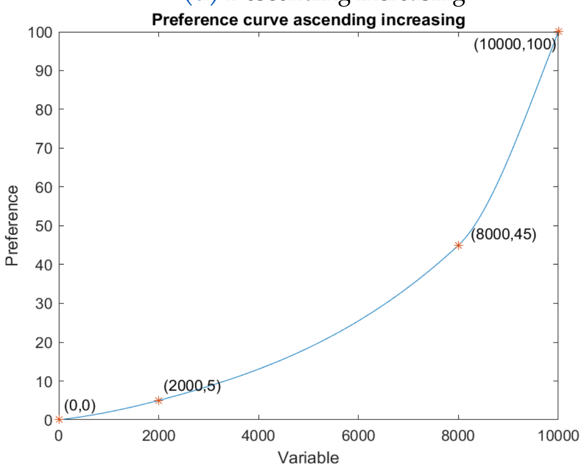
(c) Descending decreasing



(d) Descending increasing

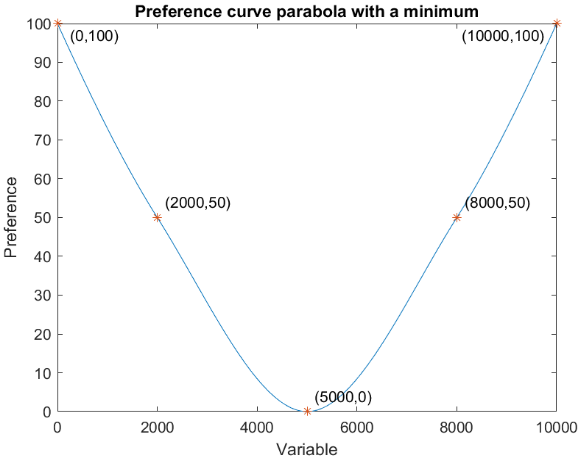


(e) Ascending decreasing

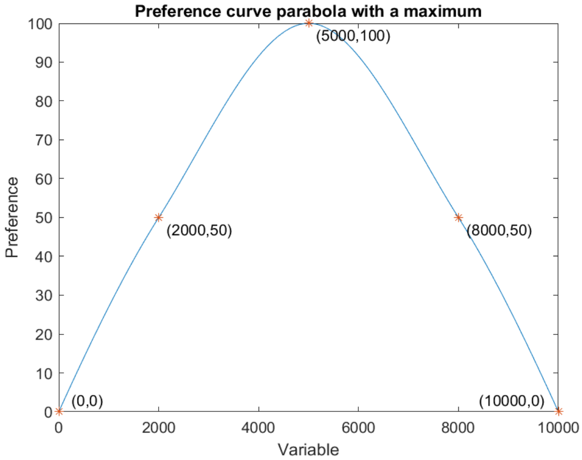


(f) Ascending increasing

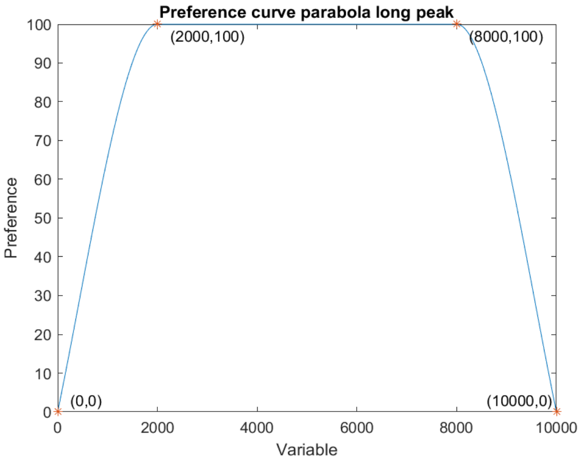
Figure D.4: Examples preference curves part 1



(a) Parabola with a minimum



(b) Parabola with a maximum



(c) Parabola long peak

Figure D.5: Examples preference curves part 2

An example of the Preference sheet in PAS is shown in fig. D.6 and fig. D.7 (regular and discrete preference curve). The stakeholder defines the points on the curve in the table on the left and the associated curve is demonstrated on the right, in both figures.

Gathering information of stakeholders is an iterative process. Since the technique and way of looking at such a problem is new to the stakeholders, Arkesteijn experienced that multiple sessions with stakeholders were needed before the right information was gathered.

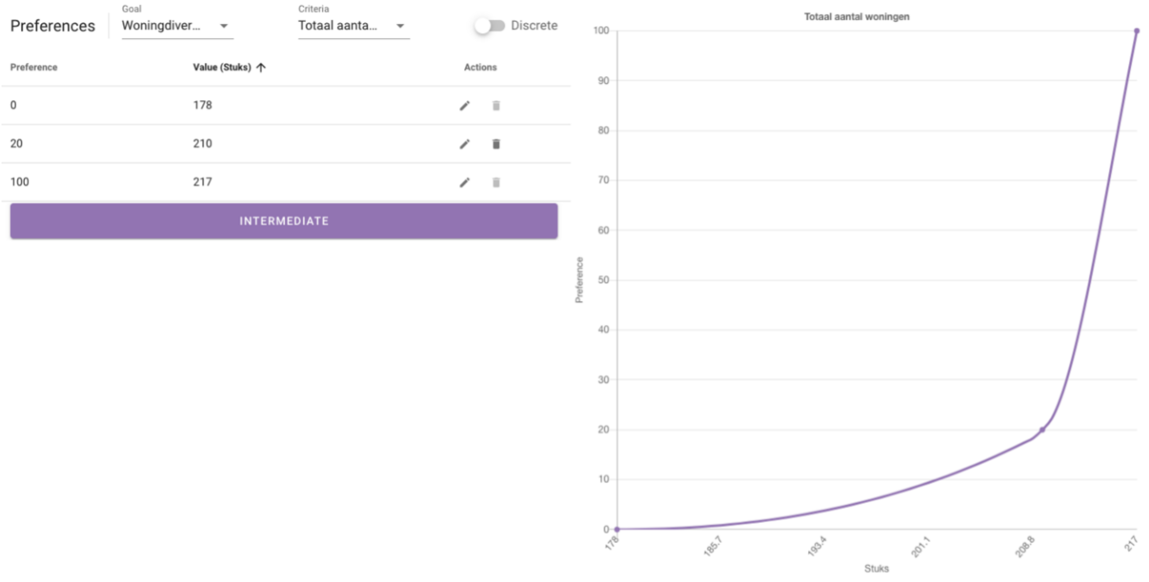


Figure D.6: Preferences in PAS

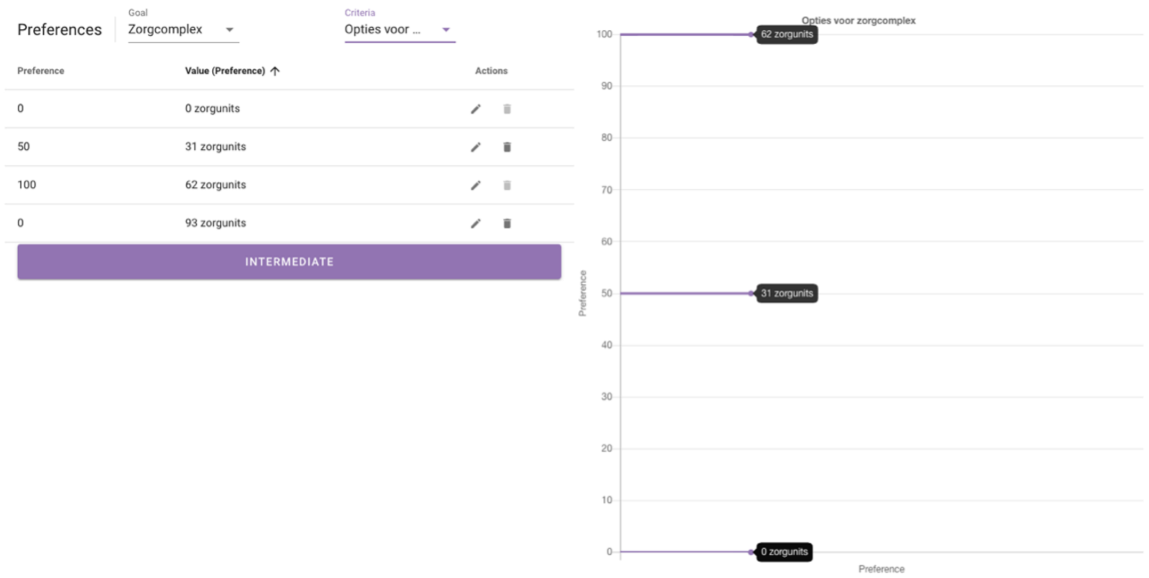


Figure D.7: Preferences over choices in PAS

D.2.4 Weights

The stakeholder assigns weights over the goals and criteria to express the importance of one aspect in relation to another aspect. An example of the Weights sheet is shown in fig. D.8.

The goals can be weighed, where the total of the weights need to be summed up to 100%. The same division can be done for a goal that is represented by more than one criterion. Again, the weights of the criteria within one goal need to be summed to 100%. Relative weights (shown in the right in fig. D.8) are determined according to the weight distribution: the weight that one criterion has times the weight of the associated goal.

Weights | Filter OPS

Goal ↓	Weight per goal	Criteria	Weight per goal per criterion	Relative weight
1. Zorgcomplex	17%	1.1 Opties voor zorgcomplex	100%	17%
2. Parkeren	17%	2.1 Parkeerkwaliteit	100%	17%
3. Meergezinswoningen	17%	3.1 Aantal woningen in Vrije sector	20%	3%
		3.2 Aantal woningen in sociaal	20%	3%
		3.3 Aantal woningen in betaalbaar	20%	3%
		3.4 Woningen MG	20%	3%
		3.5 Woningen EG	20%	3%
4. Groen	17%	4.1 Hoeveelheid groen ??	50%	9%
		4.2 Kwaliteit groen	50%	9%
5. Financieel	17%	5.1 Saldo	100%	17%
6. Aantal woningen	17%	6.1 Totaal aantal woningen	100%	17%
	100%			100%

Figure D.8: Weights in PAS

D.3 Outcome display

One of the goals of the development concerns the acceptance of the approach among the stakeholders. The stakeholders should be convinced of the design as the most desired group solution and should be explained how that solution is obtained. This convincing story differs for both applications, therefor it will be elaborated on in the appendices of both cases (appendix F.3.1, F.4.1 and G.4.1). Convincing the stakeholders also concerns the way in which the outcome is presented to the stakeholders. The visualization of the outcome should be clear and simple. The visualization of the output of the model has the same layout in both applications.

The MATLAB model consisting of a written code and will not be shown to the stakeholders, since this can work in a deterrent way. The outcome of the model (a PoR) will be shown in an Excel sheet. The PoR consists of values for the objectives that are set by the stakeholders. The outcome is dependent on the preferences that are given by the stakeholder. Therefore, the outcome can change with every change in a preference curve or constraint. The outcome of every run of the model will be shown in the Excel sheet, so the differences between the outcomes can be shown easily. Every run shows the overall preference score of the group which can be compared as well. An example of multiple outcomes in Excel are shown in fig. D.9.

The visualization of the output does not only show the design. It also exists of a sheet where the personal preference scores of the stakeholders are shown (fig. D.10). Here, stakeholders can see what their individual preference scores on their objectives in the design are. One could say this can work in a deterrent way. If a stakeholder sees that he does not score high in preference score on certain objectives, it could occur that he is not satisfied, and he will be less likely to accept the outcome. On the other hand, if a stakeholder sees that he scores well on aspects that he finds important, it will be more likely for him to accept the outcome. Even though he does not score high on objectives that are not so important for him, he could still be willing to accept the outcome since he is satisfied with the preference scores on variables that he finds more important. It is chosen to show the stakeholders the individual preference scores. The BDP case will be used to test whether this is the right approach.

Categorie	Nummer	Design variables Naam	Eenheid	PEN pref V8, Saldo	PEN pref V8, GG wonen	PEN pref V8, GG Tot groen	PEN pref V8, Tetra Pref
	P	**Optimisation value**	-	36.4888	3000	350.4486	73.346
	S	Saldo	Miljoen €	36.4888	29.7142	-29.192	28.5138
Algemeen	x1	Oppervlak	ha	434.999	434.9997	435.0006	434.999
	x2	Kosten	Miljoen €	266.5389	273.4065	226.2296	265.7385
	x3	Opbrengsten	Miljoen €	303.0277	303.1206	197.0377	294.2523
Strategisch groen	x4	Strategisch groen	ha	292.5321	292.4997	350.4486	304.63
	x5	*Gemeenschapspolder*	ha	199.9421	195.9508	130.7712	169.2494
	x7	*Plas*	ha	92.4059	18.2655	178.2627	81.0504
	x11	*Sport/Zorglandgoed*	ha	0.1756	49.3436	37.5697	39.1487
	x13	*Stadspark Weesp*	ha	0.0085	28.9398	3.845	15.1815
Woonmilieus	x20	Oppervlak wonen	ha	142.4669	142.5	84.552	130.369
	x21	Totaal woningaantal	won	2999	3000	2018	2930
	x22	*Vechtstad*	won	899	900	799	900
	x23	*Weesp*	won	650	650	650	650
	x24	*Tuinbuurt*	won	1000	1000	400	1000
	x27	*Lint nat*	won	350	350	139	350
	x29	*Landgoed*	won	100	100	30	30
		Tetra Preferentie		**73.2088**	**70.5444**	**34.2935**	**73.346**
		Duur/Tijd tot oplossing (seconde)		842.5495	34.3958	48.3638	1982.0001

Figure D.9: Example outcomes in Excel

	Gewichten	Subgewicht	Naam Optimisation value Stakeholder	PEN pref V8, Tetra Pref 73.346	Gemeente	Ontwikkelaars	Groen partij
S	1	1	Saldo		100	45.28	100
x4	1	1	Strategisch groen totaal		99.38	0	99.65
x21	1	1	Totaal woningaantal		98.17	98.68	0
x5		0.46	*Gemeenschapspolder*		93.07	100	58.75
x7	Strategisch groen: 1	0.23	*Plas*		99.93	78.34	24.13
x11		0.09	*Sport/Zorglandgoed*		96.61	0	56.03
x13		0.22	*Stadspark Weesp*		100	99.4	100
x20	1	1	Oppervlak wonen		100	4.07	100
x22		0.16	*Vechtstad*		0	100	
x23		0.3	*Weesp*		100	100	
x24	Woonmilieus: 1	0.31	*Tuinbuurt*		0	100	
x27		0.19	*Lint nat*		100	100	
x29		0.04	*Landgoed*		100	0	
			Tetra Preferentie	**73.346**			

Figure D.10: Example stakeholder outcome in Excel

E Goal attainment

The feedback of the stakeholders during the second workshop of BDP addressed the issue about the large amount of zero preferences on objectives among the stakeholders, as described in appendix F.6. Some stakeholders scored well on their objectives (a preference of 100) and others ended far away from their goals (a preference of 0). The stakeholders of BDP were discussing whether the amount of compromises should be more equally divided among the stakeholders.

Therefore, another method (goal attainment), where the compromises on a design between the stakeholders are equally distributed, was introduced. The goal attainment method should first be tested, technically, before it is compared with the Preferendus in the second application. It is only tested on BDP to be able to use it in a proper way in the second application. Therefore, the results are not shown to the re-enacted group of stakeholders of BDP again.

Goal attainment tries to search for a solution where every stakeholder makes around the same amount of compromises. This can be done according to two methods, method A and B. In this chapter, it will be investigated in which method the compromises of the stakeholders in the design are closest to each other. That method will be used in the second application to compare with the Preferendus method, such that differences between the Preferendus and goal attainment will become most apparent.

E.1 Method A

The three stakeholders as one group together means that all the preferences are taken together and then the distance to the goal (100) is tried to be minimized. The total distance for the entire group is calculated as follows:

- Multiplying the weight per objective (as shown in table F.4) and the weight per stakeholder for alternative a gives $W_{j,ai}$
- The distance of a stakeholder to one objective: 100 minus the preference score per objective per stakeholder for alternative *a* ($P_{j,ai}$)
- Multiplying the weight per objective per stakeholders ($W_{j,ai}$) by the distance of a stakeholder to one objective
- The total distance is the summation of all the distances per objective per stakeholder where weights are considered

The optimization solver will try to minimize the distance of the entire group.

$$Total\ distance = \left(\sum_{j=1}^{n} \sum_{i=1}^{n} ((100 - P_{j,ai}) * W_{j,ai}) \right) \tag{E.1}$$

Where:
j = the number of stakeholders
i = the number of objectives per stakeholder

The results of testing method A can be found in table E.2.

E.2 Method B

In this method, each stakeholders' distance is calculated separately. With the idea that each stakeholder ended up with the same amount of compromises on their goal (distance from the goal). Those compromises can be made on different objective(s) but also in different ways. Compromising all on one objective (one objective with a 0 preference, other objectives 'all' a 100 preference) or on each objective a little bit (not scoring a 100 preference on all objectives).

In this case the goal attainment method tries to minimize the distance from the goal per stakeholder. The goal for each stakeholder is to get the best preference score (100) on each objective. The total distance of a stakeholder considering all his objectives is calculated by:

- The distance of a stakeholder to one objective: 100 minus the preference (P_{ai}) per objective for alternative *a*.
- Multiplying the distance of a stakeholder per objective by the weights (W_i) he divided among his objectives. The weights in this goal attainment method are somewhat different as the three stakeholders now sum up to 3 instead of 1 (as they did in the Preferendus and method A of goal attainment which is described above). The distribution between the objectives is still the same, the new weights are shown in table E.1.

The optimization solver will try to minimize the sum for the distance per stakeholder. The optimization value (the value that is returned by the model) is the largest total distance one of the three stakeholders has.

$$Total\ distance = \left(\sum_{i=1}^{n} ((100 - P_{ai}) * W_i) \right) \tag{E.2}$$

Where:
i = the number of objectives per stakeholder

The results of testing method B can be found in table E.2.

Table E.1: Weights for goal attainment

Objective	Sub objective	Municipality	Developers	Green party
Result		0.166667	0.166667	0.200000
Total amount of greenery		0.166667	0.166667	0.200000
Total number of houses		0.166667	0.166667	0.200000
Greenery	*Gemeenschapspolder*	0.076667	0.076667	0.092000
	Plas	0.038333	0.038333	0.046000
	Sport/Zorglandgoed	0.015000	0.015000	0.018000
	Stadspark Weesp	0.036667	0.036667	0.044000
Total area housing		0.166667	0.166667	0.200000
Housing	*Vechtstad*	0.026667	0.026667	-
	Weesp	0.050000	0.050000	-
	Tuinbuurt	0.051667	0.051667	-
	Lint nat	0.031667	0.031667	-
	Landgoed	0.006667	0.006667	-
Total for each stakeholder		1	1	1

E.3 Chosen method with goal attainment

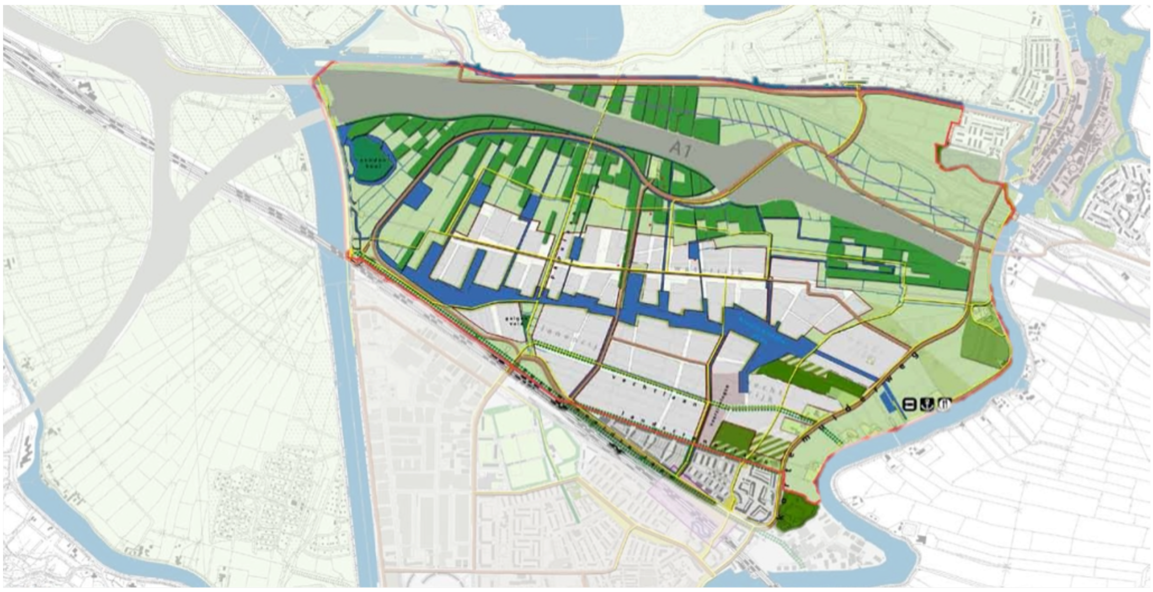
Method B shows that the distances of the stakeholders are closer to each other in comparison to method A, as indicated in table E.2.
So Method B, where all three stakeholders are considered separately, leads to an design where 'all' stakeholders make around the same amount of compromises on their individual goal. Therefore, this method will be used in second application to compare with the Preferendus.

Table E.2: Comparison between method A and B

		Method A			Method B		
Objective	**Sub objective**	**Municipality**	**Developers**	**Green party**	**Municipality**	**Developers**	**Green party**
Result		1.23	5.56	0.00	0.47	11.97	0.00
Total amount of greenery		1.88	3.54	1.88	0.57	1.67	0.68
Total number of houses		1.08	5.06	5.56	1.77	3.43	20.00
Greenery	*Gemeenschapspolder*	0.04	0.00	0.59	0.00	0.00	0.03
	Plas	1.33	1.01	0.00	0.50	1.28	2.03
	Sport/Zorglandgoed	0.53	0.10	0.53	1.50	0.00	1.80
	Stadspark Weesp	1.29	1.18	1.29	0.00	0.01	0.00
Total area housing		0.27	2.29	0.00	0.00	1.22	0.00
Housing	*Vechtstad*	0.94	0.94	-	0.02	2.48	-
	Weesp	1.76	1.44	-	5.00	1.91	-
	Tuinbuurt	1.82	0.00	-	5.10	0.07	-
	Lint nat	0.00	0.00	-	0.00	0.00	-
	Landgoed	0.00	0.24	-	0.67	0.00	-
Total distance per stakeholder		**12.17**	**21.35**	**9.86**	**15.59**	**24.05**	**24.54**

Appendix Bloemendalerpolder

This part elaborates on the test-case BDP



F Test case: Bloemendalerpolder

This appendix elaborates on the Bloemendalerpolder case and supports the conclusions of the main document related to the test-case. In the next chapters the BDP case will be explained in more detail by the means of the steps that were made in this case. This includes an introduction to the case itself (appendix F.1) and the model development (appendix F.2). Besides that, the setup of the stakeholder sessions and outcome of those sessions will be evaluated in appendix F.3 and F.4 (workshop 1 and 2). Last, the detailed conclusions and remarks, including adjustments are touched upon.

F.1 Introduction of BDP

In this chapter, the application to Bloemendalerpolder will be introduced. First, some basics of the case will be elaborated, and the infeasibility of the case will be discussed. After that, the stakeholders that play a role in the case will be discussed. The steps that are taken to come from an existing (LP) model to a model that is designed according to the PDOA will be discussed in the last section. Appendix F.2.1 will discuss in more detail what the existing (LP) model for the Bloemendalerpolder case looks like.

F.1.1 Bloemendalerpolder

The goal of the first application is to investigate if the PDOA has added value and to test how the approach can be explained to stakeholder such that eventually, the approach and outcome is accepted by the stakeholders. The goal can be reached by applying PDOA on a case called Bloemendalerpolder (BDP).

Bloemendalerpolder (shown in fig. F.1) is an urban development project, redeveloping an agricultural area, in the municipality of Weesp, Noord-Holland. The total plan area is 435 hectares, this area will be used for housing and nature development. The main idea was to create a vibrant living area including nature and ecology as this area is near 'Het Groene Hart'.

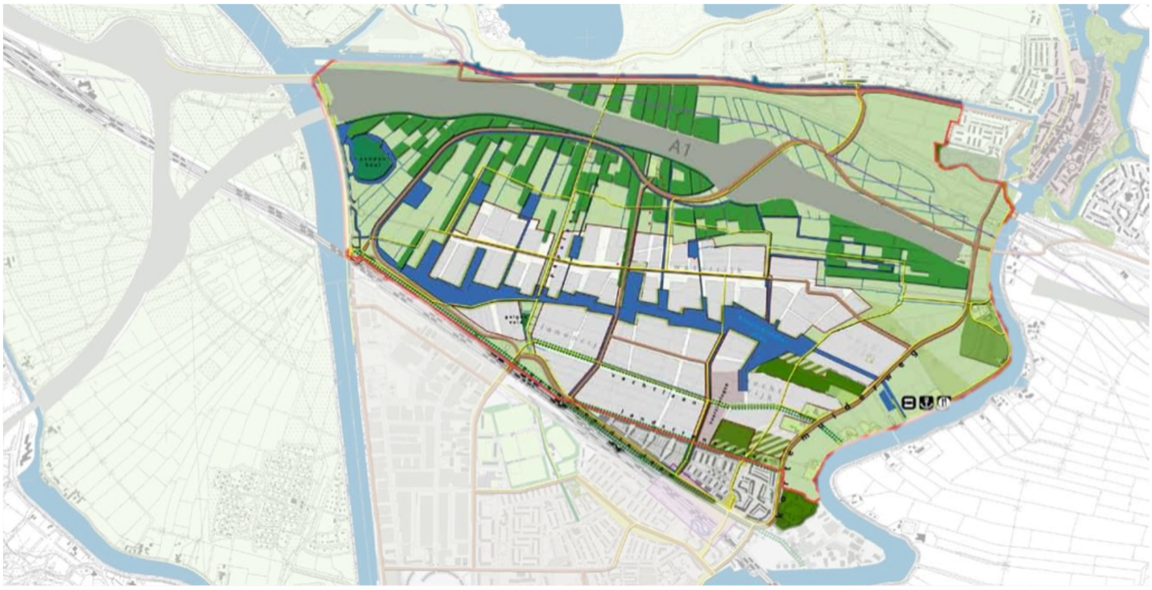


Figure F.1: Bloemendalerpolder overview

F.1.2 Infeasibility

Around 10-15 years ago Planmaat was invited to create a linear programming model for BDP, as five designs were already created but none were accepted by the involved stakeholders. The latest design included a plan to build around 1850 houses. However, the design could not be completed without a major result (revenues – costs) deficit. From that moment, Planmaat was involved. The idea of Planmaat was to get the conversation going again with the help of an LP model, convincing the involved parties that the constraints within the project did not define a feasible solution space. The LP model had to convince the stakeholders that the constraints had to change to come to a solution.

The LP model of Planmaat was optimized on result. The solution of Planmaat does not show cooperation since the optimization of the model was only focusing on one aspect, result. However, in order for the project to succeed, all parties should be involved. Optimizing only on result would not fulfill every stakeholder's needs and leading to not accepting the outcome. The green party would for example not be satisfied with an outcome that only focuses on result, since that means that there will be more space assigned to housing in the area than to green (houses generate revenues and green does not). Stakeholders should have the feeling that everyone makes some concessions in order to come to a solution.
In addition, the LP model of Planmaat did not come to a solution either, without having a major result deficit, even though it has been optimized on result. This shows that the problem was mostly related to the constraints that defined the limits of financial result. The result deficit was too high to get all the parties involved and therefore constraints should be adjusted.

It is interesting to investigate what would happen if the preferences of the stakeholders would be included in this issue. The model can be optimized to a group optimum by adding their preferences. This means that cooperation between the parties will be included in the outcome. Besides that, including preference measurement could give the model more solution space by adjusting the negotiable constraints of the project. Therefore, it is possible to investigate the added value of the PDOA on BDP in comparison to another method where cooperation is not included.

F.1.3 Stakeholders

The model that is created, will consider three stakeholders: Municipality, Developer(s) and a green party. The goals of different developers and landowners are considered as one in this model, as their main goals are the same within the project. The main goal of each stakeholder is as follows:

- **Municipality**: BDP has to become a vibrant, diverse and accessible area, where multiple functions come together, such as living and recreation.
- **Developers and/or landowners**: BDP should be as profitable as possible. The area has to increase in value as much as possible, so that the land value rises and thus generates more profit. This should be done by primarily building houses.
- **Representative of greenery (Green party)**: BDP has to become an area where greenery has the most important role, contributing to nature/ecology and recreation.

BDP is a case that took place more than ten years ago, therefore the role of the stakeholders was fulfilled by employees from Planmaat. From their work with Planmaat, they understand (mostly) the working of LP. However, working with a non-linear preference model is new to them. The municipality and the green party are represented by one stakeholder each, the developers are represented by two stakeholders.

F.1.4 Steps made in this case

An overview of the steps that are taken in this application is shown in fig. F.2. Some steps need to be made to be able to show that the PDOA approach has added value compared to basic LP modeling. First, the LP model need to be converted into a PDOA model. The steps that guide this process are described in the next sections.

An important milestone is the verification of the PDOA model, before it is used during the workshops. Within the testing phase, pencil preferences are created to be able test the technicalities of the model. The next step is to gather preferences from the stakeholders of the project, this will be done during a workshop and individual session with the stakeholders. A second stakeholder workshop was initiated to discuss the outcome (design) and to reflect on the entire process in order to fulfill the goals of this application.

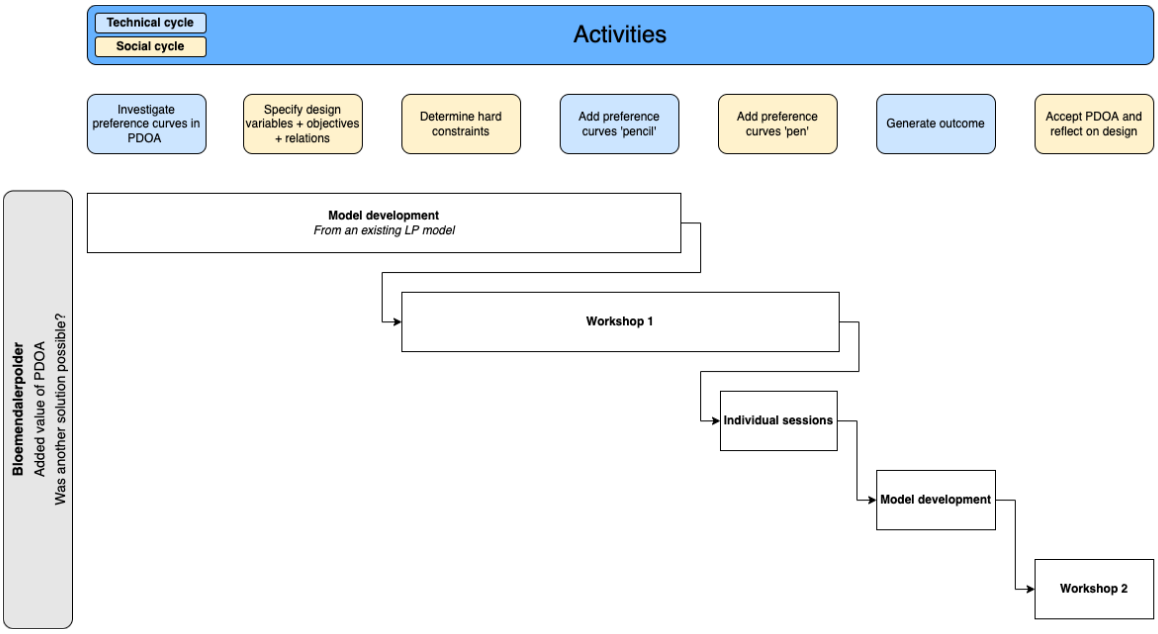


Figure F.2: Flowchart BDP

The steps that are performed in BDP, shown the figure, will be discussed in several chapters. First the model development will be discussed in appendix F.2, in which all the elements in the MATLAB model will be elaborated, including a verification of the model. How the first workshop within BDP is setup and proceeded is discussed in appendix F.3. This chapter will also address adjustment that need to be made for the second workshop. The second workshop is discussed in appendix F.4 and is also elaborating on the setup, outcomes, and an evaluation. The BDP application ends with a conclusion regarding the goal of this application (appendix F.5) and points of improvements will be discussed for the second application (appendix F.6).

F.2 Model development

To construct the model in MATLAB, the LP model of Planmaat that was created in Excel, is studied to get an idea which relations in BPD case played a role. Besides that, the model is used to gather information (cost, revenues, area usage etc.) related to the design variables. These design variables and relations in the LP model are converted to MATLAB, an explanation of what is considered in the model can be found in the paragraph MATLAB model.

As stated before, the LP model is created by Planmaat about 10-15 years ago. To be able to compare both models in a later stage, the design variables of the LP model are leading, adding extra relations or design variables is not considered in the MATLAB model that is created.

For user-friendliness, the created model is split in four parts, these four parts of the model will be discussed in the sections after the elaboration on the LP model of Planmaat.

- A database containing all the input information related to design variables, preferences, and weights
- The interface that was used for gathering the preferences
- The MATLAB model itself and the output file
- The output file contains all the model runs and the related design (preferences)

F.2.1 Model of Planmaat

The LP model of Planmaat is based on only one stakeholder, Ontwikkelingsmaatschappij Bloemendalerpolder (OMB). This party consists of the municipality and a number of developers, together they are responsible for developing the area of BDP. The different stakeholders all have an equal stake in the OMB, this makes them share the risks and possible revenues of the project. Therefore, the optimization objective of the LP model is result, as none of the parties involved want to pay for the significant losses in the project.

The LP model of Planmaat for the BDP case contains 46 variables, these variables are divided into 4 categories: general, greenery, housing and additional costs. The most important elements in the model are result (revenues or losses), types of housing and the types of greenery, these elements will create the eventual the quantitative design for the area. The types of greenery and housing are constrained, result (saldo) does not have any constraints in the model of Planmaat. This was chosen to show the involved stakeholders there was no feasible solution possible if there was a constraint to generate a positive result (making profit). All 'solutions' come with a significant loss when the other constraints are taken into account.

Besides that, several aspects are constrained in such way, that those can be seen as fixed values instead of a variable. For example, all elements of the additional costs are already pre-set, since those need to be in place for the project no matter what. The additional costs, consists of elements which make the area livable and ready for the future inhabitants like constructing infrastructure.

Within the LP model, the general variables and constraints are related to result (costs and profit), total amount of greenery and the number of houses. Result itself is not a design variable, costs and profit are the related variables which are not constrained in any sense. The total amount of greenery is a variable and is constrained on a minimum and maximum value since a certain amount of area needs to be addressed for ecology (compensation). The maximum number of houses is a constraint as well, since the municipality wants to limit the number of houses/inhabitants in the area, otherwise the extra expenses need to be taken into account for infrastructure. Within the LP model all types have a minimum and a maximum constraint. More on the constraints will follow in chapter Model development, subsection *negotiable constraints – objectives* (F.2.4).

F.2.2 Database

The information that is gathered with the use of the LP model is converted into the database, which is shown in fig. F.3. This database is an Excel file which holds all the input data for the MATLAB model, regarding the amount of variables and its properties: cost, profit, land usage etc. The variable sheet in the database also contains a technical element for the model, the lower and upper bound for the variables. The lower and upper bound give the model the ability to search in the right direction for a solution and come faster to a feasible solution. The lower bound of all variables is at least set on 0, to avoid a negative amount of greenery or housing, as that would not be possible to construct.

Besides that, the database contains several sheets that hold the preferences of the stakeholders, those sheets are linked to an interface on the first page of the Excel file. This interface will be discussed in more detail in the appendix F.2.3.

There was chosen for this type of database because it makes the MATLAB model orderly and more user-friendly; data can be changed easily without changing the model. Besides that, it gives the ability to see which data is used in a glance. As the stakeholder preferences are also in this file, they can be changed easily during stakeholder meetings, without showing the full MATLAB-code.

Categorie	Num	Design variables	Uitslag LPE	Eenheid	Minimaal	Maximaal	Leeg	Kosten_eh	Opbrengst_eh	Oppwon	Lb	Ub
Algemeen	x1	Oppervlak	434,8	ha	0	435		0	0	0	0	436
	x2	*Kosten*	*328,892*	€	0	999000000		0	0	0	0	999000000
	x3	*Opbrengsten*	*204,506*	€	0	999000000		0	0	0	0	999000000
Strategisch groen	x4	*Strategisch groen*	*332,6*	ha	265	435		0	0	0	265	435
	x5	Gemeenschapspolder	100	ha	0	200		36497	0	0	0	220
	x6	Waterland	69	ha	0	0,01		36700	0	0	0	0,011
	x7	Plas	40	ha	0	200		97780	0	0	0	220
	x8	Waterlandtak	61	ha	0	0,01		40773	0	0	0	0,011
	x9	Vechtoever	19	ha	0	0,01		12653	0	0	0	0,011
	x10	Park Muiden	0	ha	0	0,01		75810	0	0	0	0,011
	x11	Sport/Zorglandgoed	20	ha	0	50		195276	0	0	0	55
	x12	Arboretum	7,8	ha	0	0,01		210071	0	0	0	0,011
	x13	Stadspark Weesp	7,6	ha	0	30		158614	0	0	0	33
	x14	Waterarboretum/Galgenveld	8,0	ha	0	0,01		94914	0	0	0	0,011
Bijzonder	x15	Paden	1	%	1	1,01		3278449	0	0	0	1,111
	x16	Dijken	1	%	1	1,01		1691224	0	0	0	1,111
	x17	Kunstwerken	1	%	1	1,01		5697043	0	0	0	1,111
	x18	Specials	1	%	1	1,01		1990763	0	0	0	1,111
	x19	Beheerboerderij	1	%	1	1,01		940148	0	0	0	1,111
Woonmilieus	x20	*Oppervlak wonen*	*102,2*	ha	0	200		0	0	0	0	200
	x21	*Totaal woningaantal*	*1860*	won	0	3000		0	0	0	0	3000
	x22	Vechtstad	387	won	200	800		72498	92984	0,0331	0	880
	x23	Weesp	223	won	100	600		48280	92984	0,0381	0	660
	x24	Tuinbuurt	650	won	400	1000		32369	87446	0,0339	0	1100
	x25	Lint droog	132	won	0	0,01		66490	167563	0,1049	0	0,011
	x26	Lint 1/2 nat	131	won	0	0,01		86741	167563	0,1049	0	0,011
	x27	Lint nat	179	won	100	350		88909	167563	0,1049	0	385
	x28	Buurtschap	106	won	0	0,01		32911	87446	0,0339	0	0,011
	x29	Landgoed	51	won	30	110		123707	126690	0,1733	0	121
	x30	Aantal won betaalbaar	161	won	161	161,01		0	-31673	0	0	177,111
Bovenwijkse kosten	x31	Verplaatsen gas- en rioolpersleiding	1	%	0,99	1,01		4266667	0	0	0	1,111
	x32	Verplaatsen hoogspanningsleiding	1	%	0,99	1,01		2177778	0	0	0	1,111
	x33	Hoofdontsluiting 2*2	2250	m'	2.250	2.551		5700	0	0	0	2806,1
	x34	Verbindingsweg A1 - Muiden	1	%	0,99	1,01		5333333	5333333	0	0	1,111
	x35	Onderdoorgang spoor LV	2	st	1,95	2,01		6000000	0	0	0	2,211
	x36	Fietsbrug over A1	1	%	0,99	1,01		7777778	0	0	0	1,111
	x37	Herprofileren Korte Muiderweg	1	%	0,99	1,01		1266667	0	0	0	1,111
	x38	Verbinding A1 - Vechtstad	1	%	0,99	1,01		3911111	0	0	0	1,111

Figure F.3: Overview database BDP in Excel

F.2.3 Interface

During the workshops, an interface was used to gather the preferences of stakeholders. The idea behind the use of the interface was the visualization of the preference values and curves for the stakeholders. So, they could easily say something about the shape of the created preference curve. The interface consists of two parts, an Excel sheet with a panel to put in the preference values and a MATLAB model which visualizes the preference curves. These parts are linked with each other, and the panel is linked to the database, which is discussed above.

Panel interface

The panel is created in Excel and is linked to the database that is discussed above. The panel consist of two sheets, the panel that is shown to the stakeholders and a sheet that contains the constraint values. In the panel, it is possible to input values for a preference and an objective (fig. F.4). The blue colored cells are the cells that represent the preference, these include numbers between 0 and 100. As stated before, the begin and end values (the range of an objective) for objectives are always the same for every stakeholder. Because the begin and end points are dependent on the constraints of the model, they are colored in gray. The gray values cannot be changed in the panel, these are not filled in by a stakeholder. The constraint values can be changed in another sheet of the Excel. At last, there are gray values that refer to already filled in values.

The panel contains a few warning signals that activate when cells contain the wrong values. For example, when an objective value is lower than its minimal value, the cell will color red. The following warning signals are present in the panel:

- When the same objective value is used in one preference curve. The PCHIP function cannot cope with multiple exact same objective values.
- When objective values of datapoints 2 until 5 are not between the minimal and maximal value of that objective (datapoint 1 and 6).
- When the addition of the types of green and houses do not match with the minimal amount of total green or number of houses in the area.

Pencil Preferenties Bloemendalerpolder

Gemeente - M						
Algemeen						
S	*Saldotekort*		100	75	50	0
		Miljoen €	-75	10	22	35
x4	*Strategisch groen totaal*		0	100	0	0
		ha	100	270	385	435
x21	*Totaal woningaantal*		0	100	60	0
		won	0	2000	2600	3000
Strategisch groen						
x4	*Strategisch groen totaal*		0	100	0	0
		ha	100	270	385	435
x5	*Gemeenschapspolder*		0	10	85	100
		ha	40	50	150	200
x7	*Plas*		0	30	100	0
		ha	40	50	80	200
x11	*Sport/Zorglandgoed*		0	100	100	0
		ha	10	10.1	30	50
x13	*Stadspark Weesp*		0	100	100	0
		ha	10	10.1	20	30
Wonen						
x20	*Oppervlak wonen*		0	100	60	0
		ha	0	110	150	435
x21	*Totaal woningaantal*		0	100	60	0
		won	0	2000	2600	3000
x22	*Vechtstad*		0	100	100	0
		won	200	300	600	800
x23	*Weesp*		0	100	100	0
		won	100	180	400	600
x24	*Tuinbuurt*		0	100	100	0
		won	400	550	800	1000
x27	*Lint nat*		0	100	100	0
		won	100	150	300	350
x29	*Landgoed*		0	100	100	0
		won	30	45	90	110

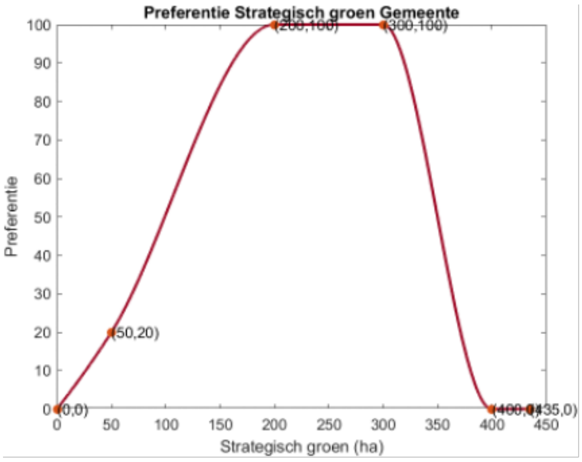
Ontwikkelaars - D						
Algemeen						
S	*Saldotekort*		100	100	10	0
		Miljoen €	-75	-60	0	35
x4	*Strategisch groen totaal*		100	80	0	0
		ha	100	150	300	435
x21	*Totaal woningaantal*		0	100	70	0
		won	0	2500	2800	3000
Strategisch groen						
x4	*Strategisch groen totaal*		100	80	0	0
		ha	100	150	300	435
x5	*Gemeenschapspolder*					
		ha	40			200
x7	*Plas*					
		ha	40			200
x11	*Sport/Zorglandgoed*					
		ha	10			50
x13	*Stadspark Weesp*					
		ha	10			30
Wonen						
x20	*Oppervlak wonen*		0	10	70	100
		ha	0	125	160	435
x21	*Totaal woningaantal*		0	100	70	0
		won	0	2500	2800	3000
x22	*Vechtstad*		0	20	80	100
		won	200	380	550	800
x23	*Weesp*		0	20	80	100
		won	100	220	400	600
x24	*Tuinbuurt*		0	20	80	100
		won	400	650	800	1000
x27	*Lint nat*		0	20	80	100
		won	100	180	250	350
x29	*Landgoed*		0	20	80	100
		won	30	50	80	110

Belangbehartigers Groen - G						
Algemeen						
S	*Saldotekort*					
		Miljoen €	-75			35
x4	*Strategisch groen totaal*		0	0	90	100
		ha	100	150	330	435
x21	*Totaal woningaantal*		100	100	0	0
		won	0	100	1000	3000
Strategisch groen						
x4	*Strategisch groen totaal*		0	0	90	100
		ha	100	150	330	435
x5	*Gemeenschapspolder*		0	20	90	100
		ha	40	115	150	200
x7	*Plas*		0	10	80	100
		ha	40	70	125	200
x11	*Sport/Zorglandgoed*		0	0	100	100
		ha	10	10.1	25	50
x13	*Stadspark Weesp*		0	0	100	0
		ha	10	10.1	20	30
Wonen						
x20	*Oppervlak wonen*		100	100	30	0
		ha	0	5	100	435
x21	*Totaal woningaantal*		100	100	0	0
		won	0	100	1000	3000
x22	*Vechtstad*					
		won	200			800
x23	*Weesp*					
		won	100			600
x24	*Tuinbuurt*					
		won	400			1000
x27	*Lint nat*					
		won	100			350
x29	*Landgoed*					
		won	30			110

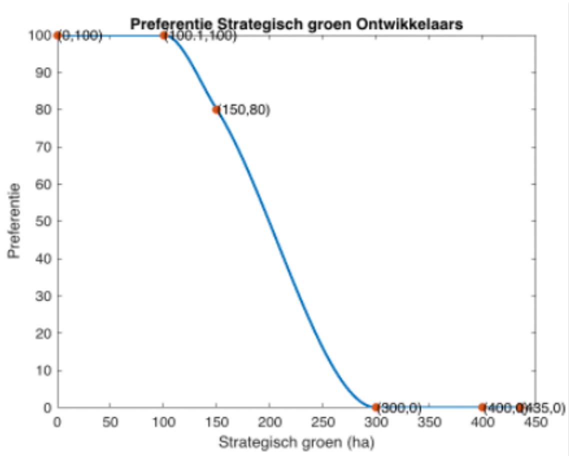
Figure F.4: Panel interface BDP

MATLAB interface

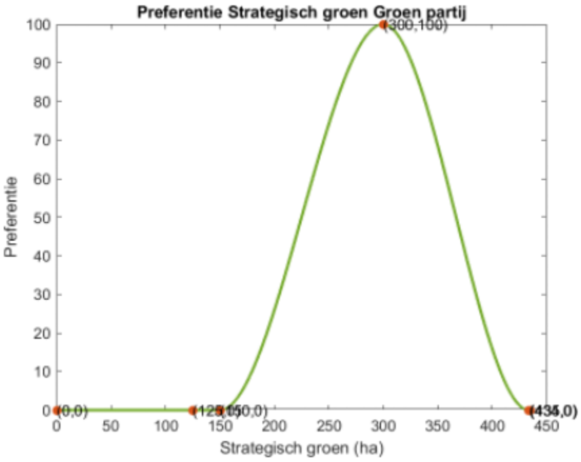
The Excel model is linked with a model in MATLAB that ensures a visualization of the preferences, using a plot function. The model shows the preference curves of each stakeholder for each objective. It can be hard for stakeholders to visualize a curve from the values they put in the panel. The MATLAB visualization model helps in this process. An example is shown in fig. F.5.



(a) Total amount of green, Municipality



(b) Total amount of green, Developers



(c) Total amount of green, Green party

Figure F.5: Visualization preference curves MATLAB interface

F.2.4 MATLAB model

To come to a solution using the preferences of the stakeholders, a model in MATLAB is created. The MATLAB model uses the input of the database that has been discussed already. The model itself consists of the following elements: design variables, relations, constraints, negotiable constraints/objectives of the stakeholders (including preference curves), an optimization method, and a solver. All these elements will be discussed in this section.

The MATLAB model consist of several blocks, to make it more user-friendly and orderly, where the elements that are described in this section are used. The code is attached in appendix H.1.

The aim is first to create the same LP model of Bloemendalerpolder in MATLAB. In the next development step, it will be analyzed if the MATLAB model returns the same solution as the LP model of Planmaat. That step is the verification of the MATLAB model.

Design variables

The design variables were already predefined in BDP. Normally, when a model is built from scratch, the goals for the project are rather vague and, in most cases, not formulated in a way that they could be measured. To convert the goals into something measurable, experts recommend to use a 'doelenboek'. The doelenboek breaks down a vague goal into (several) measurable objectives and possible design variables are derived which are linked to the objectives. For this case, there was already a model, so the design variables were already established. Therefore, this step was not needed for the MATLAB model.

As stated earlier, the LP model consisted of 46 'variables', to be able to create a functioning model the number of variables is reduced. The number of variables in the model are reduced for two reasons. Decreasing the running time of the model and to have the possibility to gather preferences over a proper number of objectives, regarding the goal of this application.

Taking a closer look at the 46 'variables' in the LP model, shows that more than half of those is not variable anymore, as they are constrained in such a way that they are fixed values as stated before. Modeling these constraints and 'variables' in another way, takes away 28 variables. In order to compare both the LP model with the simplified model, both cases need to be equal in variables. Therefore, the reduction in variables in the MATLAB model have also been applied to the LP model.

After looking into the relations and parameters, the main issue lies in the reduction in variables of the types of houses and types of green. Both types are reduced to respectively 5 and 4 types. Those remaining types should together have the same numbers as all types together before the reduction, in order to work with the numbers and constraints that were originally set in the LP model. This holds as well for the corresponding properties related to result and land usage, to be able to compare the LP model to the reduced model.

The simplified model of BDP consists of 13 objectives: result, total amount of green, 4 types of greenery (Gemeenschapspolder, Plas, Sport/Zorglandgoed and Stadspark Weesp)[1], total area for living, total number of houses and 5 types of housing (Vechtstad, Weesp, Tuinbuurt, Lint nat and Landgoed)[2]. Result, total amount of greenery, total area for living and the total number of houses are variables that are fully depending on the 4 types of greenery and 5 types of housing. Therefore, it could be stated that there are only 9 independent variables that are considered as design variables in the model.

Relations

The relations in the MATLAB model connect the objectives with the design variables, with several different relations. In the MATLAB model there are relations for: cost, profit, area usage (total area, area for green and area for living) and total number of houses.

Table F.1 shows how the 4 types of green area related to the costs of the project. The other table (F.2) shows how the 5 types of housing are related to cost, revenue and area usages per house. Cost and profit are related to each other in result (revenues minus cost).

Besides that, there are fixed costs in the project, those are related to elements that need to be in the developed area to make the area livable, such as placing trees and a drainage system. The fixed costs within the project will be referred to as 'additional costs' and can be added to the total costs of the project.

Table F.1: Properties greenery

Type	Properties	Costs (per ha)	Recreants (per ha)	Costs (per Recreants)
Gemeenschapspolder	Combination between green land & water (classic polder landscape)	€ 36.497, -	15	€ 2433,-
Plas	Space entirely filled with water	€ 97.780, -	10	€ 9778,-
Sport/ Zorglandgoed	Open field where multiple functions come together such as sports (athletics, basketball & soccer) and an experiencing forest (adventurous & educational)	€ 195.276, -	50	€ 3906,-
Stadspark Weesp	Open and accessible forest with the opportunity to walk in, meet or eat	€ 158.614, -	100	€ 1586,-

Constraints

The model consists of hard and negotiable constraints. To create a solution that is acceptable, there are still some constraints needed. The only hard constraint in the model is the total project area (435ha), this limit cannot be exceeded. A solution that covers 436 ha will not be considered as a feasible solution.

The negotiable constraints have a strong relation with the objectives within the model of the BDP case. In the case of BDP, the objectives are considering the same aspects on which there are constraints in the LP model.

[1]The types of greenery were predefined within BDP, therefore the types keep their Dutch predefined name.
[2]The types of housing were predefined within BDP, therefore the types keep their Dutch predefined name.

Table F.2: Properties housing types

Type	Density (house/ha)	Revenues (per house)	Costs (per house)	Profit (per House)	Profit (per ha)
Vechtstad	30,2	€ 92.984, -	€ 72.498, -	€ 20.486, -	€ 618.677, -
Weesp	26,2	€ 92.984, -	€ 48.280, -	€ 44.704, -	€ 1.171.245, -
Tuinbuurt	29,5	€ 87.446, -	€ 32.369, -	€ 55.077, -	€ 1.624.772, -
Lint nat	9,5	€ 167.563, -	€ 88.909, -	€ 78.654, -	€ 747.213, -
Landgoed	5,2	€ 126.690, -	€ 123.707, -	€ 2.983, -	€ 15.511, -

This a special occasion, since normally a model will be built from scratch which means that the constraints and objectives will not overlap that much. This special occasion is due to the fact the design variables of types of greenery and housing were already predetermined. Besides that, the objectives are directly linked to opening the hard constraints that are set for design variables, resulting in some objectives that are determined over the design variables.

Including preferences in the model result in negotiable constraints in the model, as the preference defines the less desired solutions with a preference of zero. The limits of the negotiable constraints in the LP model were tight. These limits were loosened when an objective was defined over the same aspect.

The modified and more open constraints within the smaller LP model, are related to the constraints in the LP model. The reduction in the number of types in greenery and housing types was done in such way that the new constraints do not affect the properties of the project. After that, the constraints were opened based on the outcome of the LP model. All variables are opened in the same order of magnitude, to keep the characteristics of the project the same. This means, by building more houses to generate more revenues, greenery should be built as well to have a place to leisure.

Negotiable constraints - Objectives

The preference curves are defined within a certain range for the values of an objective. The ranges are based on the constraints that were defined and opened in the LP model, since they consider the same aspects as the objectives. Besides that, the objectives are predefined by the LP model and have the same units as in the LP model. An explanation of the ranges is given below, followed by a table with an overview of the ranges for the objectives.

The result has a constraint. When the project has a significant negative result, the project is not of interest for the developers since they need to pay for the development without making any profit. The minimum constraint of the result was set on 10-15% loss, of the total project finances, which translates to a negative result of 35 million euros. The maximal value for result is calculated with a small calculation. Taking the maximal number of houses, times the average result of a house minus the minimal amount of green built with the cheapest types of greenery.

The 5 types of housing have two constraints, a minimum and maximum value, those are set to create a mixture of the 5 types, which will increase the livability and value of the area. A limit is set on the total number of houses, to limit the growth of the area as well as limiting the pressure on the surrounding area, as this project is near 'Het Groene Hart'. This limit is formed by the sum of the maximum of the five different types of houses. The types of greenery only have a maximum value. Gemeenschapspolder and Plas are considered to have a higher ecological value and a lower recreational value, and therefore a relative high maximum. For Stadspark Weesp and Sport/Zorglandgoed, it is the other way around, so these types have a lower maximum. Therefore, to increase the value of the area, a mixture is needed.

The last constraints are related to the land usage, the division between greenery and living. The project area of BDP cannot be filled with 100% greenery, as the goal of 'creating a livable space' will not be met. Also, the other way around, there needs to be space for green, so the total area cannot be filled with only houses. To be able to find the most desired solution, the stakeholders were able to express what they really prefer and let the preference modeling do the rest (choosing the right division between those two aspects). Therefore, the total area for living and total amount of greenery, do not have constraints. In other words: the whole area (435ha) is available for both design elements.

Table F.3: Minimal and maximal values of objectives

Objective	Unit	Minimal value	Maximal value
Result (based on revenue - costs)	€	€ -35,000,000.00 (=loss)	€ 75,000,000.00 (=profit)
Total amount of green	Ha	0	435
Total number of houses	Houses	830	3000
Gemeenschapspolder	Ha	0	200
Plas	Ha	0	200
Sport/Zorglandgoed	Ha	0	50
Stadspark Weesp	Ha	0	30
Total area housing	Ha	0	435
Vechtstad	Houses	200	900
Weesp	Houses	100	650
Tuinbuurt	Houses	400	1000
Lint nat	Houses	100	350
Landgoed	Houses	30	100

Optimization method

For BDP, the main goal of the MATLAB model is finding a design with the highest possible group preference. Preferences over the objectives of stakeholders are gathered, and preference curves are constructed. This MATLAB model uses the Preferendus method to find the design with the highest overall preference, the most desired group solution. The input for the Preferendus are the preference curves and weights assigned to the objectives, both will be discussed later, in appendix F.2.5 and appendix F.3.

Furthermore, with MATLAB it is possible to optimize on not only the design variables in the model as everything could be an objective, as long as it can be written in a formula. The model could also be optimized on different objectives in order to convince the stakeholders of the outcome. For example, when optimizing the model on the amount of greenery, the overall preference score will be lower than the optimization on total preference. This can help the stakeholders in showing them that an optimization on his 'most important' criteria will not be the most desired solution according to the group. To be able to show these different outcomes during a stakeholder meeting, the most common objective functions (total number of houses, amount of greenery, balance) are already predefined within the model.

Optimization solver

For optimization in the BDP model, the Generic Algorithm (GA) within MATLAB is used (Mathsworks, ndb), for its all-round capabilities, and it can be used with the Preferendus. When using GA as a solver, several things need to be kept in mind to get the best result. First, as the model is needed during stakeholder meetings, the running time should be as short as possible. This was already achieved by simplifying the model and reducing the number of variables in the model, so only consider elements that can vary at this point. This was taken into account when reducing the number of variables from 46 to 9 in this model. Secondly, GA will return a better result as all design variables are in the same order of magnitude. Due to that, some design variables of the LP model are rewritten into another form in the MATLAB model, for example the total number of houses is not a variable in the MATLAB model, as it can be written as an objective by a summation of all the types of housing. Those decisions will result in an improved and faster result of the model.

There are a few options that can be set with using GA. There are nine options in total that are used while running GA in combination with the Preferendus. These options are impacting the running time and the solution. The solution is impacted because the options determine where and how to look for solutions. An investigation into an optimal set of options is conducted which returns the best result in a feasible running time. The used options can be found in appendix H.1, where the code is shown, the options are visible in the Optimization part of the code.

F.2.5 Weights

As stated, earlier weights are used in the model to calculate the overall preference. Within the model, two types of weights are being used, between stakeholders and between the objectives. Weights can be described rather arbitrary, as weight factors are often assigned randomly without a well-defined explanation of the weight distribution (Binnekamp et al., 2006). It was chosen to use as much equal weights as possible in the model, to avoid discussions about weights during stakeholder meetings. Since the weights are assumed to be equal between the main objectives, it was decided not to carry out a sensitivity analysis for the BDP case.
One important element in the BDP model is that every stakeholder is equal. This is expressed in the model with equal weights between the stakeholder, every stakeholder has total weight of one third in the model, as shown in the table F.4.

Within the calculation of the overall preference, the six main objectives have an equal weight as well (1/6). As there are predefined types of greenery and housing, it is possible to express a preference between the types. To be able to use these preferences between the types, (the normal version of) Tetra is used to scale the value of each type for every stakeholder. Every stakeholder has to scale the types on the scale between 0-100 based on their own values they find important, which is added in Tetra. Together with the costs, as budget has a role in the project as well, this results in a Tetra score for each alternative. This score is then transferred to a weight for each type of greenery and housing in the overall preference calculation.

As the green party did not express a preference over the housing types, the weight distribution of this stakeholder is a bit different than the others. The weights of the objectives that he expressed a weight over, are equal in weight within the stakeholders' weight (1/3).

In the table below an overview of the weights for the calculation of the overall preference is given. Showing the weights per stakeholder, adding all the weights together gives 1.

Table F.4: Weights for Preferendus

Objective	Sub objective	Main objective weight for municipality and developers	Main objective weight for Green party	Sub objective weight (between types based on tetra)	Municipality	Developers	Green party
Result		0.166667	0.200000		0.055556	0.055556	0.066667
Total amount of greenery		0.166667	0.200000		0.055556	0.055556	0.066667
Total number of houses		0.166667	0.200000		0.055556	0.055556	0.066667
Greenery	*Gemeenschapspolder*	0.166667	0.200000	0.46	0.025556	0.025556	0.030667
	Plas			0.23	0.012778	0.012778	0.015333
	Sport/Zorglandgoed			0.09	0.005000	0.005000	0.006000
	Stadspark Weesp			0.22	0.012222	0.012222	0.014667
Total area housing		0.166667	0.200000		0.055556	0.055556	0.066667
Housing	*Vechtstad*	0.166667		0.16	0.008889	0.008889	-
	Weesp			0.3	0.016667	0.016667	-
	Tuinbuurt			0.31	0.017222	0.017222	-
	Lint nat			0.19	0.010556	0.010556	-
	Landgoed			0.04	0.002222	0.002222	-
Total		1	1		0.333333	0.333333	0.333333

F.2.6 Output file

The output file that is made for this case contributes to the user-friendliness of the model, as the model exports every run to this Excel file. So, none of the designs that the model outputs, will get lost and the Excel file makes it easy to compare the design with each other. The output file stores two important elements: objective values (the design) and preference scores on the objectives of each stakeholder, on different sheets. The output of the design (objective values) can be displayed directly to the stakeholders.

Every exported output gets a name and a timestamp, which makes it easier for the model users to compare the outcomes with each other. This also makes the output easier to be recognized in a later stage.

F.2.7 Verification of the LP and PDOA model

To be able to use the model during stakeholder meetings, the model should be verified. This verification is two folded and is elaborated below.

The first step of the verification is to compare the PDOA model in MATLAB to the LP model of Planmaat. The PDOA model needs to be optimized on the same objective as the LP model that Planmaat created, result. With the same constraints as in the LP model (for housing and greenery), the PDOA model should return the same result value as the LP model, to state that the model is verified. To be able to optimize (maximize) on result in MATLAB, an objective function needs to be created that includes the costs and profits of the variables and fixed elements. The formula for this objective (function) is shown below.

$$Result = (Variable\ revenues + fixed\ revenues) - (Variable\ costs + fixed\ costs) \quad (F.1)$$

Where:

Result: if negative it means that the project has a funding shortage, positive means profit.
Variable costs: costs of the 4 types of green and the 5 types of housing.
Variable revenues: revenues of the 5 types of housing.
Fixed costs: sum of costs of the fixed elements in the project.
revenues: sum of revenues of the fixed elements in the project.

The PDOA model in MATLAB returned the same result value as the LP model of Planmaat with the same constraints, so this verification step was successful.

The other part of the verification is to check if the model works properly. Verification for this part can be done by checking if the model returns another solution when the constraints are loosened (opened) and the model is optimized on result. And by checking the functioning of the model by optimizing on different objectives (like total number of houses, greenery, and area for living) using the new constraints of the objectives. In this case the design (output of the variables) should be different then when optimizing on result with the old constraints.

This verification step is done without considering preferences, the goal is to check the relations in the model and if the design changes for other optimization objectives. In table F.5 several solutions can be found.

Table F.5: Verification outcomes

PoR	Unit	Optimization		
		Result	Housing	Green
Result	Million €	36.49	29.71	-29.19
Total area	ha	435	435	435
Costs	Million €	267	273	226
Revenues	Million €	303	303	197
Total amount of green	ha	293	293	350
Gemeenschapspolder	ha	200	196	131
Plas	ha	92	18	178
Sport/Zorglandgoed	ha	0.1756	49	38
Stadspark Weesp	ha	0.0085	29	4
Total area housing	ha	142.5	142.5	84.5
Total number of houses	Houses	2999	3000	2018
Vechtstad	Houses	899	900	799
Weesp	Houses	650	650	650
Tuinbuurt	Houses	1000	1000	400
Lint nat	Houses	350	350	139
Landgoed	Houses	100	100	30

As can be seen in the table, optimizing on different objectives with opened constraints results in different designs. Maximizing on the total number of houses shows a design as expected, since the total number of houses is reached, and all the types show the maximum value as well (together they add up to the total number of houses). In addition, the area for living is returning a high value so there is enough space to build the maximum number of houses. Furthermore, optimizing on (maximizing) the result, will return the maximal number of houses considering the constraints (maximizing profit), in combination with the cheapest greenery types (reducing costs). When optimizing on total amount of greenery, it gives a solution that has more greenery than the other designs, and it has a negative balance of almost 30 million euros. This could be explained by the smaller total number of houses in this design and the more expensive types of greenery built.

In some designs it looks like if there is a slightly better design possible, for instance in the design that is optimized on balance, it seems obvious that an extra house in the type Vechtstad would generate more revenue and this has a positive effect on balance. This was not chosen by the model due to the options used within the solver to reduce running time, it would take the model around 15 minutes extra to find the design with one extra house.

So, looking at the results it can be stated that the model works properly and therefore is verified. From now on the model can be used during stakeholder meetings and the preferences can be added to the model.

F.3 Workshop 1

The model will be tested and evaluated during the workshops. Two workshops and one individual session per stakeholder took place to test the model. The first workshop, that will be discussed in this chapter, focused on collecting the preferences of stakeholders and generating an outcome. After workshop 1, separate individual evaluating sessions took place with each of the stakeholders, in which they could look at their preference curves again and could reflect on the first brainstorm session.

F.3.1 Set up

The stakeholders were informed before the workshop started about several things, by means of an information document appendix H.2. The information document included a short introduction about the working of the model and the goal of the session. Next to that, the document included the individual goals of the stakeholders (since the case was re-enacted) and every player was informed about the stakeholder he was representing. An introduction about preferences and preference curves was also included to make sure the stakeholders could already get familiar with the preference modeling approach and rules for the game.

One of the fundamentals aspects of the PDOA is transparency of the stakeholders related to their goals and preferences. This also means that they had to be open and honest with the other involved stakeholders during the process. To take away the feeling of a black box (that calculates the most desired solution), the gathering of the preference will be done in a group session. With the idea the stakeholders are able to hear about the goals and preferences of the other stakeholders, due to that they know what (all) the input of the model will be.

The session started with a presentation about the goal of the PDOA in which a comparison was made between a LP and non-linear preference model. The stakeholders, played by experts of Planmaat were already familiar with LP models. Therefore, the following example has been used to explain them the difference between a hard constraint and a preference curve.

In a LP model, a stakeholder would say that his limit is somewhere around 2000 houses, which means a hard constraint is set on the value of 2000. Only less than 2000 houses are allowed and a solution with 2001 will not exist. However, in reality it may be the case that the stakeholder is actually fine with some more houses, especially when he sees the possibilities that arise in solutions. By adding a preference to the total number of houses, the absolute limit could shift towards 3000 houses. A visualization of the example is shown in fig. F.6.

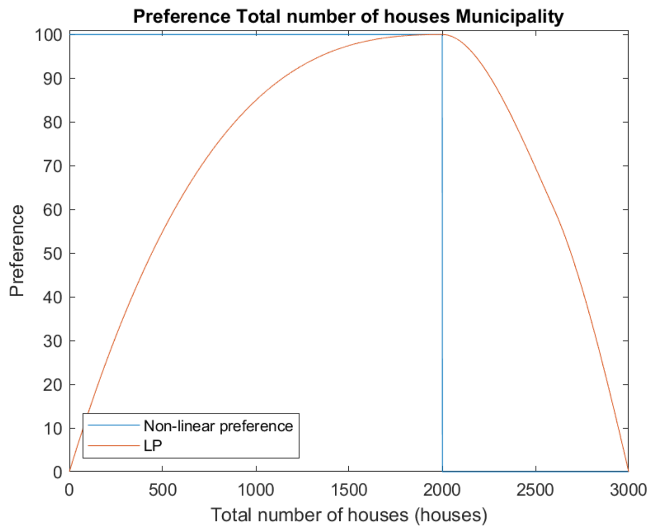


Figure F.6: Difference LP and non-linear preference in total number of houses

The presentation also addressed what preference measurement means, how a preference curves could be set up (as explained in appendix D.2.3), and what kind of shapes a curve could have. The end of the presentation showed an overview of the interfaces that were used during the session.

Pencil preferences were already conducted before the workshop started by the System Engineers to test the technical capabilities of the model and to give the stakeholder an example and idea about what a preference curve is means. The pencil preference curves were constructed for objectives that were obvious considering the point of view and goals for the project of the stakeholders, an elaboration can be found in appendix H.3. The pencil preferences that were constructed upfront are showed in appendix H.4, including an explanation on the shape of the curve.

During the workshop, the stakeholder had to change their curves from pencil preferences to pen preferences. They could also add other preference curves on other objectives where no pencil preference curves had been constructed yet. The model is created such that the preferences on objectives could be changed, filled, or emptied at any time.

The objectives where a preference could be defined on were predetermined, as also discussed in appendix F.2.4. The stakeholders could only choose to have a preference on the set of predetermined objectives, that were expressed in predefined units. For example, if stakeholders found greenery an important aspect, they could only give a preference expressed in hectare since this objective had a predefined unit of hectares. To overcome the issue that stakeholders would prefer to express a preference over the same aspect (e.g. greenery) in another unit, small conversion models were created that could be used during the session. The conversion models consisted of several properties of an aspect/objective, such that a conversion could easily be made to the unit in which that aspect/objective was expressed. The lists are conducted for housing and greenery.

Housing				
Total number of houses	2235	2804	1800	1500
Number of residents in the area	4783	6000	3852	3210
Area for living (ha)	118	120	90	100
Number of resident / ha	40,53	50	42,80	32,10
Number of houses / ha	18,94	23,36	20	15

Figure F.7: Conversion model housing

Types of greenery	Number of recreants / ha	Hectare	Total number of recreants	Hectare	Total number of recreants
Gemeenschapspolder	15	100	1500	80	1200
Plas	10	100	1000	25	250
Sport/Zorglandgoed	50	40	2000	30	1500
Stadspark Weesp	100	30	3000	35	3500
Total		270	7500	170	6450

Figure F.8: Conversion model greenery

The minimum and maximum values of the objectives were also determined upfront of the meeting, on 'pencil' basis, meaning these could change when pen preferences were constructed. In the table F.3 shown in appendix F.2.4 the minimal and maximal values for the pen preferences are considered. As discussed before in appendix D.2.3, the preference curves of different stakeholders over the same objective are defined within the same range, between the minimal and maximal value. The minimal and maximal values for the objectives were shown in the presentation as well.

The preference curves were gathered according to a structure. First, all stakeholders entered their curves related to greenery, after which housing, and result followed. The datapoints of the curves were entered in the interface Excel and could be shown with the MATLAB interface, as both discussed in chapter Model development, subsection Interface. After the gathering of the preferences, the design outcome is shown to the stakeholders very briefly by means of the output file as discussed in appendix D.3. This output file also contained the personal preference scores on the design. The focus of this workshop was not on the outcome, therefore the idea behind the working of the model was not explained to the stakeholders yet.

It was chosen not to run the code in front of the stakeholders. Experts of Planmaat advised the System Engineers that such a complicated code could scare the stakeholders. It was made sure that the model was running on another screen that was not visible for the stakeholders, while they were having a discussion.

F.3.2 Outcome

The interface panel shows that the municipality and the developers have a preference function on every objective. The green party has a preference on only the greenery parts, the total number of houses and the result. He only considered those aspects as important. The types of houses did not matter to him; therefore, he had no preference on these aspects.

Not all predetermined pencil preference curves has been transformed to a pen preference curves. The reason behind this will be discussed in appendix F.3.3.

An adjustment that was made from the pencil preferences to the pen preferences is that the pencil preference curve of result deficit was changed into result, in order to make it easier to express a preference.

As discussed earlier, the outcome of the first workshop is not focusing on the content of the preference curves, but merely on the evaluation on the process to create a preference curve, which will be discussed in the next section. Therefore, the shapes of the curves and the reasoning behind them will not be discussed in this outcome section.

F.3.3 Evaluation

The evaluation is divided in three topics. First, the minimum and maximum values are discussed. After that, there will be elaborated on the construction of the preference curves. Last, the evaluation will focus on the time management during the workshop.

Minimum and maximum values

What became clear very quickly is that the workshop immediately started with a discussion between the stakeholders about the minimum and maximum values of an objective, between which a preference curve had to be formed. This can be explained by the fact that the minimum and maximum value had to be the same for each stakeholder for an objective over which multiple stakeholders had a preference.

In addition, strategic play occurred during the determination of the minimal and maximal values for the objectives. For example, for the types of greenery. Together, the minimal value for types of greenery define the minimal total amount for green in the area. these minima define together the minimum of the total amount of green. One stakeholder (the developer) was pretending to make a concession for the minimum of total green in the area, while he was deciding on the minima for the types of green. With this tactical play, he could ensure he still got his way after all. The tactical play mainly happened with the stakeholders that did understand the technical working of the model.

Hard to draw preference curves

It was noted that some stakeholders had a hard time with drawing the preference curves. The reason was three-folded.

- Some stakeholders experienced difficulties while drawing their preference curves because it was hard for them to imagine what impact it would have on the outcome. One of the developers wanted to see an outcome first. There was an increasing need to go to the outcome of the model after drawing several preference curves, especially by the developers. Even though preference curves were explained by means of examples in the presentation, it became only clear what was actually meant with a preference curve after playing & practicing in the game and seeing the outcome. This resulted in certain stakeholders that agreed to having – almost – the same curve as the pencil curve that was drawn. Even though the pencil curve was based on numbers in the LP model and logical reasoning from the perspective of that stakeholder, it could be that this curve did not fully reflect the stakeholders' wishes but the stakeholder was still accepting it since he was lacking the capability to construct it himself.
- Stakeholders found it difficult to construct a preference curve over an objective that was already predefined with a unit. For example, the total area for living can be based on how many houses the stakeholder prefers, which density in types of houses he prefers or how many inhabitants he wants to gather in the area. Another example is when a stakeholder wanted to express a preference over greenery in the area, he had to express this in the total amount of green in hectare in the area. However, the stakeholder found it sometimes easier to express a preference over the amount of people he wants to offer a place for recreation.

It became even more difficult since types of houses and types of greenery were already predefined, over which a preference needed to be expressed. It would have been easier for the green party to express a preference over ecological value instead of over a certain type of greenery. Even with the conversion models, the stakeholders felt like there was no freedom within the model in choosing their own units in which they wanted to express their preference, since all the objectives and units were already predefined.

- There was room for some strategic play during the construction of the preference curve which made it sometimes hard for the stakeholders. All the stakeholders formed their curves during the workshop. Some stakeholders were questioned by other stakeholders about the reasoning behind a curve. In this way, stakeholders could influence each other's curves. This is not supposed to happen since a stakeholder needs to be able to form an individual preference curve.

Time management

Timewise the workshop was not necessarily efficient, as the preference curves for the individual stakeholders had to be filled in one by one. Because of this, the other stakeholders experienced some waiting time. The waiting time allowed the stakeholders to think about their preference curves on other objectives. However, this was not experienced as ideal since the System Engineer was helping in creating the curves. Together with the fact that there was a longer discussion going on about the minimum and maximum values than expected, the total session lasted two hours. And even in that time the stakeholders did not succeed in filling in their preference curves for every objective. Towards the end of the two hours session the stakeholders really wanted to see a result so they could talk about the outcome some more.

F.3.4 Adjustments towards Workshop 2

The feedback and experience brought along several adjustments for the second workshop.

One of the main feedback points of the brainstorm was that the stakeholders' discussion was mainly about the minimal and maximal value of the curves, since that was the playing field for stakeholders to get more space for a certain aspect (such as the amount of space for green or housing). This was not intended to be the discussion, but, model-wise it was not possible that the begin- and endpoints of the preference curves for one variable differed between stakeholders. After the session, the number of datapoints have been increased to a maximum of six in order to make sure a wide range in value for an objective was possible which could avoid the discussion on the minimum and maximum values.

The fact that stakeholders found it hard to draw preference curves and the lack of time contributed to the plan of having individual sessions with the stakeholders before they came together for a second brainstorm session. During the individual conversations, the idea of a preference curve could be elaborated more thoroughly and could help with completing all preferences curves. This gives the opportunity to immediately start with an outcome in the second workshop session.

F.3.5 Individual sessions

Individual sessions with the stakeholders followed after the feedback of the first workshop. The individual sessions were introduced mainly so the stakeholders could complete their curves at ease without being influenced or questioned by other stakeholders. During the sessions, the meaning of a preference curve could be discussed one more time, so that the stakeholder would understand the meaning better by seeing and hearing about the preference curve for a second time.

The individual sessions lasted around one hour maximum. After the sessions all the preference curves were completed and an outcome could be generated by the model, using the preference curves. The preference curves can be found in appendix H.5.

F.4 Workshop 2

The second workshop, which will be discussed in in this chapter, was focusing on convincing the stakeholders of the most desired group outcome after the stakeholders were fulfilled their preference curves. It starts with the setup of the workshop in which an explanation is given of the working of the model. After that, the PoR that is created will be elaborated. The chapter ends with experience and feedback points.

F.4.1 Set up

Before the workshop started, the stakeholders were provided with an information document again (appendix H.6). This document includes a small recap of the situation in BDP: a feasible solution that suited all stakeholders where there was no major result deficit. There was already a LP model made in which was optimized on result. In the workshop, the stakeholders will have another look at the problem, only now the preferences of the stakeholders are considered when designing a solution. Using these preferences could show if a different solution with more support of the stakeholders was possible for the BDP case.

Next to the recap of the situation in BDP, the document provided information about some properties of the variables that are used in the case, especially on the types of greenery and houses. In addition, the minimum and maximum values were shown in the document. Last, the rules of the workshop and the incapability's of the model were summed up such that the stakeholders know what to expect. The role of the System Engineer is made clear as well.

The workshop started again with a presentation. A small recap was given about what was done in the first workshop and the individual sessions. After that, the working of the model was demonstrated according to a simple example. This example is used by experts in the field of LP models (P. Nan, personal communication, December 20, 2021). The example is a modified, so it is able to explain what happens when in the PDOA when preferences are included.

The example implies a trade-off between two variables: red and green. An area can be filled with either red or green or a combination of both. Green will be displayed on the x-axis, while red will be displayed on the y-axis (fig. F.9). There is one constraint that is limiting the solution space, for example a budget that is available. It is visible in the example that the more the area will be filled with green, the less area will be left to fill with red. The plot shows a solution space, the area under the line.

The question is, what solution in the solution space is the most desired solution for the group, out of all feasible solutions? If stakeholders are asked individually (party A, B and C), they would all point a different solution, since different aspects are important for them. They will all optimize on different aspects if LP was used to solve the problem. In this way, a solution that satisfies the entire group will never be found or the stakeholders have to negotiate to come to a solution which takes a long time.

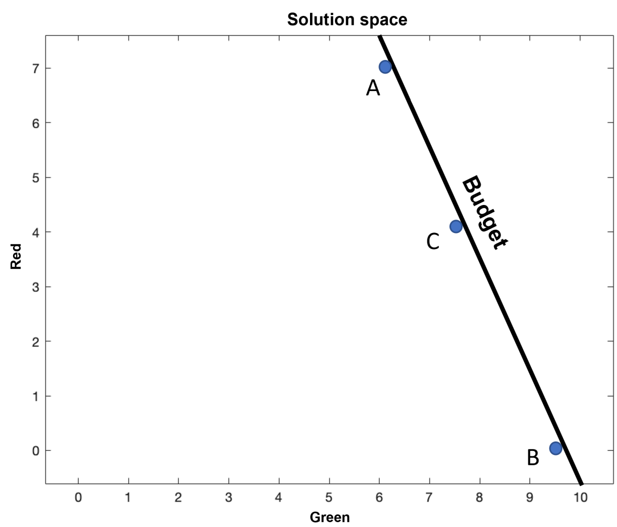


Figure F.9: Visualization of trade-off between red and green

Translating the example to the BDP case shows that if LP modelling is used, there will be optimized on different aspects (as the different stakeholders would want to). This shows different designs for each optimization on which the group of stakeholders will never reach consensus what design to choose. The designs are shown to the stakeholder and can be seen in table F.6.

Table F.6: PoR's optimizing on one objective

PoR	Unit	Optimization		
		Result	**Housing**	**Green**
Result	Million €	36.49	29.71	-29.19
Total area	ha	435	435	435
Costs	Million €	267	273	226
Revenues	Million €	303	303	197
Total amount of green	ha	293	293	350
Gemeenschapspolder	ha	200	196	131
Plas	ha	92	18	178
Sport/Zorglandgoed	ha	0.1756	49	38
Stadspark Weesp	ha	0.0085	29	4
Total area housing	ha	142.5	142.5	84.5
Total number of houses	Houses	2999	3000	2018
Vechtstad	Houses	899	900	799
Weesp	Houses	650	650	650
Tuinbuurt	Houses	1000	1000	400
Lint nat	Houses	350	350	139
Landgoed	Houses	100	100	30

The importance of cooperation was addressed in the presentation in order to come to a group solution. Including preferences is a way to provide cooperation between stakeholders. Addressing the importance of cooperation is explained by the example of looking for a balloon in a space full of balloons, as also discussed in the introduction of this thesis. After this explanation, the example of the trade-off between red and green was discussed and expanded again.

The question for the most desired solution can be answered by considering the preference for each of the variables. The LP model will be expanded with adding preference curves. Imagine that two preference curves are drawn: one for the value of red and one for the value of green. These preference curves are now considered in the plot (fig. F.10). On the x-axis and y-axis, the value of red and green are still shown.

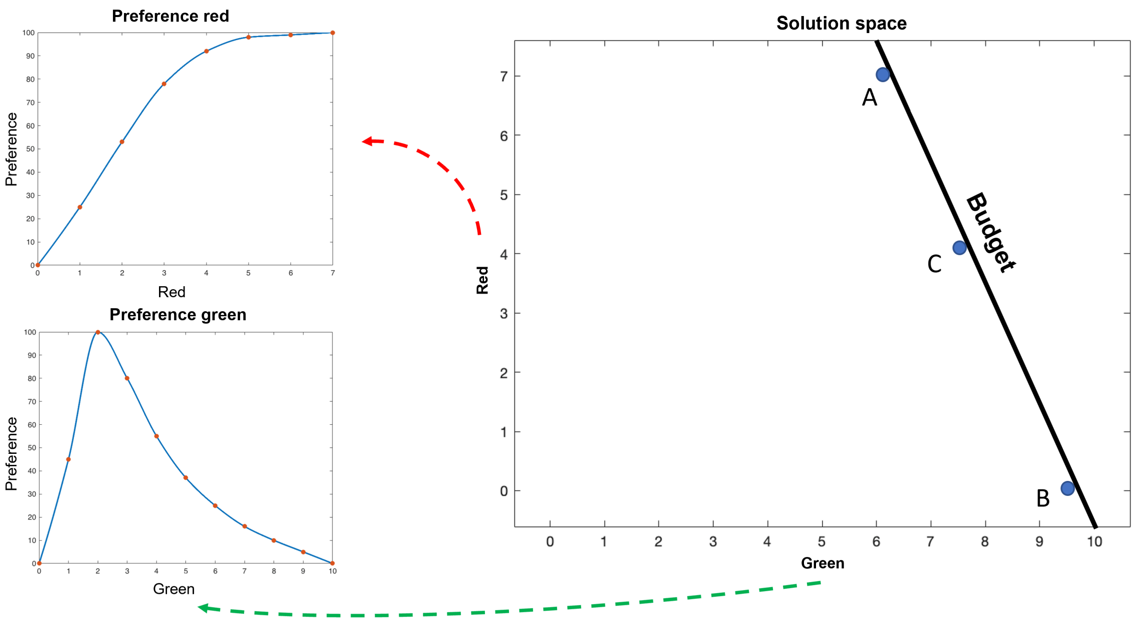


Figure F.10: Visualization of trade-off between red and green including preference curves

The plot changed from a regular plot to a raster. Each block in the raster represents the summation of the preference that is corresponding with the value of the variable red and green. An example is shown in fig. F.11. The higher the summation of the preference scores is, the darker the color of the block. The model tries to search for the optimal point, the block where the summation is the highest (and the color is the darkest).

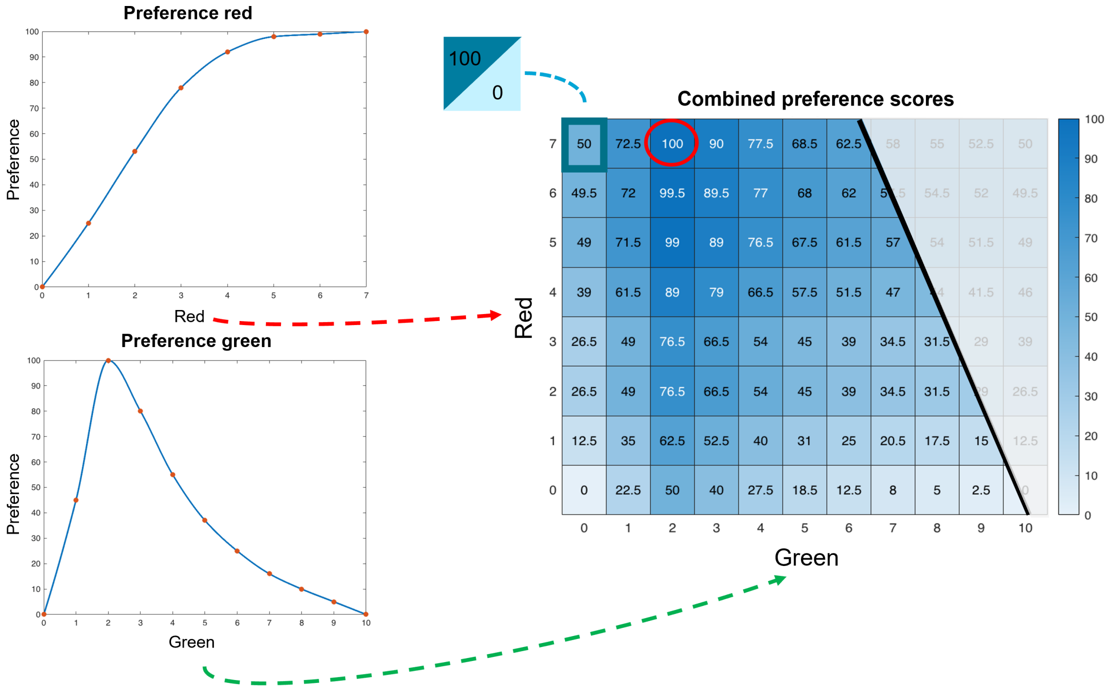


Figure F.11: Raster trade-off between red and green

What is shown in the figure is that the desired solution considering the preferences is laying on the point where the combined preference is the highest (red circle). Without the preference curves, finding this solution will take a long time or is not even possible when a group of stakeholders is negotiating. They will only look for solutions in their own benefit. When preferences of each stakeholder can be added to the model, the outcome of the model generates a design where all preferences are considered.

The model outcome (Program of Requirements) is shown to the stakeholders. The PoR of the model in which preferences are included is compared to the optimizations on other aspects. The PoR's all show the overall preference score of the group in order to compare them and convince the stakeholders that the design optimized on preferences is the solution that is most supported by the group. The added value of the PDOA will be addressed in this way as well. In addition, the personal preference scores on the design are shown to the stakeholders. Both will be discussed in the next appendix F.4.2.

In the second brainstorm, the model was only run before the workshop. This had to do with the increased running time of the model due to technical issues with the software that was used in the model. The running time of the model was so long (approximately 30 minutes) that it would not be possible to run it during the session. Not being able to run the model during the meeting had his impact on the adaptability of the input. If the stakeholders want to change their curves, they could not immediately see the result of those changes.

Lastly, the weights are discussed in the presentation since this was a feedback point from the first workshop. In the end of the presentation, the outcome of the model will be discussed, and each stakeholder can be asked if they would accept the PDOA and give feedback on the convincing story.

F.4.2 Design outcome (PoR)

The PoR of the optimization on total preference score is shown in table F.7. Figure F.7 also shows other PoR's when optimized on other criteria, such as result. Also, a comparison is made to the design of the LP model of Planmaat.

Table F.7: PoR optimized on preference and other objectives

PoR	Unit	Optimization				
		LP model	Result	Housing	Green	Preference
Preference	-	48	71	69	37	74
Result	Million €	-11	37	30	-29	35
Total area	ha	435	435	435	435	435
Costs	Million €	206	267	273	226	268
Revenues	Million €	196	303	303	197	303
Total amount of green	ha	336	292	292	350	292
Gemeenschapspolder	ha	196	200	196	131	198
Plas	ha	104	92	18	178	73
Sport/Zorglandgoed	ha	20	0	49	38	4
Stadspark Weesp	ha	15	0	29	4	18
Total area housing	ha	99	143	143	85	143
Total number of houses	Houses	1859	3000	3000	2018	3000
Vechtstad	Houses	257	900	900	799	900
Weesp	Houses	565	650	650	650	650
Tuinbuurt	Houses	641	1000	1000	400	1000
Lint nat	Houses	310	350	350	139	350
Landgoed	Houses	86	100	100	30	100

The three optimizations in the middle are just optimized on one aspect (on result, total number of houses and greenery), as happens in LP modelling. One could say, each optimization represents a goal of one stakeholder and the stakeholders will never reach consensus on which design to choose. In addition, the designs optimized on these aspects show such designs with extreme values that they would never be implemented in real life. From these optimizations, relating preference scores of the group can be calculated since the designs and preference curves are known. This makes it able to compare the results in preference scores on the different designs and show the stakeholders the delta in preference score on these designs compared to the design that is optimized on preference.

To be able to find the most desired group solution, the design should be optimized on preference. It can be seen that the PoR which is optimized on preference is the solution that is most supported by the group since it has a higher preference score than the rest of the optimizations. Therefore, it could be stated that this design (optimized on preference) has more chance to succeed since it is more supported by the stakeholders.

Also, a comparison is made to the LP design that was generated by Planmaat, where the constraints were not opened yet. The LP design was optimized on result. A relating preference score of the LP design results in a lower preference score than the optimization on total preference. For that reason, it could be said, when opening the constrains a bit, a better group alternative is possible and the DPOA has added value.

Table F.8: Personal preferences of PoR optimized on preference

Personal preference scores			
Preference value	**73.6519**		
Stakeholder	**Municipality**	**Developers**	**Green party**
Result	100	67.32	100
Total amount of green	100	0.42	99.27
Total number of houses	100	100	0
Gemeenschapspolder	99.99	100	97.94
Plas	93.2	84.22	12.03
Sport/Zorglandgoed	0	47.19	0
Stadspark Weesp	100	68.79	100
Total area housing	100	5.03	98.78
Vechtstad	0	100	0
Weesp	100	100	0
Tuinbuurt	0	100	0
Lint nat	100	100	0
Landgoed	0	100	0

The PoR optimized on preference shows several personal preference scores (table F.8). Figure F.8 shows that the municipality is scoring high on all the objectives, except for a few objectives where he scores a preference of zero. This can be seen as making compromises on several aspects in order to gain a preference of 100 on other aspects.

The developers are scoring more on average basis (around a preference of 60 on a scale of 0 to 100). In the types of houses, they score a full preference (100). This can be explained by the fact that the minimum and maximum of the housing types are defined in such a way that the maximum values together add up to the total number of houses possible in the area. So, if the total number is houses is constructed it is likely that each type of house will be on its maximum, where the preference score of the developer is 100.

The green party is scoring either high or low in preference on his objectives. A low preference can be found on the total number of houses. So, this is the aspect where the green party has to do a lot of compromises. However, he is winning on some of the types of greenery (Gemeenschapspolder and Stadspark Weesp) since he obtains his full preference score on the types.

F.4.3 Evaluation

At the end of the second workshop there was room to evaluate on the entire process of the PDOA, where several evaluation points were identified.

Too technical

Overall, the process and the convincing story was experienced as too technical and complicated by some stakeholders (the developer and the municipality). Therefore, it was suggested by them to only show the PoR which was optimized on preference, and not the other optimization outcomes. Those results should only be showed when needed. However, this was only the case for the stakeholders that do not have a mathematical background. The ones that did have a mathematical background have more understanding for the model. As it is assumed that real life stakeholders do not have a mathematical background, the convincing story should not be technical at all and needs to be explained by simple examples. The technicalities also relate to the way in which the outcome is shown. The outcome needs to be illustrated in a simple way, meaning only showing the values of the relevant objectives and other relevant aspects.

Play with the model

The stakeholders wanted to be able to play with the model before they could judge whether they would accept the outcome. The stakeholders see the model as a "*starting point for further negotiations*". The developers, for example, noted that they would like to see if the design could be bent a little to their wishes. That is, after all, how they like to work (taking advantage). Playing with the model during the workshop was not possible due to the running time of the model.

Showing personal preferences

The stakeholders were divided in the opinion if it is good to show the personal preference scores on the design. When seeing a preference of 0, he will not be very satisfied. One of the stakeholders mentioned that "*it is not convincing in terms of cooperation*". If he sees a preference of zero, it feels like he is not heard. He said: "*The spread between personal preference scores of 100 and 0 is remarkable in terms of cooperating*".

It was likely that there are a few 0 and 100 scores, because the ranges of the objectives were widened, as discussed as adjustment between workshop 1 and 2. With making the range wide, it is likely that a curve can have many values where the preference is 0 or 100.

Weights

The question was asked by the stakeholders how many times each aspect was considered in the model. Since there are a few aspects that are related to green (the total amount of greenery and the types of green) or to housing (the total number of houses, the types of houses and the total area for houses), the stakeholders were wondering if every aspect was considered in the same quantity in the model.

F.5 Conclusions BDP

The goal of the first application was mainly to investigate if the PDOA had added value in comparison to a method that is commonly used in the optimization world, LP modeling. It is considered that the non-linear preference model will have added value if the model leads to a different design than the design of the LP model, where the design of the non-linear preference model is more compliant with the stakeholders' needs. Next to that, the BDP case was used to gather feedback on the process to come to a solution (gathering preferences) and the convincing story towards stakeholders about the acceptance of the method to come to a design.

F.5.1 Verification

To answer the question, it was investigated if another solution than the outcome of the LP model which had more strict constraints and boundaries was found, when another approach (PDOA) was used. In addition, the new design was compared to other designs optimized on another aspect (like result, total amount of houses and total amount of greenery, as in a LP approach), with the same boundaries as in the model considering preferences. It can be concluded that the design not considering preferences (the LP solution) is different from the design where preferences are considered. It shows a delta in overall preference, in which the preference score is higher in the design considering preferences. This means that this design is more compliant (more responsive to the needs of the stakeholders). It can be seen that the design obtained with the PDOA also shows a higher group preference than the preferences on designs that are obtained when optimizing on other aspects, such as result or the total number of houses.

From this, it can be concluded that the PDOA looks for a most desired group solution (most fitted for purpose) and has added value, instead of a feasible solution (fit for purpose) that is found with a LP model when optimizing on one aspect rather than preference.

F.5.2 Validation

The PDOA can also be considered as usable to use since BDP shows that stakeholders are able to give input based on their preferences. However, some improvements (as discussed in appendix F.6 for the second application) are recommended to improve this process and make it easier to give input, such as starting with individual sessions and avoid predefined objectives. In addition, it is still found hard by stakeholders to give input without seeing a possible design first. This shows they find it hard to step away from the regular design process, determining what he really wants after seeing a design first. The fact that the model should be an iterative process can help overcome this problem by adjusting preference curves such that they fully reflect the stakeholders' wishes.

As discussed in appendix F.4.3, the stakeholders want to play with the model before they would accept the outcome. There are several improvements that need to be made when the approach is tested in a real-life case in order to let the stakeholders accept the approach. These will, among other improvements, be discussed in the next appendix F.6.

F.5.3 Critical notes to BDP

There are a few critical notes within the application of BDP that had an influence on the outcome and will be discussed in this section.

The first critical note is that BDP is not a real-life case but a re-enacted case. One could argue about the fact to which extend the re-enact is representing reality. It is questionable how sincere the curves are filled in and the case is re-enacted. This is one of the reasons why it is recommended to apply the approach on a second case.

Next to that, the objectives in BDP were all predetermined and expressed in fixed units. This could have had an impact on the objectives that the stakeholders wanted to have. It should be noted that the way in which objectives were defined in the BDP should be adjusted in the second case. Objectives have to be determined by stakeholders themselves and are related to the goals the stakeholders have and they should be able to express the objectives in the unit in which they want to. The fact that the design variables were already predetermined does not mean that the objectives have to be predetermined as well. The described critical note could have had an impact on the outcome.

In addition to the critical note above, the fact that pencil preferences were added and shown to the stakeholders could have influenced the stakeholders as well. Even though they defined all the curves themselves in the end, it could have influenced the outcome as well.

As discussed in the the introduction of BDP appendix F.1, the problem in the LP model of Planmaat was mostly related to the constraints that defined the limits of financial result. From this point of view, the boundaries within the model were opened by adding preferences over objectives. One could state the boundaries have not been opened from all stakeholders' goals, but only from one goal & perspective, making more revenues. With this goal in mind, other boundaries (such as for the houses that generate revenues) have been opened in the same order of magnitude.

A probably more correct way to open the constraints should be, question the stakeholders about their goals and perspective first. With all these goals and perspectives in mind, the constraints should be opened to make the goals (more) achievable. In the BDP case this was not done in this way as this case was re-enacted, which made it harder to let the stakeholders make concrete statements about their goals, as there was no real stake within the project. The way in which boundaries are opened now could have had influence on the design outcome.

F.6 Improvements for Waelpolder

The application to the BDP case shows several points of improvements to be made for the second application of the Preferendus to an urban development case. These points will be discussed after which another method to find a group solution will be investigated, following from one of the points of improvement.

Real life case

The BDP application was not a real-life case which has its impact on the outcome, as discussed in appendix F.5. In order to test the acceptance among stakeholders on the PDOA, it is recommended for the second application to be a real-life case.

Predefined objectives

As discussed in the previous chapters, the predefined objectives were a problem in the BDP case. In the next application, the preference curves should be defined on objectives that the stakeholders come up with themselves. They do not have to be the same as the design variables and the stakeholders can decide in which unit they want to express an objective. In addition, it is recommended to follow a structured way of gathering the objectives, based on the goals a stakeholder has within the project. Therefore, it is suggested to use the online tool of PAS (Arkesteijn, 2019).

Minimum and maximum of objectives

The fact that the minimum and maximum values of the objectives were discussed extensively by the stakeholders in BDP. Another approach is to not let the stakeholders decide, but let the model decide what the minimum and maximum will be for the objectives. By minimizing and maximizing the model on the objectives, it is made sure that the objectives are always defined within a range where solutions are possible, as other constraints are taken into account. In addition, this method avoids the discussion on the minimum and maximum values between the stakeholders.

Pencil preferences

The pencil preferences that were determined in BDP can be misleading to stakeholders. They should be made to test the technicalities within the model. However, they should not be shown to the stakeholders.

The pencil preferences were also constructed to help the stakeholders in getting familiar with preference curves and see an example. In order to still help the stakeholders with defining their preference curve, examples could still be shown and the System Engineer's role in defining the curve should become more important. The stakeholder should make statements over an aspect, after which the System Engineer should determine a (pen) curve with a shape that fits the statements of the stakeholder.

Start with individual sessions

The BDP case showed that the stakeholders could influence each other (strategic play) on the definition of the preference curves if this was done in a group session (workshop). However, preference curves should be formed without any influence of other stakeholders, it should only represent the wishes of one stakeholder. In addition, it is not time efficient to gather all preference curves in one group session. Stakeholders had to wait on each other, and it is not a pleasant way of working for the System Engineer since the stakeholders were demanding much attention at once. It is recommended to start the first session with individual sessions to overcome these problems.

Other optimizations

It appears to be important for the stakeholders to be able to play with the model for the acceptance of the method. They want to see other design outcomes: optimizations on other objectives and optimizations on preference with some adjustments in the curves. However, it could confuse them if all these optimizations are shown to them at the same time the final design is shown. Due to the running time of the model, it is not possible to make adjustments and run the model during the meeting. Therefore, it is recommended that the most obvious and expected optimizations by stakeholders, should be carried out upfront and should be kept behind to show on request of a stakeholder. Only if a stakeholders want to see one, the design can easily be showed.

Convincing story

The convincing story towards the stakeholders about the idea behind, and especially the working of the PDOA model was experienced as complicated and technical by the stakeholders. On the one hand, this problem could be tackled by only showing the design outcome that is most important and keeping other optimization designs behind as discussed in the point above. On the other hand, the problem could be tackled by simplifying the story about the working of the model, with simple examples which everyone can relate to.

Scoring a zero preference

At the start of the BDP case it was presumed that a preference curve always had to start and end on a value of 0 or 100. After the gathering of the preferences, it was concluded that this was not needed. This could reduce the number of zero preferences, as many of the objective values did end on their minimal or maximal value in the design. However, this adjustment will not completely remove the problem of the zero preferences.
For the next case it should be noted that the curves can end or start on any preference value, as long as the zero and hundred preferences are defined by the stakeholder.

Since the problem of having zero preferences still could occur, it is good to evaluate how the stakeholders experienced this. The personal preference scores of zero harmed the stakeholders in the belief of the Preferendus method. The Preferendus method tries to search for a group solution, where it could be that one stakeholder has to do more compromises than another. The observation of zero preferences raises the question if the stakeholders are willing to accept the outcome that is generated with such a method that does not consider the amount of compromises each stakeholder makes.

Another method has been introduced to take into account in the second application. This new method is called goal attainment and is looking for a group solution in which it takes into account the amount of compromises that each stakeholder is making. It tries to balance the compromises of the stakeholders by looking for a solution where every stakeholder is making about the same amount of compromises. It is interesting to investigate in a real-life case what method the stakeholders support the most, the Preferendus method or the goal attainment method. This can have its influence on the total acceptance for a PDOA.

Last, it is suggested that the preference scores will not be shown to the stakeholders upfront, only if they ask for it. It is concluded that the showing the personal preferences of all stakeholders in a workshop, deter the stakeholders, instead of convincing them of the approach (and design). As the zero preferences are less convincing than the high preference scores they score on other objectives.

Weights

There were several discussions in BDP about the weights and the number of times that an aspect was considered in the model. In order to tackle this problem, it is recommended to let the stakeholders define a weight distribution between their own objectives. To let the stakeholders define their own weight distribution between their objectives, it is suggested to use the online tool of PAS (Arkesteijn, 2019).

Appendix Waelpolder

This part elaborates on the real-life case Waelpolder

G Real-life case: Waelpolder

This appendix elaborates on the real-life case Waelpolder, and the steps that were made that led to the conclusions as described in the main document. The first chapter of this appendix is an introduction to the problem of Waelpolder. Followed by the model development for this case (appendix G.2). The input was gathered during stakeholder sessions, the setup and the outcome of those sessions is discussed in appendix G.3. Next, the workshop for this case is discussed, after which some adjustments to create a final PoR are elaborated. The final chapter of this appendix (G.6) of this appendix touches upon the discussion of the Waelpolder case.

G.1 Introduction of Waelpolder

In this chapter, an elaboration will be given on Waelpolder, the project that is used as second application. It will start with an introduction of the subarea that is focused on. After that, the trade-off between several aspects in the area that needs to be made is discussed. The added value of using PDOA (a priori design optimization approach) in subarea 5 will follow from here on. Last, this chapter will recap on the goal of the second application and it will elaborate on the steps that are taken in Waelpolder.

G.1.1 Waelpolder subarea 5

Waelpolder is an area development project between 's-Gravenzande and Naaldwijk in the municipality Westland (Anonymous, 2022). The area will be a residential neighborhood with a focus on greenery. Waelpolder, together with other sub projects, is part of the Waelpark area development. An overview of Waelpolder is shown in fig. G.1.

Figure G.1: Waelpolder overview

Within Waelpolder, the focus will be on subarea 5. A more detailed map of subarea 5 is shown in fig. G.2. Subarea 5 lays at the bottom on the left side of the area. The areas that are surrounding subarea 5 consist of a school (adjacent to subarea 5) and a neighborhood with houses in the subarea across the main road. Greenery is important in Waelpolder, which is why an ecozone runs through the entire area from the bottom to the top. The ecozone lays left from subarea 5.

Figure G.2: Waelpolder subarea 5

G.1.2 Trade-off

In subarea 5, a trade-off must be made between finances, quality, and use of space (fig. G.3). These three aspects may be in conflict with each other. The subarea is seen as a compensating subarea for the rest of the area. An attempt is made to financially compensate the negative result that is currently in place for the entire area, with the revenues that are generated in subarea 5. Therefore, the (financial) stakeholders want to gain a minimum around 10 million euros in the area.

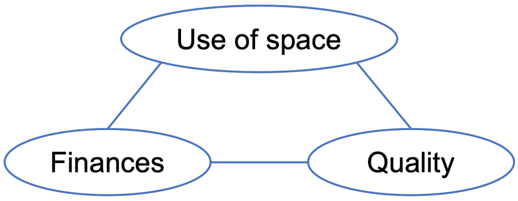


Figure G.3: Trade-off Waelpolder

The high revenues may be in conflict with the other interests that play a role in the subarea. For example, green is a highly important aspect in the area and space needs to be reserved for that, as discussed before. It will bring quality into the area but will leave less space for housing. The housing challenge is the next point which brings trouble. Next to the fact that there is a total number of houses that needs to be built in the area, there is a social issue at stake since the subarea has been designated to provide a lot of social housing. These houses bring less revenues to the area but are obliged to be built. Then there is the parking issue which brings up questions regarding the use of space. In order to meet the high parking standards in the area, a lot of space needs to be reserved for parking which has a negative impact on the quality again. Finally, there is an issue of constructing a healthcare center. On the one hand this brings social value and quality into the area, as there is diversity in the neighborhood. But, on the other hand, there needs to be enough space to build a center, it should generate enough revenues and it should not be in conflict with the quality of the area since it brings along more demand for parking spaces.

G.1.3 Stakeholders and role of Planmaat

There are three stakeholders involved within Waelpolder subarea 5: the municipality of Westland, an urban planner, and the financial director of the Ontwikkelingsmaatschappij (Development Company) 'Het Nieuwe Westland' (ONW). The project for subarea 5 is financed by two stakeholders. The municipality and Bank Nederlandse Gemeenten (BNG) are both for 50% shareholder in the project and so, they are both financially responsible. The urban planner is not only involved for the designs, but he is also interested and responsible for the quality of the project.

At the start of the application to Waelpolder in this thesis, the project was in a phase where designs were made by the urban planner and where Planmaat was checking the designs financially. This is an ongoing process from going back and forth to the urban planner, the municipality, and the financial director of ONW which takes up much time. After every design that is made, comments and adjustments will follow from the stakeholders, and everyone will wait for the urban planner to come with a new design.

G.1.4 Added value of PDOA for subarea 5

Clearly, the choices made on one of the aspects (regarding quality, use of space or finances) has its consequences on other aspects. There are a few hard demands set by the individual stakeholders that are in contrast with each other and play a role in this issue. If the stakeholders were asked individually to come up with their best design for the area, they would all choose another design since different stakeholders find other aspects important. Therefore, cooperation between the stakeholders is needed in order to come to a group solution. It would be useful to get insights in the thoughts behind their hard demands to see if there is space somewhere to come closer to each other and get on the same page. A model that provides insight into the possibilities that arise and the consequences that certain choices have could help to get everyone on the same page. The way in which the process of coming to a design is currently set up, is time inefficient by going back and forth between the stakeholders and the designing process and calculate the financial status of each design. The PDOA can make this process more efficient and it can give answers to the best trade-offs that can be made on several aspects, taking into account the different opinions and preferences of each stakeholders.

G.1.5 Goal of the second application

Since the goal of the first application was to test whether PDOA had added value, the second phase will mainly focus on the convincing story towards the stakeholders to support the approach and the outcome of the model in a real-life case. In this application, the stakeholders are in the middle of a design process. Therefore, it is assumed that the stakeholders can make a good estimation regarding the method to come to a solution, that is established in the PDOA. Since the stakeholders have a real stake within the project, they can empathize well in the situation rather than a case would be re-enacted. In addition, the real-life case enables testing if the openness, which is one of the 'pillars' of the PDOA, is accepted by the stakeholders that are in negotiating phase of the design process.

The PDOA is related to gathering preferences on several aspects before the design is made. In addition, the acceptance of the approach is related to the method behind finding the ideal group solution. The second application can give a decisive answer to the question which method to come to a solution (Preferendus or goal attainment) is most supported by the stakeholders. The PDOA can be considered as accepted if the stakeholders are giving a positive evaluation of the approach. And if they establish the added value of using the PDOA model in certain situations or phases of a project, it can be concluded that the goal for the second application is achieved.

G.1.6 Steps made in this case

An overview of the steps that are taken in this application, is shown in fig. G.4. The investigation into preference curves is already conducted in the BDP case. The model development for this application starts from scratch, which is why individual sessions to gather goals and objectives can be used to develop a model with variables, relations and hard constraint. Pencil preferences are not considered in this application. The pen preferences will be gathered in a second individual session after which the outcome can be generated. The most important step considers the last activity, testing the acceptance of the PDOA and reflection on the design. Since the approach is iterative, it is likely that some adjustments need to be made in order to come to the final design.

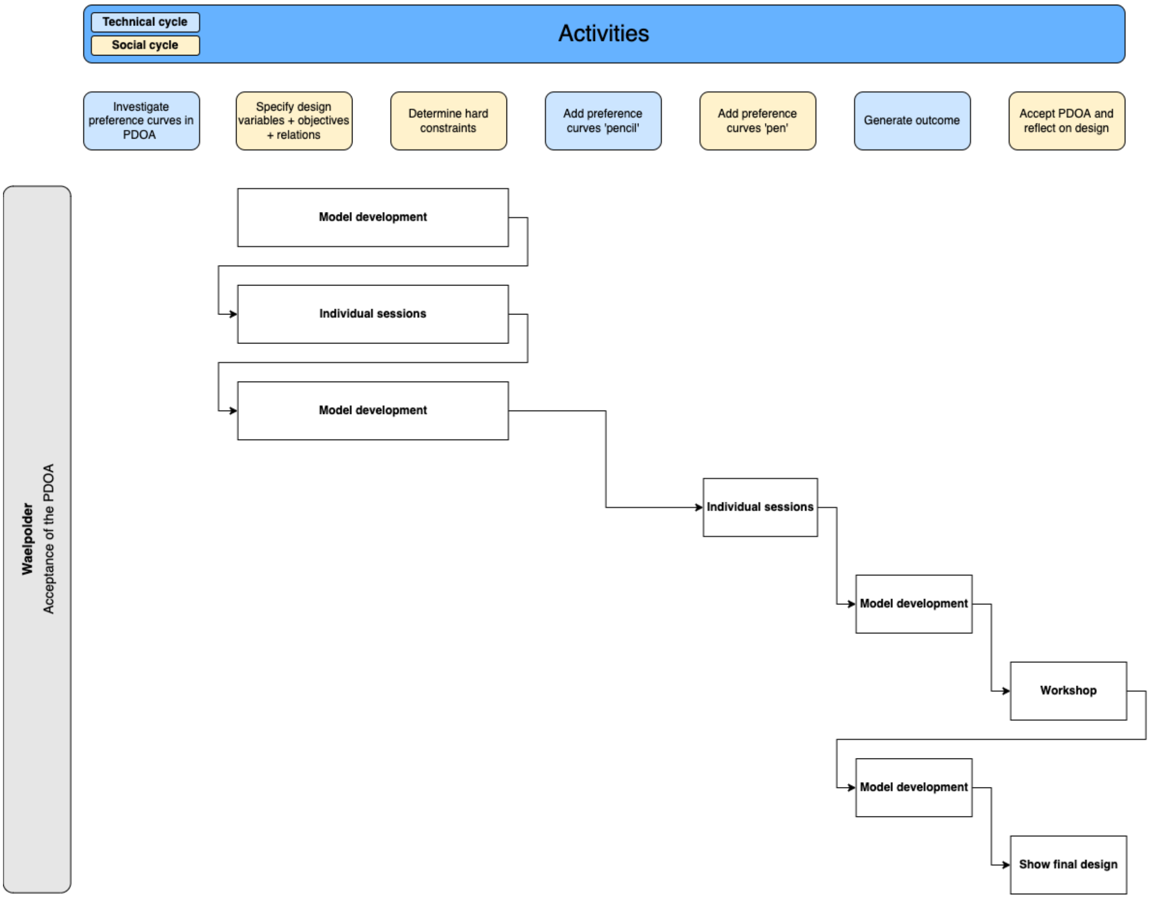


Figure G.4: Flowchart Waelpolder

The steps that are performed in Waelpolder, shown in the figure, will be discussed in several chapters. First the use of PAS will be addressed to gather the goals, objectives, and preferences in a structured way. Next, the model development will be discussed in appendix G.2, in which all the elements in the MATLAB model will be elaborated. Following from this a chapter about the weights where the distribution between weights of objectives is addressed. How the individual stakeholder sessions within Waelpolder are setup and proceeded is discussed in appendix G.3. The chapter will not only discuss the input (goals, objectives and preference curves) that the stakeholders gave, but it will also evaluate on the activities that are performed. From here on, the workshop will be elaborated in appendix G.4. The setup and outcome regarding the design will be discussed, as well as the evaluation on the approach and conclusions that can be drawn from this. The Waelpolder component follows with the final PoR (appendix G.5), including a sensitivity analysis. Last, a discussion on the results of the application to Waelpolder will be discussed in appendix G.6.

G.2 Model development

In this application case, a model is created to integrate the different objectives and preferences of the stakeholders in Waelpolder. The feedback that was provided during the application of BDP was used during the construction of this model. Besides that, creating the non linear preference model for Waelpolder was done in a different way than for BDP since there was no LP model for Waelpolder that formed a basis. The only given information was related to the costs and the different types of housing.

For user-friendliness it was decided to split the model into four different parts: a database containing all the fixed values of variables and relations related to costs. Another database linked with PAS, holding all information regarding stakeholder input (preferences and weights), the MATLAB model itself and an output file, where all the output of the MATLAB model is exported to. These four elements will be discussed in detail in the next sections.

G.2.1 Database

The information that was provided by Planmaat related to the costs and types of houses. The types of houses are considered as design variables in the model and will be discussed later. was converted to a database. This database is an Excel file which holds the input 'data' for the MATLAB model, regarding the number of variables and the properties of those variables (land usage, land values, area needed for parking, type of housing) and the lower & upper value of the variable assigned in the model. Besides that, the database holds information about the fixed values within the model for example the width of a road between the houses, total plan area, distance between trees and lampposts etc. The unit price per element, which will be used in the cost relations of the model, are stated in the database as well.

There is chosen for this type of database because it makes the MATLAB model orderly and user-friendly. The data can be changed easily without changes in the model itself which would be helpful as in the beginning phase it is assumed changes needed to be made after the first stakeholder meeting(s). Besides that, it gives the ability to see to immediately see which and if the correct data is used.

var	Woningbibliotheek	Type	Eengezins (EG) / Meergezins (MG)	Betaalbaar/Duur	Koop/Huur	Parkeren op eigen terrein j/n	Woonopp (m² bvo)	Uitgeefbaar (m² kavel)	Parkeer norm	VON woning	VON parkeren	kosten parkeren (€)	Straat (m²)	Trottoir (m²)	Parkeren (m²)	Totaal verhard opp (m2)	Groen (m²)	Water (m²)	Spelen (m²)	totaal Opp (m²)	Grondwaarde per m2 Patrick	Grondwaarde		Aantallen/verdeling	Tot opp		Minimaal	Maximaal	Lowerbound	Upperbound
x (1)	EG soc kp < €194.000	Rijwoning	EG	Soc kp	Koop	Nee	68	90	1.7	193900	0		30	20	21.25	71.25	7	0	1.35	170	252	€ 42,700		0	0		0	217	0	217.217
x (2)	EG bereikb kp < €231.500	Rijwoning	EG	Betaalbaar	Koop	Nee	83	100	2	230700	0		25	17	25	67	7	0	1.5	176	275	€ 48,300		0	0		0	217	0	217.217
x (3)	EG betaalb kp < €310.000	Rijwoning	EG	Betaalbaar	Koop	Nee	104	120	2	309900	0		30	20	25	75	7	0	1.8	204	383	€ 80,512		7	1427		0	217	0	217.217
x (4)	EG rijwoning €375.000	Rijwoning	EG	Duur	Koop	Nee	130	127.5	2	374400	0		32	21	25	78	7	0	1.9125	214	436	€ 96,326		0	0		0	217	0	217.217
x (5)	EG 2/1kap €542.500	2/1 kap	EG	Duur	Koop	Nee	155	237.5	2.1	542600	0		55	34	26.25	115.25	7	0	3.5625	363	387	€ 145,004		16	5813		0	217	0	217.217
x (6)	EG vrijstaand klein €585.900	Vrijstaand	EG	Duur	Koop	Nee	155	350	2.1	585900	0		85	20	26.25	131.25	7	0	5.25	494	382	€ 194,403		8	3948		0	217	0	217.217
x (7)	EG vrijstaand groot €672.300	Vrijstaand	EG	Duur	Koop	Nee	180	500	2.1	672300	0		107	69	26.25	202.25	7	0	7.5	717	296	€ 218,923		8	5734		0	217	0	217.217
x (8)	EG verandawoning €328.000	Rijwoning	EG	Betaalbaar	Koop	Nee	135	75	2.1	328000	0		20	10	26.25	56.25	7	0	1.125	139	337	€ 46,900		0	0		0	217	0	217.217
x (9)	EG drive-in €355.000+€25.000	Rijwoning	EG	Duur	Koop	Nee	135	100	2	355000	17500	20500	30	20	25	75	7	0	1.5	184	292	€ 53,650		0	0		0	217	0	217.217
x (10)	MG sociale huur	Appartement	MG	Soc hr	Huur	Nee	75	28	1.7	20000			14.4	14	21.25	49.65	7	0	0.42	85	235	€ 20,000		102	8677		0	217	0	217.217
x (11)	MG sociale kp < €194.000	Appartement	MG	Soc kp	Koop	Nee	58	28	1.7	193700	0		14.4	14	21.25	49.65	7	0	0.42	85	550	€ 46,800		42	3573		0	217	0	217.217
x (12)	MG kp €291.000	Appartement	MG	Betaalbaar	Koop	Nee	80	37.5	1.7	291200	0		16.8	11.2	21.25	49.25	7	0	0.5625	94	839	€ 81,542		32	3018		0	217	0	217.217
x (13)	MG duur geb P	Appartement	MG	Duur	Koop	Ja	105	63	0.5	399100	20000	17000	12	7	6.25	25.25	7	0	0.945	96	713	€ 68,550		0	0		0	217	0	217.217
x (14)	MG sociale kp < €194.000 geb P	Appartement	MG	Soc kp	Koop	Ja	58	28	0.5	193700		20500	12	7	6.25	25.25	7	0	0.42	61	433	€ 26,300		0	0		0	217	0	217.217
x (15)	MG kp betaalbaar, geb P onder de	Appartement	MG	Betaalbaar	Koop	Ja	80	37.5	0.5	291200	0	23000	12	7	6.25	25.25	7	0	0.5625	70	799	€ 56,150		0	0		0	217	0	217.217
x (16)	MG kp €291.000+€20.000 alles geb	Appartement	MG	Betaalbaar	Koop	Ja	80	38	0.5	291200	18800	46000	12	7	6.25	25.25	7	0	0.57	71	687	€ 48,650		0	0		0	217	0	217.217
x (17)	EG sociale huur	Rijwoning	EG	Soc hr	Huur	Nee	68	90	1.7	20000	0		30	20	21.25	71.25	7	0	1.35	170	118	€ 20,000		1.3	1776		0	217	0	217.217
	Zorgcomplex (62 units)						3800	1366	0						0		0	0		1366	805			0	0		0	3.5	0	3.5035
																	Uitgeefbaa 1,5% is al de helft in groen							Som :	33965					
																	Groen is meer								33831					

Figure G.5: Overview database Waelpolder

G.2.2 Preference database

Preferences and weights are gathered in the online tool PAS. After that, these can be transferred to an Excel file and after some small modifications the preference database is formed. This database is created for the same reasons as the first database, which holds the fixed information, user-friendliness. In the preference database, relative weights for each criterion per stakeholder are calculated, in such a way that the sum of all criteria per stakeholder adds up to one. The weights will be elaborated in the appendix G.3.3. The weights tab in the preference database is also linked to the MATLAB model.

G.2.3 MATLAB model

To come to a group solution, a MATLAB model is needed to generate a design that takes into account the requirements and the needs of the stakeholders. How the MATLAB model uses the input of the two databases have been discussed already. The model itself consists of several elements: design variables, relations, constraints, objectives of the stakeholders (including preference curves), Two methods optimization methods, solvers. All these elements will be discussed in this section.

The MATLAB model for both methods consist of several blocks, to make it more user-friendly, where the elements that are described in this section are used. The differences between the two methods used, is the objective function used in the code, the rest of the code is the same. Both scripts are attached in appendix I.1 and an explanation is given when needed.

Design variables

The model contains 20 design variables, those will create a final design (Program of Requirements, PoR) and are all related to the objectives of stakeholders by the relations in the model. 17 of the 20 design variables are types of houses. The other design variables are a healthcare center; a division factor for 'unused area' that will be divided between extra greenery or extra space for parking compared to the minimal amount; and the amount of parking spaces under a roof.

The 17 types of houses all have different properties. The types can be divided into several categories: single-family & multi-family houses and social (rent and owner-occupied), affordable & expensive houses. All houses have a different living area, plot area, space for parking and land values.

The healthcare center is planned to be a nursing home, where there is a possibility to locate a GP service as well. The healthcare center has four appearances, due to the characteristics of a healthcare center; it has the option to have 0 units for residents, meaning there will not be a healthcare center, 31, 62 and 93 units. Those options differ in properties and will be discussed in the relations of the model.

The division factor (0-1) divides the area that is not used for building houses and minimal parking standards and minimal green standard roads, green etc. (everything that is connected to the houses), between extra greenery and extra space to park cars. This division factor is depended on the preferences for green and parking area. It is assumed that the entire area should be filled with a function, so no space is left. When fulfilling the minimal norm for greenery and parking, it could be that there is extra room for another house or more space for green or parking (depending on the preferences on those criteria). The model will make a trade-off in the division of the extra space that is left for green, parking or houses.

The last variable relates to the parking spaces that are built with a roof above them. This roof will be covered in green, which adds to the total amount of green in the plan area. The idea behind this roof, which comes at an extra cost, is that it makes it possible to use the same area twice, for parking and for green.

All variables have a lower and upper bound in the model, to be able to let the solver search in the right direction for a solution. The minimal value of the housing types is 0 as negative houses cannot be built. The maximal value for this housing types is set on the maximal number of houses (217). The healthcare complex has 4 options between the value of 0 and 3. The division factor has to be between 0 and 1 as it is a factor. Lastly the maximum value for parking spaces with a roof is set on 500 parking spaces, as more than 500 spaces would be too expensive to construct.

Relations

Relations are the connecting elements in the MATLAB model, and is therefore one of the most important elements. The relations in the MATLAB model connect the design variables with each other and connect the objectives of the stakeholders with the design variables. Within the model, there are quite a few relations. Some speak for themselves, for example the total number of houses, others are more difficult, like the costs of the project. An overview of all the relations including an explanation is given below. Relations are used in three places within the code, in the objective function, constraints and in the calculations of the final output of the output file. As they form the basis for calculations in the three separate places of the code.

Healthcare center

As earlier described, there are four options for the healthcare center. The options are based on a number of healthcare units (0, 31, 62 and 93). The options affect several elements: extra parking spaces needed, revenue plot area and quiet neighborhood. In table G.1, an overview of the different properties of each option is given. The revenue per unit is 17.500 euros. The plot area is set on 1366 square meters for 62 units, this is information was provided by the municipality who compared other healthcare centers in the region. Based on this, plot sizes are then estimated for the 31 and 93 units. In the case of 93 units, it is assumed that the plot size needed per unit is a 3 m^2 smaller as the building will have six levels (still within the limits of the zoning plan) instead of four.

Parking spaces up to 62 units are already taken into account by a shared parking area with the school in the subarea next to subarea 5. When 93 units are created, additional parking spaces must be created for 31 units. Using the parking norm for the healthcare center (0,7 per unit), and the area for a single parking space (12,5 m^2) this leads to 271,25 m^2 needed for additional parking spaces.
The larger the healthcare center gets, the more activity in the area is created (traffic and noise hindrance) which affects the quietness of the neighborhood negatively. The numbers in the table row for quiet neighborhood represent the percentage of houses that can still be labeled as a house in a quiet area. The bigger the healthcare center, the lower this percentage will get.

Table G.1: Overview properties healthcare center

Number of units	0	31	62	93
Revenue (euro)	€ 0	€ 542,500	€ 1,085,000	€ 1,627,500
Plot area (m^2)	0	717	1366	1740
Extra parking spaces (m^2)	0	0	0	271.25
Quiet neighborhood (-)	0.5	0.3	0.2	0.0

Houses

The total number of houses in the design is he sum of all the different types of houses that are built, the housing mixture. The houses in the categories single-family and multi-family, are the sum of these types of houses, that fall under categories. Which type of housing is categorized as single or multi-family, can be found in table G.2. The same holds for the social (rental and owner-occupied), affordable and expensive housing types, information about this category can be found in the same table.
The percentage of houses with a built-in parking space is calculated by the houses built in the design that have built-in parking spaces (which are the last 4 types of houses), divided by the total number of houses in the design.

The revenue for housing is calculated by taking the sum of land values of the built housing types. The revenues per type of housing can be found in table G.2.
The total area per housing type can be found in table G.2, multiplying those with the houses in the design gives the total area needed for housing. This total area is including pavement (roads and footpath) and the plot area, per housing type. Area for parking and greenery are left out as they are variable and will be discussed below.

Area usage

Parking spaces with a roof are able to use the same land twice, once for greenery and once for parking as there is a green roof above the parking space. With the introduction of the division factor for 'unused' land between greenery and parking, both elements became variable as well. The total amount of greenery consists of the minimum that should be in place per house (times the number of total houses) and the area that is assigned to greenery by the division factor of 'unused' land. The total area of greenery is not used as an output value, as the stakeholders prefer amount of greenery per house. This means the total area of greenery must be divided by the total number of houses in the subarea. The playground area is based on the total plot area in the design. The playground area needs to be 1.5% of the total amount plot area is subarea 5 ONW (2022). Each type of housing has its own parking norm (table G.2). With the housing mix in the design, the minimal total amount of parking spaces can be calculated. The area that is assigned to extra parking by the division factor of 'unused' land, will create extra space for parking. Those two elements will lead to the total space needed for parking for housing.

The total area is defined by adding the following elements: total area for housing, amount of green per house times the total number of houses, playground area, plot area for healthcare center, (possibly) extra parking for the healthcare center and parking for housing.

Table G.2: Overview of housing properties

Types of houses	Single-family housing / Multi-family housing	Social / affordable / expensive	Owner occupied/ Rental	Built-in parking space	Land value	Plot area (m^2)	Living area (gbo) (m^2)	Parking norm	Roads (m^2)	Footpath (m^2)	Total pavement (m^2) (excl parking)	Greenery (m^2)	Total area (m^2) (excl parking and greenery)
EG soc kp <€194.000	Single	Social	Owner Occupied	No	€ 42,700	90	68	1.7	30	20	50	5	140
EG bereikb kp <€231.500	Single	Affordable	Owner Occupied	No	€ 48,300	100	83	2	25	17	42	5	142
EG betaalb kp <€310.000	Single	Affordable	Owner Occupied	No	€ 80,512	120	104	2	30	20	50	5	170
EG rijwoning €375.000	Single	Expensive	Owner Occupied	No	€ 96,326	127.5	130	2	32	21	53	5	181
EG 2/1kap €542.500	Single	Expensive	Owner Occupied	No	€ 145,004	237.5	155	2.1	55	34	89	5	327
EG vrijstaand klein €585.900	Single	Expensive	Owner Occupied	No	€ 194,403	350	155	2.1	85	20	105	5	455
EG vrijstaand groot €672.300	Single	Expensive	Owner Occupied	No	€ 218,923	500	180	2.1	107	69	176	5	676
EG verandawoning €328.000	Single	Affordable	Owner Occupied	No	€ 46,900	75	135	2.1	20	10	30	5	105
EG drive-in €355.000+€25.000	Single	Expensive	Owner Occupied	No	€ 53,650	100	135	2	30	20	50	5	150
MG sociale huur	Multi	Social	Rental	No	€ 20,000	28	75	1.7	14.4	14	28.4	5	56
MG sociale kp <€194.000	Multi	Social	Owner Occupied	No	€ 46,800	28	58	1.7	14.4	14	28.4	5	56
MG kp €291.000	Multi	Affordable	Owner Occupied	No	€ 81,542	37.5	80	1.7	16.8	11.2	28	5	66
MG duur geb P	Multi	Expensive	Owner Occupied	Yes	€ 68,550	63	105	0.5	12	7	19	5	82
MG sociale kp <€194.000 geb P	Multi	Social	Owner Occupied	Yes	€ 26,300	28	58	0.5	12	7	19	5	47
MG kp betaalbaar, geb P onder dek	Multi	Affordable	Owner Occupied	Yes	€ 56,150	37.5	80	0.5	12	7	19	5	57
MG kp €291.000+€20.000 alles geb P	Multi	Affordable	Owner Occupied	Yes	€ 48,650	38	80	0.5	12	7	19	5	57
EG sociale huur	Single	Social	Rental	No	€ 20,000	90	68	1.7	30	20	50	5	140

Finances
The costs of the project are based on information that was provided by experts of Planmaat. They have expertise constructing the financial plan with the designs that already have been created. The financial relations that are in the plan are translated into the MATLAB model. There are 58 different kinds of costs considered in this project, from ground works up to maintenance of greenery. Those costs are depending on other relations: total greenery, total area for parking, total number of houses, total amount of plot area in the project and the amount of pavement (roads and footpaths) that is included in the total area for housing.
Total revenue is related to the revenue generated with the realization of a healthcare center and the total revenue of the houses. Balance is the difference between the revenues and costs of the project.

Remaining relations
Parking spaces with a roof are related to the total area for parking, as a maximum of 70% of the total area for parking can be equipped with a roof. The parking spaces with a roof are connected to costs of the project, as it comes at a cost of 1250 euros per square meter.

Constraints

The model consists of several hard and two negotiable constraints. The constraints enable the model to identify and exclude unacceptable designs and are defined by agreements made between the parties, legislation and policy or physical limitations.

The total area that the design covers should be equal to the total plan area, as the design could not exceed the plan area. The other way around, holds the same, due to the introduction of the division factor which will assign 'unused land' to green or space for parking.

Total number of houses is 217, this is based on the total number of houses that should be built in the entire plan, 720 minus the houses scheduled in the other subareas. Within the total number of houses a minimum of 34 affordable houses need to be built. For social housing there are two minimum constraints: 104 social rental houses and 144 social houses in total (rental and owner-occupied), those numbers are based on subsidy which the project applied for (policy).

The total number of parking spaces with a roof is set on the minimum of 500 parking spaces or 70% of the total parking spaces. This is done due to physical limitations, as parking spaces with a roof can only be constructed in a parking lot, and not along the road. Equipping parking space along the road with a roof, would obstruct the views and it is more expensive to construct and maintain than in the parking lot, according to the stakeholders in Waelpolder.

The greenery and the parking norm are considered as negotiable constraints. The minimal area for greenery per house is set on 5 m^2 per house, this is stated by one of the stakeholders as possible option, since there is an area with green next to this subarea. The maximal area of greenery per house is set on 50 m^2 per house, as the municipality's goal is to build 50 m^2 of greenery per house in the future, as stated in the policy of the municipality, Gemeente Westland (2020). The percentage of the parking norm is set on 80%, as this was meant to trigger some stakeholders to see what is possible with the design in the parking norm is lowered. The maximal deviation from the parking norm value is set on 150% of the norm, as more would create too much pavement in the area. Besides that, it is a game of give and take. So, when a party wants the maximum of greenery, some compromises should be made on other aspects.

Another constraint is the maximum for a 'quiet neighborhood', expressed in the total number of houses that can be seen as quiet and peaceful living. Peaceful living is determined by the number of 'not-living activities' in the area. Since there is already a school planned in another subarea and some houses are located along the main road in Waelpolder, the maximal percentage of houses that can be labeled as quiet living is therefore 50%, according to the urban planner.

Since the constraints are the same as the objectives, the constraint values that are described above can be found in table G.3, objectives below.

Objectives of stakeholders

Stakeholders express their preference over the objectives. There are 14 different objectives in this model. The three stakeholders have in total 31 objectives. With the gathered preference data 31 preference curves will be formed using PCHIP.

To form these preference curves in a proper way, the minimal and maximal values these objectives could have, must be calculated. Calculating the minimal and maximal values was done by minimizing and maximizing the model on the objective values. An overview of these values can be found in the table below, this table is considered when the stakeholders give their preferences. The minimal and maximal values of the objectives can change if the values of the constraints are modified during the iterative process. The values are shown in table G.3.

Table G.3: Minimal and maximal values for objectives

Objectives	Unit	Minimal value	Maximal value
Revenues	Million €	5.2	15.75
Greenery per house	m² / house	5	50
Deviation parking norm	-	0.8	1.5
Houses with built-in parking	-	0	0.52
Total number of houses	Houses	178	217
Total social housing	Houses	144	183
Social rental	Houses	104	183
Social owner-occupied	Houses	0	79
Affordable housing	Houses	34	73
Expensive housing	Houses	0	39
Single-family housing	Houses	0	217
Multi-family housing	Houses	0	217
Healthcare center	Option	0	3
Quiet neighborhood	-	0	0.5

Two optimization methods

For the Waelpolder case, two different methods are used to test which suits the needs of the stakeholders the most: goal attainment and Preferendus. As the latter is already discussed in the general part of this thesis, the focus in this part is on explaining how the goal attainment works compared to the Preferendus.

The Preferendus searches for the most desired group solution. It could occur that some stakeholders make more compromises than others leading to disagreements among the stakeholders. A solution to that problem could be the goal attainment method, as this method searches for a solution where all stakeholders make an equal amount of compromises, based on their preference curves.

The goal attainment method tries to minimize the distance from the goal per stakeholder. The goal for each stakeholder is to get the best preference score (100) on each objective. The distance of a stakeholder to one objective is calculated by 100 minus the preference score per objective. Adding those distances per objective for one stakeholder can be done by multiplying the distance by the weights he divided among his objectives. Sometimes it is not possible for a stakeholder, considering only his own preferences, to obtain an ultimate personal preference score of 100 on a design. As his preferences between different objectives are in conflict with each other. The optimization solver will try to minimize the distance sum per stakeholder, leading to an alternative where all stakeholders make the same amount of compromises on their individual goal. The mathematical explanation of goal attainment can be found in method B of appendix E.

Optimization solvers

To come to a design, solvers need to be used in the model, both methods have the option of different solvers. For the Preferendus, there are many solvers possible, several solvers were tested to come to the best outcome. Due to the complexity of the model and the number of variables in the model, the outcome of the solvers differs a lot, in design and overall preference, but also in running time. There is a need to be able to work with integer values within the model, as it is not possible, for example, to build a quarter of a house. This problem should be considered when choosing a solver. The design should not contain anything that cannot be build (e.g., half a house), to minimize resistance for the method of stakeholders involved. Several solvers were tested in the Preferendus method: Fmincon, Generic Algorithm, Surrogate optimization, and Multistart. All those solvers have their advantages and disadvantages. A short explanation will follow about the four solvers used.

Fmincon can find a local optimum quickly. Running it with a few other sets of initial points (x0) could lead to the conclusion that the optimum that is found could be a global optimum instead of a local optimum (Mathsworks, nda). It does not have the possibility to run with integer values, leading to rounding the numbers yourself, and then do a second run with the (rounded) outcome as fixed values to check the preference again. This process is time consuming on the long run. Due to the complexity of this model (high number of variables and the large amount of local optima), it is not likely that Fmincon will find a global optimum. And with rounding the numbers, Fmincon is not suited to generate a final design outcome. It could be used for optimizations in between, and to give an indication of the highest overall preference score.

Generic Algorithm can find a global optimum in a reasonable time (10-30 minutes). The advantage of Generic Algorithm is the ability to work with integer values (Mathsworks, ndb), which makes it a less complicated solver to use, as rounding of numbers is not needed. The downside of this solver is that it cannot handle the complexity of this project effectively. Most of the time (19 out of 20 times) Generic Algorithm is getting stuck on a quite low overall preference score (local optimum) or returns a solution that is not possible with the constraints in the model. This is based on experience with the model while trying to generate outcomes. The many runs that are needed leads to long running times, as the model needs to run more than 'twice' to be sure a global optimum is found. Even with adjusting the options, the problem holds or gets even worse.

Surrogate optimization can find a global optimum in a reasonable time (10-30 minutes) as well (Mathsworks, ndd). And has the same abilities as Generic Algorithm, working with integer values. The positive side of this solver is that it does not get stuck on a local optimum like the Generic Algorithm does. Most of the time (17 out of 20 times, based on experience) Surrogate optimizations return the same design with the preference score that only differs 0.5. The same design differs not significantly, one house in another type of housing and greenery and area for parking that changes a little bit. Leading to the conclusion that it can find the global optimum without significant problems.

Multistart can find the global optimum as well (Mathsworks, ndc), but it will take up to 4 hours per model run. It does not have the ability to run with integer values, leading to the same problems as in the Fmincon solver, the need to round the numbers and checking if the overall preference is still the same. Due to the running time of this solver, this solver is not suited to be used (in stakeholder meetings) and rounding the numbers. The goal attainment method works only with the Multistart as a solver, due to the complexity of the objective function and the number of variables in this project.

Based on the description of the solvers mentioned above and extensive research of the solvers including the accompanied options for those solvers, Surrogate optimization was chosen to be used when optimizing on overall preference[1]. The Surrogate optimization solver gave the highest preference score and a steady outcome when optimizing on preference. Playing with the options in this solver (after finding an ideal option set) resulted in only a faster or slower running time to come to a solution, not to another design configuration. Changing the options (to a certain extend), did not affect the outcome of the model positive nor negatively. Besides that, this solver did not get stuck on lower preference values like the Generic Algorithm would do. Running time for this model with Surrogate optimization was around 10-30 minutes, which is acceptable considering the complexity of the model and the outcome this solver gives.

G.2.4 Weights

Weights are used in the model to calculate the overall preference or the total distance from the goal of a stakeholder for a design. Within the model two types of weights are being used, between the stakeholders and between the objectives of each stakeholder.

Weights can be described as rather arbitrary since weight factors are often assigned randomly, without a well-defined explanation of the weight distribution Binnekamp et al. (2006). Therefore, it was chosen to use equal weights between the stakeholders, to focus on the process only and to avoid discussions about weights between the stakeholders. This means that the weights between the three stakeholders is 1/3, which adds up to one for the Preferendus. For goal attainment, the weights between the stakeholders are equal as well, but due to the properties in the objective function of this method, each stakeholder has a weight of 1 (which adds up to three).

[1]To enable convergence of the optimization algorithm (Genetic Algorithm) results within Matlab two extreme alternatives were added to each scale (0 and 100) which, compared to the current enhanced approach, is suboptimal. The enhanced approach is to make changes to the GA solver itself to enable proper convergence. However, this requires a change of programming language and conversion of all decision models to Python. At the time of executing the graduation project it was no longer feasible to make this change. Most important, when verifying the results obtained by the Matlab approach to the state-of-the-art Python approach with a modified GA algorithm, it was concluded that although the result differ, they can be considered an approximation.

G.2.5 Output file

The output file that is made for this case contributes to the user-friendliness of the model, as the model exports every run to this Excel file. So, none of the designs that the model outputs, will get lost and the Excel file makes it easy to compare the design/outcomes with each other. The output file stores three important elements, the output of X-values (design variables), objective values and preference scores on the objectives (including distance from goal) of each stakeholder, on different sheets.

Every exported output gets a name and a timestamp, which makes it easier for the model users to compare the outcomes with each other. This also makes the output easier to be recognized in a later stage.

With some adjustments in Excel, the output that is displayed to the stakeholders can be generated as well. In this display some output values are left out since they are only relevant to the model operators. The model operators are the only people who can see the preference values per objective. The stakeholders only see the values of the objectives. Those adjustments are done automatically, with referrals in Excel, after it is clear what will be displayed to the stakeholders. Saving the design variable values in the output file makes it possible to run the model again with these design variables as initial point (or as fixed values). This can be handy when preference curves change or when constraints change. In the beginning phase of this project, it was assumed that this could happen, as this process of gathering information and preferences is iterative and likely to change during the process.

G.2.6 Verification of the PDOA model

To be able to use the model for generating a design, the model should be verified. This verification is two folded, checking if it gives the same output as for a particular design that Planmaat already calculated and optimizing on other objectives.

Comparison to the designs of Planmaat

Checking if the non linear preference model returns the same output as a design that Planmaat already calculated, is done with five different designs. The goal of this verification step is to check if the relations in the model are setup correctly. Therefore, the focus is on revenues, costs and total area used in the design, from which the first two are exactly known in the designs of Planmaat. The later, total area used, is not exactly known due to the division between green and area for parking, but total area used should be equal or less than the plan area. If there is extra space that is divided between extra greenery and parking (with the division factor), the plan is considered to fit in the total area available. The MATLAB model should return the same value for revenues and costs as the plans from Planmaat and the design should fit in the total plan area, to state that the model is verified.

The verification is done by entering the housing mixture of the model of Planmaat as fixed numbers into the MATLAB model, by adjusting the lower and upper bound of the variables. In this way, the MATLAB model is not able to search for an optimum and always will calculate with the given housing mixture. All the five MATLAB outcomes returned the same amount of revenues and costs as the five designs from Planmaat. In addition, all five designs fit in the total plan area since the total area used was less and there was space left to divide between extra greenery and parking.

Optimizing on other objectives

Optimizing on other objectives is used to check if the model works properly. When optimizing on different objectives, the model should return a different design when another objective is used, to state that the model is verified. In addition, with the different optimizations it could be tested if designs are in line with the expectations. In table G.4 several optimizations to different objectives can be found.

Six optimizations have been done on: maximal social houses, minimal total houses, maximal deviation from parking norm, maximal amount of green per house, maximal revenues and balance. At the top, the optimization value per design is given, which represents the value of the criteria that is optimized on.

The optimization on maximal number of social houses should return 183 houses as optimization value, based on the constraints for maximal number of houses in total (217) and the minimal number of affordable houses (34). As can be seen in table G.4, the optimization value shows 183 houses. The rest of the design shows that the revenues are low, which is expected. The social houses generate the least revenues compared to the affordable and expensive houses. When the maximum of social houses is built, resulting in lower revenues since less houses can be built in the more profitable types.

The optimization on the minimal total amount of houses is returning 178 houses. Based on the minimal amount that is needed in the social sector (144) and the affordable sector (34), the optimization value meets the expectations. Looking further to the design, the two discussed types of houses (social and affordable) are at their expected numbers. The design shows that the revenues will not be large, which is expected since only the minimal number of houses are built. With the minimal number of total houses built, it is expected that there is much space left for house types that have a big plot size, a healthcare center, greenery, or parking. The design shows that the largest option for a healthcare center is chosen and that the amount of green is around half of what can be maximum at. Furthermore, it shows that all the houses are built as single-family houses, which are the ones with the largest plot area (compared to multi-family houses). Because the extra space goes to all single-family houses and the biggest healthcare center, the design still shows a minimum amount in the parking norm.

The optimization value for the optimization on maximal deviation from the parking norm is showing the expected value of 1.5 (150%). This value was expected since a constraint is set in the model on 1.5. Because the pavement for parking is taking up such a big area, it is expected that there is less space for greenery, houses, or a healthcare complex. This can be seen in the design since the maximum number of houses is not built, only 196 houses will be built. The design also shows that there will be no healthcare complex. As expected, the number of square meters for covered parking will be large. The area for parking is large, which means that it is logical to choose for covered parking because this will give the opportunity to put green in the area. Almost all green that is built in the area, will be on top of the roofs in the parking lot. The parking places with a roof will increase the costs and since there will only be built 196 houses, the total revenues on the project will be low.

When optimizing on the amount of green, the optimization value reaches the expected value, the value that is set by a constraint, of 50. Since there is a lot of space reserved for green in the area, it is expected that this will impact the options for the healthcare center, houses, and parking. The design shows that the maximum number of houses is not reached, as well as there will be no healthcare complex. In addition, the design shows that there will be more houses built in the multi-family category instead of in single-family houses. This is as expected since the multi-family houses take up less space. What happens within the housing mix is also straight forward, only the types of houses with a small plot area are chosen by the model.

An optimization on revenues returns a value of around 15.8 million euros. What would be expected to reach this is that the total number of houses are built and that the minimum number of social houses will be built so the rest can be affordable and expensive houses (the house types that generate most revenues). The design shows that this is the case for the total number of houses since 217 houses are built. Next to the minimum number of social houses (144), affordable and expensive houses are built. It is expected that within the housing mix, the types that generate most revenues are built, if possible. Within the social houses, the minimum number of rented houses (104) is built. Because the rented social houses generate less revenues than the owner-occupied houses, only the minimum is built. The rest is filled with owner-occupied houses (up to the minimum of 144 social houses in total). The rest of the area is filled with houses that generate high revenues, within single-family and multi-family houses. Furthermore, it would be logical for the parking norm and green norm to be as low as possible because this will leave space for the aspect that generates revenues (houses). The design is choosing what is expected since the green and parking norm are almost at their minima.

The design in which there is optimized on balance shows an optimization value of 10.2 million. Balance considers costs and revenues. Therefore, it is expected that the model will try to maximize the revenues and minimize the costs. It is expected that the model maximizes the revenues by leaving as much space as possible to build the maximum number of houses. Minimizing the costs could consider choices such as not building parking spaces with a roof or not leaving much space for greenery. The design shows a minimum value for the parking norm and a low amount of green which verifies that the model does what is expected. In addition, it shows that there will be no parking spaces with a roof. The design contains the maximum number of houses, as expected. It only builds the minimum number of social houses (144) since these types do not generate the highest revenues. The rest of the houses are affordable or expensive ones.

It can be concluded that the verification steps are positively fulfilled since the model does what is expected, so the model can be used to generate designs based on the preferences of the stakeholders.

Table G.4: Verification optimizations

		Unit	Max social houses	Min total houses	Max distance from parking norm	Max green per house	Max revenues	Max balance
	Optimization value	**-**	**183**	**178**	**1.5**	**50**	**15.797**	**10.4148**
Finances	Revenues	Million €	6.4507	6.7831	5.6578	6.0822	15.797	12.4859
Green	Greenery per house	m² / house	13.5925	26.356	27.8954	50	5.5432	8.9366
Parking	Deviation parking norm	-	0.831	0.8009	1.5	0.9438	0.8007	0.8
	Houses with built-in parking	%	7.8341	0	0	10.9005	0	0
	Parking spaces with a roof	m²	325	0	4487.5	0	37.5	0
Category houses	Total number of houses	Houses	217	178	196	211	217	217
	Affordable housing	Houses	34	34	38	36	36	34
	Total social housing	Houses	183	144	158	175	144	144
	Social rental	Houses	180	144	158	175	104	144
	Social owner-occupied	Houses	3	-	-	-	40	-
	Expensive housing	Houses	-	-	-	-	37	39
	Single-family housing	Houses	179	178	195	92	37	73
	Multi-family housing	Houses	38	-	1	119	180	144
Quiet neighborhood	Quiet neighborhood	-	0.5	0.0	0.5	0.5	0.2	0.0
Healthcare center	Healthcare center	Units	-	93	-	-	62	93
Housing differentiation	EG soc kp <€194.000	Houses	3	-	-	-	-	-
	EG sociale huur	Houses	167	144	158	79	-	-
	EG bereikb kp <€231.500	Houses	9	-	-	-	-	34
	EG betaalb kp <€310.000	Houses	-	-	-	-	-	-
	EG rijwoning €375.000	Houses	-	-	-	-	-	-
	EG 2/1kap €542.500	Houses	-	-	-	-	1	39
	EG vrijstaand klein €585.900	Houses	-	-	-	-	36	-
	EG vrijstaand groot €672.300	Houses	-	-	-	-	-	-
	EG verandawoning €328.000	Houses	-	34	37	13	-	-
	EG drive-in €355.000+€25.000	Houses	-	-	-	-	-	-
	MG sociale huur	Houses	13	-	-	96	104	144
	MG sociale kp <€194.000	Houses	-	-	-	-	40	-
	MG kp €291.000	Houses	8	-	1	-	36	-
	MG duur geb P	Houses	-	-	-	-	-	-
	MG sociale kp <€194.000 geb P	Houses	-	-	-	-	-	-
	MG kp betaalbaar, geb P onder dek	Houses	17	-	-	23	-	-
	MG kp €290.000+€20.000 alles geb P	Houses	-	-	-	-	-	-

G.3 Stakeholder sessions 1 & 2

This chapter will focus on the individual stakeholder sessions where the goals, criteria, weights and preferences of the stakeholders are gathered. First, a setup of the stakeholder sessions will be discussed after which the outcome of the sessions per stakeholder will be elaborated on. Lastly, several feedback points will be discussed related to the process of gathering this information.

G.3.1 Set up

The stakeholder sessions were set up individually. The first session is focusing on gathering goals and criteria. The second session was built upon the first, where preference curves are gathered over the criteria that are defined by the stakeholders in the first session. An overview of the activities in the individual sessions is shown in fig. G.6.

Figure G.6: Overview activities stakeholder sessions

Both sessions started with a presentation in which each stakeholder was informed about the goal of the session. The presentation emphasized on the added value of the model and on the issues in subarea 5. Related questions were summed up in the end of the presentation so that the stakeholder knows what kind of input is expected of him during the sessions.

The goals & criteria were collected according to a speaking sheet in which the problems related to Waelpolder subarea 5 were shown to the stakeholders. The problems are, as described before, related to four subjects: housing, financial, use of space and a healthcare center.

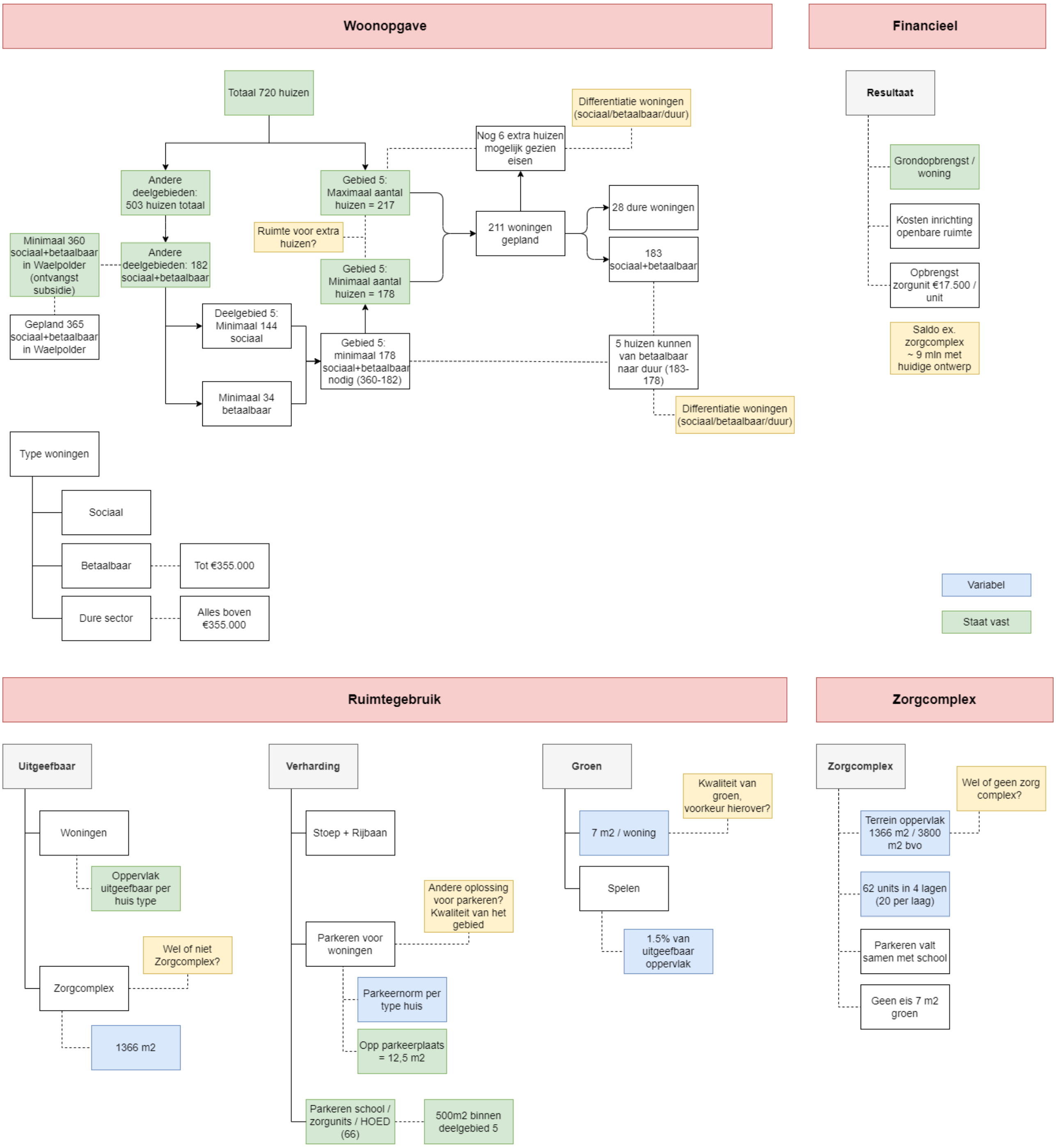


Figure G.7: Speaking sheet Waelpolder, as showed to the stakeholders

According to the speaking sheet, goals of the stakeholders related to the different subjects could be determined. The discussion about which criteria should be used to assess the goal followed from here on. Related questions that were asked to the stakeholders to help them in determining the goals and criteria were:

- *What main goal do you have within the project?*
- *What problems are you facing at the moment?*
- *What criteria should be used to assess the goal?*
- *Which hard requirements should be kept in mind within this project?*
- *Given this overview (speaking sheet), which constraints would you like to twist if you are able to twist something?*
- *Where do you still see room for adjustments/possibilities? And why?*

The second sessions emphasized on the preference curves. PAS is used to gather the preference curves. The idea behind a preference curve and the added value of gathering preference curves in such a project was explained to the stakeholders and the multiple shapes that a curve can take, were shown.

The stakeholders first were told what a solution space is, by the following explanation.

> *A solution space is an area that is emerging where all possible solutions lie. The area is limited by hard requirements that cannot be violated. Requirements can be added by different stakeholders. Outside the space, there are no possible solutions for the design problem. A visualization is shown in fig. G.8. To find the solution in the solution space, it is tried to let the stakeholders express a preference on their criteria that come from goals they have within a project.*

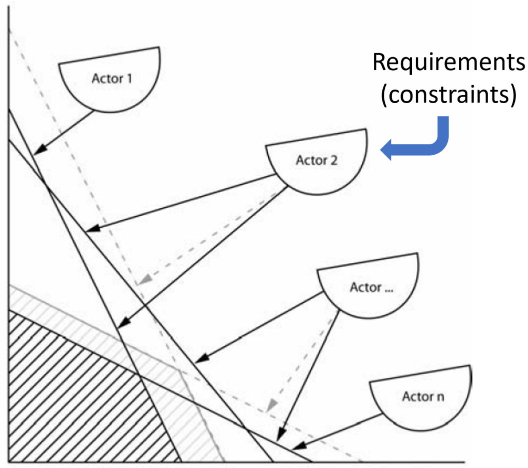


Figure G.8: Visualization solution space

A preference curve is always constructed in the same way, as is discussed in appendix D.2.3. The stakeholders were told that a preference curve has added value because it can sometimes open a solution space by shifting the hard requirements that are set by stakeholders, such that the gray area (in fig. G.8) emerges. This explanation was similar to the example that is used in the BDP case (appendix F.3.1). Second, a preference curve can help by searching where the optimal point in the solution space lays (the solution that is most desired) since it can search for the point where the preference is the highest. Several examples of shapes were shown, going from fast in- and decreasing to slow in- and decreasing and the other way around (appendix D.2.3). The explanation was clarified by means of a simple preference curve based on the total number of houses.

Examples of questions to help the stakeholder find the top, bottom, and intermediate preference points in the second individual session are:

- *At what value of X would you be most happy?*
- *At what value of X would you be very dissatisfied?*
- *How quickly do you get angry/unhappy/happy from ... (some) more/less from the value of X?*
- *At what point can you still tolerate a certain value of X?*

The System Engineer plays a role in both individual sessions. In the first session, the System Engineer walks through every element on the speaking sheet, such that the stakeholders can speak up and think about every aspect. In the second session, the PAS web tool is used. The System Engineer helps the stakeholders with fitting preference curves in this session. The System Engineer should ask the right questions and fill in the numbers such that the curves appear, and change numbers when stakeholder want them to be modified.
In the end of the second session, the stakeholders had to fill in a weight distribution over their defined goals and criteria. This is explained according to the elaboration that is given in appendix D.2.4 (The use of Pas, section Weights).

G.3.2 Outcome

The sessions give information about Waelpolder subarea 5 and reflect on the experience of the process. In this section, a brief explanation will follow on the information regarding the goals of each stakeholder within Waelpolder. The preferences that are conducted following from these goals are elaborated in appendix I.3. The next section will dive into the evaluation.

Financial director

The financial directors' main goal for subarea 5 is to maximize the revenues to compensate for the shortcomings in the other subareas of the project. Looking at the housing issue, he wants to maximize the number of houses in the area, especially the houses that generate the most revenues. Next to that, he wants differentiation in types of houses and in the architecture of those types, to prevent a uniform area. The healthcare center can be built in his point of view, but only when it generates more revenue than replacing the center with houses. He will go for combination of houses and healthcare center that yields the most revenue.

The financial director has four goals, which are measured in eight objectives in total. The detailed preference curves and the elaboration on those preference curves, related to the eight objectives can be found in appendix I.3.1.

Urban planner

As main goal, the urban planner wants to meet all the wishes of the residents in subarea 5 so that they enjoy living there. The wishes include enough green, space for parking and a good appearance of the neighborhood. Financially, he wants to generate revenues such that there is enough money that can be spend on (urban) quality and pleasant living. Pleasant living is, among enough greenery, related to a quiet neighborhood. Furthermore, he addressed that a healthcare center can take up space that can be used for lucrative living. As far as housing is concerned, he thinks that a mix of houses contributes to a good quality of the neighborhood.

The urban planner has six goals, which are measured in twelve objectives in total. The preference curves and the elaboration on those preference curves, related to the twelve objectives can be found in appendix I.3.3.

Municipality

The main goal of the municipality is to create affordable and social housing in the subarea. Next to that, she wants to create an attractive and good living environment which means meeting at least the standards set for greenery and parking in the cooperation agreement that is set up between BNG and the municipality. The municipality wants a healthcare center since it brings social value for the municipality Westland.

The municipality has five goals, which are measured in eleven objectives in total. The preference curves and the elaboration on those preference curves, related to the eleven objectives can be found in appendix I.3.2.

G.3.3 Weights

As explained earlier, stakeholders were able to assign weights to their different objectives themselves to indicate the importance of the different objectives. Using PAS, they first assigned weights to their goals. When a goal consisted of more than one criterion, they divided a weight between the criteria within the goal. Multiplying the weight of the goal and the weight per criterion, leads to a relative weight that is used in the model. This relative weight per stakeholder adds up to one. An overview of weights per objective per stakeholder for goal attainment is shown in table G.5, for the Preferendus everything is divided by three table G.6. As can be seen, the three stakeholders have different objectives, when a stakeholder does not have a particular objective, the weight is indicated with a dash.

Table G.5: Weights for goal attainment

Stakeholder	Financial director	Urban planner	Municipality
Revenues	0.9	0.07	0.15
Greenery per house	0.05	0.29	0.25
Deviation parking norm	-	0.145	0.2
Houses with built-in parking	-	0.145	-
Total number of houses	0.0125	0.015555556	0.028285714
Total social housing	0.0025	0.031111111	-
Social rental	-	-	0.058571429
Social owner-occupied	-	-	0
Affordable housing	0	0.031111111	0.028285714
Expensive housing	0.02	0.015555556	0.028285714
Single-family housing	0.0125	0.015555556	0.028285714
Multi-family housing	0.0025	0.031111111	0.028285714
Healthcare center	-	0.07	0.2
Quiet neighborhood	-	0.14	-
Total	**1**	**1**	**1**

Table G.6: Weights for Preferendus

Stakeholder	Financial director	Urban planner	Municipality
Revenues	0.3	0.023333333	0.05
Greenery per house	0.0166667	0.096666667	0.083333333
Deviation parking norm	-	0.048333333	0.066666667
Houses with built-in parking	-	0.048333333	-
Total number of houses	0.0041667	0.005185185	0.009428571
Total social housing	0.0008333	0.01037037	-
Social rental	-	-	0.01952381
Social owner-occupied	-	-	0
Affordable housing	0	0.01037037	0.009428571
Expensive housing	0.0066667	0.005185185	0.009428571
Single-family housing	0.0041667	0.005185185	0.009428571
Multi-family housing	0.0008333	0.01037037	0.009428571
Healthcare center	-	0.023333333	0.066666667
Quiet neighborhood	-	0.046666667	-
Total	**0.333333**	**0.333333**	**0.333333**

G.3.4 Evaluation

The evaluation of the individual sessions will discuss several points regarding the construction of the preference curves. In addition, it will address the role of the System Engineer during the sessions.

Proxy curves

Sometimes, when shaping the preference curve, other criteria than purely the criterion itself are kept in mind by the stakeholders. The preference curve over the criterion then becomes a so-called 'proxy' curve: a curve where the stakeholder shapes the curve in such a way that it will be beneficial to reach another objective. For example, the municipality used the green standard as the basis for the definition of her preference curve of the total number of houses. She wants the minimum number of houses so it will leave enough space for greenery. However, greenery is already another objective in Waelpolder. It is difficult for the stakeholders to look purely at one criterion without thinking how this objective can help in reaching another objective.

Parabolic curves

The fact that stakeholders find it hard to only focus on one objective alone is the reason for some parabolic preference curves. The municipality's preference curve for revenues has a parabolic shape for example. One could argue that it is odd that a stakeholder would not be happy with more revenues if the focus would only be the financial aspect. However, the municipality already thinks one step ahead and knows that the high revenues can only be reached when expensive houses are built. She lets the curve raise up to 10 million since that is the point from where she will be satisfied (one objective). She lets the curve drop after 10 million revenues because she does not want expensive houses in the area (another objective). In this way, a parabolic curve appears. The same applies to the revenues curve for the urban planner. He deliberately let the curve have a top (at 6 million) for a small amount of revenues, so he could ask for money to improve the quality of the area when more revenues are generated than 6 million. It seems difficult for the stakeholders to only think about one aspect, and not let two aspects define one curve.

Intermediate point on the curve

It was observed by the System Engineer that the stakeholders find it a technical challenge to already determine their preference curve because they do not know what the impact will be on the outcome. They find it difficult that they do not know what the outcome would look like. The issue that the stakeholders do not have a clue what the impact on the outcome will be, has an impact on the determination of the intermediate preference point on the curve. Stakeholders find it hard to determine an intermediate point that defines the shape of their curve. The impact of their curve is not known yet, so they are gambling on the intermediate point and are rounding it off to whole numbers. Statements as *"Just make it 100 houses"* are common. Here, the System Engineer plays an important role, helping the stakeholder identify the intermediate point because a stakeholder finds it difficult to identify this by himself. The System Engineer translates the story of a stakeholder into a certain preference curve shape, after which the stakeholder confirms if this shape reflects what he is thinking.

Mixed roles SE and stakeholder

One of the pitfalls of the System Engineer helping a stakeholder is that the distinguish in different roles between the stakeholder and System Engineer are mixed up. It can quickly feel as if the System Engineers generates an outcome. This is in contrast with the model, the model outputs a best design based on the input of the stakeholders. The stakeholders should not let the System Engineer decide on the input. The same holds in the other direction and is easier to monitor for the System Engineer. For example, the financial director was asking at some point: *"Do you want me to be happy with the maximum number of houses in the multi-family sector?"*. The System Engineer does not want anything, the stakeholder wants something. These kinds of situations should be avoided.

Clear definitions

A clear definition of the criterion is important and should be communicated to the stakeholder. After the first session, a criterion 'Result' was created. In the second session, it turned out that the stakeholders were constantly talking about revenues. Therefore, 'Result' was changed to 'Revenues' between session 1 and 2.

G.4 Workshop

This chapter will elaborate on the workshop with the stakeholders in Waelpolder. First, a set up of the workshop is discussed, after which the design outcome is shown. The evaluation of the workshop is addressed in appendix G.4.4 and will elaborate on the experiences of the stakeholders. The chapter will end with discussing the conclusions regarding the validation of the PDOA in which the goal of this application will be addressed.

G.4.1 Set up

All three stakeholders participated in the workshop. This was the first moment that the results of the approach were shown to the stakeholders. The workshop started again with a presentation which will be elaborated on in this section. First, the added value of the approach and outcome for subarea 5 was addressed, as discussed in the section Introduction of Waelpolder appendix G.1. After that, the idea behind the model, cooperation between parties to come to a group solution, was emphasized according to a simple example: choosing a combination of fruit at the market. The example (described in italics below) shows that cooperation between parties is needed to come to a solution in a more efficient way. Modeling cooperation in a mathematical model can be done by means of preferences, which were gathered during the stakeholder sessions.

Imagine you go to the market with a group of three people, and you can only fill one bag of fruit for the entire group. The question could be asked what will happen when the group can only return with one bag of fruit.

*What **will not** happen is that each person fills a bag on its own and afterwards the three bags will be merged into one, as this means two third of the fruit will be thrown away and the process to fill one bag is not quick and efficient. What probably **will** happen is that the people communicate with each other and ask for each other's preferences for types and quantities of fruit. They try to gather knowledge in advance about what everyone would like and fill one bag at once. By asking for underlying thoughts, a group solution (one bag of fruit) can be reached sooner and in an easier way.*

The same holds for Waelpolder subarea 5. If it were up to the stakeholders individually, everyone would choose a different design (different bag of fruit). Everyone wants to achieve an optimal result on different aspects. This can make the negotiation process long, going back and forth to the designer for every round of negotiations. That is why cooperation between parties is so important to get an unanimously answer to the question: what is the best (most desired) solution for the group?

The approach that is introduced assumes cooperation. But how can cooperation be modeled? Cooperation can be modeled if preferences are considered since the group choice for a design can be based on these preferences. So, the model starts looking for a solution in mutual interest.

After gathering the preferences, it was explained what is exactly done with those preferences. Two methods or two ways of thinking to come to a solution for the problem were explained to the stakeholders. This was again explained according to a simple example from the market. The difference between the methods was emphasized after which the question was asked which method the stakeholders would prefer, based on the stories they heard.

Imagine, a group of three people can spend €5,- on the market for a bag of fruit and have to fill only one bag as a group. The composition of the bag of fruit can be determined in two ways:

Preferendus method:
Based on everyone's preference there is a certain composition of fruit that gets the highest overall group preference. However, someone can be far away from his ideal composition of fruit and must do a lot of compromises.

Goal attainment method:
The method looks for a composition of fruit where everyone gives in about the same amount on his personal ideal composition of fruit (his personal goal).

Both ways relate to another method to come to a composition of fruit for the three people (a group solution). The Preferendus method finds the best solution for the group, by optimizing on overall preference. It could be the case that some stakeholders have to do more compromises than others. The goal attainment method finds a group solution by minimizing the distance to a goal, in which the compromises of everyone in the group are about equal. Everyone gives in about the same amount from his goal to reach a group solution.

These methods are used in the approach and are elaborated to understand the working of both methods better.

Preferendus method:

Imagine a group wants a combination of apples and oranges in their bag. Let's say that the bag of fruit is restricted by maximum weight that one can still carry. In addition, there is a certain budget that is limiting the composition of fruit that can be chosen. Both limiting constraints define a solution space which is visualized in fig. G.9.

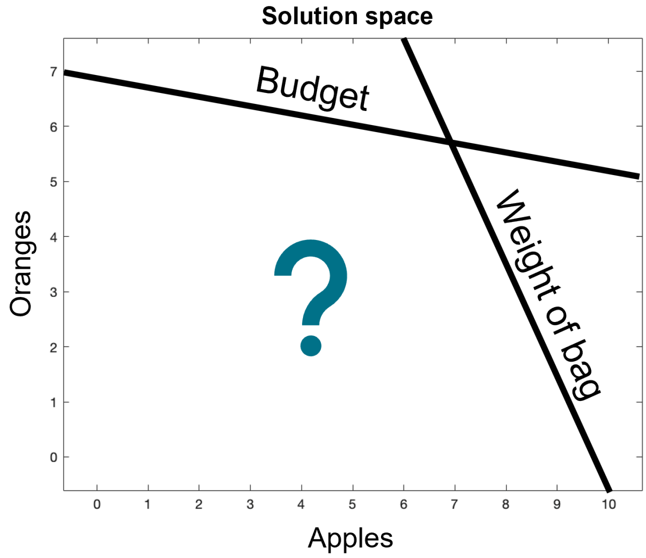


Figure G.9: Solution space apples and oranges

How can the group cooperate and look for a group solution (the most desired combination of fruit)? By adding preferences. If preferences over apples and oranges will be added, it can be found which combination of fruit makes the group the happiest. For each combination of apples and oranges, the joint preference score can be calculated by looking at the individual preference scores on the number of apples and oranges. In this way, a grid of joint preference scores is created for all combinations of fruit. The model will search for the point where the combined preference is the highest which is the optimal point in the solution space. The score of the design is represented by an overall preference score (the red circled score in fig. G.10).

Looking at the problem at a more detailed level, the preference curves will not be split in only two curves for the group. Every stakeholder will have their own preference curves for apples and oranges that the model will consider, so in total six curves will be considered. How the model will search for a solution will be the same.

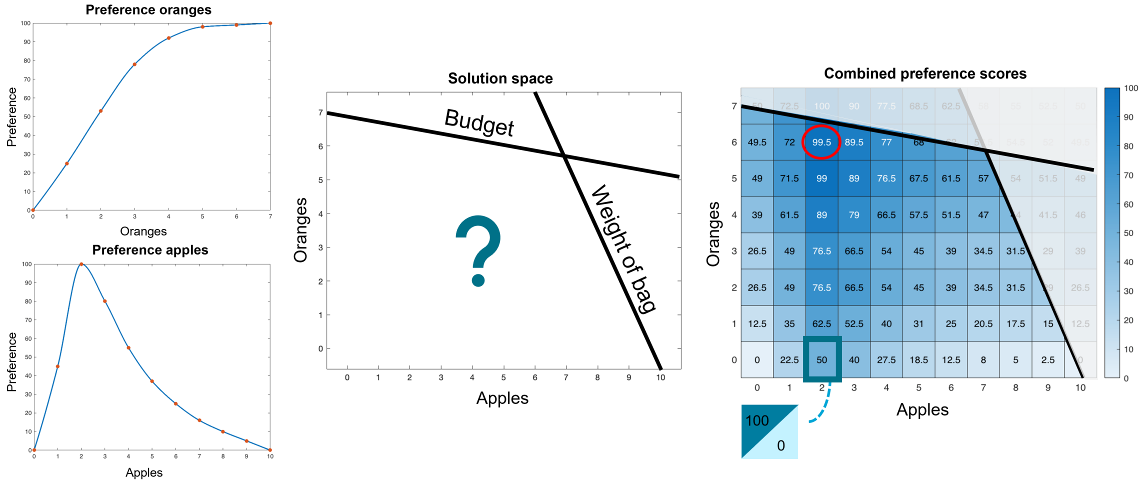


Figure G.10: Grid trade-off between apples and oranges

Goal attainment method:

Looking at the other method, finding the optimal group solution will go somewhat different. There is still a (the same) solution space where a solution should be found by means of the preferences. However, this method searches for a solution by looking at the personal best goals of the stakeholders. A solution will be found by focusing on the amount that everyone gives in on their personal best solution. The method tries to minimize the distance Between the group solution and the personal goal for every stakeholder. But it keeps in mind that this distance should be equal for all the stakeholders. So, the amount of compromises each stakeholder does is equal.

Translating this to the fruit example can be explained as follows. Each stakeholder has an ultimate goal: an ultimate composition of apples and oranges. It is likely that the group solution, using this method, will have another composition of apples and oranges. It can be determined how well the group solution scores in comparison to the ultimate composition of a stakeholders. This can be done by looking at the preference score of each stakeholder on the group solution (based on his preference curves for apples and oranges). How the group solution scores on in comparison to the ultimate composition of each stakeholder is represented by the red dot (shown in figure X). The arrow shows the distance between the group solution and the personal best solution. The distance represents how much a stakeholder must concede on his own ultimate solution with the group solution. The red dots have about the same distance to the personal goal of every stakeholder, which means the stakeholders make about the same amount of concessions.

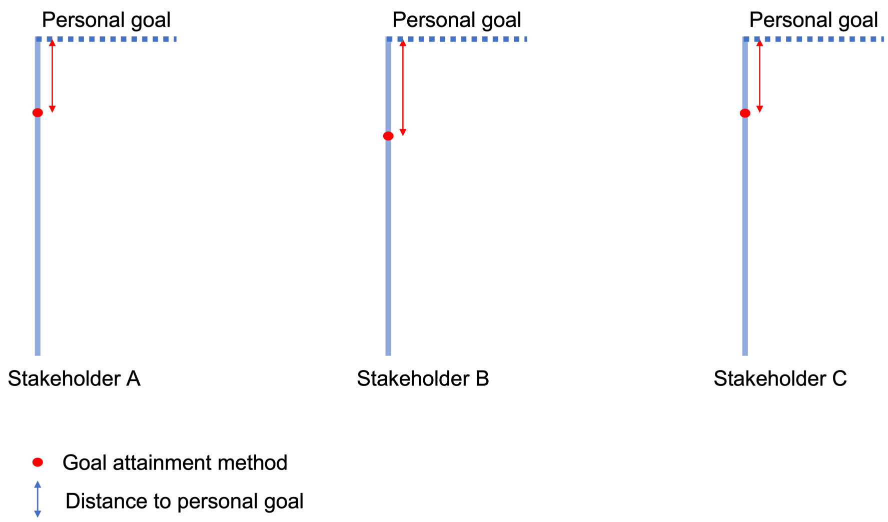


Figure G.11: Visualization of goal attainment

The difference between the methods can be explained by translating the Preferendus outcome to the same scales as the goal attainment method. Figure G.12 shows the different way of thinking for both methods. It has to be kept in mind that this is only a visualization of the differences between both methods, and possibly is not mathematically correct. What can be seen, is that the distance to the personal goal is somewhat the same in the goal attainment since the arrows almost have equal length (the red dots are almost on the same height). This is another case for the design generated with the Preferendus, represented by the black dots. With the Preferendus method, the personal scores on the group solution differ way more between the stakeholders. In the example, stakeholder B is getting close to his personal goal and stakeholder A is not. The black dots are not all on the same height.

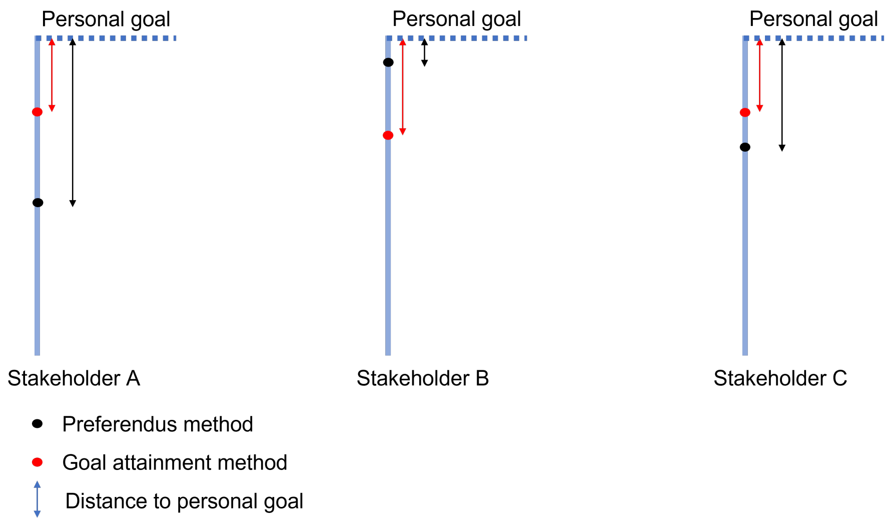


Figure G.12: Difference Preferendus and goal attainment

The presentation continued with the known starting points for subarea 5: a design with a revenue of 10 million and another design (including a healthcare center) with a revenue of 14 million. After the existing designs were shown, the design created with the two methods could be shown. It was not made clear, on purpose, which design was generated with which method. From this point, the question was asked which design they would choose and why they did or did not choose one.

Another question throughout the workshop was if the stakeholders would accept design outcome. It was not possible to test whether the stakeholders would accept the outcome since, in this project, they are the not the ones that create such a detailed design. They are the ones that define the outlines for a tender. Within boundaries of the tender, they want to see what a company will create as a detailed design. Therefore, the stakeholders are not in a position that they would or would not accept the outcome of the model. So, the outcome of the model is only used to give them answers on the issues that the stakeholders had for this project, taking into account everyone's preferences.

G.4.2 Design outcome (PoR)

There are two PoR's generated. The first PoR (Preferendus design) was optimized on preference, in which some stakeholders make more compromises than others. The second PoR (goal attainment design) minimized the distance to the goal. The designs are showed in table G.7.

Table G.7: PoR for Preferendus and goal attainment

		Unit	Optimization with Preferendus	Optimization with goal attainment
	Preference	-	**73.6393**	72.3
	Distance to goal	-	37.9741	**27.9082**
Finances	Revenues	Million €	11.7971	12.5167
Green	Greenery per house	m^2 / house	50	49.0253
Parking	Deviation parking norm	-	0.8	0.8
	Houses with built-in parking	%	8.2949	13.0188
	Parking spaces with a roof	m^2	2500	2375
Category houses	Total number of houses	Houses	217	217
	Affordable housing	Houses	43	34
	Total social housing	Houses	144	144
	Social rental	Houses	112	104
	Social owner-occupied	Houses	32	40
	Expensive housing	Houses	30	39
	Single-family housing	Houses	54	11
	Multi-family housing	Houses	163	206
Quiet neighborhood	Quiet neighborhood	-	0.2	0.2
Healthcare center	Healthcare center	Units	62	62
Housing differentiation	EG soc kp <€194.000	Houses	21	-
	EG sociale huur	Houses	-	-
	EG bereikb kp <€231.500	Houses	1	-
	EG betaalb kp <€310.000	Houses	4	-
	EG rijwoning €375.000	Houses	9	-
	EG 2/1kap €542.500	Houses	3	-
	EG vrijstaand klein €585.900	Houses	7	11
	EG vrijstaand groot €672.300	Houses	-	-
	EG verandawoning €328.000	Houses	-	-
	EG drive-in €355.000+€25.000	Houses	9	-
	MG sociale huur	Houses	112	104
	MG sociale kp <€194.000	Houses	4	40
	MG kp €291.000	Houses	29	34
	MG duur geb P	Houses	2	28
	MG sociale kp <€194.000 geb P	Houses	7	-
	MG kp betaalbaar, geb P onder dek	Houses	9	-
	MG kp €290.000+€20.000 alles geb P	Houses	-	-

Preferendus design

Looking at the PoR generated with the Preferendus (table G.7), the total revenues for subarea 5 are around 11.8 million. The deviation from the parking norm is 0.8, which means that 80% of the parking norm is considered in the design. This will give extra space for aspects such as housing and greenery. Around 8% of all the houses will have built-in parking space. The percentage of all the parking spaces in the rest of the area with a roof, that can only be constructed in a parking lot and not along the road, is around 70, which translates to 2500 square meter. There is extra room for green at the top of this roof. The amount of greenery per house is therefore relatively high, also at its maximum, around 50. The maximum number of houses (217) will be built in this design. The houses will be divided in affordable houses (43) the minimum number of social houses (144) and expensive houses (30). Both the affordable and expensive houses are above its minimum of respectively 34 and 0, which will generate extra revenues in this design. The social houses will mainly be rental (112) rather than owner-occupied (30). Furthermore, the division between single-family and multi-family houses is such that there will be three times as much multi-family houses than single-family houses. This ratio is expected since multi-family houses take up less space. A healthcare center will be built and consists of 62 units. The PoR shows a well-distributed housing mix, where 13 out of 17 housing types are built.

Goal attainment design

The PoR generated with goal attainment, shows another design than the PoR with the Preferendus. The revenues are around 12.5 million, which is higher than with the Preferendus. The amount of green is around the same size, namely 49 m^2. The deviation from the parking norm is equal to the other design (0.8). The number of square meters of parking spaces with a roof is somewhat lower than in the other design. The percentage of houses that will be built with a built-in parking space lies a little higher at 13%. The total amount of houses is 217, where the affordable houses are at its minimum of 34. This is 9 houses less than in the design with the Preferendus. The number of social houses is, again, at its minimum of 144. The distinction is social houses is different from the other design. The design generated with the goal attainment method shows more houses in the owner-occupied sector. The number of affordable houses is higher, at its maximum of 39, than in the other design. What can be seen is that the ratio between single-family and multi-family houses lies a lot more towards the multi-family houses. The difference in housing mix contribute to a difference in total revenues between the designs. As in the other design with the Preferendus, a healthcare complex of 62 units will be built. There is less of a housing mix in the design with Goal Attainment. Only 6 types of houses will be built versus 13 in the other design.

Personal scores on the PoR's

It is interesting to look at the personal scores of the stakeholders in both designs. For the Preferendus design, the preference scores and distances to a goal are calculated per stakeholder. In this way, the designs of the two methods can be compared by looking at the different personal scores of the stakeholders. The outcomes per stakeholder are showed in table G.8.

Table G.8: Personal preferences and distances to goal for both methods

Method	Preferendus			Goal attainment		
Optimization value	**73.6**	37.97		**27.91**	72.3	
Stakeholder	**Financial director**	**Urban planner**	**Munici-pality**	**Financial director**	**Urban planner**	**Munici-pality**
Revenues	66.94	89.49	95.41	76.21	85.07	90.19
Greenery per house	0	99.96	99.94	0	93.63	90.74
Deviation parking norm	0	100	100	0	100	100
Houses with built-in parking	0	29.98	0	0	44.75	0
Total number of houses	100	100	0	100	100	0
Total social housing	100	0	0	100	0	0
Social rental	0	0	2.01	0	0	0
Social owner-occupied	0	0	0	0	0	0
Affordable housing	15.89	20.39	97.97	100	0	80
Expensive housing	13.45	20	0.88	100	100	0
Single-family housing	0.55	72.42	97.57	0.01	17.25	82.23
Multi-family housing	0.55	99.74	66.95	0.01	56.17	15.23
Healthcare center	0	100	100	0	100	100
Quiet neighborhood	0	40	0	0	40	0
Revenues	29.75	0.74	0.69	21.41	1.05	1.47
Greenery per house	5	0.01	0.02	5	1.85	2.32
Deviation parking norm	0	0	0	0	0	0
Houses with built-in parking	0	10.15	0	0	8.01	0
Total number of houses	0	0	2.83	0	0	2.83
Total social housing	0	1.56	0	0	1.56	0
Social rental	0	0	5.74	0	0	5.86
Social owner-occupied	0	0	0	0	0	0
Affordable housing	0	2.48	0.06	0	3.11	0.57
Expensive housing	1.73	1.24	2.80	0	0	2.83
Single-family housing	1.24	0.86	0.07	1.25	2.57	0.50
Multi-family housing	0.25	0.01	0.93	0.25	1.36	2.40
Healthcare center	0	0	0	0	0	0
Quiet neighborhood	0	8.40	0	0	8.40	0
Total distance per stakeholder	**37.97**	**25.44**	**13.14**	**27.91**	**27.91**	**18.77**

Financial director

The financial director finds revenue by far the most important of all his objectives since he assigned a weight of 90% to this objective. The preference score for the financial director is 67 on revenues in the first design with the Preferendus. On the other design, generated with goal attainment, his distance from his goal on this aspect is 21. The Preferendus design, with a preference of 67 relates to a distance from his goal, considering the weight of this objective, of 29.7. This shows that the financial director scores closer to his goal in the goal attainment design.

Looking to the scores on both designs in total for the financial director, it can be concluded that the financial director scores better on the design obtained with goal attainment. The distance from his personal goal, taking into account all his objectives and weights, is smaller in the goal attainment design (27,9) than in the design with the Prefendus where the overall preference score is 62 (relating to a distance from his goal of 38). This is expected since the revenues are highly important for the financial director and the revenues are higher in the goal attainment design.

Urban planner

The urban planner scores well in both designs on the objective he finds most important (green, with weight of 29%). The preference score is 100 on green in the design obtained with the Preferendus. Considering the weight of this objective, the distance from his goal on this objective is 0. In the goal attainment design, the distance to his goal on the green objective is 1.8. This means he scores well on the most important objective in both designs, but he scores the best in the design with the Preferendus. On the second most important objectives (parking norm, built-in parking and quiet living all with a weight of 14%), he scores varying in the Preferendus design: respectively a preference score of 100, 30 and 40 (considering the weights on these objectives the distances are respectively: 0, 10.2 and 8.4). In the goal attainment design, the distances to the goal per objective are respectively: 0, 8 and 8.4. Looking at these three second best objectives, the goal attainment design would be the best fit for the urban planner. This makes it interesting to have a look at the entire design, taking into account all the objectives of the urban planner.

What can be seen is that the distance from his personal goal, is smaller in the Preferendus design (75 which relates to a distance of 25.4) than in the design with goal attainment (27.9). Based on this, it would be likely that the urban planner chooses the design created with the Preferendus method.

Municipality

The municipality scores well on her most important objectives in both designs. She finds green the most important objective looking at the weight (25%) and she has a preference of 100 on this objective in the Preferendus design. A preference of 100 relates, considering the weight of this objective, to a distance on her goal on this objective of 0. In the goal attainment design, her distance from her goal on the green objective is 2.3. Based on this information, the Preferendus model would be best for the municipality. Her second most important objectives are parking (20%) and the healthcare center (20%), on which she both scores a preference of 100 in the designs (in both cases the distance from the goal is 0).

Taking into account all the objectives from the municipality, she has a smaller distance to her goal in the Preferendus design than in the goal attainment design. Her distance from her personal goal is 13.1 in the Preferendus design (based on a preference score of 86.9) compared to 18.8 in the goal attainment design. Based on this, it would be likely that the municipality will go for the design created with the Preferendus.

G.4.3 Other optimizations

Due to the running time of the model, other designs (considering other constraint values) were made before the workshop. These designs consider the most obvious changes in constraints, based on the stakeholder statements that were made during the individual sessions.

The other optimizations consider a combination of the existing constraints (5 m^2, 0.8 and 217 houses) as they were used in the model and other constraint values for amount of greenery, deviation of parking norm and total number of houses, respectively 7m^2, 1 and 211 houses.

The outcome of the different scenarios can be found in appendix I.5.

G.4.4 Evaluation

The main feedback points and insights that were gained during the workshop, about the experience and acceptance of the PDOA, are listed below.

Insights in consequences

The process and model give many insights, including the consequences of certain choices or requirements. It is easy to show how the design changes when certain changes in the input are made. It can show what possibilities arise when certain norms are adjusted. For example, if the municipality will lower the parking norm, the stakeholders could agree that the extra space that is gained will be used for the quality of the area. The municipality seemed positive about greenery on top of parking roofs when she saw the design, so there are possibilities to place greenery on top of the parking roofs. The tool allows to negotiate about the minimal and maximal constraint values, since it can give insights in an easy manner. In addition, the design showed that it was preferred by the entire group to build a healthcare center. The PDOA model can show a design related to a decision on this consideration in an easy and quick manner. During the project, the stakeholders have been discussing about the healthcare issue for a long time. This shows that these insights that the PDOA can give is an added value of the approach.

Being able to play with the model is seen as important added value for the stakeholders. The financial director said during workshop: "*The possibilities to turn the knobs and the (added) information value of seeing the consequences of those changes, makes it a good tool to come to a decision together*".

Phase to use the PDOA

It is interesting to use it at the beginning of a process where a group of stakeholders come together and want to develop an area. These kinds of processes are iterative, so the model should be iterative as well. It should be used continuously throughout the process (with adjustments). The urban planner stated during the workshop: *"I find the method interesting to use at the beginning of a project, with the agreement to repeat and update the process and model from time to time"*.

The outcome is concrete (PoR), which makes it easier for the stakeholders to define their expectations on certain aspects within the project. And being able to see whether these expectations are taken into account in the design. The urban planner mentioned that normally, a design process can be 'floaty' and unclear as a master plan for an area will be elaborated which contains vague terms as 'develop in line with the market' (*marktconform uitwerken*). There may be several interpretations on these vague terms. This is also another reason why it is likely to use the method at the beginning of a process.

Iterative process

As already mentioned above, the stakeholders see added value in the approach when it is iterative. This has to do with the phase of the project they want to use the PDOA. In addition, the construction of preference curves before seeing a design, is experienced as hard. As stakeholders inherently would like to see what is possible by the means of a design, before expressing what they prefer, like how it normally goes in a design process. This makes it even more important for the process to be iterative so the curve can be changed after seeing the first iteration outcome.

Cooperation agreement is leading

The basis of Waelpolder is a cooperation agreement, in which certain norms and standards were fixed. Especially the municipality finds it hard to move away from this cooperation agreement in the individual sessions since she does not see the possibilities when deviating from these standards in the design yet. The agreement was sometimes leading over what the municipality wanted in an ideal situation. This was for example the case for the parking norm or the green norm. The described problem shows, again, that the model would be suited to use in a stage earlier than where the project is in at the moment. Namely, the stage where a cooperation agreement is being made.

Individual best design

It is helpful that the individual best designs can be shown. With that, stakeholders can see how far the group solution is situated from their personal best solution. The designs optimized on each stakeholder are shown in appendix I.5.

Follow up of the PDOA in Waelpolder

The stakeholders of Waelpolder would like to follow up on this process. There is a discussion how the model outcome can be used in the tender phase, the phase where the project for subarea 5 is currently at. Questions were also raised if the model could be used for other subareas. This shows that the stakeholders see the added value of this method, especially if it will be used in an earlier phase.

The above-described feedback points are rather vague and focusing on the process. It is interesting to zoom in on some concrete adjustments or realizations that the stakeholders had after participating in this process. The most interesting insights were obtained from the municipality, the stakeholder that sets all the hard requirements. The concrete insights that were gathered during the Workshop for the project are listed below.

The total number of houses

The entire group realized during the workshop that it is not logical at all, that the total number of houses is limited to 211 houses. The model showed the possibilities with more houses when using a previous assumed maximum of 217 houses (the maximum that was given by experts of Planmaat). Questions were raised why 211 houses were chosen in the first place. The maximum will not be adjusted anymore since this a too time-intensive process, especially for the phase that the project is currently in. Adjustments in the number of houses would mean they have to submit a new zoning plan, and currently the stakeholders are satisfied with the minimum appeals against the current plan. However, it does show that the group would choose for more houses if they would be in the position to set this number once again and that the number of 211 is not based on anything.

Generate more affordable houses
The municipality has realized that affordable houses generate more revenues than expected, so she would accept making more of these types than is currently agreed upon, while first she was against this idea.

Parking norm
The municipality does not choose for the possibilities that arise with a lower parking standard (80%). But that the standard can be set at a minimum of 90% if shared cars are introduced. The representative of the municipality wants to use the approach within the municipality to provide insights to policymakers into what it means when the parking standard is lowered.

G.4.5 Conclusions regarding validation of PDOA

Regarding the first question to the stakeholders, which method they would prefer only based on the story line, they unanimously chose the Preferendus. They choose the method where one stakeholder may do more compromises than the other. They want the highest achievable group solution and not a moderate solution as is this is likely to obtain with the goal attainment method (in their opinion). They have the feeling that the goal attainment method is not looking for extreme solutions and therefore is not looking for an optimal group design. In addition, the stakeholders think it is realistic that one stakeholder should do more compromises than another one since this happens in real-life projects as well.

"Ik ben niet zo van ieder evenveel. En je moet toch komen tot de verschillende preferenties en dan komen tot de meest ideale oplossing of keuze (financieel directeur). Als je op zoek bent naar iets unieks, dan krijg je dat er dus niet uit bij de goal attainment methode. Je krijgt met die methode waarschijnlijk heel veel gemiddelden designs (stedenbouwkundige)."

Quote translated: *"I am not so much of everybody equal. And you still have to come to the different preferences and then come to the most ideal solution or choice (financial director). If you are looking for something unique, you won't get that out of the goal attainment. You will probably get a lot of average designs with that method (urban planner)."*

From these reasonings, they conclude that they prefer the Preferendus. This conclusion is based on the story of both methods without seeing any design generated with both methods.

Once the stakeholders see the designs generated with both methods, they choose the design that suits them the most, regardless from the method that is used. This is sometimes the design generated with the Preferendus and sometimes the design generated with the goal attainment method, but never leads to an unanimously answer related to a method. The stakeholders did not get to see which design was generated with which method. This shows that the stakeholders will always choose for the design that suits him the best, even though it may hurt other stakeholders.

It is interesting to see if the stakeholders chose the design that was expected, as reasoned in appendix G.4.2. The financial director and the municipality both chose the design that was expected that they would choose. For the financial director, this was the design generated with goal attainment. The municipality chose the design generated with the Preferendus. Only the urban planner chose a different design than expected. It was expected of him to choose the Preferendus design, due to the better score on quality. However, during the stakeholder session he was not really choosing one design. He liked the Preferendus design because of the housing differentiation. But he also liked the goal attainment design since the revenues were higher in that design. He had the idea that he could spend the extra money that was generated in this design on the quality of the area. The design choice of the urban planner is depending on how the money will be spend in the design.

From these observations it can be concluded that the Preferendus is preferred by the stakeholders to use as method within the approach. The Preferendus is chosen based on only the storyline (not everyone should do an equal amount of compromises). In addition, in the choice for a design, it does not matter whether the design is obtained with the Preferendus or with goal attainment, the stakeholders will always choose the design that fits them best.

The question if the stakeholders would accept such a process, where everyone communicates open to each other and therefore can come to an integral model, can be answered with yes. The stakeholders were positive about several aspects in this process and can see the added value of it. For example, the stakeholders appreciate that the model can give insights into the consequences of certain choices considering requirements, in an effortless and quick manner. They see the added value of the model when they would use it in an early phase of an urban development project, where they are still able to make adjustments in the requirements and constraints. The project of Waelpolder was in a phase where there was already a cooperation agreement. The model gives insights in the possibilities when the fixed, hard standards in this agreement would be loosened. These insights let the stakeholder doubt about some of the values of the standards that are set in the agreement because the stakeholders saw that more is possible than thought of beforehand. Examples of the values that the stakeholders have doubts about are the parking norm and the maximum number of houses, that are set in the cooperation agreement. These could, according to the stakeholders, be respectively lower and higher, after they saw the possibilities when doing this.

The stakeholders find it hard to give input and define an intermediate point on the curve, without seeing any design first. They consider it difficult to imagine what the outcome will look like based on their input. The stakeholders find it hard to step away from the regular design process of designing first and assessing & thinking what they want afterwards. This indicates that it is important for the approach to be iterative, so curves can still be adjusted during the process if stakeholders change their mind.

G.5 Final PoR and verification

The model development is an iterative process, with the input of the workshop, a second iteration was made. The adjustments for this iteration will be discussed in appendix G.5.1. The stakeholders mentioned in the workshop, that they prefer the Preferendus method as not every stakeholder should make the same amount of compromises. Therefore, it was chosen to only use the Preferendus for this second iteration, as the stakeholders already decided on the method.

It was for two reasons chosen to send the outcome of this iteration to the stakeholders one more time after the adjustments were made. Firstly, as it was not possible to make the changes during the workshop due to the running time of the model. Secondly, the stakeholders already answered the question about the acceptance of the process and as discussed before, they are not in a position to accept a design. Therefore, setting up a new workshop with all the stakeholders would not have any added value and would be a waste of time for all parties involve. However, it could be of value for the stakeholders to able to see what is possible in the new design that includes the adjustments.

G.5.1 Adjustments for second iteration

Several adjustments should be made as a result of the workshop in order to create a new ideal group solution. The adjustments are:

- The total number of houses should be set at a maximum of 211 and no longer 217. This affects all the maxima in the preference curves that are related to the housing types, by six houses.
- The minimum of the parking standard should be set at 90% (0.9) and no longer at 80% (0.8). A deviation of 90% (0.9) of the norm could possibly still be achieved if shared cars are introduced, else it is 100% of the parking norm. Which is why a new minimum of 90% (0.9) is chosen by the group of stakeholders instead of 100% (1).
- The minimal green norm should be set at 7 m^2/house and not at 5 m^2/house. This has no further effect on the preference curves and the results, because the designs already showed an amount of green higher than 7 m^2/house. The adjustment in minimal amount of green per house (from 5 to 7), did not affect the result, as in most of the outcomes the green per house is between 35-50 m^2 per house, which satisfies the municipality and urban planner.
- The unit of parking spaces with a roof is changed from percentage to square meters. This makes it more quantifiable for the stakeholders how much area of greenery will be placed above the parking spaces.

The new set of preference curves that are used to generate the final PoR, including the adjustment described above, can be found in appendix I.4. The new table with the adjustment minima and maxima of the objectives is shown in table G.9.

Table G.9: Adjusted minimal and maximal values for objectives

Adjusted objectives	Unit	Minimal value	Maximal value
Revenues	Million €	5.2	14.9
Greenery per house	m² / house	7	50
Deviation parking norm	-	0.9	1.5
Houses with built-in parking	-	0	0.5
Total number of houses	Houses	178	211
Total social housing	Houses	144	177
Social rental	Houses	104	177
Social owner-occupied	Houses	0	73
Affordable housing	Houses	34	67
Expensive housing	Houses	0	33
Single-family housing	Houses	0	211
Multi-family housing	Houses	0	211
Healthcare center	Option	0	3.5
Quiet neighborhood	-	0	0.5

G.5.2 PoR second iteration

Considering the adjustments and using the Peferendus method, a new PoR is generated. This PoR is shown in table G.10. As can be seen, the total revenues for subarea 5 are around 12.63 million euros. The deviation of the parking norm is 1, meaning that 100% of the original parking norm is used in this outcome. Around 23.5% of all the houses will have built-in parking space. This will give extra space for aspects such as housing and greenery. The total area of all the parking spaces with a roof, that can only be constructed in a parking lot and not along the road, is 2687.5 m^2. This means there is 2687.5 m^2 of green at the top of the roof. The amount of greenery per house is therefore relatively high, also at its maximum, 50 m^2 per house.

The maximum number of houses (211) will be built in this design, due to the new constraint. This constraint affects the mix of housing as well. The houses will be divided in affordable houses (34), the minimum number of social houses (144) and expensive houses (33). The expensive houses are above its minimum of 0, this will generate extra revenues in this design. The social houses are set to a minimum, rental is in this design at its minimum value (104) and owner-occupied (40) fills the rest to reach the minimum of social housing (144). Furthermore, the division between single-family and multi-family houses is such, that mainly multi-family houses are built instead of single-family houses. Only one type of single-family housing is built. This could be expected since multi-family houses take up less space, meaning there is space for greenery and area for parking cars. A healthcare center will be built and consists of 62 units.

Table G.10: PoR of the second iteration

		Unit	Preference second iteration
	Optimization value	**-**	**78.196**
Finances	Revenues	Million €	12.6306
Green	Greenery per house	m^2 / house	50
Parking	Deviation parking norm	-	1
	Houses with built-in parking	%	23.5514
	Parking spaces with a roof	m^2	2687.5
Category houses	Total number of houses	Houses	211
	Affordable housing	Houses	34
	Total social housing	Houses	144
	Social rental	Houses	104
	Social owner-occupied	Houses	40
	Expensive housing	Houses	33
	Single-family housing	Houses	21
	Multi-family housing	Houses	190
Quiet neighborhood	Quiet neighborhood	-	0.2
Healthcare center	Healthcare center	Units	62
Housing differentiation	EG soc kp <€194.000	Houses	-
	EG sociale huur	Houses	-
	EG bereikb kp <€231.500	Houses	-
	EG betaalb kp <€310.000	Houses	-
	EG rijwoning €375.000	Houses	-
	EG 2/1kap €542.500	Houses	-
	EG vrijstaand klein €585.900	Houses	21
	EG vrijstaand groot €672.300	Houses	-
	EG verandawoning €328.000	Houses	-
	EG drive-in €355.000+€25.000	Houses	-
	MG sociale huur	Houses	104
	MG sociale kp <€194.000	Houses	2
	MG kp €291.000	Houses	34
	MG duur geb P	Houses	12
	MG sociale kp <€194.000 geb P	Houses	38
	MG kp betaalbaar, geb P onder dek	Houses	-
	MG kp €290.000+€20.000 alles geb P	Houses	-

G.5.3 Verification of PoR

Weights are being used in the model; this means the model should be verified on sensitivity towards those weights. This can be done with a sensitivity analysis using the Preferendus, as this was the preferred method by the stakeholders, to use to generate a PoR. Weights are used on two levels, between the objectives of the stakeholder and between the stakeholders. The emphasis for the sensitivity analysis lays on the later, as the weights between objectives have been defined by the stakeholders and for the weights between the stakeholders' assumptions were made. It was assumed that stakeholders have the same amount of power and therefore have the same weight in the model. It is interesting to see what happens if this would not be the case and if the model is sensible for such changes. Both sensitivity analyses are conducted and elaborated below.

Sensitivity analysis for stakeholders' weights

During the sensitivity analysis, the weights of three stakeholder are changed to 50% for one stakeholder, and 25% for each of the other two stakeholders. The outcome of three model runs, one for each stakeholder, are displayed in table G.11.

Comparing the designs where the municipality, urban planner and financial director have alternately a larger weight than the other two stakeholders, with the second iteration design, the delta is respectively: 1.5, 5.1 and 10.2 in overall preference in advantage of the second iteration.
The mix in types of houses is in all three designs (with different weights for each stakeholder) different. But as the categories of houses do not change significantly, this has no significant influence on the overall preference of the design.

Larger weight for the municipality or urban planner
The cases where the municipality or the urban planner has a higher weight show almost comparable differences with respect to the PoR from the second iteration. This can be explained by the fact that both stakeholders have relatively overlapping/equal goals and preference curves. The two designs with the higher weight only differ 0.3 million euros between each other, parking spaces with a roof is for the urban planner twice as high, in the housing categories there is a difference of 5 in expensive and affordable living.

Comparing two designs where the municipality or urban planner has more power to the PoR of second iteration, in both designs there is no difference in amount of greenery per house, all are at 50 m^2. Both designs have around 10% less houses with built-in parking spaces. The PoR of the second iteration is in the middle of the two designs related to parking spaces with a roof. The number of single-family houses is twice as high as in both designs. A deviation in affordable and expensive houses can be noticed as well. The design where the municipality has more power, the affordable houses are 45 (instead of 34 in the 2^{nd} iteration) at a cost of expensive houses. For the urban planner this same category is increased to 50 houses.

So, there is a difference in designs when the weight distribution between stakeholders is changed for those two stakeholders. The change is relatively small, in the case of greenery there is no change, this could be explained by the relatively overlapping preferences for two of the three stakeholders in the project, the municipality and urban planner.

Larger weight for the financial director
When the design where the financial director has more weight, who has another goal compared to the other stakeholders, is compared to the designs where the municipality or the urban planner has more weight, there are quite some differences. The revenues are around 1.5 million higher, greenery is almost at the minimum at 7.8 m^2 per house. No parking spaces with a roof are built, since greenery is not important for him, so double land use is not chosen by the model. The maximum number of expensive houses is built since he is in the understanding that expensive houses generate more revenues. More houses in the single-family category are built as well.

Comparing the design where the financial director has more weight than the two other stakeholders to the PoR of second iteration, the categories of housing do not change a lot. Five extra affordable houses are built, at a cost of five houses in the expensive category. About one third of the houses are built in single-family houses, compared to ten percent in the second iteration. The biggest difference is in the total amount of greenery, the amount of green is 8 m^2 per house where the minimum is 7m^2. The houses that have built-in parking spaces is 20% less and no parking spaces with a roof are built. One could say, giving the financial director more weight, affects the quality of the area/project.
The design where the financial director has the most power, contains almost the bare minimum of greenery. Therefore, it is less likely that the municipality and urban planner would accept this design, compared to the design where all stakeholders have equal weights.

Conclusions sensitivity model for stakeholders' weights
Comparing the three designs, shows that the weights of the stakeholders within the project have an impact on the final design. The conclusion can be drawn that the model is sensitive to changing the weights between stakeholders, since differences in design can be seen between the second iteration and the designs where the stakeholder's weight distribution is different. The amount of changes is depending on which stakeholder gets more weight, as the goals of the financial director are less in line compared to the goals of the municipality and the urban planner. Therefore, the model is more sensitive to changes in the weight of the financial director.

Therefore, it is recommended to reconsider how the weights are distributed between the stakeholders, when the model is used in the future. As explained earlier, the weights between stakeholders are kept equal in this case to avoid discussions about the weight distribution and the limited time for the project.
As the municipality and the financial director are both equal shareholders in this project, this could give an indication about how to divide the weights. When the financial director says something about the financial aspect and when the objectives are related to plan quality, the urban planner will step in and could take the position of the financial director. In this case the financial director and the urban planner act as one party (this party has a weight of 50% in the project), where the urban planner says something about project quality and the financial director gives input on the financial related topics.

Table G.11: Sensitivity analysis, different weights between stakeholders

		Unit	Preference second iteration	Municipality 50%	Urban planner 50%	Financial director 50%
	Optimization value	**-**	**78.196**	**76.6614**	**73.0387**	**67.9347**
Finances	Revenues	Million €	12.6306	11.7111	12.0049	13.4407
Green	Greenery per house	m² / house	50	49.9454	49.9847	7.8058
Parking	Deviation parking norm	-	1	1.0569	1.2133	1.001
	Houses with built-in parking	%	23.5514	13.7441	14.218	5.2133
	Parking spaces with a roof	m²	2687.5	1825	3550	0
Category houses	Total number of houses	Houses	211	211	211	211
	Affordable housing	Houses	34	45	50	39
	Total social housing	Houses	144	144	144	144
	Social rental	Houses	104	104	104	104
	Social owner-occupied	Houses	40	40	40	40
	Expensive housing	Houses	33	22	17	28
	Single-family housing	Houses	21	40	37	75
	Multi-family housing	Houses	190	171	174	136
Quiet neighborhood	Quiet neighborhood	-	0.2	0.2	0.2	0.2
Healthcare center	Healthcare center	Units	62	62	62	62
Housing differentiation	EG soc kp <€194.000	Houses	-	-	1	37
	EG sociale huur	Houses	-	13	-	12
	EG bereikb kp <€231.500	Houses	-	-	1	-
	EG betaalb kp <€310.000	Houses	-	5	18	-
	EG rijwoning €375.000	Houses	-	10	-	1
	EG 2/1kap €542.500	Houses	-	4	3	-
	EG vrijstaand klein €585.900	Houses	21	8	13	24
	EG vrijstaand groot €672.300	Houses	-	-	-	-
	EG verandawoning €328.000	Houses	-	-	1	-
	EG drive-in €355.000+€25.000	Houses	-	-	-	1
	MG sociale huur	Houses	104	91	104	92
	MG sociale kp <€194.000	Houses	2	33	24	3
	MG kp €291.000	Houses	34	18	16	30
	MG duur geb P	Houses	12	-	1	2
	MG sociale kp <€194.000 geb P	Houses	38	7	15	-
	MG kp betaalbaar, geb P onder dek	Houses	-	13	5	5
	MG kp €290.000+€20.000 alles geb P	Houses	-	9	9	4

Sensitivity analysis for objective weights

The weights between the objectives of stakeholders are analyzed as well, but not to a large extend as those weights were assigned by the stakeholders themselves. During the sensitivity analysis the weights of objectives, the weights given by the stakeholders, are changed to equal weights between the objectives per stakeholder. The results are shown in table G.12.

Comparing the outcome where equal weights between objectives for each stakeholder are used to the outcome of the second iteration, it can be seen the design has a delta of 16.1 in preference score in advantage of the second iteration outcome. The second iteration generates 1.14 million more revenues. The deviation in parking norm, greenery per house and healthcare center are equal in both designs. The second iteration has twice as many houses with built-in parking spaces and about 30 parking spaces with a roof less than the model with equal weights between objectives. There are Almost no differences in the housing categories. Besides the ratio single-family and multi-family houses. The mix in types of houses is in both designs different. But as the categories of houses do not change, it can be stated that this has no significant influence on the overall preference of the design, since the preferences are expressed over the categories of houses.

The conclusion can be drawn that the model is sensitive to changing the weights of objectives. It is especially sensitive to changes when stakeholders assign weights with a large spread in between (low and high weights) based on the change in revenues. For this objective the financial stakeholder gave a weight of 90%, which contributed to a change of 1.14 million when changed to a moderate weight. This sensitivity analysis made it clear that stakeholders should reconsider their objective weights if they do not accept the solution.

Table G.12: Sensitivity analysis, equal weights between objectives

		Unit	Preference second iteration	Preference qual weights between objectives
	Optimization value	**-**	**78.196**	**62.0925**
Finances	Revenues	Million €	12.6306	11.4907
Green	Greenery per house	m² / house	50	49.9739
Parking	Deviation parking norm	-	1	1.0144
	Houses with built-in parking	%	23.5514	11.3744
	Parking spaces with a roof	m²	2687.5	3062.5
Category houses	Total number of houses	Houses	211	211
	Affordable housing	Houses	34	34
	Total social housing	Houses	144	144
	Social rental	Houses	104	104
	Social owner-occupied	Houses	40	40
	Expensive housing	Houses	33	33
	Single-family housing	Houses	21	55
	Multi-family housing	Houses	190	156
Quiet neighborhood	Quiet neighborhood	-	0.2	0.2
Healthcare center	Healthcare center	Units	62	62
Housing differentiation	EG soc kp <€194.000	Houses	-	7
	EG sociale huur	Houses	-	2
	EG bereikb kp <€231.500	Houses	-	1
	EG betaalb kp <€310.000	Houses	-	5
	EG rijwoning €375.000	Houses	-	14
	EG 2/1kap €542.500	Houses	-	15
	EG vrijstaand klein €585.900	Houses	21	2
	EG vrijstaand groot €672.300	Houses	-	-
	EG verandawoning €328.000	Houses	-	7
	EG drive-in €355.000+€25.000	Houses	-	2
	MG sociale huur	Houses	104	102
	MG sociale kp <€194.000	Houses	2	29
	MG kp €291.000	Houses	34	1
	MG duur geb P	Houses	12	-
	MG sociale kp <€194.000 geb P	Houses	38	4
	MG kp betaalbaar, geb P onder dek	Houses	-	4
	MG kp €290.000+€20.000 alles geb P	Houses	-	16

G.6 Discussion Waelpolder

There are a few discussion points within the application of Waelpolder that could had an influence on the acceptation of the PDOA and should be kept in mind for future applications of PDOA.

As evaluated, a preference curve should be based only one objective, and should not be based on another objective such that the curve becomes a 'proxy' curve, and advantage can be taken from it. A curve where the stakeholder shapes the curve in such a way that it will be beneficial to reach another objective is intentionally done by the stakeholder (strategic play) and can influence the design outcome. This happened for example with the municipality who used the green standard as the basis for the definition of her preference curve of the total number of houses, as described in appendix G.4.4. This raises the question if the stakeholders can say something about certain objectives. If they use an objective as proxy to reach a high preference score on another objective, this can have an impact on the design and how it reflects reality.

In addition, the preference curve should be designed based on only one objective, and not more objectives. A curve should not be defined based on 2 aspects, where the beginning of the curve is considering one aspect and the end of the curve is considering another aspect. This could happen especially with parabolic preference curves. For example, the municipality's preference curve for revenues has a parabolic shape, as described in appendix G.4.4. In contrast with the 'proxy' curves, considering two objectives in one curve happens unintentionally by the stakeholder. The fact that this happened in Waelpolder can have an impact on the design and how this really reflects reality.

The former discussion point goes hand in hand with the fact that stakeholders should have the same understanding of the objective than that is laid down in the relations within the model. If the stakeholder interprets the objective in another way than the relation in the model is telling, misunderstandings can occur. These can have an influence on the design outcome. An example of this problem in Waelpolder is that the System Engineers developed a relation to calculate the result (revenues minus costs), based on the goals and statements of the stakeholders. It appeared that what the stakeholders were saying did not relate to result but purely to revenues. So, this relation had been changed in between the sessions. For Waelpolder, this issue was foreseen in time. However, it must be taken into account that this can happen or has happened in Waelpolder (that the System Engineers do still not know about).

As stated before, there was already a cooperation agreement within Waelpolder. The agreement resulted in the fact that there was little possibility to explore the options when boundaries would be opened. It was difficult for the stakeholders to make a distinction in what they wanted ideally, and what they were obliged to by the fixed standards as agreed upon in the contract (reality). It was tried to let them reason their curves from an idealistic perspective. However, they kept the reality in mind and stakeholders found it difficult to make a distinction between what they wanted ideally, and what was possible looking at the reality. This can have an impact on the preference curve and therefore on the design.

Furthermore, the role of the System Engineer should be mentioned. Since the System Engineer helps the stakeholder in the process of designing the preference curve, it may occur that he has an influence on the shape of the curve. This happened especially when specifying the intermediate point on the curve since the stakeholders found this difficult. The help of the System Engineer can have an influence on the design.

All described discussion points can have its influence on the design outcome. However, as stated in the goal of this application, it was investigated if the stakeholders would accept the approach, and not the design itself, as the stakeholders are not in the position or phase to accept the design, as discussed earlier. So, the points would probably not influence the acceptance on the approach. It can be seen as a recommendation for future projects where stakeholders are accepting the design.

Both methods, goal attainment and the Preferendus, that are compared and tested to use as optimization approach are applied to the Waelpolder case where the solution space was relatively small (looking at the boundaries). Therefore, the designs generated with both methods did not differ that much. Since the differences are small, the difference in working of the methods will come out less, so less hard conclusions regarding the preferred method can be drawn.

H Additional appendix Bloemendalerpolder

Appendix H consists of the additional appendices for Bloemendalerpolder.

H.1 MATLAB Script BDP

The MATLAB script for BDP is shown on the following pages.

Contents

- Design variables:
- Data input variables
- General / fixed data for the model
- Bounds for design variables
- Constraints
- Data preference curve
- Weights of criteria
- Objective function
- GA options
- Optimization
- Calculations of some totals
- Weights of criteria after optimisation
- Final Preference based on optimisation values (xbest)
- Display
- Save output To the Excel output file


```
function PFM_BDP_Klein_Pref_model_Loop_v91
```

```
clc, clear, close all
```

Design variables:

```
%46 design variables

%Algemeen
% x(1)  - Totale oppervlak                            In Ha
% x(2)  - Kosten                                      In Euro
% x(3)  - Opbrengsten                                 In Euro

%Strategisch groen
% x(4)  - Strategisch Groen                           In Ha
% x(5)  - Gemeenschapspolder                          In Ha
% x(6)  - Waterland                                   In Ha
% x(7)  - Plas                                        In Ha
% x(8)  - Waterlandtak                                In Ha
% x(9) - Vechtoever                                   In Ha
% x(10) - Park Muiden                                 In Ha
% x(11) - Sport/Zorglandgoed                          In Ha
% x(12) - Arboretum                                   In Ha
% x(13) - Stadspark Weesp                             In Ha
% x(14) - Waterarboretum/ Galgenveld                  In Ha
% x(15) - Paden                                       In Percentage
% x(16) - Dijken                                      In Percentage
% x(17) - Kunstwerken                                 In Percentage
% x(18) - Specials                                    In Percentage
% x(19) - Beheerboerderij                             In Percentage

% Woonmilieus
% x(20) - Oppervlak wonen                             In Ha
% x(21) - Totaal woningaantal                         In #Woningen
% x(22) - Vechtstad                                   In #Woningen
% x(23) - Weesp                                       In #Woningen
% x(24) - Tuinbuurt                                   In #Woningen
% x(25) - Lint droog                                  In #Woningen
% x(26) - Lint 1/2 nat                                In #Woningen
% x(27) - Lint nat                                    In #Woningen
% x(28) - Buurtschap                                  In #Woningen
% x(29) - Landgoed                                    In #Woningen
% x(30) - Aantal betaalbare woningen                  In #Woningen

%Bovenwijkse kosten
% x(31) - Verplaasten gas- en rooilpersleiding        In Percentage
% x(32) - Verplaatsen hoogspanningsleiding            In Percentage
% x(33) - Hoofdontsluiting 2*2                        In per meter
% x(34) - Verbindingsweg A1 - Muiden                  In Percentage
% x(35) - Onderdoorgang spoor Langzaam verkeer        In units
% x(36) - Fietsbrug over A1                           In Percentage
% x(37) - Herprofileren Korte Muiderweg               In Percentage
% x(38) - Verbinding A1 - Vechtstad                   In Percentage
% x(39) - Herinrichten Papenlaan                      In per meter
% x(40) - Bijdrage aan dijkverzwaring                 In Percentage
% x(41) - Dijkdoorbraak Vecht tbv vaarverbetering     In Percentage
% x(42) - Sluis naar Vecht                            In units
% x(43) - Sluis naar Muidertrekvaart                  In units
% x(44) - Waardering inbrengwaarde                    In Percentage
% x(45) - Beheer strategisch groen                    In Percentage
```

Data input variables

```
D = readtable("Data Excel Pen preferenties alle partijen.xlsx", 'Sheet', 'Data'); %Loading the database data
```

General / fixed data for the model

```
Tot_var = 9 % Number of vaiables
Num_S = 3 % Number of stakeholders
Num_DP = 6 % Number of data points for preference
IntCon = [5 6 7 8 9]; % vaiable numbers that need to be interger
Minimaal = D.Minimaal; % Minimal constraint values
Maximaal = D.Maximaal;  % Maximal constraint values
K = D.Kosten_eh'; % costs per design variable per unit
Revenues = D.Opbrengst_eh; % revenue per design variable per unit

Upperbound = D.Ub([5 7 11 13 22 23 24 27 29]); %data upperbound
Lowerbound = D.Lb([5 7 11 13 22 23 24 27 29]);  %data lowerbound
```

```
Oppwon = D.Oppwon; % calculation factor for plot area for housing.
opptot = D.Maximaal(1) % total plan area in hectare
budget = D.Maximaal(2); % total investment budget in euro

x0 = D.UitslagLPE; % initial point, equal to solution LP model Planmaat

Fixed = D.Aantal; % values of fixed elements in the model

%The costs for the fixed elements or the 'fixed costs'
Vastekosten = Fixed(6)*K(6) + Fixed(8)*K(8) +Fixed(9)*K(9) +Fixed(10)*K(10) + Fixed(12)*K(12) +Fixed(14)*K(14)... %fixed types of greenery (not used)
               +Fixed(25)*K(25) +Fixed(26)*K(26) +Fixed(28)*K(28) +Fixed(30)*K(30)... % fixed housing types (not used)
               + Fixed(15)*K(15) + Fixed(16)*K(16) + Fixed(17)*K(17) + Fixed(18)*K(18) + Fixed(19)*K(19)... % greenery costs in general
               + Fixed(31)*K(31) + Fixed(32)*K(32) + Fixed(33)*K(33) + Fixed(34)*K(34) + Fixed(35)*K(35) + Fixed(36)*K(36) + Fixed(37)*K(37) + Fixed(38)*K(38) + Fixed(39)*K(39)...
               + Fixed(40)*K(40) + Fixed(41)*K(41) + Fixed(42)*K(42) + Fixed(43)*K(43) + Fixed(44)*K(44) + Fixed(45)*K(45) % costs to make the area livable
%The revenues for the fixed elements or the 'fixed revenues'
Vasteopbrengst = Fixed(6)*Revenues(6) + Fixed(8)*Revenues(8) +Fixed(9)*Revenues(9) +Fixed(10)*Revenues(10) + Fixed(12)*Revenues(12) +Fixed(14)*Revenues(14)... %fixed types of greenery (no
               +Fixed(25)*Revenues(25) +Fixed(26)*Revenues(26) +Fixed(28)*Revenues(28) +Fixed(30)*Revenues(30)... % fixed housing types (not used)
               +Fixed(15)*Revenues(15) + Fixed(16)*Revenues(16) + Fixed(17)*Revenues(17) + Fixed(18)*Revenues(18) + Fixed(19)*Revenues(19)...  %% greenery costs in general
               +  Fixed(31)*Revenues(31) + Fixed(32)*Revenues(32) + Fixed(33)*Revenues(33) + Fixed(34)*Revenues(34) + Fixed(35)*Revenues(35) + Fixed(36)*Revenues(36)...
               + Fixed(37)*Revenues(37) + Fixed(38)*Revenues(38) + Fixed(39)*Revenues(39) + Fixed(40)*Revenues(40) + Fixed(41)*Revenues(41) + Fixed(42)*Revenues(42) + ...
               Fixed(43)*Revenues(43) + Fixed(44)*Revenues(44) + Fixed(45)*Revenues(45) %revenues for making the area livable
```

Bounds for design variables

```
lb = Lowerbound'; %lower bound
ub = Upperbound'; %upper bound
```

Constraints

```
%Standard Matlab form is A*x <= b.
%For minimal number of houses x(1)+x(2)+x(3)+x(4)+x(5)>=600
%For minimal number of industrial estate x(6)>= 0 m2
% total budget available  stcost*(x(1)+x(2)+x(3)+x(4)+x(5)+x(6)+x(7)) <= budget

function [c,ceq] = Constraints(x)
    % General constraints
      calg(:,3) = -((((x(:,1).*Revenues(5) +x(:,2).*Revenues(7) +x(:,3).*Revenues(11)  +  x(:,4).*Revenues(13)) +   (x(:,5).*Revenues(22) +x(:,6).*Revenues(23)...
          +x(:,7).*Revenues(24) +x(:,8).*Revenues(27) +x(:,9).*Revenues(29)))+Vasteopbrengst) - (((x(:,1).*K(5) +x(:,2).*K(7) +x(:,3).*K(11) +x(:,4).*K(13))...
          +(x(:,5).*K(22) +x(:,6).*K(23) +x(:,7).*K(24)  +x(:,8).*K(27) +x(:,9).*K(29)))+Vastekosten))+ (-35); % Maximal losses

      calg(:,1) = ((x(:,1) + x(:,2) + x(:,3)  + x(:,4))  +   (x(:,5)* Oppwon(22) +x(:,6)*Oppwon(23)+    x(:,7)*Oppwon(24) ...
          +     x(:,8)*Oppwon(27)+      x(:,9)*Oppwon(29))) -  Maximaal(1)  -0.001 ; % Maximal area BDP in Ha

      calg(:,2) = -((x(:,1) + x(:,2) + x(:,3)  + x(:,4))  +   (x(:,5)* Oppwon(22) +x(:,6)*Oppwon(23)+   x(:,7)*Oppwon(24) ...
          +     x(:,8)*Oppwon(27)+      x(:,9)*Oppwon(29))) +  Maximaal(1)  -0.001; % Minimaal area BDP in Ha
      ca = [calg];

    % Constrainst greenery
      cgroen(:,1) =   - (x(:,1) + x(:,2) + x(:,3)  + x(:,4)) +Minimaal(4);    % Minimal of total greenery
      cgroen(:,2) =    (x(:,1) + x(:,2) + x(:,3)  + x(:,4)) -Maximaal(4);     % Maximal of total greenery

     cgroen = [cgroen];

   % Constraints living
     cwon(:,1) =    -(x(:,5) +x(:,6) +x(:,7) +x(:,8) + x(:,9)) +   Minimaal(21);    %Minimal number of houses
     cwon(:,2) =    (x(:,5) +x(:,6) +x(:,7) +x(:,8) + x(:,9)) -    Maximaal(21); % Maximal number of houses
     cwon(:,3) =    -(x(:,5)* Oppwon(22) +x(:,6)*Oppwon(23)+     x(:,7)*Oppwon(24)+ x(:,8)*Oppwon(27)+  x(:,9)*Oppwon(29)) +  Minimaal(20);  %Minimal area for living
     cwon(:,4) =     (x(:,5)* Oppwon(22) +x(:,6)*Oppwon(23)+     x(:,7)*Oppwon(24)+ x(:,8)*Oppwon(27)+  x(:,9)*Oppwon(29)) -  Maximaal(20);  %Maximal area for living
     cwon = [cwon];

     c = [ca, cgroen, cwon];
     ceq=[];

end
nonlcon = @Constraints;

A=[];     b=[];

Aeq = []; beq= [];
```

Data preference curve

```
%Preferenties Stakeholders
DG = readtable("Data Excel Pen preferenties alle partijen.xlsx",'Sheet', 'PreferentiesG','PreserveVariableNames', true); %Loading preferences Green party
DD = readtable("Data Excel Pen preferenties alle partijen.xlsx",'Sheet', 'PreferentiesD','PreserveVariableNames', true); %Loading preferences Developers
DM = readtable("Data Excel Pen preferenties alle partijen.xlsx",'Sheet', 'PreferentiesM','PreserveVariableNames', true); %Loading preferences Municipality

%Creating maxtrixes per objective, combining the different stakeholders to 1 matrix per objective

Ma_Saldo = [DG.Gsval' DG.Gspref'
        DD.Dsval' DD.Dspref'
        DM.Msval' DM.Mspref']    % Preferences for balance/result for 3 stakeholders

Ma_x4 = [DG.Gx4val' DG.Gx4pref'
         DD.Dx4val' DD.Dx4pref'
         DM.Mx4val' DM.Mx4pref']; % Preferences for Total area of greenery for 3 stakeholders

Ma_x5 = [DG.Gx5val' DG.Gx5pref'
         DD.Dx5val' DD.Dx5pref'
         DM.Mx5val' DM.Mx5pref']; % Preferences for gemeenschapspolder (greenery) for 3 stakeholders

Ma_x7 = [DG.Gx7val' DG.Gx7pref'
         DD.Dx7val' DD.Dx7pref'
         DM.Mx7val' DM.Mx7pref']; % Preferences for Plas (greenery) for 3 stakeholders

Ma_x11 = [DG.Gx11val' DG.Gx11pref'
          DD.Dx11val' DD.Dx11pref'
          DM.Mx11val' DM.Mx11pref']; % Preferences for Sport-/ zorglandgoed (greenery) for 3 stakeholders

Ma_x13 = [DG.Gx13val' DG.Gx13pref'
          DD.Dx13val' DD.Dx13pref'
          DM.Mx13val' DM.Mx13pref']; % Preferences for Stadspark (greenery) for 3 stakeholders

Ma_x20 = [DG.Gx20val' DG.Gx20pref'
          DD.Dx20val' DD.Dx20pref'
          DM.Mx20val' DM.Mx20pref']; % Preferences for total area for living  for 3 stakeholders
```

```
Ma_x21 = [DG.Gx21val' DG.Gx21pref'
          DD.Dx21val' DD.Dx21pref'
          DM.Mx21val' DM.Mx21pref']; % Preferences for total number of houses for 3 stakeholders

Ma_x22 = [DG.Gx22val' DG.Gx22pref'
           DD.Dx22val' DD.Dx22pref'
           DM.Mx22val' DM.Mx22pref']; % Preferences for Vechtstad (housing) for 3 stakeholders

Ma_x23 = [DG.Gx23val' DG.Gx23pref'
           DD.Dx23val' DD.Dx23pref'
           DM.Mx23val' DM.Mx23pref']; % Preferences for Weesp (housing) for 3 stakeholders

Ma_x24 = [DG.Gx24val' DG.Gx24pref'
           DD.Dx24val' DD.Dx24pref'
           DM.Mx24val' DM.Mx24pref']; % Preferences for Tuinbuurt (housing) for 3 stakeholders

Ma_x27 = [DG.Gx27val' DG.Gx27pref'
           DD.Dx27val' DD.Dx27pref'
           DM.Mx27val' DM.Mx27pref']; % Preferences for Lint nat (housing) for 3 stakeholders

Ma_x29 = [DG.Gx29val' DG.Gx29pref'
           DD.Dx29val' DD.Dx29pref'
           DM.Mx29val' DM.Mx29pref']; % Preferences for Landgoed (housing) for 3 stakeholders
```

Weights of criteria

```
wn = 17; % Total Number of main objectives multiplied by number of stakholders ((3*6)-1) as the green party doesnt have a preference over types of living

w_sG   = 1/wn; %weights per stakeholder for balance/result
w_sD   = 1/wn;
w_sM   = 1/wn;
w_x4G  = 1/wn; %weights per stakeholder for total area of greenery
w_x4D  = 1/wn;
w_x4M  = 1/wn;
w_x21G = 1/wn; %weights per stakeholder for Total number of houses
w_x21D = 1/wn;
w_x21M = 1/wn;

GG_wn = 1/wn; %weights for 4 types of greenery (based on tetra) for the green party
w_x5G  = 0.46*GG_wn;
w_x7G  = 0.23*GG_wn;
w_x11G = 0.09*GG_wn;
w_x13G = 0.22*GG_wn;

GD_wn = 1/wn; %weights for 4 types of greenery (based on tetra) for the Developers
w_x5D  = 0.46*GD_wn;
w_x7D  = 0.23*GD_wn;
w_x11D = 0.09*GD_wn;
w_x13D = 0.22*GD_wn;

GM_wn = 1/wn; %weights for 4 types of greenery (based on tetra) for the Municipality
w_x5M  = 0.46*GM_wn;
w_x7M  = 0.23*GM_wn;
w_x11M = 0.09*GM_wn;
w_x13M = 0.22*GM_wn;

w_x20G = 1/wn; %weights per stakeholder for Total area for living
w_x20D = 1/wn;
w_x20M = 1/wn;

HD_wn = 1/wn; %weights for 5 types of housing (based on tetra) for the Developers
w_x22D = 0.16*HD_wn;
w_x23D = 0.30*HD_wn;
w_x24D = 0.31*HD_wn;
w_x27D = 0.19*HD_wn;
w_x29D = 0.04*HD_wn;

HM_wn = 1/wn; %weights for 5 types of housing (based on tetra) for the Municipality
w_x22M = 0.16*HM_wn;
w_x23M = 0.30*HM_wn;
w_x24M = 0.31*HM_wn;
w_x27M = 0.19*HM_wn;
w_x29M = 0.04*HM_wn;

%Weights of criteria for green party, used later on to calculate the final preference for the green party
wn = 5; %number of main objectives of the green party

wg_s   = 1/wn;  % weights of the balance/result of the green party
wg_x4  = 1/wn;  % weights of the total area for greenery of the green party
wg_x21 = 1/wn;  % weights of the total number of houses of the green party

G_wn = 1/wn; %weights for 4 types of greenery (based on tetra) for the green party
wg_x5  = 0.46*G_wn;
wg_x7  = 0.23*G_wn;
wg_x11 = 0.09*G_wn;
wg_x13 = 0.22*G_wn;

wg_x20 = 1/wn; % weights of the total area for living of the green party

H_wn = 0/wn; % No preference over the types of housing
wg_x22 = 0;
wg_x23 = 0;
wg_x24 = 0;
wg_x27 = 0;
wg_x29 = 0;

wg =[wg_s wg_x4 wg_x21 wg_x5  wg_x7     wg_x11  wg_x13  wg_x20  wg_x22  wg_x23 wg_x24  wg_x27  wg_x29 ];% Total array of weight elements of the Green party that will be used later on (not
```

Objective function

```
function Opt = ObjFunction(x)

%In Matlab optimization problems are always defined as minimization
%problems. Thus, the sign of the objective function was changed to "-"
%   General
    %Value of variable costs
```

```
Var_kosten = (x(:,1).*K(5) +x(:,2).*K(7) +x(:,3).*K(11) +x(:,4).*K(13))  + (x(:,5).*K(22) +x(:,6).*K(23) +x(:,7).*K(24)  +x(:,8).*K(27) +x(:,9).*K(29));
%Value of varable revenues
Var_opbr =  (x(:,1).*Revenues(5) +x(:,2).*Revenues(7) +x(:,3).*Revenues(11)  +  x(:,4).*Revenues(13)) +   (x(:,5).*Revenues(22) +x(:,6).*Revenues(23) ...
            +x(:,7).*Revenues(24) +x(:,8).*Revenues(27) +x(:,9).*Revenues(29)) ;

Saldo = ((Var_opbr+Vasteopbrengst) - (Var_kosten+Vastekosten)); % value of balance/result
X4 = (x(:,1) + x(:,2) + x(:,3)  + x(:,4)); % value of total area of greenery
X21 = (x(:,5) +x(:,6) +x(:,7) +x(:,8) + x(:,9)); % value of total number of houses
%types of greenery
X5 = x(:,1); % Value for area of Gemeenschapspolder
X7 = x(:,2); % Value for area of plas
X11 = x(:,3);  % Value for area of Sport/ zorglandgoed
X13 = x(:,4); % Value for area of stadspark
% living
X20 = (x(:,5)* Oppwon(22)   +x(:,6)*Oppwon(23)+     x(:,7)*Oppwon(24)+      x(:,8)*Oppwon(27)+      x(:,9)*Oppwon(29)); % value of total area of living
% housing types
X22 = (x(:,5)); % Value for number of houses of type Vechtstad
X23 = (x(:,6)); % Value for number of houses of type Weesp
X24 = (x(:,7)); % Value for number of houses of type Tuinbuurt
X27 = (x(:,8)); % Value for number of houses of type lint nat
X29 = (x(:,9));% Value for number of houses of type Landgoed


% Loop to calculate the preferences  per stakeholder using
% PCHIP and the earlier created matrix, for balance/ result
    CS = 0;
PreffunSa = [];
for i=1:Num_S % for each stakeholder
    if sum(Ma_Saldo(i,(Num_DP+1):(Num_DP*2)))~=0 % if there are preference values in the matrix
        PreffunSa(:,i) = pchip(Ma_Saldo(i,1:Num_DP), Ma_Saldo(i,(Num_DP+1):(Num_DP*2)), Saldo); % calculate the preference using PCHIP
        CS = CS+1; % If a stakeholder has a preference the weight factor within the loop increases with 1
    else
        PreffunSa(:,i) = zeros(size(x,1),1); % If a stakeholder didn't give a preference nothing happens
    end
end
GS = 1/CS; % weight for calculating the average preference of a objective (not used any more, only in an early phase)
PreffunS = GS * PreffunSa(:,1) +  GS * PreffunSa(:,2) + GS * PreffunSa(:,3); % average preference of the stakeholders over the same objective,
                                                                                               %(not used any more, only in an early phase)

PreffunSG =  PreffunSa(:,1) ; % Preference of Green party over Balance/result
PreffunSD =  PreffunSa(:,2) ;% Preference of Developers over Balance/result
PreffunSM =  PreffunSa(:,3) ; % Preference of Municipality over Balance/result

% Loop to calculate the preferences  per stakeholder using
% PCHIP and the earlier created matrix, for total area of greenery
Cx4 = 0;
Preffun_x4 = [];
for i=1:Num_S
    if sum(Ma_x4(i,(Num_DP+1):(Num_DP*2)))~=0
        Preffun_x4(:,i) = pchip(Ma_x4(i,1:Num_DP), Ma_x4(i,(Num_DP+1):(Num_DP*2)), X4);
        Cx4 = Cx4+1;
    else
        Preffun_x4(:,i) = zeros(size(x,1),1);
    end
end
Gx4 = 1/Cx4;
PreffunX4 = Gx4 * Preffun_x4(:,1) +  Gx4 * Preffun_x4(:,2) + Gx4 * Preffun_x4(:,3);

PreffunX4G = Preffun_x4(:,1);
PreffunX4D = Preffun_x4(:,2);
PreffunX4M = Preffun_x4(:,3);

% Loop to calculate the preferences  per stakeholder using
% PCHIP and the earlier created matrix, for Gemeenschapspolder
Cx5 = 0;
Preffun_x5 =[];
for i=1:Num_S
    if sum(Ma_x5(i,(Num_DP+1):(Num_DP*2)))~=0
        Preffun_x5(:,i) = pchip(Ma_x5(i,1:Num_DP), Ma_x5(i,(Num_DP+1):(Num_DP*2)), X5);
        Cx5 = Cx5+1;
    else
        Preffun_x5(:,i) = zeros(size(x,1),1);
    end
end
Gx5 = 1/Cx5;
PreffunX5 = Gx5 * Preffun_x5(:,1) +  Gx5 * Preffun_x5(:,2) + Gx5 * Preffun_x5(:,3);

PreffunX5G = Preffun_x5(:,1);
PreffunX5D = Preffun_x5(:,2);
PreffunX5M = Preffun_x5(:,3);

% Loop to calculate the preferences  per stakeholder using
% PCHIP and the earlier created matrix, for plas
Cx7 = 0;
Preffun_x7 = [];
for i=1:Num_S
    if sum(Ma_x7(i,(Num_DP+1):(Num_DP*2)))~=0
        Preffun_x7(:,i) = pchip(Ma_x7(i,1:Num_DP), Ma_x7(i,(Num_DP+1):(Num_DP*2)), X7);
        Cx7 = Cx7+1;
    else
        Preffun_x7(:,i) = zeros(size(x,1),1);
    end
end
Gx7 = 1/Cx7;
PreffunX7 = Gx7 * Preffun_x7(:,1) +  Gx7 * Preffun_x7(:,2) + Gx7 * Preffun_x7(:,3);

PreffunX7G = Preffun_x7(:,1);
PreffunX7D= Preffun_x7(:,2);
PreffunX7M = Preffun_x7(:,3);

% Loop to calculate the preferences  per stakeholder using
% PCHIP and the earlier created matrix, for Sport/zorglandgoed
Cx11 = 0;
Preffun_x11 = [];
for i=1:Num_S
    if sum(Ma_x11(i,(Num_DP+1):(Num_DP*2)))~=0
        Preffun_x11(:,i) = pchip(Ma_x11(i,1:Num_DP), Ma_x11(i,(Num_DP+1):(Num_DP*2)), X11);
        Cx11 = Cx11+1;
    else
```

```
            Preffun_x11(:,i) = zeros(size(x,1),1);
        end
    end
    Gx11 = 1/Cx11;
    PreffunX11 = Gx11 * Preffun_x11(:,1) +  Gx11 * Preffun_x11(:,2) + Gx11 * Preffun_x11(:,3);

    PreffunX11G = Preffun_x11(:,1);
    PreffunX11D = Preffun_x11(:,2);
    PreffunX11M = Preffun_x11(:,3);

    % Loop to calculate the preferences  per stakeholder using
    % PCHIP and the earlier created matrix, for Stadspark
    Cx13 = 0;
    Preffun_x13 = [];
    for i=1:Num_S
        if sum(Ma_x13(i,(Num_DP+1):(Num_DP*2)))~=0
            Preffun_x13(:,i) = pchip(Ma_x13(i,1:Num_DP), Ma_x13(i,(Num_DP+1):(Num_DP*2)), X13);
            Cx13 = Cx13+1;
        else
            Preffun_x13(:,i) = zeros(size(x,1),1);
        end
    end
    Gx13 = 1/Cx13;
    PreffunX13 = Gx13 * Preffun_x13(:,1) +  Gx13 * Preffun_x13(:,2) + Gx13 * Preffun_x13(:,3);

    PreffunX13G = Preffun_x13(:,1);
    PreffunX13D = Preffun_x13(:,2);
    PreffunX13M = Preffun_x13(:,3);

    % Loop to calculate the preferences  per stakeholder using
    % PCHIP and the earlier created matrix, for total area of living
    Cx20 = 0;
    Preffun_x20 = [];
    for i=1:Num_S
        if sum(Ma_x20(i,(Num_DP+1):(Num_DP*2)))~=0
            Preffun_x20(:,i) = pchip(Ma_x20(i,1:Num_DP), Ma_x20(i,(Num_DP+1):(Num_DP*2)), X20);
            Cx20 = Cx20+1;
        else
            Preffun_x20(:,i) = 0;
        end
    end
    Gx20 = 1/Cx20;
    PreffunX20 = Gx20 * Preffun_x20(:,1) +  Gx20 * Preffun_x20(:,2) + Gx20 * Preffun_x20(:,3);

    PreffunX20G = Preffun_x20(:,1);
    PreffunX20D = Preffun_x20(:,2);
    PreffunX20M = Preffun_x20(:,3);

    % Loop to calculate the preferences  per stakeholder using
    % PCHIP and the earlier created matrix, for total number of houses
    Cx21 = 0;
    Preffun_x21 = [];
    for i=1:Num_S
        if sum(Ma_x21(i,(Num_DP+1):(Num_DP*2)))~=0
            Preffun_x21(:,i) = pchip(Ma_x21(i,1:Num_DP), Ma_x21(i,(Num_DP+1):(Num_DP*2)), X21);
            Cx21 = Cx21+1;
        else
            Preffun_x21(:,i) = zeros(size(x,1),1);
        end
    end
    Gx21 = 1/Cx21;
    PreffunX21 = Gx21 * Preffun_x21(:,1) +  Gx21 * Preffun_x21(:,2) + Gx21 * Preffun_x21(:,3);

    PreffunX21G = Preffun_x21(:,1);
    PreffunX21D = Preffun_x21(:,2);
    PreffunX21M = Preffun_x21(:,3);

    % Loop to calculate the preferences  per stakeholder using
    % PCHIP and the earlier created matrix, for Vechtstad
    Cx22 = 0;
    Preffun_x22 = [];
    for i=1:Num_S
        if sum(Ma_x22(i,(Num_DP+1):(Num_DP*2)))~=0
            Preffun_x22(:,i) = pchip(Ma_x22(i,1:Num_DP), Ma_x22(i,(Num_DP+1):(Num_DP*2)), X22);
            Cx22 = Cx22+1;
        else
            Preffun_x22(:,i) = zeros(size(x,1),1);
        end
    end
    Gx22 = 1/Cx22;
    PreffunX22 = Gx22 * Preffun_x22(:,1) +  Gx22 * Preffun_x22(:,2) + Gx22 * Preffun_x22(:,3);

    PreffunX22D = Preffun_x22(:,2);
    PreffunX22M = Preffun_x22(:,3);

    % Loop to calculate the preferences  per stakeholder using
    % PCHIP and the earlier created matrix, for Weesp
    Cx23 = 0;
    Preffun_x23 = [];
    for i=1:Num_S
        if sum(Ma_x23(i,(Num_DP+1):(Num_DP*2)))~=0
            Preffun_x23(:,i) = pchip(Ma_x23(i,1:Num_DP), Ma_x23(i,(Num_DP+1):(Num_DP*2)), X23);
            Cx23 = Cx23+1;
        else
            Preffun_x23(:,i) = zeros(size(x,1),1);
        end
    end
    Gx23 = 1/Cx23;
    PreffunX23 = Gx23 * Preffun_x23(:,1) +  Gx23 * Preffun_x23(:,2) + Gx23 * Preffun_x23(:,3);

    PreffunX23D = Preffun_x23(:,2);
    PreffunX23M = Preffun_x23(:,3);

    % Loop to calculate the preferences  per stakeholder using
    % PCHIP and the earlier created matrix, for Tuinbuurt
    Cx24 = 0;
    Preffun_x24 = [];
    for i=1:Num_S
        if sum(Ma_x24(i,(Num_DP+1):(Num_DP*2)))~=0
```

```
            Preffun_x24(:,i) = pchip(Ma_x24(i,1:Num_DP), Ma_x24(i,(Num_DP+1):(Num_DP*2)), X24);
            Cx24 = Cx24+1;
        else
            Preffun_x24(:,i) = zeros(size(x,1),1);
        end
    end
    Gx24 = 1/Cx24;
    PreffunX24 = Gx24 * Preffun_x24(:,1) +  Gx24 * Preffun_x24(:,2) + Gx24 * Preffun_x24(:,3);

    PreffunX24D = Preffun_x24(:,2);
    PreffunX24M = Preffun_x24(:,3);

    % Loop to calculate the preferences  per stakeholder using
    % PCHIP and the earlier created matrix, for lint nat
    Cx27 = 0;
    Preffun_x27 = [];
    for i=1:Num_S
        if sum(Ma_x27(i,(Num_DP+1):(Num_DP*2)))~=0
            Preffun_x27(:,i) = pchip(Ma_x27(i,1:Num_DP), Ma_x27(i,(Num_DP+1):(Num_DP*2)), X27);
            Cx27 = Cx27+1;
        else
            Preffun_x27(:,i) = zeros(size(x,1),1);
        end
    end
    Gx27 = 1/Cx27;
    PreffunX27 = Gx27 * Preffun_x27(:,1) +  Gx27 * Preffun_x27(:,2) + Gx27 * Preffun_x27(:,3);

    PreffunX27D = Preffun_x27(:,2);
    PreffunX27M = Preffun_x27(:,3);

    % Loop to calculate the preferences  per stakeholder using
    % PCHIP and the earlier created matrix, for Landgoed
    Cx29 = 0;
    Preffun_x29 = [];
    for i=1:Num_S
        if sum(Ma_x29(i,(Num_DP+1):(Num_DP*2)))~=0
            Preffun_x29(:,i) = pchip(Ma_x29(i,1:Num_DP), Ma_x29(i,(Num_DP+1):(Num_DP*2)), X29);
            Cx29 = Cx29+1;
        else
            Preffun_x29(:,i) = zeros(size(x,1),1);
        end
    end
    Gx29 = 1/Cx29;
    PreffunX29 = Gx29 * Preffun_x29(:,1) +  Gx29 * Preffun_x29(:,2) + Gx29 * Preffun_x29(:,3);

    PreffunX29D = Preffun_x29(:,2);
    PreffunX29M = Preffun_x29(:,3);

    %Total array of weights and preferences
    w =[w_sG w_sD w_sM w_x4G w_x4D w_x4M w_x21G w_x21D w_x21M w_x5G w_x5D w_x5M w_x7G w_x7D w_x7M w_x11G w_x11D w_x11M w_x13G w_x13D w_x13M...
            w_x20G w_x20D w_x20M w_x22D w_x22M w_x23D w_x23M w_x24D w_x24M w_x27D w_x27M w_x29D w_x29M ];
       P =[PreffunSG PreffunSD PreffunSM  PreffunX4G PreffunX4D PreffunX4M   PreffunX21G PreffunX21D PreffunX21M  PreffunX5G PreffunX5D PreffunX5M      PreffunX7G PreffunX7D PreffunX7M...
            PreffunX11G PreffunX11D PreffunX11M         PreffunX13G PreffunX13D PreffunX13M     PreffunX20G PreffunX20D PreffunX20M   PreffunX22D PreffunX22M ...
            PreffunX23D PreffunX23M      PreffunX24D PreffunX24M    PreffunX27D PreffunX27M   PreffunX29D PreffunX29M ];
    % Green party: array of weights and preferences
    PG= [PreffunSa(:,1) Preffun_x4(:,1) Preffun_x21(:,1) Preffun_x5(:,1) Preffun_x7(:,1) Preffun_x11(:,1) Preffun_x13(:,1)...
            Preffun_x20(:,1) Preffun_x22(:,1) Preffun_x23(:,1) Preffun_x24(:,1) Preffun_x27(:,1) Preffun_x29(:,1)];
    wg =[wg_s wg_x4 wg_x21 wg_x5  wg_x7 wg_x11  wg_x13  wg_x20  wg_x22  wg_x23 wg_x24  wg_x27  wg_x29 ];
    % Developers array of preferences
    PD= [PreffunSa(:,2) Preffun_x4(:,2) Preffun_x21(:,2) Preffun_x5(:,2) Preffun_x7(:,2) Preffun_x11(:,2) Preffun_x13(:,2)...
                Preffun_x20(:,2) Preffun_x22(:,2) Preffun_x23(:,2) Preffun_x24(:,2) Preffun_x27(:,2) Preffun_x29(:,2)];
    % Municipality array of  preferences
    PM= [PreffunSa(:,3) Preffun_x4(:,3) Preffun_x21(:,3) Preffun_x5(:,3) Preffun_x7(:,3) Preffun_x11(:,3) Preffun_x13(:,3)...
            Preffun_x20(:,3) Preffun_x22(:,3) Preffun_x23(:,3) Preffun_x24(:,3) Preffun_x27(:,3) Preffun_x29(:,3)];

    Opt=Tetra_solver2(w,P); % optimisation fuction using the preferendus
end
```

GA options

```
% TETRA options used in the optimisation solver
opts = optimoptions(@ga, ...
                    'PopulationSize', 5000, ...
                    'MaxGenerations', 1000, ...
                    'FunctionTolerance', 1e-15, ...
                    'UseVectorized',true,...
                    'Display', 'iter',...
                    'MaxStallGenerations', 150,...
                    'NonlinearConstraintAlgorithm', 'penalty',...
                    'CrossoverFraction', 0.185,...
                    'PlotFcn', @gaplotbestindiv);
```

Optimization

```
tic;
rng default;
[xbest, fbest, exitflag ] = ga(@ObjFunction, Tot_var, A, b, Aeq, beq, lb, ub,nonlcon,IntCon,opts); %retuns 9 xbest values, fbest = optimisation value and an exitflag which indicates the ty
Duurrun = toc;
```

Calculations of some totals

```
Tot_oppgr = (xbest(:,1) + xbest(:,2) + xbest(:,3)  + xbest(:,4)); % Final Total area of greenery
Tot_oppwon = (xbest(:,5)* Oppwon(22)    +xbest(:,6)*Oppwon(23)+ xbest(:,7)*Oppwon(24)+  xbest(:,8)*Oppwon(27)+  xbest(:,9)*Oppwon(29));  % Final Total area of housing
Tot_opp = (Tot_oppgr + Tot_oppwon);  % Final Total area of the design
Tot_huizen = (xbest(:,5) +xbest(:,6) +xbest(:,7) +xbest(:,8) + xbest(:,9));  % Final Total number of houses
%Variable costs
Var_kosten = (xbest(:,1).*K(5) +xbest(:,2).*K(7) +xbest(:,3).*K(11) +xbest(:,4).*K(13))    +   (xbest(:,5).*K(22) +xbest(:,6).*K(23) +xbest(:,7).*K(24)...
             +xbest(:,8).*K(27) +xbest(:,9).*K(29));
%variable revenues
Var_opbr =  (xbest(:,1).*Revenues(5) +xbest(:,2).*Revenues(7) +xbest(:,3).*Revenues(11)  +  xbest(:,4).*Revenues(13)) +   (xbest(:,5).*Revenues(22)...
         +xbest(:,6).*Revenues(23) +xbest(:,7).*Revenues(24) +xbest(:,8).*Revenues(27) +xbest(:,9).*Revenues(29)) ;
```

Weights of criteria after optimisation

```
wn = 6; %Number of main objectives

wb_s   = 1/wn; %weight for balance/result
wb_x4  = 1/wn; %weight for Total area of greenery
wb_x21 = 1/wn; %weight for total number of houses

Gb_wn = 1/wn; % Main objective types of greenery that splits into 4
wb_x5  = 0.46*Gb_wn; %weight for Gemeenschapspolder
wb_x7  = 0.23*Gb_wn; %weight for Plas
wb_x11 = 0.09*Gb_wn; %weight for Spor/ zorglandgoed
wb_x13 = 0.22*Gb_wn; %weight for stadspark

wb_x20 = 1/wn; %weight for total area of living

H_wn = 1/wn; % Main objective types of housing that splits into 5
wb_x22 = 0.16*H_wn; %weight for Vechtstad
wb_x23 = 0.3*H_wn;  %weight for Weesp
wb_x24 = 0.31*H_wn; %weight for Tuinbuurt
wb_x27 = 0.19*H_wn; %weight for Lint nat
wb_x29 = 0.04*H_wn; %weight for Landgoed

wbest =[wb_s wb_x4 wb_x21 wb_x5  wb_x7  wb_x11  wb_x13  wb_x20  wb_x22  wb_x23 wb_x24  wb_x27  wb_x29 ]; %Total weights
```

Final Preference based on optimisation values (xbest)

```
    Saldo = ((Var_opbr+Vasteopbrengst) - (Var_kosten+Vastekosten)); %Final value of balance/result (revenues- costs)
    X4 = Tot_oppgr;   % Final value of total area for greenery
    X21 = Tot_huizen; % Final value of total number of houses
    %Types of greenery
    X5 = xbest(:,1);    % Final value of Gemeenschapspolder
    X7 = xbest(:,2);   % Final value of plas
    X11 = xbest(:,3); % Final value of Sport/zorglandgoed
    X13 = xbest(:,4);    % Final value of stadspark
    % Living
    X20 = Tot_oppwon;  % Final value of total area for housing
    % Housing types
    X22 = (xbest(:,5));    % Final value of Vechtstad
    X23 = (xbest(:,6));     % Final value of Weesp
    X24 = (xbest(:,7));     % Final value of Tuinbuurt
    X27 = (xbest(:,8));     % Final value of Lint nat
    X29 = (xbest(:,9));     % Final value of Landgoed


    % Loop to calculate final preference per stakeholder using
    % PCHIP, Xbest and the earlier created matrix, for balance/ result
    CS = 0;
    for i=1:Num_S % for each stakeholder
        if sum(Ma_Saldo(i,(Num_DP+1):(Num_DP*2)))~=0 % if there are preference values in the matrix
            PreffunSa(:,i) = pchip(Ma_Saldo(i,1:Num_DP), Ma_Saldo(i,(Num_DP+1):(Num_DP*2)), Saldo); % calculate the final preference using PCHIP
            CS = CS+1; % If a stakeholder has a preference the weight factor within the loop increases with 1
        else
            PreffunSa(:,i) = NaN; % If a stakeholder didn't give a preference nothing happens
        end
    end
    GS = 1/CS; % weight for calculating the final average preference of a objective

    Snan = PreffunSa;
    Snan(isnan(Snan))= 0; % Filtering out the NaN values to be able to calculate the final average preference
    preffunS = GS * Snan(:,1) +  GS * Snan(:,2) + GS * Snan(:,3);% Final average preference of the stakeholders over the same objective,
    PreffunSG =  PreffunSa(:,1) ; % Final Preference of Green party over Balance/result
    PreffunSD =  PreffunSa(:,2) ;% Final Preference of Developers over Balance/result
    PreffunSM =  PreffunSa(:,3) ; % Final Preference of Municipality over Balance/result


    % Loop to calculate final preference per stakeholder using
    % PCHIP, Xbest and the earlier created matrix, for total area of greenery
    Cx4 = 0;
    for i=1:Num_S
        if sum(Ma_x4(i,(Num_DP+1):(Num_DP*2)))~=0
            Preffun_x4(:,i) = pchip(Ma_x4(i,1:Num_DP), Ma_x4(i,(Num_DP+1):(Num_DP*2)), X4);
            Cx4 = Cx4+1;
        else
            Preffun_x4(:,i) = NaN;
        end
    end
    Gx4 = 1/Cx4;
    x4nan = Preffun_x4;
    x4nan(isnan(x4nan))= 0;
    preffunX4 = Gx4 * x4nan(:,1) +  Gx4 * x4nan(:,2) + Gx4 * x4nan(:,3);
    PreffunX4G = Preffun_x4(:,1);
    PreffunX4D = Preffun_x4(:,2);
    PreffunX4M = Preffun_x4(:,3);

    % Loop to calculate final preference per stakeholder using
    % PCHIP, Xbest and the earlier created matrix, for Gemeenschapspolder
    Cx5 = 0;
    for i=1:Num_S
        if sum(Ma_x5(i,(Num_DP+1):(Num_DP*2)))~=0
            Preffun_x5(:,i) = pchip(Ma_x5(i,1:Num_DP), Ma_x5(i,(Num_DP+1):(Num_DP*2)), X5);
            Cx5 = Cx5+1;
        else
            Preffun_x5(:,i) = NaN;
        end
    end
    Gx5 = 1/Cx5;
    x5nan = Preffun_x5;
    x5nan(isnan(x5nan))= 0;
    preffunX5 = Gx5 * x5nan(:,1) +  Gx5 * x5nan(:,2) + Gx5 * x5nan(:,3);
    PreffunX5G = Preffun_x5(:,1);
    PreffunX5D = Preffun_x5(:,2);
    PreffunX5M = Preffun_x5(:,3);

    % Loop to calculate final preference per stakeholder using
    % PCHIP, Xbest and the earlier created matrix, for Plas
    Cx7 = 0;
    for i=1:Num_S
        if sum(Ma_x7(i,(Num_DP+1):(Num_DP*2)))~=0
            Preffun_x7(:,i) = pchip(Ma_x7(i,1:Num_DP), Ma_x7(i,(Num_DP+1):(Num_DP*2)), X7);
```

```
        Cx7 = Cx7+1;
    else
        Preffun_x7(:,i) = NaN;
    end
end
Gx7 = 1/Cx7;
x7nan = Preffun_x7;
x7nan(isnan(x7nan))=0;
preffunX7 = Gx7 * x7nan(:,1) +  Gx7 * x7nan(:,2) + Gx7 * x7nan(:,3);
PreffunX7G = Preffun_x7(:,1);
PreffunX7D= Preffun_x7(:,2);
PreffunX7M = Preffun_x7(:,3);

% Loop to calculate final preference per stakeholder using
% PCHIP, Xbest and the earlier created matrix, for sport/zorglandgoed
Cx11 = 0;
for i=1:Num_S
    if sum(Ma_x11(i,(Num_DP+1):(Num_DP*2)))~=0
        Preffun_x11(:,i) = pchip(Ma_x11(i,1:Num_DP), Ma_x11(i,(Num_DP+1):(Num_DP*2)), X11);
        Cx11 = Cx11+1;
    else
        Preffun_x11(:,i) = NaN;
    end
end
Gx11 = 1/Cx11;
x11nan = Preffun_x11;
x11nan(isnan(x11nan))=0;
preffunX11 = Gx11 * x11nan(:,1) +  Gx11 * x11nan(:,2) + Gx11 * x11nan(:,3);
PreffunX11G = Preffun_x11(:,1);
PreffunX11D = Preffun_x11(:,2);
PreffunX11M = Preffun_x11(:,3);

% Loop to calculate final preference per stakeholder using
% PCHIP, Xbest and the earlier created matrix, for Stadspark
Cx13 = 0;
for i=1:Num_S
    if sum(Ma_x13(i,(Num_DP+1):(Num_DP*2)))~=0
        Preffun_x13(:,i) = pchip(Ma_x13(i,1:Num_DP), Ma_x13(i,(Num_DP+1):(Num_DP*2)), X13);
        Cx13 = Cx13+1;
    else
        Preffun_x13(:,i) = NaN;
    end
end
Gx13 = 1/Cx13;
x13nan = Preffun_x13;
x13nan(isnan(x13nan))=0;
preffunX13 = Gx13 * x13nan(:,1) +  Gx13 * x13nan(:,2) + Gx13 * x13nan(:,3);
PreffunX13G = Preffun_x13(:,1);
PreffunX13D = Preffun_x13(:,2);
PreffunX13M = Preffun_x13(:,3);

% Loop to calculate final preference per stakeholder using
% PCHIP, Xbest and the earlier created matrix, for area of living
Cx20 = 0;
for i=1:Num_S
    if sum(Ma_x20(i,(Num_DP+1):(Num_DP*2)))~=0
        Preffun_x20(:,i) = pchip(Ma_x20(i,1:Num_DP), Ma_x20(i,(Num_DP+1):(Num_DP*2)), X20);
        Cx20 = Cx20+1;
    else
        Preffun_x20(:,i) = NaN;
    end
end
Gx20 = 1/Cx20;
x20nan = Preffun_x20;
x20nan(isnan(x20nan))=0;
preffunX20 = Gx20 * x20nan(:,1) +  Gx20 * x20nan(:,2) + Gx20 * x20nan(:,3);
PreffunX20G = Preffun_x20(:,1);
PreffunX20D = Preffun_x20(:,2);
PreffunX20M = Preffun_x20(:,3);

% Loop to calculate final preference per stakeholder using
% PCHIP, Xbest and the earlier created matrix, for Total number of houses
Cx21 = 0;
for i=1:Num_S
    if sum(Ma_x21(i,(Num_DP+1):(Num_DP*2)))~=0
        Preffun_x21(:,i) = pchip(Ma_x21(i,1:Num_DP), Ma_x21(i,(Num_DP+1):(Num_DP*2)), X21);
        Cx21 = Cx21+1;
    else
        Preffun_x21(:,i) = NaN;
    end
end
Gx21 = 1/Cx21;
x21nan = Preffun_x21;
x21nan(isnan(x21nan))=0;
preffunX21 = Gx21 * x21nan(:,1) +  Gx21 * x21nan(:,2) + Gx21 * x21nan(:,3);
PreffunX21G = Preffun_x21(:,1);
PreffunX21D = Preffun_x21(:,2);
PreffunX21M = Preffun_x21(:,3);

% Loop to calculate final preference per stakeholder using
% PCHIP, Xbest and the earlier created matrix, for Vechtstad
Cx22 = 0;
for i=1:Num_S
    if sum(Ma_x22(i,(Num_DP+1):(Num_DP*2)))~=0
        Preffun_x22(:,i) = pchip(Ma_x22(i,1:Num_DP), Ma_x22(i,(Num_DP+1):(Num_DP*2)), X22);
        Cx22 = Cx22+1;
    else
        Preffun_x22(:,i) = NaN;
    end
end
Gx22 = 1/Cx22;
x22nan = Preffun_x22;
x22nan(isnan(x22nan))=0;
preffunX22 = Gx22 * x22nan(:,1) +  Gx22 * x22nan(:,2) + Gx22 * x22nan(:,3);
PreffunX22D = Preffun_x22(:,2);
PreffunX22M = Preffun_x22(:,3);

% Loop to calculate final preference per stakeholder using
% PCHIP, Xbest and the earlier created matrix, for Weesp
```

```
    Cx23 = 0;
    for i=1:Num_S
        if sum(Ma_x23(i,(Num_DP+1):(Num_DP*2)))~=0
            Preffun_x23(:,i) = pchip(Ma_x23(i,1:Num_DP), Ma_x23(i,(Num_DP+1):(Num_DP*2)), X23);
            Cx23 = Cx23+1;
        else
            Preffun_x23(:,i) = NaN;
        end
    end
    Gx23 = 1/Cx23;
    x23nan = Preffun_x23;
    x23nan(isnan(x23nan))=0;
    preffunX23 = Gx23 * x23nan(:,1) +  Gx23 * x23nan(:,2) + Gx23 * x23nan(:,3);
    PreffunX23D = Preffun_x23(:,2);
    PreffunX23M = Preffun_x23(:,3);

    % Loop to calculate final preference per stakeholder using
    % PCHIP, Xbest and the earlier created matrix, for Tuinbuurt
    Cx24 = 0;
    for i=1:Num_S
        if sum(Ma_x24(i,(Num_DP+1):(Num_DP*2)))~=0
            Preffun_x24(:,i) = pchip(Ma_x24(i,1:Num_DP), Ma_x24(i,(Num_DP+1):(Num_DP*2)), X24);
            Cx24 = Cx24+1;
        else
            Preffun_x24(:,i) = NaN;
        end
    end
    Gx24 = 1/Cx24;
    x24nan = Preffun_x24;
    x24nan(isnan(x24nan))=0;
    preffunX24 = Gx24 * x24nan(:,1) +  Gx24 * x24nan(:,2) + Gx24 * x24nan(:,3);
    PreffunX24D = Preffun_x24(:,2);
    PreffunX24M = Preffun_x24(:,3);

    % Loop to calculate final preference per stakeholder using
    % PCHIP, Xbest and the earlier created matrix, for Lint nat
    Cx27 = 0;
    for i=1:Num_S
        if sum(Ma_x27(i,(Num_DP+1):(Num_DP*2)))~=0
            Preffun_x27(:,i) = pchip(Ma_x27(i,1:Num_DP), Ma_x27(i,(Num_DP+1):(Num_DP*2)), X27);
            Cx27 = Cx27+1;
        else
            Preffun_x27(:,i) = NaN;
        end
    end
    Gx27 = 1/Cx27;
    x27nan = Preffun_x27;
    x27nan(isnan(x27nan))=0;
    preffunX27 = Gx27 * x27nan(:,1) +  Gx27 * x27nan(:,2) + Gx27 * x27nan(:,3);

    PreffunX27D = Preffun_x27(:,2);
    PreffunX27M = Preffun_x27(:,3);

    % Loop to calculate final preference per stakeholder using
    % PCHIP, Xbest and the earlier created matrix, for Landgoed
    Cx29 = 0;
    for i=1:Num_S
        if sum(Ma_x29(i,(Num_DP+1):(Num_DP*2)))~=0
            Preffun_x29(:,i) = pchip(Ma_x29(i,1:Num_DP), Ma_x29(i,(Num_DP+1):(Num_DP*2)), X29);
            Cx29 = Cx29+1;
        else
            Preffun_x29(:,i) = NaN;
        end
    end
    Gx29 = 1/Cx29;
    x29nan = Preffun_x29;
    x29nan(isnan(x29nan))=0;
    preffunX29 = Gx29 * x29nan(:,1) +  Gx29 * x29nan(:,2) + Gx29 * x29nan(:,3);
    PreffunX29D = Preffun_x29(:,2);
    PreffunX29M = Preffun_x29(:,3);

%Final preference values and weights, per objective per stakeholder

Prefbest =[PreffunSG PreffunSD PreffunSM  PreffunX4G PreffunX4D PreffunX4M   PreffunX21G PreffunX21D PreffunX21M  PreffunX5G PreffunX5D PreffunX5M      PreffunX7G PreffunX7D PreffunX7M...
            PreffunX11G PreffunX11D PreffunX11M         PreffunX13G PreffunX13D PreffunX13M     PreffunX20G PreffunX20D PreffunX20M   PreffunX22D PreffunX22M      PreffunX23D PreffunX23M
            PreffunX24D PreffunX24M    PreffunX27D PreffunX27M   PreffunX29D PreffunX29M ];
wtetra =[w_sG w_sD w_sM w_x4G w_x4D w_x4M w_x21G w_x21D w_x21M w_x5G w_x5D w_x5M w_x7G w_x7D w_x7M w_x11G w_x11D w_x11M w_x13G w_x13D w_x13M...
             w_x20G w_x20D w_x20M w_x22D w_x22M w_x23D w_x23M w_x24D w_x24M w_x27D w_x27M w_x29D w_x29M ];


%Those values are then inserted in tetra once again to inestigate if this
%retuns the same value, as described in the use of the Preferendus part of the Thesis
Tetrabest = Tetra_solver2(wtetra,Prefbest);
```

Display

```
%several values that are displayed after running the model. The purple text indicatates what value is displayed
display(Duurrun,'Elapsed time in seconds');
display(Tot_opp, 'Total area (should be equal to plan BDP');
display( (Var_kosten+Vastekosten), 'General costs');
display( (Var_opbr+Vasteopbrengst), 'General revenues');
display((Tot_oppgr), 'Total area for greenery');
display((xbest(1:4)), 'area per type of greenery');
display((Tot_huizen), 'Total number of houses');
display((Tot_oppwon), 'Total area for living');
display((xbest(5:9)), 'nuber of houses in each housing type');

display(-fbest,'Optimisation value '); %Overall preference

display(exitflag,'exitflag'); %exitflag
display(((Var_opbr+Vasteopbrengst) - (Var_kosten+Vastekosten)), 'Saldotekort (negatief is tekort)');
display(-Tetrabest,'one value in Tetra Tetra');
```

Save output To the Excel output file

```
name = "PEN V91, Tetra, 34 Obj ";
datum = string(datetime('now'));
```

```
sal =((Var_opbr+Vasteopbrengst) - (Var_kosten+Vastekosten));
filename = 'Output.xlsx'; % Name output Excel file

%Average preference for Excel file
overall =  [preffunS preffunX4 preffunX21       preffunX5       preffunX7       preffunX11      preffunX13      preffunX20 preffunX22 preffunX23 preffunX24   preffunX27  preffunX29];
overallaf =  round(overall,2);
% Design preference (average) for Excel file
overalldesign =  [preffunS  preffunX4   preffunX5       preffunX7       preffunX11      preffunX13      preffunX20  preffunX21 preffunX22 preffunX23 preffunX24   preffunX27  preffunX29];
overalldesignaf =  round(overalldesign,2);

%Minucipality preference for Excel file
gemeente =[PreffunSa(:,3) Preffun_x4(:,3) Preffun_x21(:,3) Preffun_x5(:,3) Preffun_x7(:,3) Preffun_x11(:,3) Preffun_x13(:,3) Preffun_x20(:,3) Preffun_x22(:,3) Preffun_x23(:,3) Preffun_x24
gemeenteaf =  round(gemeente,2);
% Developers preference for Excel file
dev =[PreffunSa(:,2) Preffun_x4(:,2) Preffun_x21(:,2) Preffun_x5(:,2) Preffun_x7(:,2) Preffun_x11(:,2) Preffun_x13(:,2) Preffun_x20(:,2) Preffun_x22(:,2) Preffun_x23(:,2) Preffun_x24(:,2)
devaf =  round(dev,2);
%Green party preference for Excel file
groen =[PreffunSa(:,1) Preffun_x4(:,1) Preffun_x21(:,1) Preffun_x5(:,1) Preffun_x7(:,1) Preffun_x11(:,1) Preffun_x13(:,1) Preffun_x20(:,1) Preffun_x22(:,1) Preffun_x23(:,1) Preffun_x24(:,1
groenaf = round(groen,2);

% Total average preference (1 value Weighted average) of final outcome
totpref = sum( wbest .* [preffunS preffunX4 preffunX21  preffunX5       preffunX7       preffunX11      preffunX13      preffunX20 preffunX22 preffunX23 preffunX24   preffunX27  preffunX29

% Design outcome for Excel file
waardes = [Tot_opp (Var_kosten+Vastekosten)  (Var_opbr+Vasteopbrengst) Tot_oppgr  xbest(1) xbest(2)  xbest(3) xbest(4)  Tot_oppwon Tot_huizen xbest(5) xbest(6) xbest(7) xbest(8) xbest(9)]
xbestaf = round(waardes,4);

%Average preference of stakholders over the objectives
groenafnan = groenaf;
groenafnan(isnan(groenafnan))=0;
gemgem = sum( wbest .* gemeenteaf);
gemdev= sum( wbest .* devaf);
gemgroen = sum(wg .* groenafnan);

%Values for the preference scheet in Excel: Average preference, and per stakeholder; Municiapilty, Developers, Green party
OverallPref = [ name, -fbest, "Totaal" overallaf datum nan totpref -Tetrabest];
GemeentePref = [ nan ,nan ,  "Gemeente" gemeenteaf nan gemgem];
DevPref = [ nan, nan , "Ontwikkelaars" devaf nan gemdev];
GroenPref = [nan , nan , "Groen partij" groenaf nan gemgroen];

% Values for the design sheet in Excel; The objective values and the average preference per objective
output = [ name, "Ontwerp", -fbest, sal, xbestaf, datum, totpref, -Tetrabest, Duurrun];
Prefdesign = [nan,  "Totale pref per criteria", -fbest,  overalldesignaf(1), "-" "-" "-" overalldesignaf(2:13) datum totpref -Tetrabest];

% Writing the values to the design sheet of the Excel file
writematrix(output,filename, 'Sheet', 'ML Ontwerp', 'WriteMode','append')
writematrix(Prefdesign, filename, 'Sheet', 'ML Ontwerp', 'WriteMode','append')

% Writing the values to the preference sheet of the Excel file
writematrix(OverallPref, filename, 'Sheet', 'ML preferentie', 'WriteMode','append')
writematrix(GemeentePref, filename, 'Sheet', 'ML preferentie', 'WriteMode','append')
writematrix(DevPref, filename, 'Sheet', 'ML preferentie', 'WriteMode','append')
writematrix(GroenPref, filename, 'Sheet', 'ML preferentie', 'WriteMode','append')
```

```
end
```

H.2 Information document stakeholders Workshop 1

Bloemendalerpolder in een nieuw jasje

Introductie & doel van de workshop

Planmaat heeft in 2007 een Lineair Programmeren (LP) model gemaakt voor het vastlopende project Bloemendalerpolder (BDP), dat zich in de buurt van Weesp bevindt. Bij BDP kon er geen geschikte oplossing gevonden worden voor de gebiedsinrichting dat geen saldotekort opleverde. Op dat moment werd Planmaat ingeschakeld om naar dit vraagstuk te kijken. Planmaat heeft een LP model gemaakt van het gebied, waarbij geminimaliseerd is naar saldotekort. Hier is een ontwerp – een optimale verdeling tussen variabelen als woningen en groen – uitgerold waar wij ons oog nog eens op laten vallen. Wij doen onderzoek naar het meenemen van preferenties van stakeholders over deze variabelen, waardoor het LP model niet-lineair (NLP) wordt. In het geval van BDP willen we de preferenties van stakeholders meenemen in het eerder gemaakte LP model. Met behulp van deze preferenties kunnen we kijken of een andere oplossing met meer draagvlak mogelijk was voor de BDP case.

Deze workshop is ontwikkeld om op een gevalideerde manier data te verkrijgen over de preferenties die binnen BDP aanwezig zijn. Er zijn binnen het project een aantal randvoorwaardes gesteld, zoals voor het totaal aantal woningen in het gebied. Tijdens de workshop moet duidelijk worden wat de preferenties van alle stakeholders zijn voor de waardes van de variabelen binnen de randvoorwaarden. Er zijn een aantal 'potlood' preferenties gemodelleerd om iedereen een beeld te geven. Het idee is om van hieruit de 'pen' preferenties te maken. Uit gesprekken tussen stakeholders, waarbij verschillende standpunten worden ingenomen, zal duidelijk moeten worden wat de verschillende stakeholders belangrijk vinden en wat hun doel is binnen het project. Vanuit hier zal een preferentie(verloop) duidelijk moeten worden.

Verschil LP en NLP en het modelleren van preferenties

De vergelijking tussen een LP model en een NLP model wordt gemaakt om te onderzoeken of NLP geschikt is om als besluitvormingsinstrument te worden ingezet bij stedenbouwkundige planvorming. Waar zit het verschil tussen de LP modellen van Planmaat en ons NLP model?

Omdat er voor NLP modellen minder aannames worden gemaakt en preferenties in een vroege fase worden meegenomen, geeft het een betere weerspiegeling van de realiteit. Het realistischer maken van de input zorgt voor een realistischere output. Hierdoor heeft de uitkomst van het model uiteindelijk ook meer waarde dan een LP model, wat zich kan uiten in een betere implementatie van het ontwerp.

Doordat er preferenties worden toegevoegd op de randvoorwaardes wordt de oplossingsruimte vergroot t.o.v. het LP model. De grenzen worden als het ware opengegooid NLP biedt hiermee meer mogelijkheden voor een uitkomst.

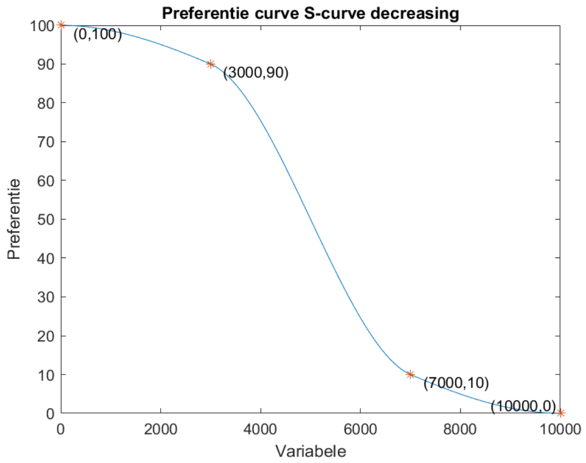
Voor BDP nemen wij de niet lineaire preferenties van de stakeholders mee. Hierdoor kan er ook geoptimaliseerd worden naar de totale preferentie i.p.v. alleen op kosten of saldotekort. Het is tevens mogelijk om te optimaliseren op twee tegenstrijdige criteria binnen een ruimtelijk ordeningsprobleem. Daarbij kan het meenemen van de preferenties ook aantonen dat de oplossing het meeste draagvlak heeft, hierdoor kan men eerder tot consensus komen.

In ons onderzoek gebruiken wij de term 'preferentie' als volgt: een voorkeur over verschillende waarden die een variabele kan aannemen. Deze voorkeur betreft de voorkeur binnen waardes van een variabele, en niet tussen variabelen.

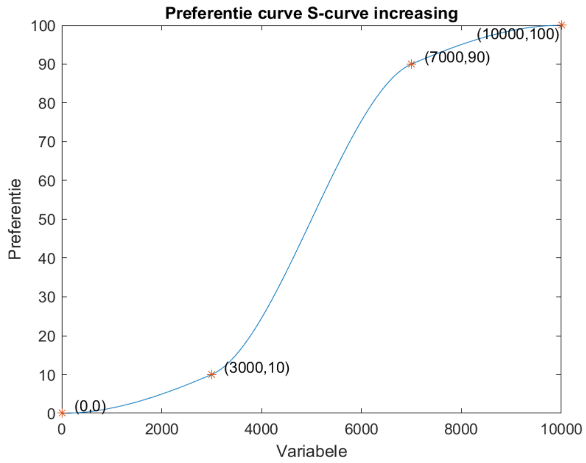
Om de preferenties te kunnen modelleren zijn er data punten nodig. Om een niet lineaire preferentie curve te maken, zijn er voor een mooie curve 4 data punten nodig. Deze data punten bevatten de preferentie voor een bepaalde waarde van een variabele. In een ideale situatie liggen twee van deze datapunten op de minimale en maximale waarden van de variabele. Hierbij worden dus de waardes met een preferentie (P) van 0 en 100 uitgedrukt. Om de curve een vorm te geven, zijn er nog twee punten tussen deze waardes nodig.

De preferenties van de stakeholders op eenzelfde variabele liggen op dit moment in hetzelfde bereik. Mocht dit niet het geval zijn wordt de preferentie van 0 of 100 doorgetrokken om hetzelfde bereik te behouden.

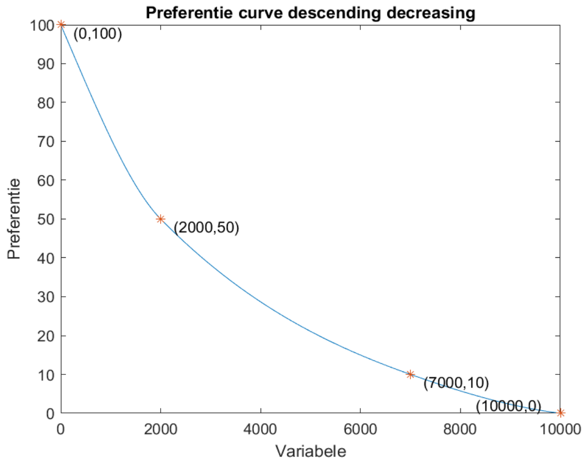
De vormen die de curves aan kunnen nemen zijn hieronder weergegeven.



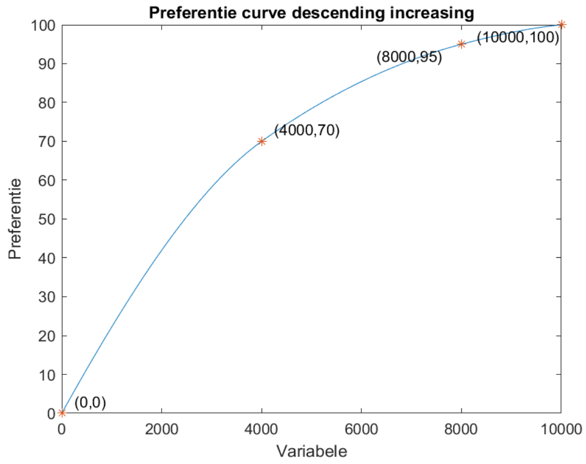
(a) S-curve decreasing



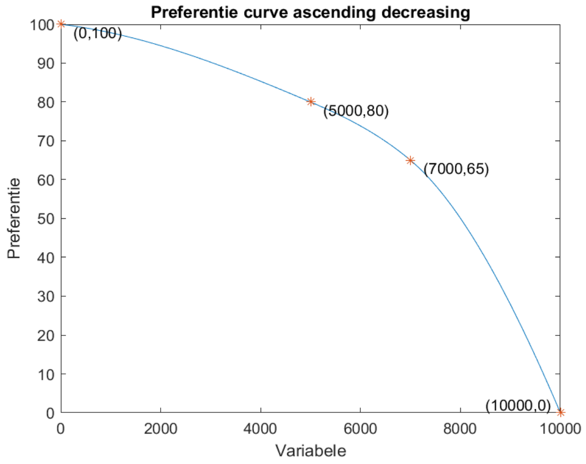
(b) S-curve increasing



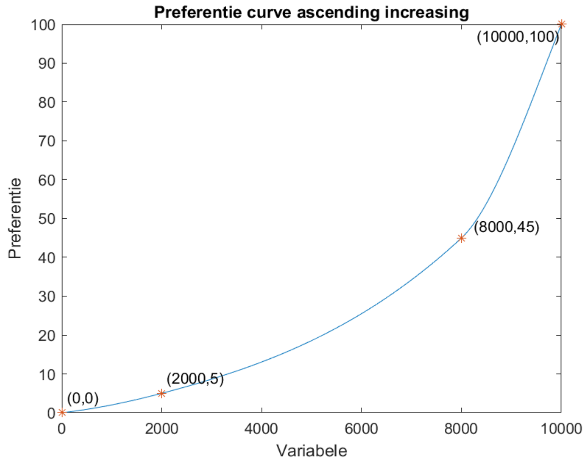
(c) Descending decreasing



(d) Descending increasing

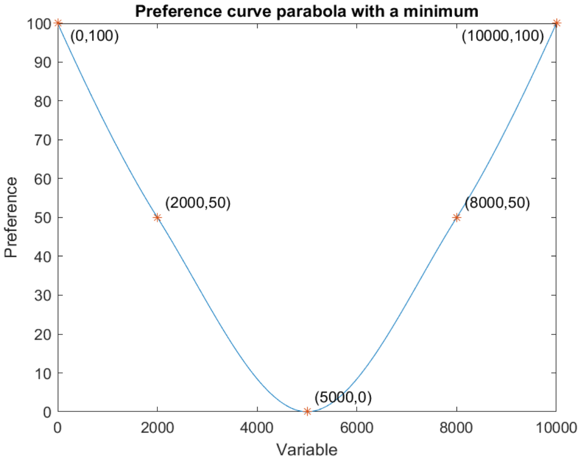


(e) Ascending decreasing

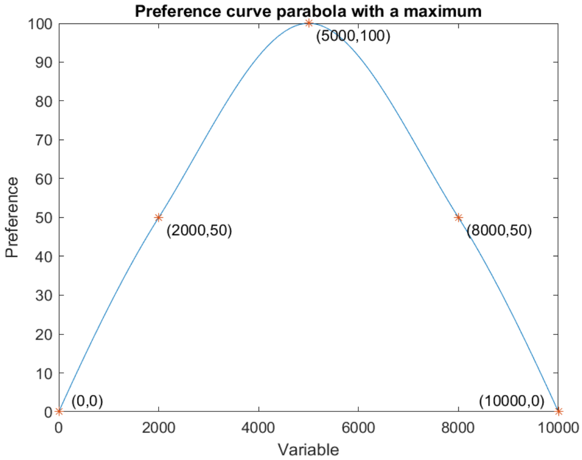


(f) Ascending increasing

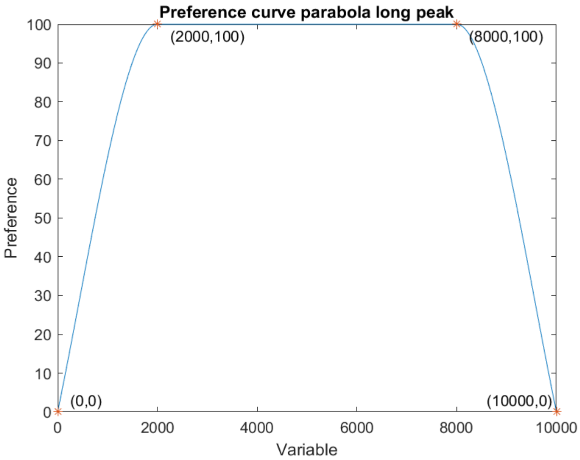
Figure H.1: Examples preference curves part 1



(a) Parabola with a minimum



(b) Parabola with a maximum



(c) Parabola long peak

Figure H.2: Examples preference curves part 2

Beschrijving BDP

Tijdens de workshop zal er worden gediscussieerd over de inrichting van BDP. In bovenstaand overzicht is het gebied van BDP weergegeven. Het gebied beslaat 435 hectare. Er wordt in de case vanuit gegaan dat het gehele gebied gebruikt zal worden.

In het project BDP zijn er een aantal stakeholders die een rol spelen. Deze stakeholders hebben allemaal een eigen doel en interesse binnen het project.

- Gemeente: *BDP moet een levendig, divers, en toegankelijk gebied worden waarin meerdere functies samenkomen zoals wonen en recreatie.*
- Ontwikkelaars en/of grondbezitters: *BDP moet zoveel mogelijk geld opleveren. Het gebied moet zoveel mogelijk waard worden, zodat de grondwaarde stijgt en het dus meer oplevert. Dit moet voornamelijk gebeuren door het bouwen van huizen.*
- Belangbehartigers groen: *BDP moet een gebied worden waar groen de belangrijkste rol speelt wat bijdraagt aan de natuur en de recreatie.*

De 'potlood' preferenties zijn gebaseerd op bovenstaande statements. Er wordt tijdens de workshop vanuit gegaan dat elke stakeholder zijn doelen en interesses introduceert, waarbij een eigen invulling gegeven mag worden aan bovenstaande statements. Zo zullen de 'potlood' preferenties getransformeerd worden naar 'pen' preferenties.

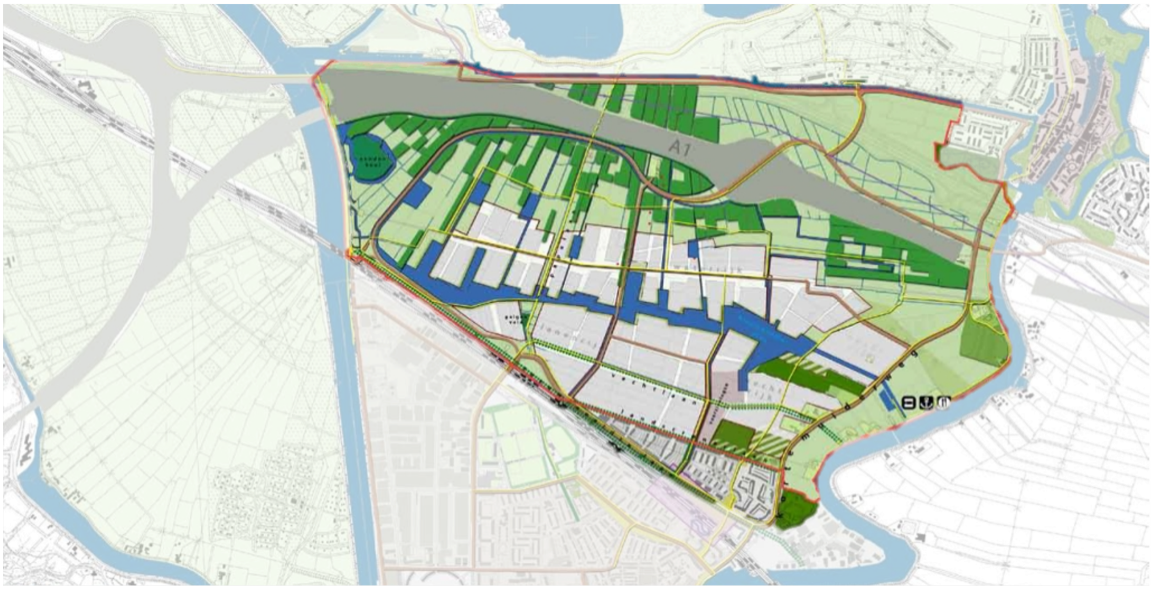


Figure H.3: Gebiedsoverzicht Bloemendalerpolder

Voor de ontwikkeling van het gebied vormen de gemeente en een groep ontwikkelaars samen het OMB (Ontwikkelingsmaatschappij BPD). Het OMB deelt de risico's en de kosten/winst die aan het project verbonden zijn. Het OMB investeert samen in het project en heeft dus ook gezamenlijke belangen. Een belangrijk aspect in de kosten en opbrengsten is de inbrengwaarde binnen het project, dit is het bedrag van de grond die in het bezit is van het OMB en dus ook moet worden terugverdiend om geen saldotekort op te lopen. Momenteel staat deze inbrengwaarde op €0,-. Er wordt voor nu vanuit gegaan dat de inbrengwaarde niet wordt meegenomen in de kosten van het project.

Ontwerpvariabelen & eigenschappen

Het model is gecreëerd om een afweging te kunnen maken tussen ruimtegebruik en geld. Er zijn een aantal bepalende ontwerpvariabelen binnen het model die daarbij een rol spelen. De verschillende ontwerpvariabelen hebben betrekking op:

- Kosten & Opbrengsten. Deze vormen samen het saldotekort waarop geoptimaliseerd kan worden.
- Totale oppervlak aan groen. Het groene gebied kan worden opgevuld met een combinatie van 4 verschillende types groen, met elk andere eigenschappen.
- Totaal aantal woningen in het gebied. Het totale woningaantal wordt gevuld door een combinatie van verschillende woonmilieus. Er bestaan 5 soorten woonmilieus, met elk een andere woondichtheid (woningen/ha). Het aantal woningen is gerelateerd aan het oppervlak dat is bestemd voor wonen, uitgedrukt in hectare.

De kosten worden gevormd door drie aspecten. Allereerst de verschillende types groen. Daarnaast brengt het bouwen van de woonmilieus ook kosten met zich mee. Deze kosten zijn variabel gezien het afhangt van de hoeveelheid groen en de hoeveelheid woningen. Tot slot zijn er nog vaste kosten voor het groen (o.a. fietspaden, dijken en kustwerken) en vaste kosten die bovenwijkse kosten worden genoemd om het gebied aantrekkelijk/klaar te maken voor bewoners. De opbrengsten hebben alleen betrekking op de woonmilieus.

Zoals eerder besproken zijn er al een aantal 'potlood' preferenties gemaakt. Dit zijn voor de hand liggende preferenties die alvast zijn gemodelleerd om een beeld te geven van wat wij uiteindelijk verwachten van de stakeholders te krijgen. De volgende 'potlood' preferenties van bijbehorende stakeholders zijn momenteel aanwezig in het model:

- Saldotekort → Gemeente & Ontwikkelaars
- Oppervlak groen → Gemeente, Ontwikkelaars & Belangbehartigers groen
- Verdeling oppervlak groen → Gemeente & Belangbehartigers groen
  - Het oppervlak groen wordt verdeeld onder 4 verschillende typen groen, te zien in tabel H.1.
- Totale woningaantal → Gemeente, Ontwikkelaars & Belangbehartigers groen
- Oppervlakte wonen → Gemeente, Ontwikkelaars & Belangbehartigers groen
- Woonmilieus → Gemeente & Ontwikkelaars
  - Er bestaan 5 verschillende woonmilieus met elk hun eigen woningdichtheid tabel H.2.

Table H.1: Eigenschappen types groen

Type	Eigenschap	Kosten (per ha)
Gemeenschapspolder	Combinatie tussen gras, land & water (klassiek polderlandschap)	€ 36.497, -
Plas	Ruimte volledig gevuld met water	€ 97.780, -
Sport/Zorglandgoed	Open veld waar meerdere functies samenkomen zoals sporten (atletiek, basketbal & voetbal) en een belevenisbos (avontuurlijk & educatief)	€ 195.276, -
Stadspark Weesp	Open en toegankelijk bos met de gelegenheid om in te wandelen, samen te komen of te eten	€ 158.614, -

Table H.2: Eigenschappen typen woningen

Type	Eigenschap (won/ha)	Kosten (per huis)	Opbrengsten (per huis)
Vechtstad	30,2	€ 72.498, -	€ 92.984, -
Weesp	26,2	€ 48.280, -	€ 92.984, -
Tuinbuurt	29,5	€ 32.369, -	€ 87.446, -
Lint nat	9,5	€ 88.909, -	€ 167.563, -
Landgoed	5,2	€ 123.707, -	€ 126.690, -

Overzicht ontwerpvariabelen binnen BDP

De ontwerpvariabelen die zich in het BDP model bevinden zijn weergegeven in een overzicht (table H.3). De minimale en maximale waardes zijn weergegeven om een idee te geven binnen welke ordegrootte een preferentie bepaald moet worden.

De minimale en maximale waardes zijn gebaseerd op de eerdere uitkomst van het LP model van Planmaat. Daarnaast is er een eigen interpretatie aan toegevoegd. Dit zal worden toegelicht tijdens de workshop.

Table H.3: Overzicht ontwerpvariabelen

Naam	Naam variabele	Eenheid	Minimale waarde	Maximale waarde
S	Saldotekort (bepaald door ontwerpvariabelen Kosten en Opbrengsten)	€	-75.000.000 (=winst)	35.000.000 (=verlies)
X (4)	Strategisch groen totaal	Ha	265	435
X (21)	Totaal woningaantal	Won	0	3.000
X (5)	Gemeenschapspolder	Ha	0	200
X (7)	Plas	Ha	0	200
X (11)	Sport/Zorglandgoed	Ha	0	50
X (13)	Stadspark Weesp	Ha	0	30
X (20)	Oppervlak wonen	Ha	0	170
X (22)	Vechtstad	Won	200	800
X (23)	Weesp	Won	100	600
X (24)	Tuinbuurt	Won	400	1.000
X (27)	Lint nat	Won	100	350
X (30)	Landgoed	Won	30	110

Spelregels workshop

Om problemen tijdens het verzamelen van gegevens te voorkomen, en deze gegevens op een open en transparante manier vast te leggen, moeten er garanties en spelregels opgesteld worden.

- Iedere stakeholder heeft even veel macht (uitgedrukt in gewichten in het model).
- Iedere stakeholder wordt geacht open te zijn over de preferenties en doelen die hij/zij heeft, om geen vertekend beeld te krijgen.
- Alle gegevens zullen met elkaar gedeeld worden. De workshop is fictief, daarom wordt er geacht dat gegevens open op tafel zullen worden gegooid. De stakeholders zullen elkaars preferenties en curves kunnen zien. De uitkomsten van het model kunnen na elke ronde worden getoond. Hierbij kunnen ook de 'deelpreferenties' worden getoond.

Onze rol tijdens de workshop: Als leider hebben wij inzicht in hoe het model werkt, en daarmee kunnen wij aangeven wat er nodig is voor een andere oplossing. Daardoor oefenen wij als leider ook invloed uit op de uiteindelijke uitkomst. Om dit te minimaliseren zijn er protocollen en spelregels nodig.
Eigenlijk hebben we de rol van een Urban System Engineer:

- Inhoudelijk-technische ontwikkeling van het model in relatie tot de ontwerpopgave.
- Ontwikkeling en ontwerpen van nieuwe sturingsmaatregelen voor het functioneren van het model.
- Sturing en leiding (faciliteren) van de workshops.
- Stakeholders helpen bij het formuleren van een duidelijk doel dat uiteindelijk omgezet kan worden in een preferentie die te gebruiken is in het model.

De workshop heeft ook een functie als feedback moment. Tijdens/na de workshop is er de mogelijkheid voor stakeholders om feedback te geven op de manier hoe de workshop verliep. Hierin kan onder andere worden besproken of de stakeholders de workshop geschikt vonden, wat zij wel/niet fijn vonden en wat zij voor real-world stakeholder workshops anders zouden willen zien.

Wat kan het model en waar liggen momenteel nog de grenzen van ons model?

Op dit moment is ons wiskundig & beslis ondersteunende model nog niet optimaal. Dit geeft een aantal beperkingen en grenzen voor de stakeholder bijeenkomst.

- Het model beschikt nog niet over de juiste mate van gebruiksvriendelijkheid, dit heeft gevolgen voor de interface. Een van de doelen van ons onderzoek is om te bepalen hoe wij de interface zó kunnen maken dat het eindresultaat straks ook overdraagbaar is naar de stakeholders. Feedback op dit gebied van de stakeholders zal dan ook gewaardeerd worden.

- De preferenties die momenteel als potloodpreferenties zijn meegenomen, kunnen tijdens de meeting worden aangepast.
- De preferenties zijn gebaseerd op 4 datapunten.
- De preferenties worden nu bepaald worden binnen een bepaald bereik. Dit bereik moet voor één variabele hetzelfde zijn voor alle partijen. Wanneer dit niet mogelijk is wordt dit opgelost door de begin- en eindpunten door te trekken zodat de preferentie precies binnen het bereik valt.
- In het model worden er op twee momenten gewichten meegenomen. Allereerst tussen de preferenties van stakeholders over eenzelfde variabelen. Daarnaast worden er gewichten tussen de variabelen meegenomen. Er is vanuit gegaan dat deze gewichten vaststaan en daar niet over gediscussieerd kan worden.

Omdat het in deze fase van ons afstuderen draait om het aantonen van de meerwaarde van het modelleren van preferenties t.o.v. LP, zijn er een aantal elementen niet meegenomen. Het gaat hierbij om zowel elementen als de interface en het versimpelen van de case in het aantal variabelen. Deze zullen in een latere fase meegenomen worden als we verder onderzoek gaan doen naar het toepassen op bredere schaal en de gebruiksvriendelijkheid van het model.

Het model is geen ruimtelijk model, het geeft alleen een kwantitatief Programma van Eisen. Daarna moet een stedenbouwkundige nog een ontwerp maken. Daarnaast is het is geen faseringsmodel. De beslissing welke activiteiten je wanneer moet doen moet later nog blijken.

H.3 Elaboration on pencil preferences

H.3.1 Municipality

Aim for the area: Make Bloemendalerpolder a lively, diverse, and accessible area in which multiple functions come together, including living and recreation.

Budget gap: ascending decreasing
The municipality wants to invest in the project, so therefore they already calculate some financial losses. However, their limit will be at 35 million, as they are not able to go to the municipal council with a design that has a higher deficit. Of course, they will try to make as much profit as possible. However, this is not their main priority since they are a governmental body. Because the municipality takes this into account, their preference will not drop fast in in the beginning. The higher the budget gap, the faster the preference will drop.

Total amount of green: parabola
The municipality wants to have some green in the area, but not too much. There also needs to be space for housing and traffic in the area. Therefore, the curve is parabolic: it has an optimum at a certain point. The preference will be zero when the entire area is filled with greenery.

Total amount of houses: parabola
There will be an optimum for the municipality since the amount needs to be such that there is a proper distribution between different kind of houses. The municipality wants their inhabitants to offer living space, but also wants to keep the area livable. By filling the area with the maximum number of houses (e.g., with flats with apartments), the area will not succeed in remaining other functions and lose their appearance. There is a certain optimum of houses where some parts in the area can have a lower, and some parts can have a higher density of houses. Being able to offer different types of houses will also attract different kind of inhabitants, which makes the area diverse.

Gemeenschapspolder: descending increasing
The community polder is relatively cheap to create. The preference will increase fast in the beginning. However, if a certain amount is reached, the preference will not increase that fast anymore. This type of green does not have a function other than 'nature' so, the preference is soon already high.

Plas: parabola
The lake is relatively cheap to create. This variable will have a top because the lake will only be there to enjoy it. It will not have any other function, and therefore it can be stated that after a certain amount of plas the preference will drop again.

Sport/Zorglandgoed: parabola with long top
The sportpark will have a function: accommodating multiple sports. This will give an optimum in the variable value. After reaching a certain amount of accommodation area, the preference will drop since there is no need for more space of that function. The preference of 100 will be in between two values since there is not a sufficient explanation to have only one optimum.

Stadspark Weesp: parabola with long top
The Stadspark will have a function: give inhabitants the opportunity to meet each other and to walk or run. This will give an optimum in the variable value. After reaching a certain amount of park area, the preference will drop since there is no need for more space of that function. The preference of 100 will be in between to values since there is not a sufficient explanation to have only one optimum.

Total area of living: parabola
The same applies as to the amount of green. There will be an optimum since there needs to be space for other functions as well. If the area is fully filled with living, the preference will be zero. Curve will be parabolic.

House types: parabola with long top
The different house types will have an optimum. After a certain number of houses is reached of each type, the preference will drop. However, this optimum is not really specified for the municipality. They set boundaries for the minimal and maximum number of houses of each type, which will be made soft by adding a preference which will increase or decrease. This will make the boundaries softer.

H.3.2 Developers/Landowners

Aim for the area: BDP should make as much money as possible. The area must become worth as much as possible, so that the land value goes up and so it makes more money. This should be done mainly by building houses.

Budget gap: S-curve decreasing
The revenues in the project are conducted only from selling the houses. The developers try to make as much profit as possible on this. They want the budget gap to return a profit and not a loss. Whenever profit is made, their preference will be relatively high. However, the moment there is a budget gap, their preference will immediately be very low.

Total amount of green: S-curve decreasing
They want a park since it will give an added value to the area (so, more value and attractiveness for the area and more chance of selling houses). However, they do not want the entire area filled with a park since there would be no space for houses anymore. They want to keep enough space left for building houses. After this point, the preference will drop and will extent until the maximum.

Total number of houses: parabola
They want as much houses as possible. This will generate revenues. So, the number of houses needs to be maximized in the eyes of the developers. However, as mentioned above, they still want some space for park and green since this will give more value to the houses as well. Therefore, the parabolic top of the curve will lay much more to the right in comparison to the municipality. With this distribution, a lot of houses are built, but there will also be space for some green. After the top, the preference will decrease fast.

Total area of living: ascending increasing
With the current limits for the area that is reserved for living, the preference is 100 when the maximal limit is reached. The developers need this amount of space for living in order to make profit. For a long time until reaching this point, the preference will be low because the developers cannot really make money if such a small area is filled with houses.

House types: parabola
The house types will have an optimum, since it is assumed that the developers can only sell a certain number of houses to inhabitants. The top will be more specified in comparison to the municipality. The developers have more knowhow from the amount they can sell of a certain type and therefore have a more specified preference than the municipality. After this point, the preference will drop and will extend until the maximum.

H.3.3 Green party

Aim for the area: develop an area where green is taken into account which contributes to recreation.

Total amount of green: descending increasing As much green as possible. In a perfect world, they want the whole area filled with green, so no housing. For each square meter that is realized for housing there needs to be compensated for plants and animals. The curve is descending increasing. At first, their preference will raise a lot with every hectare of extra green in the area. If there is certain amount of green reached, the expectations are more or less met. Every extra hectare of green after that point will raise the preference, but not that much anymore.

Total number of houses: S-curve decreasing
Their preference will be zero soon. The curve follows an S-curve, since the green party would (at the beginning) understand that some area will be reserved for living. But the preference will drop fast soon. And the maximum for the area is smaller than the developers and the municipality.

Gemeenschapspolder: S-curve increasing
The green party wants a minimum amount of this type. Therefore, the preference only rises when a certain value is reached. The preference will increase after that until the green party is satisfied with a certain amount.

Plas: S-curve increasing
The green party wants a minimum amount of this type. Therefore, the preference only rises when a certain value is reached. The preference will increase after that until the green party is satisfied with a certain amount.

Sport/Zorglandgoed: parabola

This variable has an optimum since this variable fulfills a function. After enough space is created to fulfill the function, the preference will drop again. The preference will only increase when a certain amount of area is reserved for the accommodation of sports.

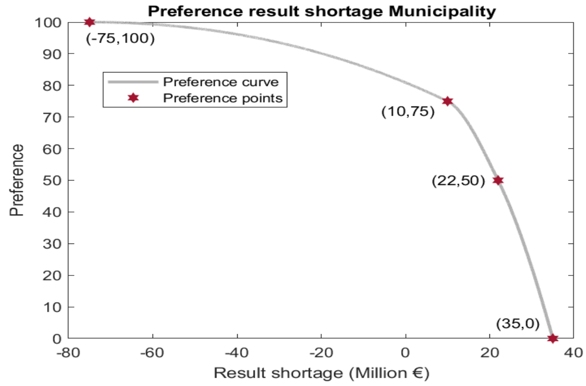
Stadspark Weesp: parabola

This variable has an optimum since this variable fulfills a function. After enough space is created to fulfill the function, the preference will drop again. The preference will only increase when a certain amount of area is reserved for the accommodation of the park.

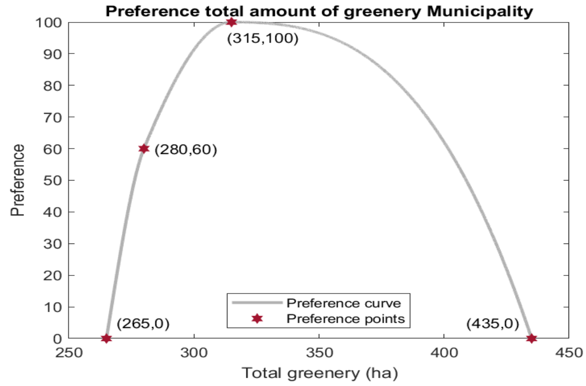
Area for living: S-curve decreasing

The green party does not want much space for living in the area. Their preference will drop gradually.

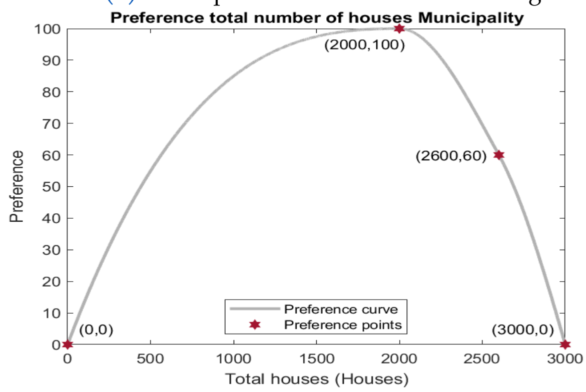
H.4 BDP Pencil preferences



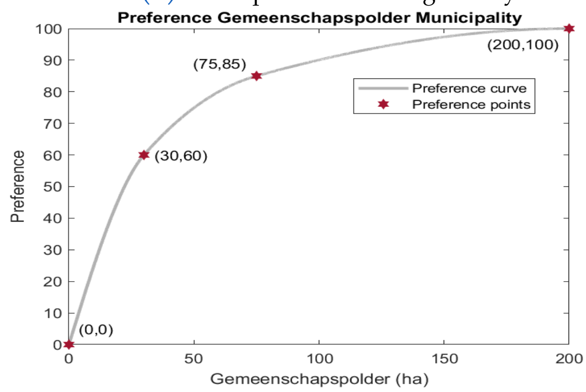
(a) Pencil preference curve result shortage



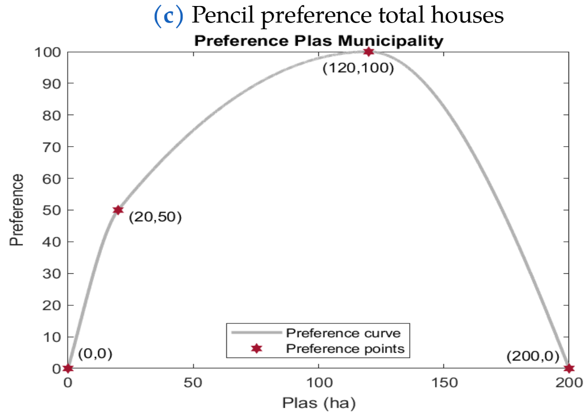
(b) Pencil preference total greenery



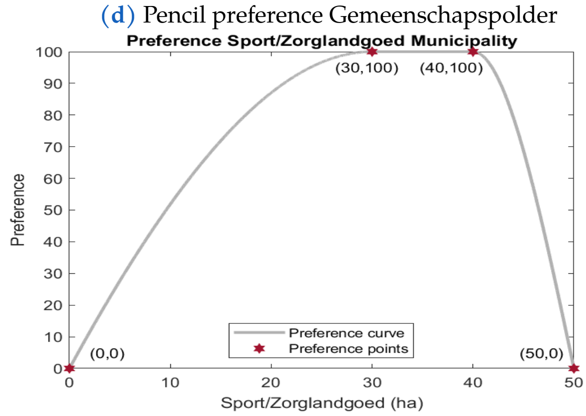
(c) Pencil preference total houses



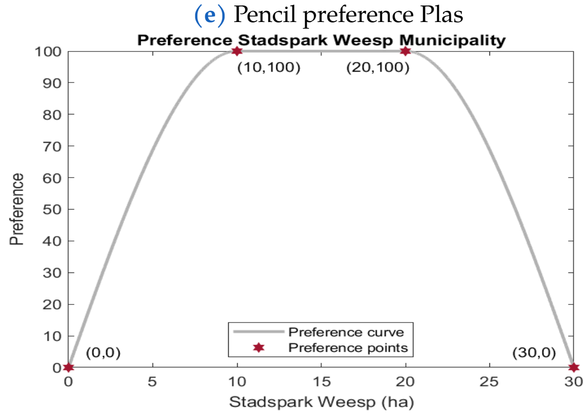
(d) Pencil preference Gemeenschapspolder



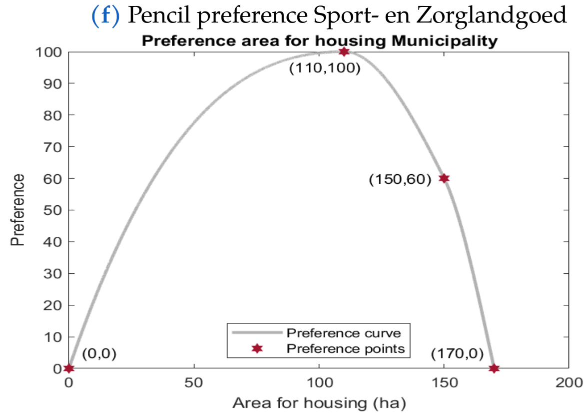
(e) Pencil preference Plas



(f) Pencil preference Sport- en Zorglandgoed

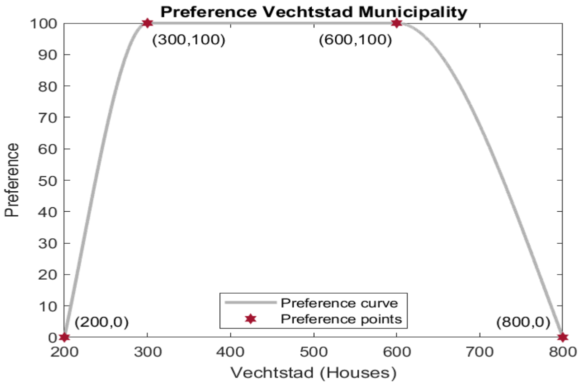


(g) Pencil preference Stadspark

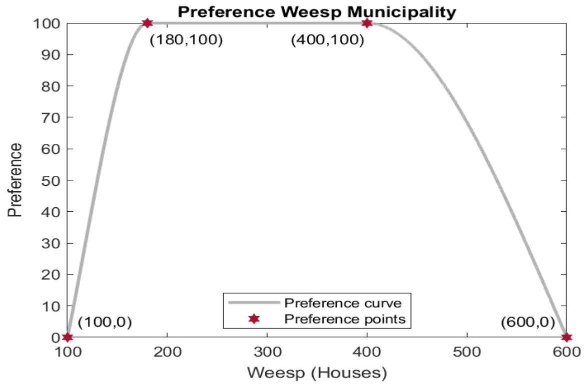


(h) Pencil preference area for housing

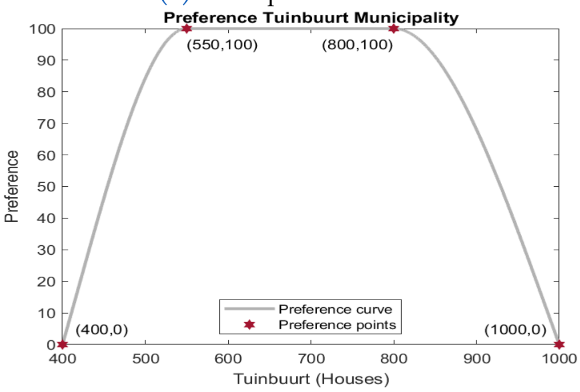
Figure H.4: Pencil preference curves municipality part 1



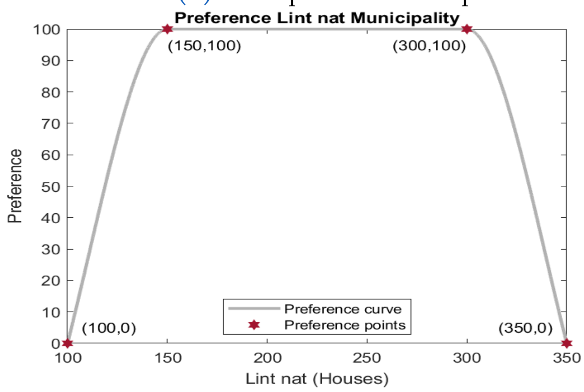
(a) Pencil preference Vechtstad



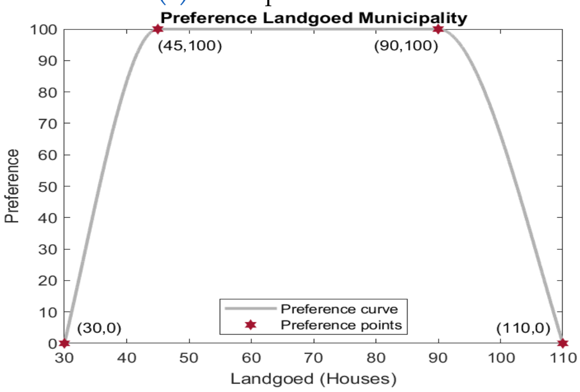
(b) Pencil preference Weesp



(c) Pencil preference Tuinbuurt

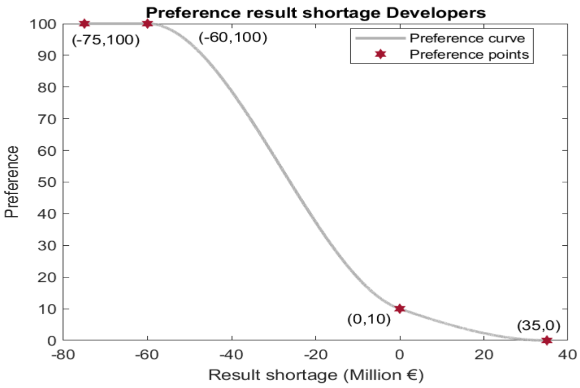


(d) Pencil preference Lint nat

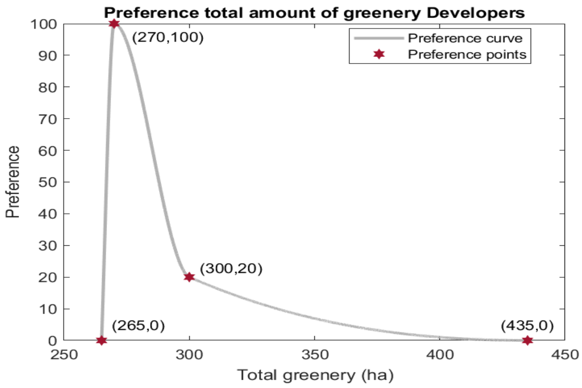


(e) Pencil preference Landgoed

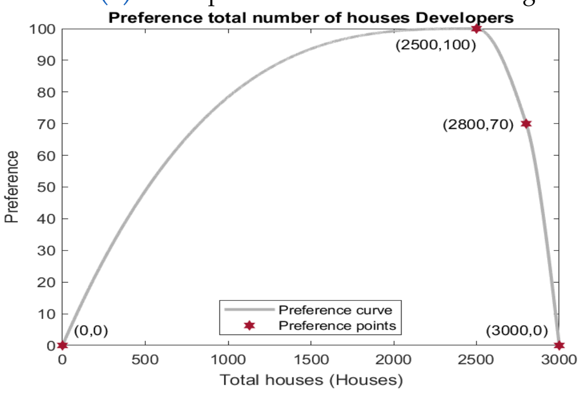
Figure H.5: Pencil preference curves municipality part 2



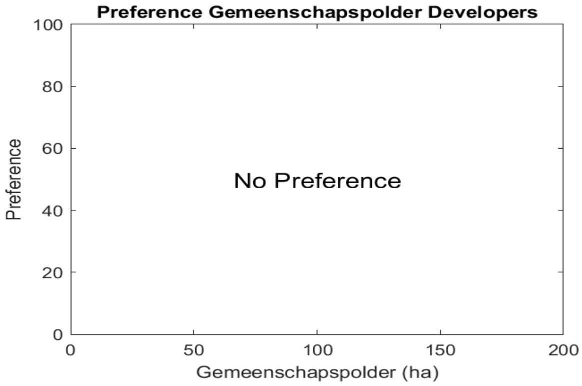
(a) Pencil preference curve result shortage



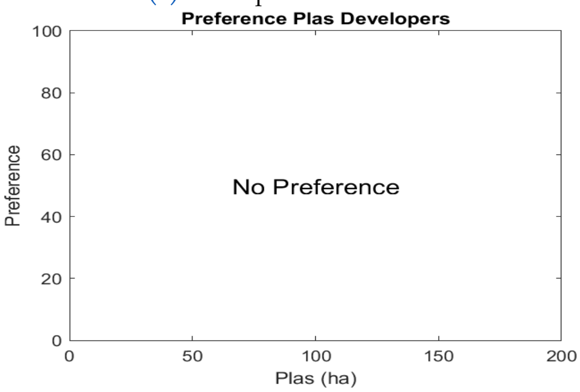
(b) Pencil preference total greenery



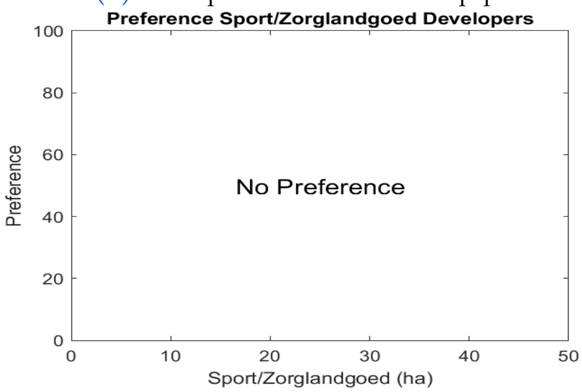
(c) Pencil preference total houses



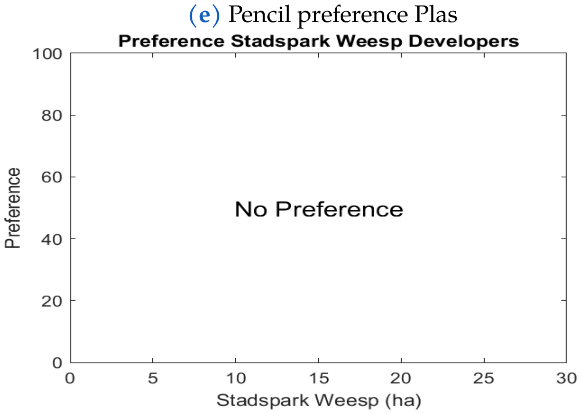
(d) Pencil preference Gemeenschapspolder



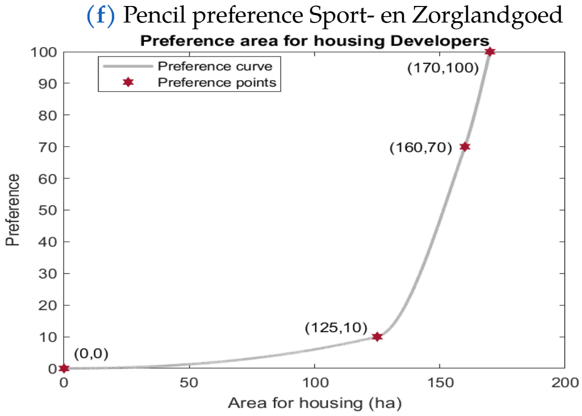
(e) Pencil preference Plas



(f) Pencil preference Sport- en Zorglandgoed

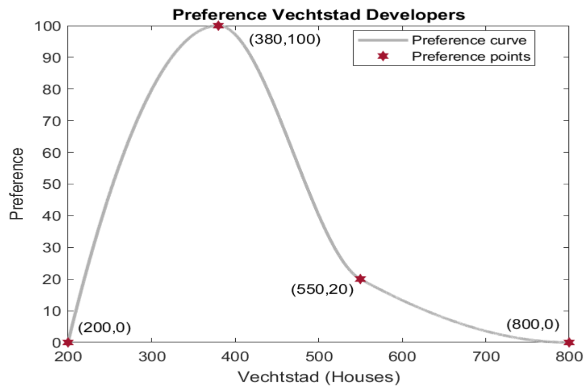


(g) Pencil preference Stadspark

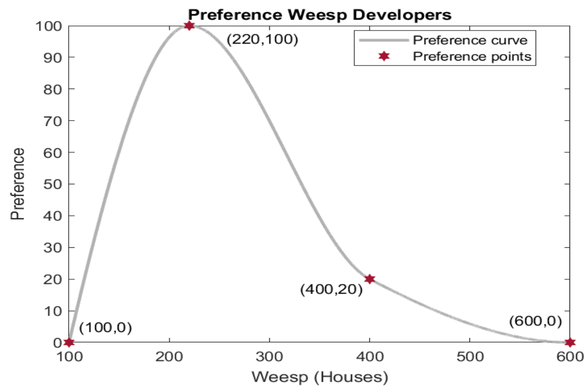


(h) Pencil preference area for housing

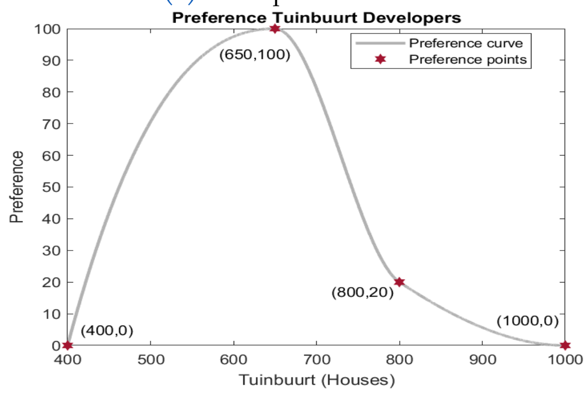
Figure H.6: Pencil preference curves developers part 1



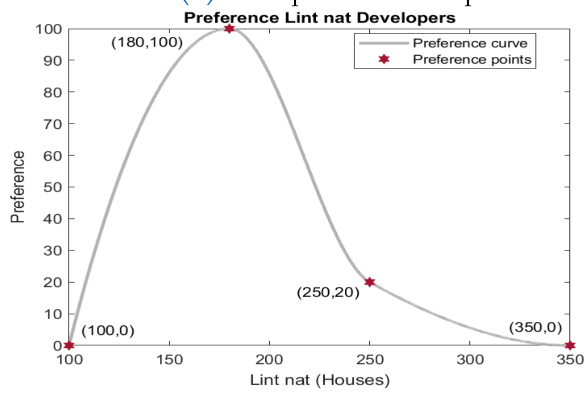
(a) Pencil preference Vechtstad



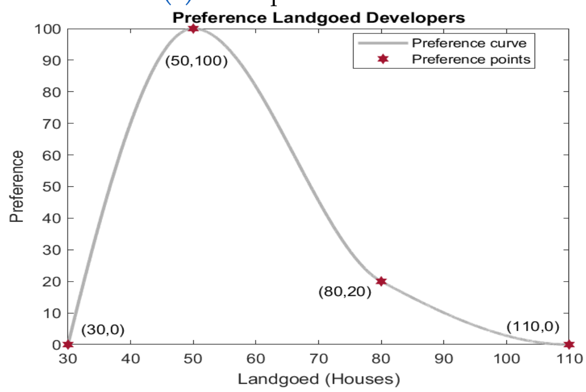
(b) Pencil preference Weesp



(c) Pencil preference Tuinbuurt

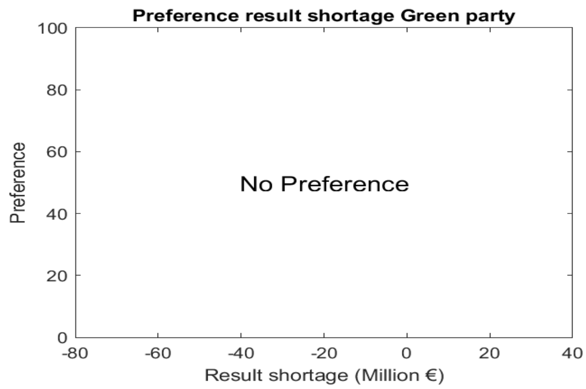


(d) Pencil preference Lint nat

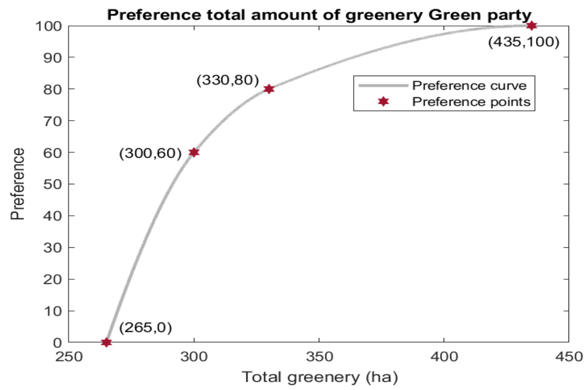


(e) Pencil preference Landgoed

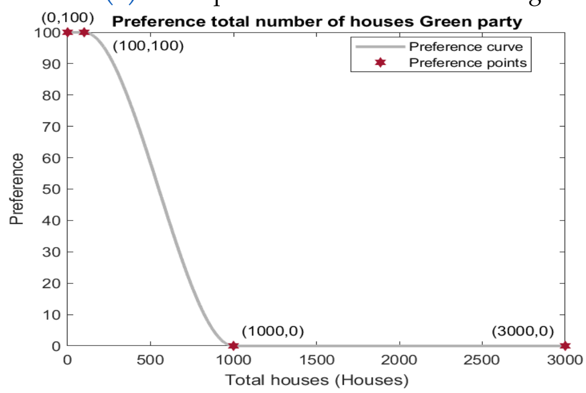
Figure H.7: Pencil preference curves developers part 2



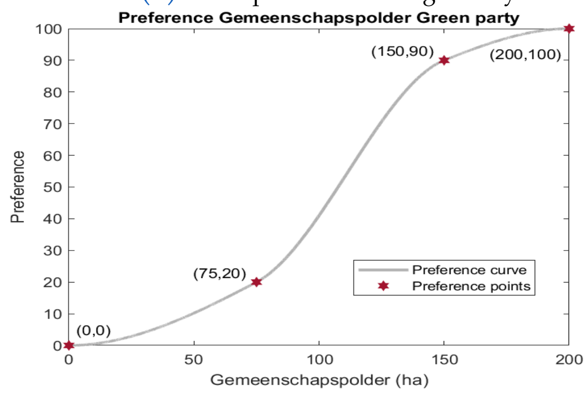
(a) Pencil preference curve result shortage



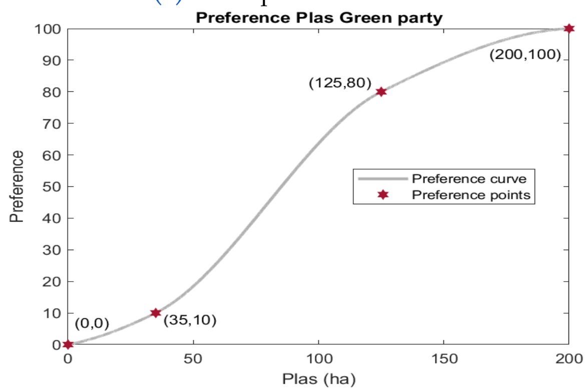
(b) Pencil preference total greenery



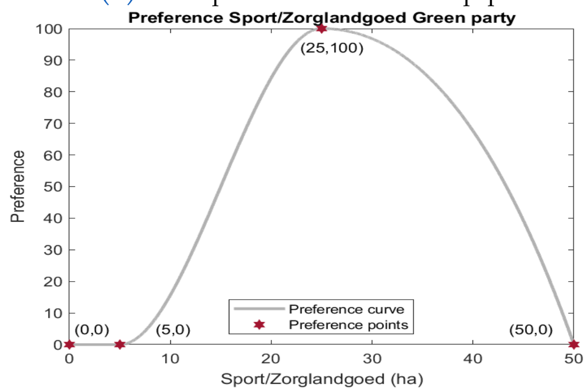
(c) Pencil preference total houses



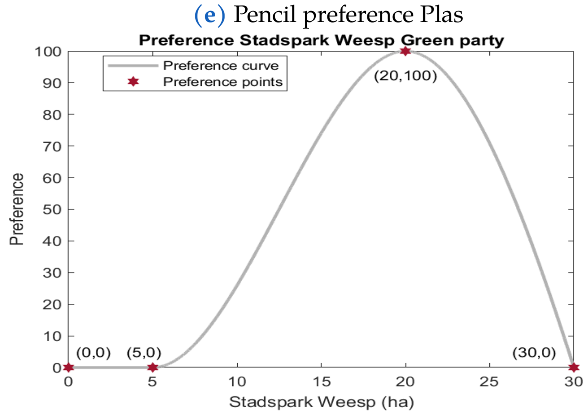
(d) Pencil preference Gemeenschapspolder



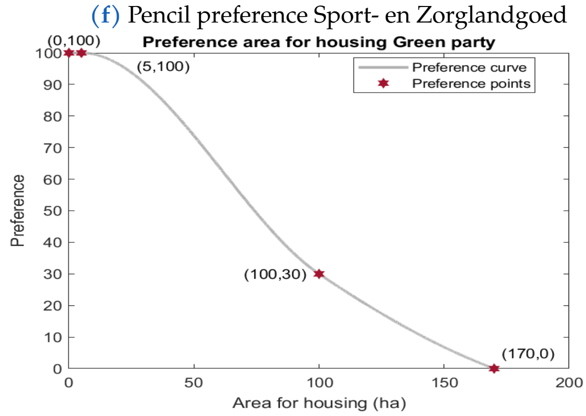
(e) Pencil preference Plas



(f) Pencil preference Sport- en Zorglandgoed

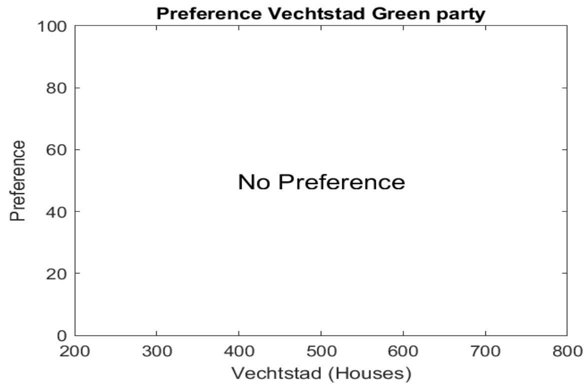


(g) Pencil preference Stadspark

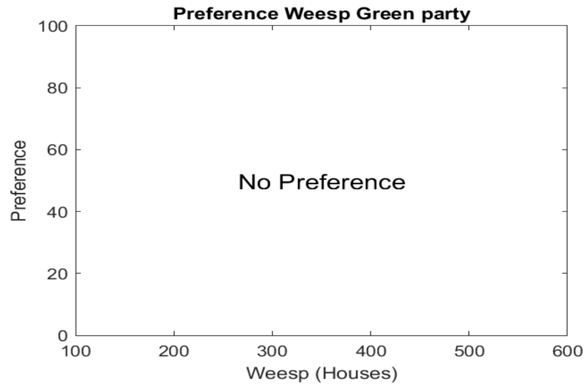


(h) Pencil preference curve area for housing

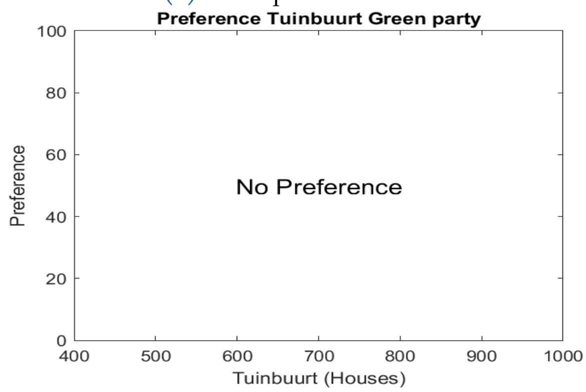
Figure H.8: Pencil preference curves green party part 1



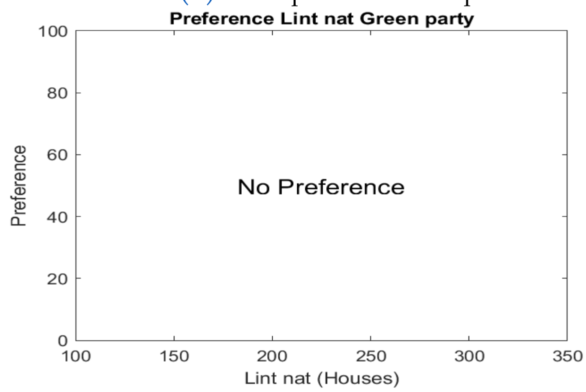
(a) Pencil preference Vechtstad



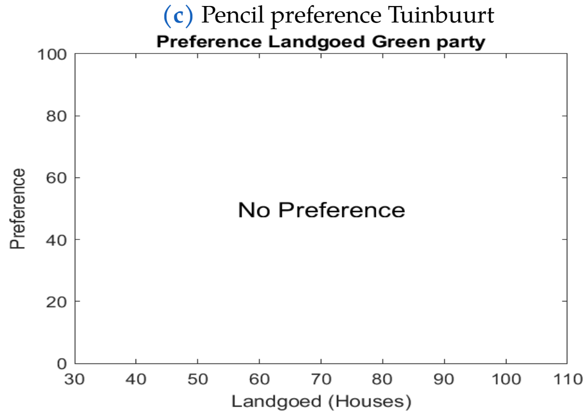
(b) Pencil preference Weesp



(c) Pencil preference Tuinbuurt



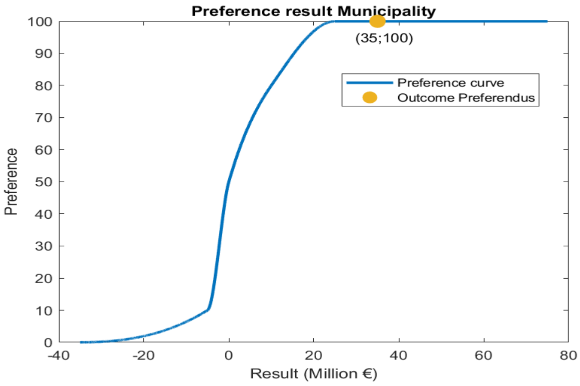
(d) Pencil preference Lint nat



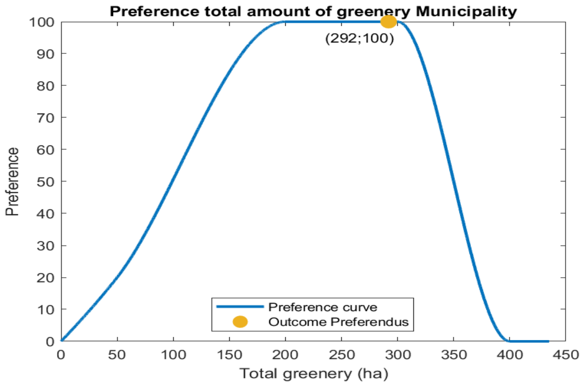
(e) Pencil preference Landgoed

Figure H.9: Pencil preference curves green party part 2

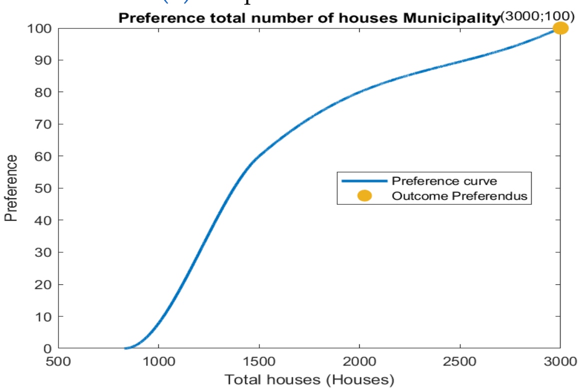
H.5 BDP Pen Preferences



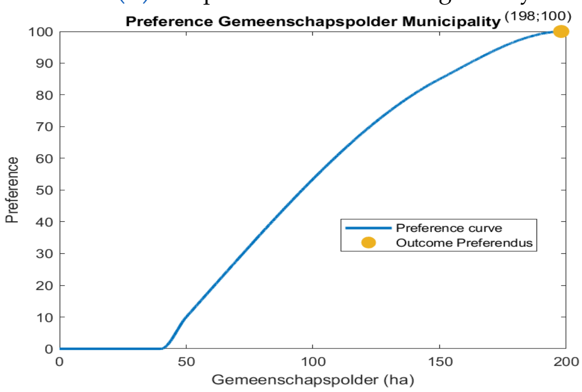
(a) Pen preference curve result



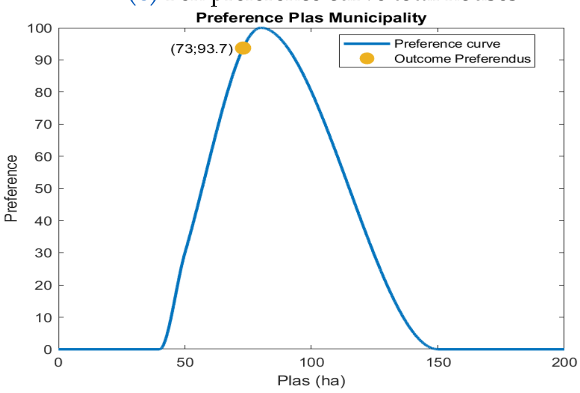
(b) Pen preference curve total greenery



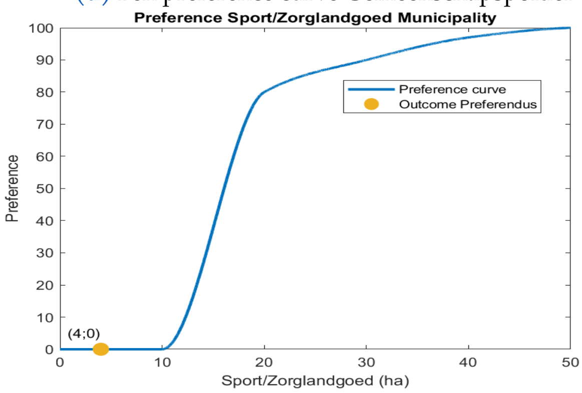
(c) Pen preference curve total houses



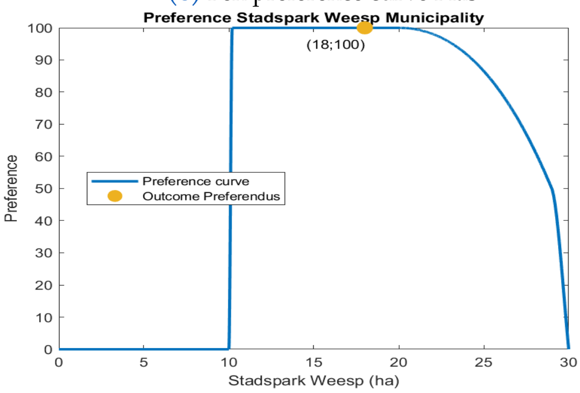
(d) Pen preference curve Gemeenschapspolder



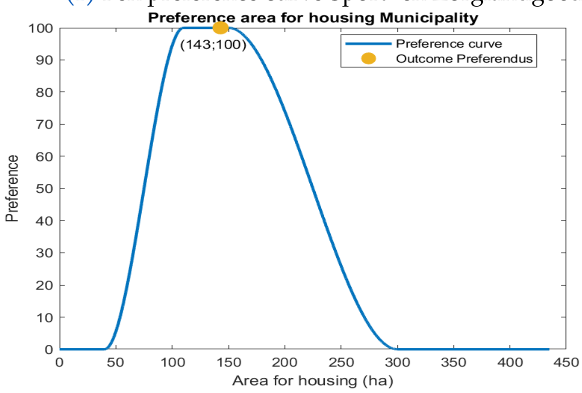
(e) Pen preference curve Plas



(f) Pen preference curve Sport- en Zorglandgoed

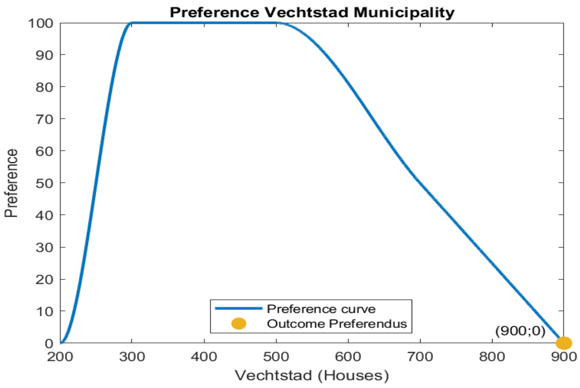


(g) Pen preference curve Stadspark

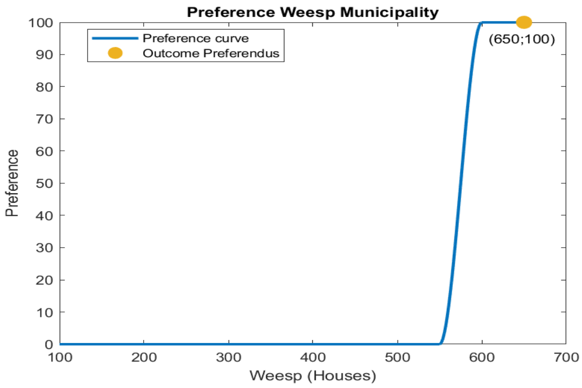


(h) Pen preference curve area for housing

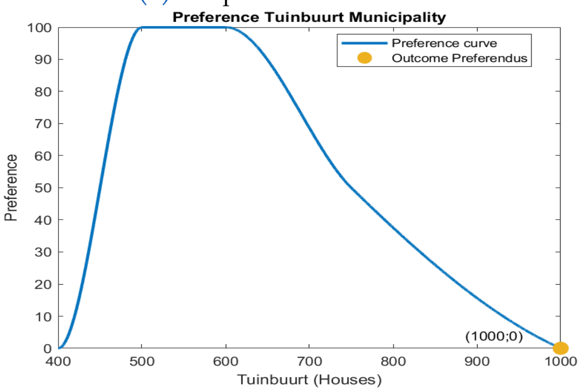
Figure H.10: Pen preference curves municipality part 1



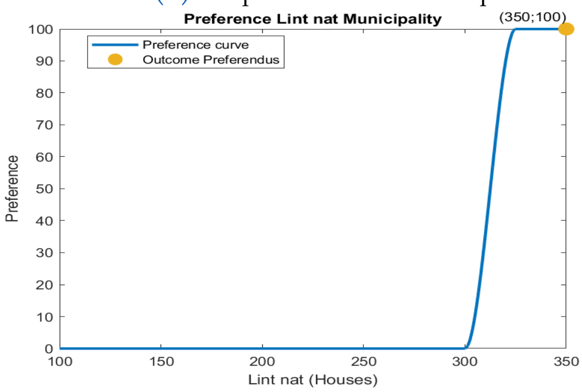
(a) Pen preference curve Vechtstad



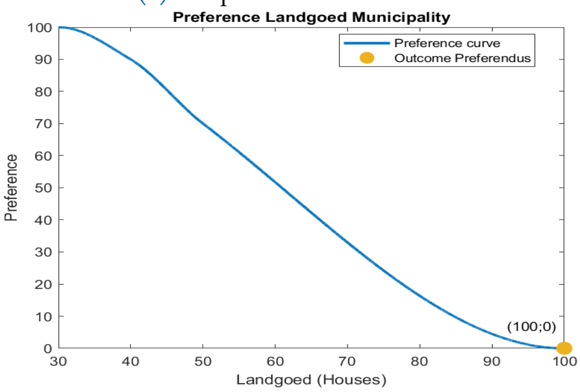
(b) Pen preference curve Weesp



(c) Pen preference curve Tuinbuurt

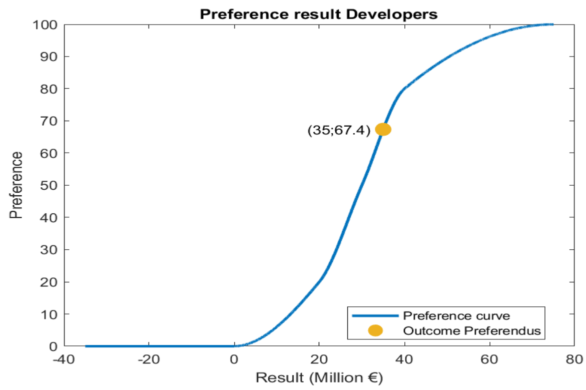


(d) Pen preference curve Lint nat

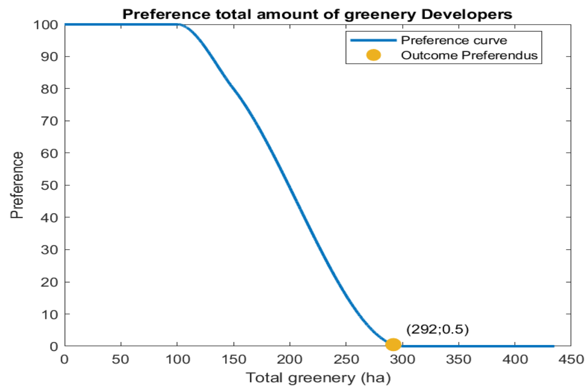


(e) Pen preference curve Landgoed

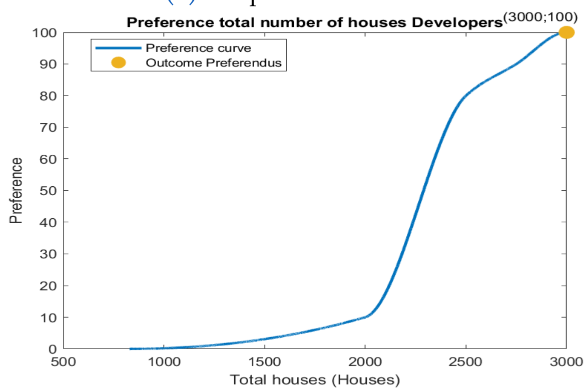
Figure H.11: Pen preference curves municipality part 2



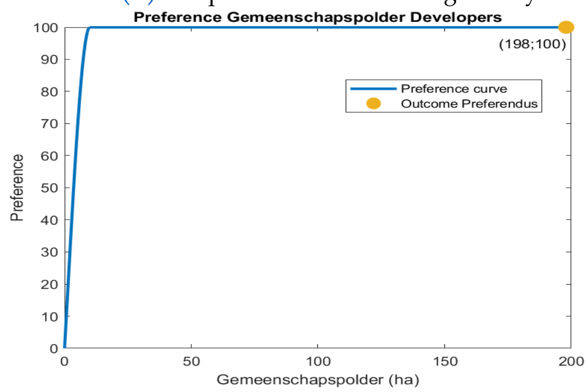
(a) Pen preference curve result



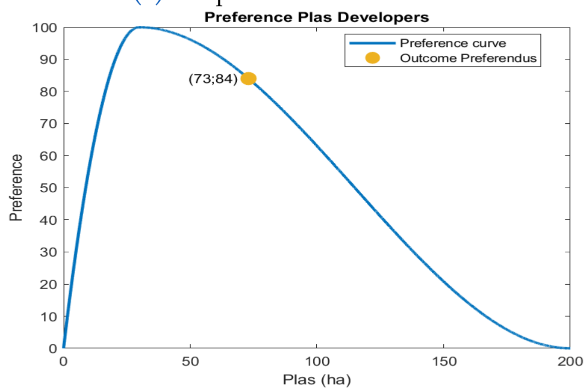
(b) Pen preference curve total greenery



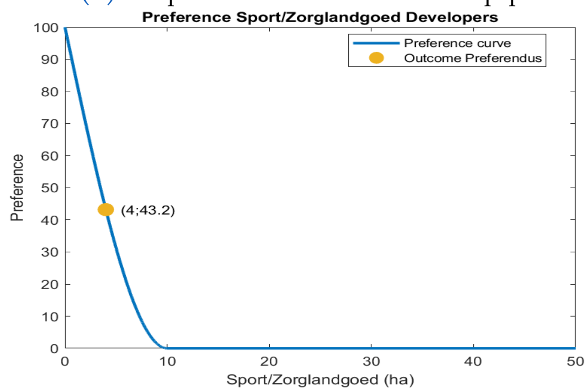
(c) Pen preference curve total houses



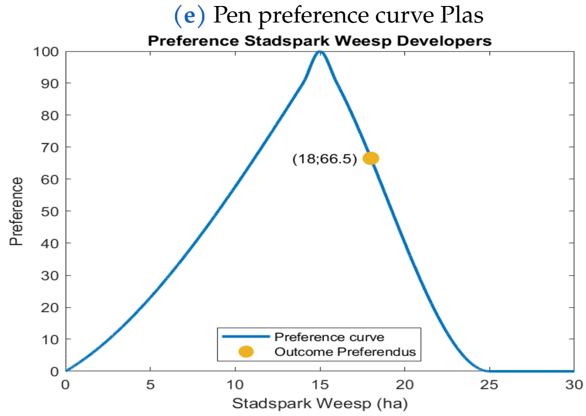
(d) Pen preference curve Gemeenschapspolder



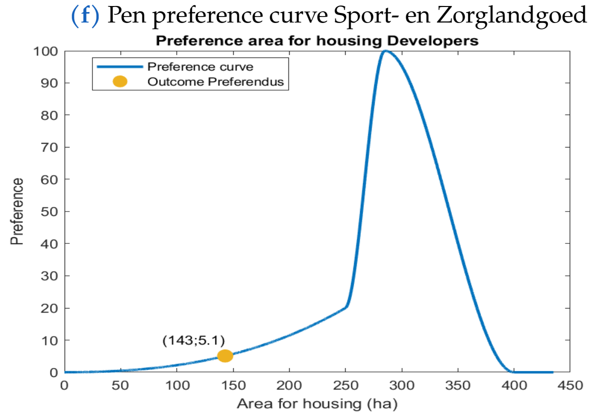
(e) Pen preference curve Plas



(f) Pen preference curve Sport- en Zorglandgoed

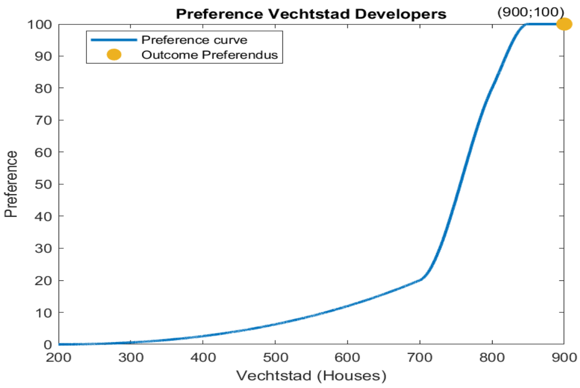


(g) Pen preference curve Stadspark

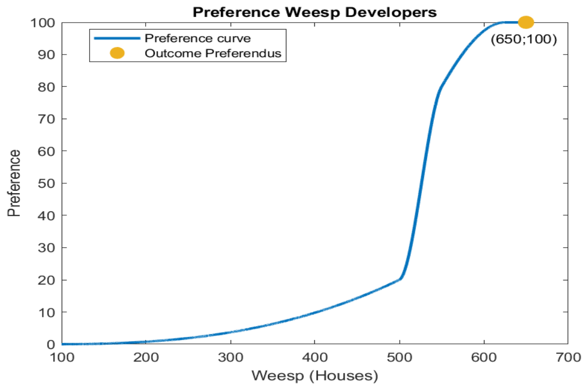


(h) Pen preference curve area for housing

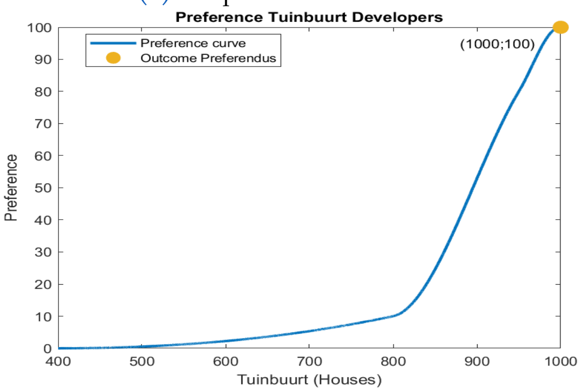
Figure H.12: Pen preference curves developers part 1



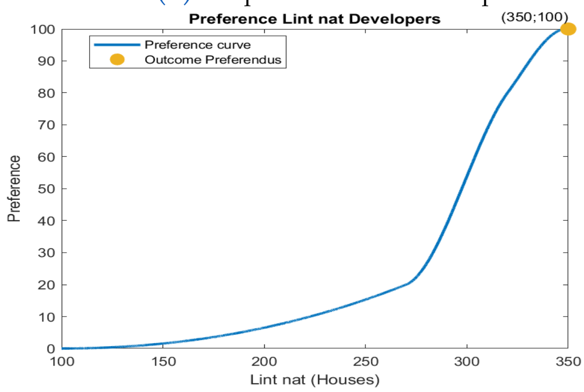
(a) Pen preference curve Vechtstad



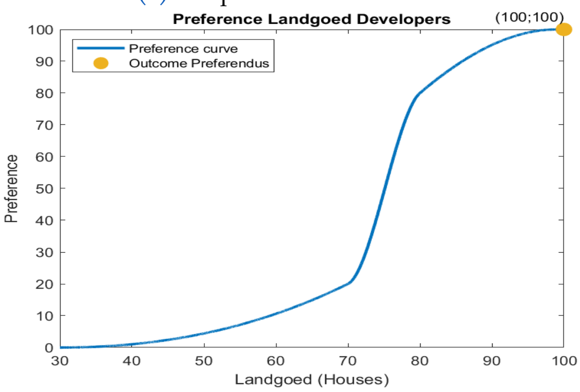
(b) Pen preference curve Weesp



(c) Pen preference curve Tuinbuurt

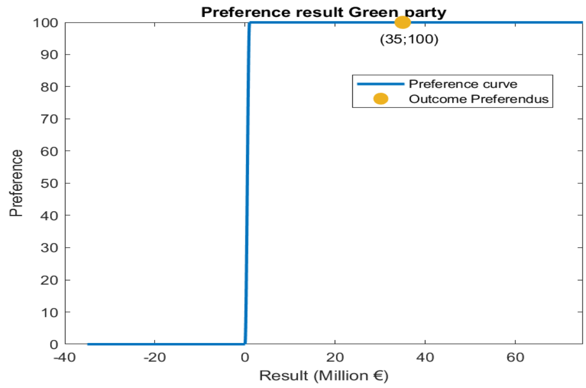


(d) Pen preference curve Lint nat

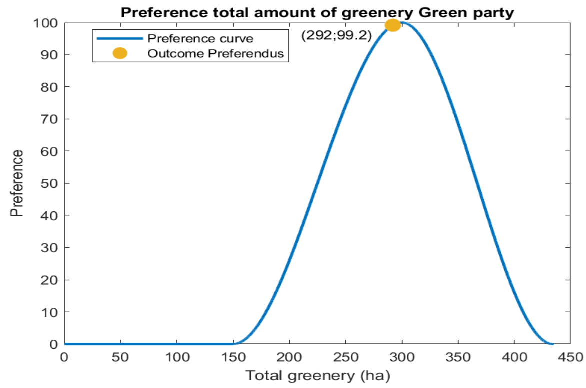


(e) Pen preference curve Landgoed

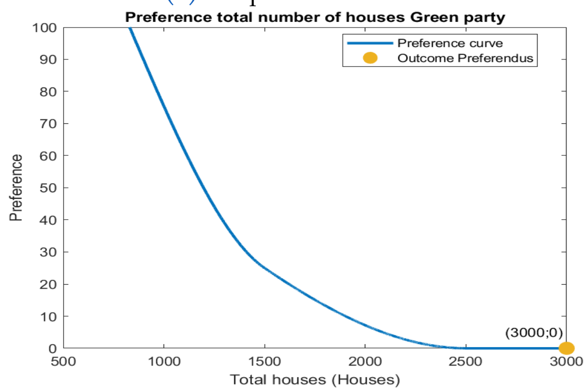
Figure H.13: Pen preference curves developers part 2



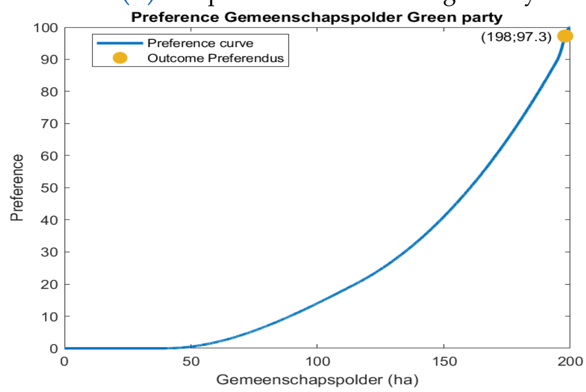
(a) Pen preference curve result



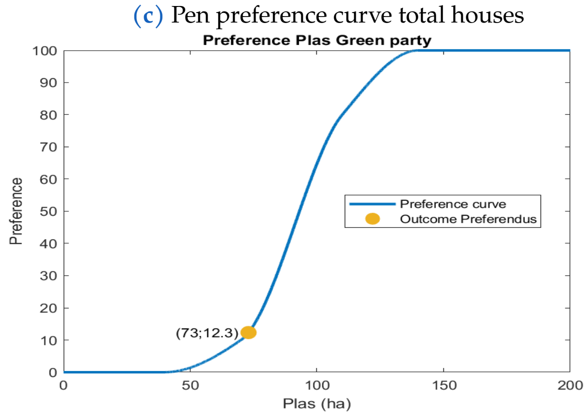
(b) Pen preference curve total greenery



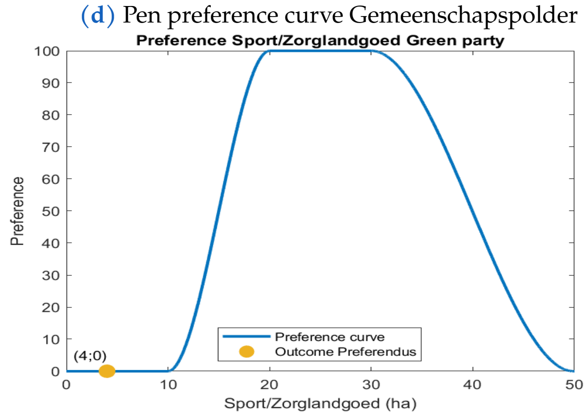
(c) Pen preference curve total houses



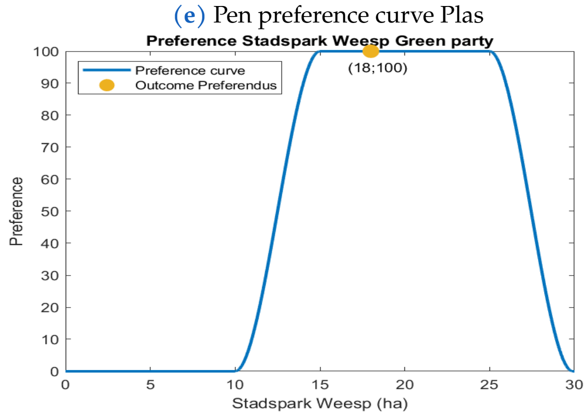
(d) Pen preference curve Gemeenschapspolder



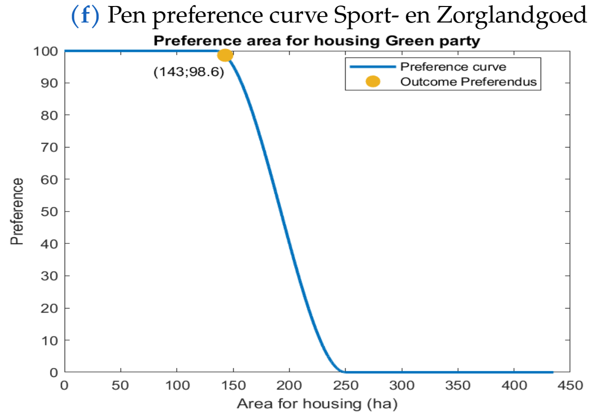
(e) Pen preference curve Plas



(f) Pen preference curve Sport- en Zorglandgoed



(g) Pen preference curve Stadspark



(h) Pen preference curve area for housing

Figure H.14: Pen preference curves green party part 1

H.6 Information document stakeholders Workshop 2

Plangebied

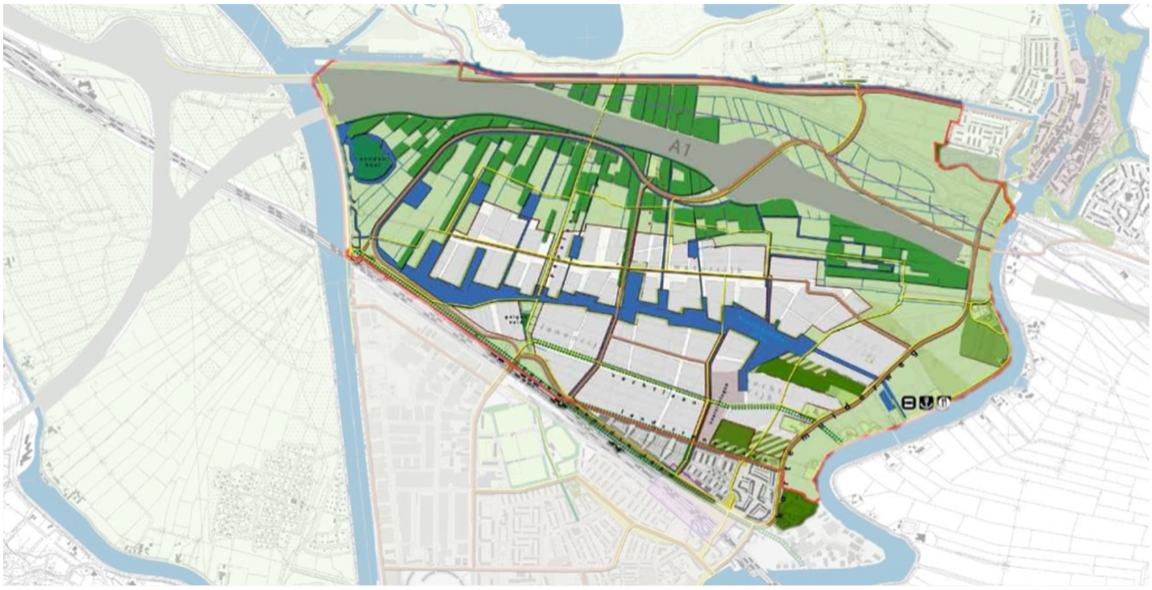


Figure H.15: Gebiedsoverzicht Bloemendalerpolder

Planmaat heeft in 2007 een Lineair Programmeren (LP) model gemaakt voor het vastlopende project Bloemendalerpolder (BDP), dat zich in de buurt van Weesp bevindt. Bij BDP kon er geen geschikte oplossing gevonden worden voor de gebiedsinrichting dat geen saldotekort opleverde. Op dat moment werd Planmaat ingeschakeld om naar dit vraagstuk te kijken. Planmaat heeft een LP model gemaakt van het gebied, waarbij geminimaliseerd is naar saldotekort. Hier is een ontwerp – een optimale verdeling tussen variabelen als woningen en groen – uitgerold waar wij ons oog nog eens op laten vallen. Wij doen onderzoek naar het meenemen van preferenties van stakeholders over deze variabelen, waardoor het LP model niet-lineair (NLP) wordt. In het geval van BDP willen we de preferenties van stakeholders meenemen in het eerder gemaakte LP model. Met behulp van deze preferenties kunnen we kijken of een andere oplossing met meer draagvlak mogelijk was voor de BDP case.

Tijdens de workshop zal er worden gediscussieerd over de inrichting van BDP. In bovenstaand overzicht is het gebied van BDP weergegeven. Het gebied beslaat 435 hectare. Er wordt in de case vanuit gegaan dat het gehele gebied gebruikt zal worden.

Voor de ontwikkeling van het gebied vormen de gemeente en een groep ontwikkelaars samen het OMB (Ontwikkelingsmaatschappij BPD). Het OMB deelt de risico's en de kosten/winst die aan het project verbonden zijn. Het OMB investeert samen in het project en heeft dus ook gezamenlijke belangen. Een belangrijk aspect in de kosten en opbrengsten is de inbrengwaarde binnen het project, dit is het bedrag van de grond die in het bezit is van het OMB en dus ook moet worden terugverdiend om geen saldotekort op te lopen. Momenteel staat deze inbrengwaarde op €0,-. Er wordt voor nu vanuit gegaan dat de inbrengwaarde niet wordt meegenomen in de kosten van het project.

Informatie variabelen

De variabelen die worden meegenomen in het model beschikken over verschillende eigenschappen. De hieronder getoonde tabellen tonen de eigenschappen van de verschillende types groen en woningen.

Er zijn preferentiecurves over de variabelen gemaakt. Deze variabelen hebben een bereik van waarden. De waarden zijn gebaseerd op harde eisen die zijn gesteld.

Table H.4: Eigenschappen typen groen

Type	Eigenschap	Kosten (per ha)	Recreanten (per ha)	Kosten (per recreant)
Gemeenschapspolder	Combinatie tussen gras, land & water (klassiek polderlandschap)	€ 36.497, -	15	€ 2433,-
Plas	Ruimte volledig gevuld met water	€ 97.780, -	10	€ 9778,-
Sport/Zorglandgoed	Open veld waar meerdere functies samenkomen zoals sporten (atletiek, basketbal & voetbal) en een belevenisbos (avontuurlijk & educatief)	€ 195.276, -	50	€ 3906,-
Stadspark Weesp	Open en toegankelijk bos met de gelegenheid om in te wandelen, samen te komen of te eten	€ 158.614, -	100	€ 1586,-

Table H.5: Eigenschappen typen woningen

Type	Dichtheid (won/ha)	Opbrengsten (per huis)	Kosten (per huis)	Winst (per huis)	Winst (per ha)
Vechtstad	30,2	€ 92.984, -	€ 72.498, -	€ 20.486	€ 618.677
Weesp	26,2	€ 92.984, -	€ 48.280, -	€ 44.704	€ 1.171.245
Tuinbuurt	29,5	€ 87.446, -	€ 32.369, -	€ 55.077	€ 1.624.772
Lint nat	9,5	€ 167.563, -	€ 88.909, -	€ 78.654	€ 747.213
Landgoed	5,2	€ 126.690, -	€ 123.707, -	€ 2.983	€ 15.511

Table H.6: Overzicht randvoorwaarden variabelen

Naam	Naam variabele	Eenheid	Minimale waarde	Maximale waarde
S	Saldo (bepaald door ontwerpvariabelen Kosten en Opbrengsten)	€	- 35.000.000 (=verlies)	75.000.000 (=winst)
X (4)	Strategisch groen totaal	Ha	0	435
X (21)	Totaal woningaantal	Won	830	3.000
X (5)	Gemeenschapspolder	Ha	0	200
X (7)	Plas	Ha	0	200
X (11)	Sport/Zorglandgoed	Ha	0	50
X (13)	Stadspark Weesp	Ha	0	30
X (20)	Oppervlak wonen	Ha	0	435
X (22)	Vechtstad	Won	200	900
X (23)	Weesp	Won	100	650
X (24)	Tuinbuurt	Won	400	1.000
X (27)	Lint nat	Won	100	350
X (30)	Landgoed	Won	30	100

Spelregels workshop

De eerste workshop ging vooral om het verzamelen van voorkeuren. Er werden garanties en spelregels opgesteld om problemen tijdens het verzamelen van gegevens te voorkomen en deze gegevens op een open en transparante manier vast te leggen. De volgende garanties en spelregels waren opgesteld tijdens het verzamelen van voorkeuren van stakeholders:

- Iedere stakeholder wordt geacht open te zijn over de preferenties en doelen die hij/zij heeft, om geen vertekend beeld te krijgen.
- Alle gegevens zullen met elkaar gedeeld worden. De workshop is fictief, daarom wordt er geacht dat gegevens open op tafel zullen worden gegooid. De stakeholders zullen elkaars preferenties en curves kunnen zien. De uitkomsten van het model kunnen na elke ronde worden getoond. Hierbij kunnen ook

de 'deelpreferenties' worden getoond, de preferenties per stakeholder.

- Tussen iedere stakeholder bestaat even veel macht (uitgedrukt in gewichten in het model).

In de tweede workshop zal de focus liggen op de acceptatie van de uitkomst. De uitkomst van het model zal de meeste aandacht krijgen. Verwacht wordt dat er discussies kunnen ontstaan over het ontwerp. Hierbij zullen weer een aantal nieuwe spelregels van toepassing zijn:

- De randvoorwaarden en de preferentiecurves kunnen niet meer worden aangepast tijdens de workshop. De workshop is enkel en alleen bedoeld om de uitkomst en de acceptatie van de uitkomst te bespreken. De uiteindelijke curves zijn opgegeven in de individuele sessie en er wordt vanuit gegaan dat deze volledig zijn.
- Er wordt geacht dat stakeholders elkaar respecteren. Dit houdt in dat stakeholders elkaars voorkeurscurves dienen te accepteren, het is immers de individuele voorkeur die is opgesteld binnen harde randvoorwaarden, waar de ander niks over te zeggen heeft.
- De gewichten tussen variabelen worden op een transparante manier gecommuniceerd. De gewichten tussen de stakeholders en de variabelen in het model worden gezien als gelijk. De gewichten tussen de verschillende types groen en woningen zijn gebaseerd (aan de hand van Tetra software) op de voorkeuren die zijn opgegeven door de stakeholders in de individuele sessie.

Onze rol tijdens de tweede workshop: Als leider hebben wij inzicht in hoe het model werkt, en daarmee kunnen wij aangeven wat er nodig is voor een andere oplossing. Daardoor oefenen wij als leider ook invloed uit op de uiteindelijke uitkomst. Om dit te minimaliseren zijn er protocollen en spelregels opgesteld.
Eigenlijk hebben we de rol van een Urban System Engineer:

- Inhoudelijk-technische ontwikkeling van het model in relatie tot de ontwerpopgave.
- Ontwikkeling en ontwerpen van nieuwe sturingsmaatregelen voor het functioneren van het model.
- Sturing en leiding (faciliteren) van de workshops.
- Stakeholders helpen bij het formuleren van een duidelijk doel dat uiteindelijk omgezet kan worden in een preferentie die te gebruiken is in het model.
- Overbrengen van de werking van het model.

De tweede workshop heeft ook een functie als feedback moment. Tijdens/na de workshop is er de mogelijkheid voor stakeholders om feedback te geven op de manier hoe de workshop verliep. Hierin kan onder andere worden besproken of de stakeholders de workshop geschikt vonden, wat zij wel/niet fijn vonden en wat zij voor real-world stakeholder workshops anders zouden willen zien.

Wat kan het model en waar liggen momenteel nog de grenzen van ons model?

Op dit moment is ons wiskundig & beslis ondersteunende model nog niet optimaal. Dit geeft een aantal beperkingen en grenzen voor de stakeholder bijeenkomst.

- Het model beschikt nog niet over de juiste mate van gebruiksvriendelijkheid, dit heeft gevolgen voor de interface. Een van de doelen van ons onderzoek is om te bepalen hoe wij de interface zó kunnen maken dat het eindresultaat straks ook overdraagbaar is naar de stakeholders. Feedback op dit gebied van de stakeholders zal dan ook gewaardeerd worden. De interface zal meer een rol spelen in de eerste workshop t.o.v. de tweede workshop.
- De preferenties zijn gebaseerd op 6 datapunten. Dit is naar aanleiding van ervaring van de eerste workshop, om discussies over randvoorwaardes te voorkomen.
- In het model worden er op twee momenten gewichten meegenomen. Allereerst tussen de preferenties van stakeholders over eenzelfde variabelen. Daarnaast worden er gewichten tussen de variabelen meegenomen. Er is vanuit gegaan dat deze gewichten vaststaan en daar niet over gediscussieerd kan worden. Er is wel rekening gehouden met de gewichten tussen de verschillende typen groen en woningen. Deze gewichten zijn gebaseerd op aangegeven voorkeuren.

Het model is versimpeld in het aantal variabelen dat mee wordt genomen ten opzichte van de uitgebreide BDP case. Dit is gedaan, omdat in deze fase van ons onderzoek de focus ligt op het aantonen van de meerwaarde van het modelleren van preferenties t.o.v. LP modellen waarin dit niet gebeurd.

Het model is geen ruimtelijk model, het geeft alleen een kwantitatief Programma van Eisen. Daarna moet een stedenbouwkundige nog een ontwerp maken. Daarnaast is het is geen faseringsmodel. De beslissing welke activiteiten je wanneer moet doen, moet later nog blijken.

I Additional appendix Waelpolder

Appendix I consists of the additional appendices for Waelpolder.

I.1 MATLAB Script Preferendus Waelpolder

The MATLAB script for the Preferendus used in Waelpolder is shown on the following pages.

Contents

- Design variables:
- Loading data
- Bounds for design variables
- Data house types
- Fixed values
- Data preference curve
- Weights of objectives
- Constraints
- Objective function
- Relations
- Preference scores
- Optimisation value
- Options
- First optimisation
- Calculations of the relations with xbest
- Final Costs to develop the area
- Final preference based on optimization values (xbest)
- Second optimization: 1 solution in Tetra (using xbest)
- Distance from goal
- Display
- Save output to the Excel output file


```
function PFM_Waelpolder_V6opbr_surro_w211
```

```
clc, clear, close all
```

Design variables:

```
% Design variables x(1)-x(17) refer to the house types
% x(1)  - EG soc kp < €194.000
% x(2)  - EG bereikb kp < €231.500
% x(3)  - EG betaalb kp < €310.000
% x(4)  - EG rijwoning €375.000
% x(5)  - EG 2/1kap €542.500
% x(6)  - EG vrijstaand klein €585.900
% x(7)  - EG vrijstaand groot €672.300
% x(8)  - EG verandawoning €328.000
% x(9)  - EG drive-in €355.000+€25.000
% x(10) - MG sociale huur
% x(11) - MG sociale kp < €194.000
% x(12) - MG kp €291.000
% x(13) - MG duur geb P
% x(14) - MG sociale kp < €194.000 geb P
% x(15) - MG kp betaalbaar, geb P onder dek
% x(16) - MG kp €291.000+€20.000 alles geb P
% x(17) - EG sociale huur

% x(18) - Zorgcomplex --> 4 options for the healthcare center: 0, 31, 62 or 93 units

% x(19) - Division factor. Factor indicating how the division of the unused area will be, between green and parking (dependent on both preferences).
%         Extra space for greenery = x(19) and extra space for parking = (1-x(19)).

% x(20) - Number of parking spaces with a roof (12.5 m2 per parking space).
```

Loading data

Loading data to use in the model

```
Dv = readtable("Database Waelpolder.xlsx", 'Sheet', 'Vaste waarden', 'PreserveVariableNames', true); % Data regarding fixed values
Dk = readtable("Database Waelpolder.xlsx", 'Sheet', 'Financieel'   , 'PreserveVariableNames', true); % Data of costs and revenues for area development
Dg = readtable("Database Waelpolder.xlsx", 'Sheet', 'gegevens'     , 'PreserveVariableNames', true); % Data regarding the house types
```

Bounds for design variables

Surrogate optimization requires that the lower- & upperbound and integer variables are listed.

```
Lowerbound = [Dg.Lowerbound(1:18); 0; 0];   % Defining the lowerbound of the design variables, the last two variables are not defined in the database
Upperbound = [Dg.Upperbound(1:18); 1; 500]; % Defining the upperbound of the design variables, the last two variables are not defined in the database

lb = Lowerbound';                           % Translating the lower bounds
ub = Upperbound';                           % Translating the upper bounds

IntCon = [1:18 20];                         % Defining the design variables that are integer
```

Data house types

Defining variables that represent different properties of the house types and will be calulated with in the model

```
Uitgeef = Dg.("Uitgeefbaar (m² kavel)");    % Plot area per house type in m2
Straat = Dg.("Straat (m²)");                % Area for street per house type in m2
Stoep = Dg.("Trottoir (m²)");               % Area for sidewalk per house type in m2
Parkeren = Dg.("Parkeren (m²)");            % Area for parking per house type in m2 (parking norm * 12.5 per parking space)
Spelen = Dg.("Spelen (m²)");                % Area for playground per house type in m2

min_Groen = 7.0;                            % Minimal green norm (in m2) that needs to be maintained per house type
min_parkafw = 0.9;                          % Minimal deviation from parking norm that needs to be maintained per house type
```

Fixed values

Defining variables that are fixed and will be calulated with in the model

```
V_waarde = Dv.Waarde;               % Defining a variable that is loading the fixed values from the database Excel

Opp_gebied = V_waarde(1);           % Total plan area in m2

% Inflation
Startjaar= V_waarde(2);             % Base year of unit prices
Boekjaar =V_waarde(3);              % Year on which the costs should be based
Kostenstijging = V_waarde(4);       % Cost increase of unit prices per year
f_Prijsstijging = 1+Kostenstijging.^(Boekjaar-Startjaar); % Factor price increase

Opp_parkeeropl  = 0;                % V_waarde(7); % Area parking solution in subarea 5 , Oppervlakte parkeer oplossing in deelgebied 5 --> Kan weg?

% Pavement and elevation
Verhardingb = V_waarde(8);          % Pavement width in meters
H_oph_verharding= V_waarde(9);      % Elevation of pavement in meters
H_oph_uitg = V_waarde(10);          % Elevation plot area in meters
H_oph_groen = V_waarde(10);         % Elevation green in meters
H_teelaarde =V_waarde(12);          % Height of soil in green area in meters
H_zand = V_waarde(13);              % Height of sand with pavement in meters
Af_Lm = V_waarde(14);               % Distance between lampposts in meters
Af_bomen= V_waarde(15);             % Distance between trees long avenue in meters
Lv_drain = V_waarde(16);            % Length of vertical drainage in meters

p_rij = V_waarde(17);               % Percentage of pavement that is carriageway
p_park = V_waarde(18);              % Percentage of pavement that is parking
p_stoep = V_waarde(19);             % Percentage of pavement that is sidewalk

% Soil
Gr_vrij_ag =V_waarde(20);           % Land/Soil cleared from other areas
Gr_verwerken_ag = V_waarde(21);     % Soil to be processed from other areas
Gr_tekort_ag = V_waarde(22);        % Shortage of soil in other areas

% Revenues
profx = Dg.("Grondwaarde Patrick"); % Defining a variable that is loading the land vlaue from the database Excel

% Costs per activitity
kopr = Dk.Kostopr .*f_Prijsstijging;    % Clearing operations
koph = Dk.Kostoph .*f_Prijsstijging;    % Elevation of the site
kgv      = Dk.Kostgv .*f_Prijsstijging;     % Soil transportation
kbm  = Dk.Kostbm .*f_Prijsstijging;     % Site preparation (Bouwrijp maken)
kwm      = Dk.Kostwm  .*f_Prijsstijging;    % Hard and soft landscaping (Woonrijp maken)
kawe = Dk.Kostawe .*f_Prijsstijging;    % Additional work elements

K_parkeerdek = 1250*12.5;               % Costs of a roof above parking space
```

Data preference curve

Preference curves of stakeholders loaded from the preferences Excel

```
PrefF= readtable("Preferenties Waelpolder aangepast w211.xlsx", 'Sheet', 'PreferentiesF','PreserveVariableNames',true); %Loading data preference stakeholder F
PrefS= readtable("Preferenties Waelpolder aangepast w211.xlsx", 'Sheet', 'PreferentiesS','PreserveVariableNames',true); %Loading data preference stakeholder S
PrefG= readtable("Preferenties Waelpolder aangepast w211.xlsx", 'Sheet', 'PreferentiesG','PreserveVariableNames',true); %Loading data preference stakeholder G

%Preference curves Financial director (Financieel) (F):
Preff1 = PrefF.f1pref(~isnan(PrefF.f1pref));    % Stakeholder F - Preference for objective number 1: Revenue
Valf1 = PrefF.f1val(~isnan(PrefF.f1val));       % Stakeholder F - Values for objective number 1: Revenue
Preff2 = PrefF.f2pref(~isnan(PrefF.f2pref));    % Stakeholder F - Preference for objective number 2: Tot green per house
Valf2 = PrefF.f2val(~isnan(PrefF.f2val));       % Stakeholder F - Values for objective number 2: Tot green per house
Preff3 = PrefF.f3pref(~isnan(PrefF.f3pref));    % Stakeholder F - Preference for objective number 3: Total affordable houses
Valf3 = PrefF.f3val(~isnan(PrefF.f3val));       % Stakeholder F - Values for objective number 3 : Total affordable houses
Preff4 = PrefF.f4pref(~isnan(PrefF.f4pref));    % Stakeholder F - Preference for objective number 4: Total expensive houses
Valf4 = PrefF.f4val(~isnan(PrefF.f4val));       % Stakeholder F - Values for objective number 4: Total expensive houses
Preff5 = PrefF.f5pref(~isnan(PrefF.f5pref));    % Stakeholder F - Preference for objective number 5: Houses EG (single-family)
Valf5 = PrefF.f5val(~isnan(PrefF.f5val));       % Stakeholder F - Values for objective number 5 : Houses EG (single-family)
Preff6 = PrefF.f6pref(~isnan(PrefF.f6pref));    % Stakeholder F - Preference for objective number 6:  Total number of houses
Valf6 = PrefF.f6val(~isnan(PrefF.f6val));       % Stakeholder F - Values for objective number 6: Total number of houses
Preff7 = PrefF.f7pref(~isnan(PrefF.f7pref));    % Stakeholder F - Preference for objective number 7: Total social houses
Valf7 = PrefF.f7val(~isnan(PrefF.f7val));       % Stakeholder F - Values for objective number 7: Total social houses
Preff8 = PrefF.f8pref(~isnan(PrefF.f8pref));    % Stakeholder F - Preference for objective number 8: Houses MG (multi-family)
Valf8 = PrefF.f8val(~isnan(PrefF.f8val));       % Stakeholder F - Values for objective number 8: Houses MG (multi-family)

%Preference curves Urban planner (Stedenbouwekundig) (S):
Prefs1 = PrefS.s1pref(~isnan(PrefS.s1pref));    % Stakeholder S - Preference for objective number 1: Revenue
Vals1 = PrefS.s1val(~isnan(PrefS.s1val));       % Stakeholder S - Values for objective number 1: Revenue
Prefs2 = PrefS.s2pref(~isnan(PrefS.s2pref));    % Stakeholder S - Preference for objective number 2: Tot green per house
Vals2 = PrefS.s2val(~isnan(PrefS.s2val));       % Stakeholder S - Values for objective number 2: Tot green per house
Prefs3 = PrefS.s3pref(~isnan(PrefS.s3pref));    % Stakeholder S - Preference for objective number 3: Deviation from parking norm
Vals3 = PrefS.s3val(~isnan(PrefS.s3val));       % Stakeholder S - Values for objective number 3: Deviation from parking norm
Prefs4 = PrefS.s4pref(~isnan(PrefS.s4pref));    % Stakeholder S - Preference for objective number 4: Build parking spaces
Vals4 = PrefS.s4val(~isnan(PrefS.s4val));       % Stakeholder S - Values for objective number 4: Build parking spaces
Prefs5 = PrefS.s5pref(~isnan(PrefS.s5pref));    % Stakeholder S - Preference for objective number 5: Quiet neighbourhood
Vals5 = PrefS.s5val(~isnan(PrefS.s5val));       % Stakeholder S - Values for objective number 5: Quiet neighbourhood
Prefs6 = PrefS.s6pref(~isnan(PrefS.s6pref));    % Stakeholder S - Preference for objective number 6: Total affordable houses
Vals6 = PrefS.s6val(~isnan(PrefS.s6val));       % Stakeholder S - Values for objective number 6: Total affordable houses
Prefs7 = PrefS.s7pref(~isnan(PrefS.s7pref));    % Stakeholder S - Preference for objective number 7: Houses EG (single-family)
Vals7 = PrefS.s7val(~isnan(PrefS.s7val));       % Stakeholder S - Values for objective number 7: Houses EG (single-family)
Prefs8 = PrefS.s8pref(~isnan(PrefS.s8pref));    % Stakeholder S - Preference for objective number 8: Houses MG (multi-family)
Vals8 = PrefS.s8val(~isnan(PrefS.s8val));       % Stakeholder S - Values for objective number 8: Houses MG (multi-family)
Prefs9 = PrefS.s9pref(~isnan(PrefS.s9pref));    % Stakeholder S - Preference for objective number 9: Total social houses
Vals9 = PrefS.s9val(~isnan(PrefS.s9val));       % Stakeholder S - Values for objective number 9: Total social houses
Prefs10 = PrefS.s10pref(~isnan(PrefS.s10pref)); % Stakeholder S - Preference for objective number 10: Total number of houses
Vals10 = PrefS.s10val(~isnan(PrefS.s10val));    % Stakeholder S - Values for objective number 10: Total number of houses
Prefs11 = PrefS.s11pref(~isnan(PrefS.s11pref)); % Stakeholder S - Preference for objective number 11: Total expensive houses
Vals11 = PrefS.s11val(~isnan(PrefS.s11val));    % Stakeholder S - Values for objective number 11: Total expensive houses
Prefs12 = PrefS.s12pref(~isnan(PrefS.s12pref)); % Stakeholder S - Preference for objective number 12: Healthcare center
Vals12 = PrefS.s12val(~isnan(PrefS.s12val));    % Stakeholder S - Values for objective number 12: Healthcare center

%Preference curves Municipality (Gemeente) (G):
Prefg1 = PrefG.g1pref(~isnan(PrefG.g1pref));    % Stakeholder G - Preference for objective number 1: Revenue
Valg1 = PrefG.g1val(~isnan(PrefG.g1val));       % Stakeholder G - Values for objective number 1: Revenue
Prefg2 = PrefG.g2pref(~isnan(PrefG.g2pref));    % Stakeholder G - Preference for objective number 2:  Tot green per house
Valg2 = PrefG.g2val(~isnan(PrefG.g2val));       % Stakeholder G - Values for objective number 2:  Tot green per house
Prefg3 = PrefG.g3pref(~isnan(PrefG.g3pref));    % Stakeholder G - Preference for objective number 3: Deviation from parking norm
Valg3 = PrefG.g3val(~isnan(PrefG.g3val));       % Stakeholder G - Values for objective number 3: Deviation from parking norm
Prefg4 = PrefG.g4pref(~isnan(PrefG.g4pref));    % Stakeholder G - Preference for objective number 4: Houses social (rental)
Valg4 = PrefG.g4val(~isnan(PrefG.g4val));       % Stakeholder G - Values for objective number 4: Houses social (rental)
Prefg5 = PrefG.g5pref(~isnan(PrefG.g5pref));    % Stakeholder G - Preference for objective number 5: Houses EG (single-family)
```

```
Valg5 = PrefG.g5val(~isnan(PrefG.g5val));       % Stakeholder G - Values for objective number 5: Houses EG (single-family)
Prefg6 = PrefG.g6pref(~isnan(PrefG.g6pref));    % Stakeholder G - Preference for objective number 6: Total expensive houses
Valg6 = PrefG.g6val(~isnan(PrefG.g6val));       % Stakeholder G - Values for objective number 6: Total expensive houses
Prefg7 = PrefG.g7pref(~isnan(PrefG.g7pref));    % Stakeholder G - Preference for objective number 7: Total affordable houses
Valg7 = PrefG.g7val(~isnan(PrefG.g7val));       % Stakeholder G - Values for objective number 7: Total affordable houses
Prefg8 = PrefG.g8pref(~isnan(PrefG.g8pref));    % Stakeholder G - Preference for objective number 8: Houses MG (multi-family)
Valg8 = PrefG.g8val(~isnan(PrefG.g8val));       % Stakeholder G - Values for objective number 8: Houses MG (multi-family)
Prefg9 = PrefG.g9pref(~isnan(PrefG.g9pref));    % Stakeholder G - Preference for objective number 9: Total number of houses
Valg9 = PrefG.g9val(~isnan(PrefG.g9val));       % Stakeholder G - Values for objective number 9: Total number of houses
Prefg10 = PrefG.g10pref(~isnan(PrefG.g10pref)); % Stakeholder G - Preference for objective number 10: Houses social (buy)
Valg10 = PrefG.g10val(~isnan(PrefG.g10val));    % Stakeholder G - Values for objective number 10: Houses social (buy)
Prefg11 = PrefG.g11pref(~isnan(PrefG.g11pref)); % Stakeholder G - Preference for objective number 11: Healthcare center
Valg11 = PrefG.g11val(~isnan(PrefG.g11val));    % Stakeholder G - Values for objective number 11: Healthcare center
```

Weights of objectives

Defining the relative weights that are used in the model, defined by the stakeholder over his objectives

```
Gewichten= readtable("Preferenties Waelpolder aangepast w211.xlsx", 'Sheet', 'Gewichten','PreserveVariableNames', true); % Loading weights data

W_f  = Gewichten.("Relative weight")(1:8)';     % Relative weights for stakeholder F, adds upto 1 per stakeholder
W_g  = Gewichten.("Relative weight")(9:19)';    % Relative weights for stakeholder G, adds upto 1 per stakeholder
W_s  = Gewichten.("Relative weight")(20:31)';   % Relative weights for stakeholder S, adds upto 1 per stakeholder

W_f_tot1 = W_f ./3;     % Relative weights for stakeholder F, adds upto 1 for the 3 stakeholders together
W_g_tot1 = W_g ./3;     % Relative weights for stakeholder G, adds upto 1 for the 3 stakeholders together
W_s_tot1 = W_s ./3;     % Relative weights for stakeholder S, adds upto 1 for the 3 stakeholders together

Wtot_tot1 = [W_f_tot1 W_g_tot1 W_s_tot1];       % All relative weights for all stakeholders, adds upto 1 for the 3 stakeholders together
```

Constraints

```
%Standard Matlab form is A*x <= b.
%Examples:
%For minimal number of houses x(1)+x(2)+x(3)+x(4)+x(5)>=600

A=[];

b=[];

Aeq = []; beq= [];
```

Objective function

```
    function f = objConstrFcn(x)
```

```
    % In Matlab optimization problems are always defined as minimization
    % problems. Thus, the sign of the objective function was changed to "-"
```

Relations

```
    %Houses
    Tot_woningen = x(:,1)+ x(:,2)+x(:,3)+x(:,4)+x(:,5)+x(:,6)+x(:,7)+x(:,8)+x(:,9)+x(:,10)...
                   +x(:,11)+x(:,12)+x(:,13)+x(:,14)+x(:,15)+x(:,16)+x(:,17); % Total number of houses
    Tot_schuur = x(:,10)+x(:,17);                                            % Total number of social (rental) houses
    Tot_sckoop = x(:,1)+x(:,11)+x(:,14);                                     % Total number of social (owner-occupied) houses
    Tot_duur = x(:,4)+x(:,5)+x(:,6)+x(:,7)+x(:,9)+x(:,13);                   % Total expensive houses
    Tot_betaalbaar = x(:,2)+ x(:,3)+x(:,8)+x(:,12)+x(:,15)+x(:,16);          % Total affordable houses
    Tot_sociaal = x(:,1)+x(:,10)+x(:,11)+x(:,14)+x(:,17) ;                   % Total social houses

    Tot_rij = x(:,1) + x(:,2) + x(:,3) +x(:,4) +x(:,8) +x(:,9)+ x(:,17);     % Total number of terraced houses
    Tot_2kap = x(:,5);                                                       % Total number of semidetached houses
    Tot_vrij = x(:,6) +x(:,7);                                               % Total number of detached houses
    Tot_MG = x(:,10) +x(:,11) +x(:,12) + x(:,13) +x(:,14)+x(:,15) +x(:,16);  % Total number of appartments
    Tot_EG = Tot_rij + Tot_2kap + Tot_vrij;                                  % Total number of single-family houses
    won_bebouwdpark = x(:,13) +x(:,14) +x(:,15) + x(:,16);                   % Total number of houses where there are build parking spaces

    P_bebouwdpark = won_bebouwdpark./Tot_woningen;                           % Percentage of houses with build parking spaces from total number of houses

    % Loop for the different options of the healthcare center (x(18)) and the associated values
    if (x(:,18) >= 0.5) & (x(:,18)  < 1.5)      % Option 1 (between 0.5 and 1.4): 31 units
        zorgopp = 31*21 +66;                    % Total area needed for option 1, build in 4 layers
        zorgwinst = 31* 17500;                  % Profit for 31 units
        zorgextrapark = 0;                      % No extra parking spaces needed
        Rustwonen =  repmat(0.3,size(x,1),1);   % Percentage houses that can be labeled as 'quiet living'
    elseif (x(:,18)  >= 1.5) & (x(:,18)  < 2.5) % Option 2 (between 1.5 and 2.5): 62 units
        zorgopp = 1366;                         % Standard area usage, build in 4 layers
        zorgwinst = 62*17500;                   % Profit for 62 units
        zorgextrapark = 0 ;                     % No extra parkingspaces needed
        Rustwonen = repmat(0.2,size(x,1),1);    % Percentage houses that can be labeled as 'quiet living'
    elseif (x(:,18)  >= 2.5) & (x(:,18)  < 3.5) % Option 3 (between 2.5 and 3.4): 93 units
        zorgopp = 93*18 +66;                    % Total area needed, build in 6 layers
        zorgwinst = 93*17500;                   % Profit for 93 units
        zorgextrapark = 31*0.7*12.5;            % Area for extra parking spaces (m2)
        Rustwonen =  repmat(0.0,size(x,1),1);   % Percentage houses that can be labeled as 'quiet living'
    else                                        % Option 0: 0 units
        zorgopp = 0 ;                           % No area needed
        zorgwinst = 0;                          % No profit
        zorgextrapark = 0;                      % No area for extra parking spaces
        Rustwonen = repmat(0.5,size(x,1),1);    % Percentage houses that can be labeled as 'quiet living'
    end

    % Area usage
    Tot_uitgeefbaar = sum(Uitgeef(1:17)'.*x(:,1:17),2) ;                          % Total plot area
    Minimaal_groen = min_Groen .* Tot_woningen;                                   % Minimal total area for greenery

    Tot_spelen =  sum(Spelen(1:17)'.*x(:,1:17),2);                                % Total area for a playground, dependent on total plot area

    Minimaal_parkeren =min_parkafw*(sum(Parkeren(1:17)'.*x(:,1:17),2)) +zorgextrapark;  % Minimal total area for parking, based on the minimum obtained
    Norm_parkeren = (sum(Parkeren(1:17)'.*x(:,1:17),2));                          % Total area for parking, based on standard norm (=1)
    Tot_rijbaan =  sum(Straat(1:17)'.*x(:,1:17),2);                               % Total area for road
    Tot_stoep =  sum(Stoep(1:17)'.*x(:,1:17),2);                                  % Total area for sidewalk
```

```
Tot_oppervlak =  Tot_uitgeefbaar + Minimaal_parkeren + Tot_rijbaan +Tot_stoep +...  % Total area for the number of houses
                 Tot_spelen + Minimaal_groen +zorgopp ;                             % This should be equal to the total plan area

Opvulling =  Opp_gebied -(Tot_uitgeefbaar + Minimaal_parkeren + Tot_rijbaan + ...   % Area that is 'not used' in the plans and
             Tot_stoep + Tot_spelen + Minimaal_groen +zorgopp +Opp_parkeeropl);     % will be divided between extra green and extra parkingspaces

Tot_groen = min_Groen .* Tot_woningen + Opvulling.*x(:,19);                         % Total area for greenery

Tot_parkeren =min_parkafw .* sum(Parkeren(1:17)'.*x(:,1:17),2)...                   % Total area for parking, including parking spaces for
              +zorgextrapark + Opvulling .*(1-x(:,19));                             % the healtcare center and extra parking from division factor

Tot_parkerenwon = min_parkafw .* sum(Parkeren(1:17)'.*x(:,1:17),2) + ...            % Total area for parking for the houses
                  Opvulling .*(1-x(:,19));                                          % (without healthcare complex parking spaces)

Tot_verharding = Tot_parkeren + Tot_rijbaan +Tot_stoep  ;                           % Total pavement area

Weglengte = Tot_verharding./Verhardingb;                                            % Road length and sewer length depending on total paved area

groendek = x(:,20).*12.5;                  % Area greenery on roof of parking spaces (in m2)
Tot_groen_dek = groendek + Tot_groen;      % Total greenert in the area (on parking deck and in the rest of the area)
groenwon = Tot_groen_dek./Tot_woningen;    % Total area of green per house in m2

parkafw = Tot_parkerenwon./Norm_parkeren;  % Deviation from (the standard) parking norm

% Revenues
Tot_opbrengst = ((sum(profx(1:17)'.*x(:,1:17),2))+ zorgwinst + 681000)/1000000;      % Total revenues


% Costs to develop the area
% Opr        Clearing operations
Opr1        =       Opp_gebied .*kopr(1);   %        Clearing agricultural land, incl. dumping costs
Opr2        =       Opp_gebied .*kopr(2);   %        Milling terrain
Opr3        =       Opp_gebied .*kopr(3);   %        Leveling terrain
Tot_Opr     =       Opr1 + Opr2 + Opr3;         %    Total costs clearing operations

% Oph       Elevation of the site
Oph1        =   H_oph_verharding .* Tot_verharding .*koph(1);       %        Adding sand in front of paving (delivery)
Oph2        =   H_oph_uitg .* Tot_uitgeefbaar .*koph(2);       %    Soil supply in front of the plot area (release)
Oph3        =       H_oph_groen .* Tot_groen .*koph(3);                 %    Soil supply from green space (release)

balans  = (Gr_vrij_ag+ (Weglengte .* 8.75 .* 0.4)) - (Gr_verwerken_ag + (H_oph_uitg .* Tot_uitgeefbaar) + (H_oph_groen .* Tot_groen));
tekort  = (Gr_tekort_ag+ (Weglengte .* 8.75 .* 0.4) + (H_oph_uitg .* Tot_uitgeefbaar)+ (H_oph_groen .* Tot_groen));
verdeling = ((Weglengte .* 8.75 .* 0.4) - (H_oph_uitg .* Tot_uitgeefbaar)- (H_oph_groen .* Tot_groen));
Oph4     = - ((balans ./ tekort).*verdeling).*koph(4);   %    Delivering soil shortage

Oph5        =       (Opp_gebied ./ 6 .* Lv_drain) .*koph(5);        %        Apply vertical drainage
Oph6        =       (Opp_gebied ./ 10 ) .*koph(6);              %    Apply horizontal drainage
Oph7        =       (Opp_gebied ./ 500) .*koph(7);              %    Applying sack beacons
Oph8        =       (Opp_gebied ./ 500)  .*koph(8);             %    Monitor sack beacons
Oph9        =       Opp_gebied  .*koph(9);                      %    Covering embankment
Tot_Oph     =       Oph1 + Oph2 + Oph3 + Oph4 + Oph5 + Oph6 + Oph7 + Oph8 + Oph9;   %        Total costs elevation of the site

%Gv  Soil transportation
Gv1     =   (Weglengte .* 8.75 .* 0.4) .*kgv(1);    %        Transport of soil within sub-area
Gv2     =   0 .*kgv(2);                                 %    Transport soil to other sub-area
Tot_Gv      = Gv1 + Gv2     ;                                   %    Total costs transport of soil

%Bm         Site preparation (Bouwrijp maken)
Bm1     =   (Weglengte .* 8.75 .* 0.4) .*kbm(1);    %        Excavated sewer trench (soil)
Bm2     =   Weglengte.*8.75.*0.6 .*kbm(2);          %        Excavated sewer trench (sand, reuse)
Bm3     =   Weglengte .*kbm(3);                         %    Applying drainage
Bm4     =   Weglengte .*kbm(4);                         %    Laying sewer DWA including manholes
Bm5     =   Tot_woningen .*kbm(5);                  %        Installation of house connections DWA
Bm6     =   0 .*kbm(6);                                 %    Connecting DWA to existing sewer
Bm7     =   Weglengte .*kbm(7);                         %    Installation of sewer HWA including manholes
Bm8     =   Tot_woningen .*kbm(8);                  %        Installation of house connections HWA
Bm9     =   0 .*kbm(9);                                 %    Connecting HWA to existing sewer
Bm10        =       (Tot_verharding ./ 100) .*kbm(10);          %    Installing gully connections
Bm11        =       Weglengte .*kbm(11);                    %        Installing drainage p90 incl. manholes
Bm12        =       ((Weglengte .* 8.75 .* 0.4)+ (Weglengte.*8.75.*0.6)) .*kbm(12);     %        Fill up sewer trench with sand incl. compaction
Bm13        =       (Weglengte.*8.75.* 0.4) .*kbm(13);          %    Delivering missing sand
Bm14        =       0.02 .* (Bm1+ Bm2+ Bm3+ Bm4+ Bm5+ Bm6+ Bm7+ Bm8+ Bm9+ Bm10+ Bm11+ Bm12+ Bm13); %        Temporary provisions sewerage
Bm15        =       2 .* Weglengte .*kbm(15);                   %    Overhaul and inspection sewers
Bm16        =       Weglengte .* 6  .*kbm(16);                  %    Construction of granulate road
Bm17        =       Weglengte .* 6 *kbm(17);                    %    Maintenance construction road granulate
Bm18        =       (0.05 .* Weglengte .* 6) .*kbm(18);         %    Temporary pavements
Bm19        =       300 .* 2 .*kbm(19)-44010;                   %    Installation of shoring equipment
Tot_Bm      =       Bm1 + Bm2 + Bm3 + Bm4 + Bm5 + Bm6 + Bm7 + Bm8 + Bm9 + Bm10 +...
            Bm11 + Bm12 + Bm13 + Bm14 + Bm15 + Bm16 + Bm17 + Bm18 +Bm19;        %    Total costs site preparation

%Wm   Hard and soft landscaping (Woonrijp maken)
Wm1     =   (Weglengte .* 6)  .*kwm(1);                 %    Filling out foundation construction roads
Wm2     =   (Weglengte .* 6 .* 0.05) .*kwm(2);          %    Removing temporary pavements
Wm3     =   H_zand .* Tot_verharding  .*kwm(3);         %    Adding sand in front of pavement

Wm5     =   Tot_verharding .* p_rij .*kwm(5);       %        Installing baked pavement and edge protections (traffic lane)
Wm6     =   Tot_verharding .* p_park .*kwm(6);          %    Install concrete pavement and edge closures (parking)
Wm7     =   Tot_verharding .* p_stoep .*kwm(7);         %    Install concrete pavers edging (sidewalk)
Wm4     =   (Tot_verharding .* p_rij + Tot_verharding .* p_park + Tot_verharding .* p_stoep ) .*kwm(4);     %        Apply street layer

Wm8     =   ( Tot_verharding .* p_rij).* 0.05 .*kwm(8);     %        Apply traffic calming mat measures
Wm9     =   ( Tot_verharding .* p_rij + Tot_verharding .* p_park + Tot_verharding .* p_stoep ) .*kwm(9);    %        Maintain pavements
Wm10        =       ((2.* Weglengte) ./ 35) .*kwm(10);          %    Leveling manhole cover edges
Wm11        =       (Tot_verharding ./ 100) .*kwm(11);          %    Installing gullies
Wm12        =       (Weglengte./ Af_Lm) .*kwm(12);          %        Installing lighting incl. cable
Wm13        =       Opp_gebied .*kwm(13);                   %        Adding traffic signs/street name signs
Wm14        =       Opp_gebied .*kwm(14);                   %        Installation of street furniture
Wm15        =       H_teelaarde .* Tot_groen .*kwm(15);         %    Applying soil in green areas
Wm16        =       0.3 .* Tot_groen .*kwm(16);                 %    Applying planting
Wm17        =       (Weglengte ./ Af_bomen)  .*kwm(17);     %        Applying avenue tree in pavement incl. soil improvement
Wm18        =       (Weglengte ./ Af_bomen  .* 10    ) .*kwm(18) ;      %    Applying root guide trees in pavement
Wm19        =       0.7 .* Tot_groen *kwm(19);                          %        Fertilize and sow lawns
Wm20        =       ( 0.3 .* Tot_groen +0.7 .* Tot_groen) .*kwm(20);    %        Maintenance of green spaces
Wm21        =       (Weglengte ./ Af_bomen) .*kwm(21);                  %        Maintenance trees
Tot_Wm      =       Wm1 + Wm2 + Wm3 + Wm4 + Wm5 + Wm6 + Wm7 + Wm8 + Wm9 + Wm10+...
            Wm11 + Wm12 + Wm13 + Wm14 + Wm15 + Wm16 + Wm17 + Wm18 + Wm19 + Wm20 + Wm21;         %    Total costs hard and soft landscaping

%Awe         Additional work elements
Awe1        = 2 .*kawe(1);          %        Outflow basins culverts
```

```
Awe2        = 1 .*kawe(2);          %        Culverts within development fields
Awe3        = 1 .*kawe(3);          %        Constructing play facility
Tot_Awe     =       Awe1 + Awe2 + Awe3;     %        Total costs additional work elements

% Costs parking deck (parkingspaces with a roof)
Tot_pdek = x(:,20) * K_parkeerdek; %  Total cost for parking spaces with parking deck

Tot_kos = Tot_Opr + Tot_Oph + Tot_Gv + Tot_Bm + Tot_Wm + Tot_Awe + Tot_pdek ; % Total cost to develop/build area

%Ik  (In)directe kosten
Ik1 =       Tot_kos;                                %        Direct costs
Ik2 =       Tot_kos.*0.07;                      %    Non-recurring costs, construction site costs, implementation costs
Ik3 =       (Tot_kos + Tot_kos.*0.07).*0.115;       %        AK, WR. Contributions (e.g. RAW/FCO)
Ik4 =       0.*Tot_kos;                             %        Contingencies
Tot_Ik      =       Ik1 + Ik2 + Ik3 + Ik4;          %        Total costs Including indirect costs

Tot_kosten = Tot_Ik/1000000;                %    Total costs including indirect costs expressed in millions

Tot_Saldo = (Tot_opbrengst- Tot_kosten);    %    Result after optimalisation
```

Preference scores

```
% Preference Stakeholder F
Preffun_f1 = pchip(Valf1, Preff1, Tot_opbrengst);  % Preference function over objective F1
Preffun_f2 = pchip(Valf2, Preff2, groenwon);       % Preference function over objective F2
Preffun_f3 = pchip(Valf3, Preff3, Tot_betaalbaar); % Preference function over objective F3
Preffun_f4 = pchip(Valf4, Preff4, Tot_duur);       % Preference function over objective F4
Preffun_f5 = pchip(Valf5, Preff5, Tot_EG);         % Preference function over objective F5
Preffun_f6 = pchip(Valf6, Preff6, Tot_woningen);   % Preference function over objective F6
Preffun_f7 = pchip(Valf7, Preff7, Tot_sociaal);    % Preference function over objective F7
Preffun_f8 = pchip(Valf8, Preff8, Tot_MG);         % Preference function over objective F8

Preffun_f = [Preffun_f1 Preffun_f2 Preffun_f3 Preffun_f4 Preffun_f5 Preffun_f6 Preffun_f7 Preffun_f8]; % Preferences for all objectives of stakeholder F
                                                                                                        % in one array

% Preference Stakeholder G
Preffun_g1 = pchip(Valg1, Prefg1, Tot_opbrengst);  % Preference function over objective G1
Preffun_g2 = pchip(Valg2, Prefg2, groenwon);       % Preference function over objective G2
Preffun_g3 = pchip(Valg3, Prefg3, parkafw);        % Preference function over objective G3
Preffun_g4 = pchip(Valg4, Prefg4, Tot_schuur);     % Preference function over objective G4
Preffun_g5 = pchip(Valg5, Prefg5, Tot_EG);         % Preference function over objective G5
Preffun_g6 = pchip(Valg6, Prefg6, Tot_duur);       % Preference function over objective G6
Preffun_g7 = pchip(Valg7, Prefg7, Tot_betaalbaar); % Preference function over objective G7
Preffun_g8 = pchip(Valg8, Prefg8, Tot_MG);         % Preference function over objective G8
Preffun_g9 = pchip(Valg9, Prefg9, Tot_woningen);   % Preference function over objective G9
Preffun_g10 = pchip(Valg10, Prefg10, Tot_sckoop);  % Preference function over objective G10
Preffun_g11 = pchip(Valg11, Prefg11, x(:,18));     % Preference function over objective G11

Preffun_g = [Preffun_g1 Preffun_g2 Preffun_g3 Preffun_g4 Preffun_g5 Preffun_g6 Preffun_g7 Preffun_g8 Preffun_g9 Preffun_g10 Preffun_g11]; % Preferences
                                                                                                      % for all objectives of stakeholder G in one array

% Preference Stakeholder S
Preffun_s1 = pchip(Vals1, Prefs1, Tot_opbrengst);  % Preference function over objective S1
Preffun_s2 = pchip(Vals2, Prefs2, groenwon);       % Preference function over objective S2
Preffun_s3 = pchip(Vals3, Prefs3, parkafw);        % Preference function over objective S3
Preffun_s4 = pchip(Vals4, Prefs4, P_bebouwdpark);  % Preference function over objective S4
Preffun_s5 = pchip(Vals5, Prefs5, Rustwonen);      % Preference function over objective S5
Preffun_s6 = pchip(Vals6, Prefs6, Tot_betaalbaar); % Preference function over objective S6
Preffun_s7 = pchip(Vals7, Prefs7, Tot_EG);         % Preference function over objective S7
Preffun_s8 = pchip(Vals8, Prefs8, Tot_MG);         % Preference function over objective S8
Preffun_s9 = pchip(Vals9, Prefs9, Tot_sociaal);    % Preference function over objective S9
Preffun_s10 = pchip(Vals10, Prefs10, Tot_woningen);% Preference function over objective S10
Preffun_s11 = pchip(Vals11, Prefs11, Tot_duur);    % Preference function over objective S11
Preffun_s12 = pchip(Vals12, Prefs12, x(:,18));     % Preference function over objective S12

Preffun_s = [Preffun_s1 Preffun_s2 Preffun_s3 Preffun_s4 Preffun_s5 Preffun_s6 Preffun_s7 Preffun_s8 Preffun_s9 Preffun_s10 Preffun_s11 Preffun_s12];
                                                                                    % Preferences for all objectives of stakeholder S in one array

P = [Preffun_f Preffun_g Preffun_s];               % All preferences together
```

Optimisation value

```
W_gg = repmat(Wtot_tot1,size(x,1),1);
f.Fval = - sum(W_gg .* P,2);            %optimisation fuction

% Common constraints
f.Ineq(:,1) =  + ( Tot_oppervlak +Opp_parkeeropl + Opvulling ) -  Opp_gebied  -0.001;  % Maximum plan area
f.Ineq(:,2) = - (Tot_oppervlak+Opp_parkeeropl  +Opvulling )+  Opp_gebied  -0.001;      % Minimum plan area
f.Ineq(:,3) = - Opvulling + 0.001;                                                     % The 'unused area' cannot be below zero

% Constrainst greenery/parking
f.Ineq(:,4) =    (groenwon) -50;                                                       % Maximum green per house
f.Ineq(:,5) =    (parkafw) -1.5;                                                       % Maximum deviation from parking norm
f.Ineq(:,6) =    -(groenwon) + min_Groen;                                              % Minimum green per house
f.Ineq(:,7) =    -(parkafw) +min_parkafw;                                              % Minimum deviation from parking norm
f.Ineq(:,8) =    (groendek) -0.7 .* Tot_parkerenwon;                                   % Maximum area of parking spaces with a roof

%Constraints wonen
f.Ineq(:,9) = x(:,1) + x(:,2) + x(:,3) +x(:,4) +x(:,5) +x(:,6) +x(:,7) +x(:,8) +x(:,9) +x(:,10)... % Maximum number of houses
              +x(:,11) +x(:,12) + x(:,13) +x(:,14) +x(:,15) + x(:,16)+ x(:,17)- 211 ;
f.Ineq(:,10) = - ( x(:,1) +x(:,10) +x(:,11) +x(:,14) +x(:,17)) +144;                           % Minimum total social houses
f.Ineq(:,11) = -( x(:,2) + x(:,3) +x(:,8) +x(:,12) +x(:,15) + x(:,16)) + 34 ;                  % Minimum affordable houses
f.Ineq(:,12) = - ( x(:,10)+ x(:,17) ) + 104;                                                   % Minimum social rental houses
```

```
end

% Fill in a title for the run that will be showed above the design in the output Excel
name = "V6 W211 surrogate, max pref, gr7 pp0.9, ";
```

Options

Set of options for the Surrogate optimization

```
surropt = optimoptions(@surrogateopt, ...
                    'MaxFunctionEvaluations', 1000, ...
                    'MinSurrogatePoints', 60,...
                    'MinSampleDistance', 1e-11,...
                    'ConstraintTolerance', 1e-6,...
                    'Display', 'iter',...
                    'UseVectorized',true,...
                    'PlotFcn',{@surrogateoptplot,@optimplotx});
```

First optimisation

The first optimization will be run with Surrogate optimization

```
tic;                    % Start moment to Calculate the runtime
rng('shuffle');

% Intial population used when needed, for exaplme when a run needs to be done again or start from this point
% surropt.InitialPoints = [1    11      8       0       4       4       4       5       0       118     1       0       0       18      25      12      6       0       0.9622124       50]


% Surrogate optimization
 [xbest, fbest, exitflag ] = surrogateopt(@objConstrFcn, lb, ub,IntCon, A, b, Aeq, beq, surropt);
% xbest = retuns 20 best values of x (design variables)
% fbest = optimisation value
% exitflag = indicates the type of solution found or problems

x_out = [xbest';fbest];         % Defining an output variable consisting of xbest and fbest
assignin('base','x_out',x_out)  % Display(x_out) in the output Excel

Duurrun = toc;          % Calculates the runtime;
```

Calculations of the relations with xbest

Filling in the xbest values in the relation

```
%Houses
    Tot_woningen = xbest(:,1) + xbest(:,2) + xbest(:,3) +xbest(:,4) +xbest(:,5) +xbest(:,6) +xbest(:,7) +xbest(:,8) +xbest(:,9) +xbest(:,10)...
                +xbest(:,11) +xbest(:,12) + xbest(:,13) +xbest(:,14) +xbest(:,15) + xbest(:,16)+ xbest(:,17); % Total number of houses
    Tot_schuur = xbest(:,10)+ xbest(:,17); % Total number of social (rental) houses
    Tot_sckoop = xbest(:,1) + xbest(:,11) + xbest(:,14); % Total number of social (owner-occupied) houses
    Tot_duur = xbest(:,4) +xbest(:,5) +xbest(:,6) +xbest(:,7) +xbest(:,9) +xbest(:,13); % Total expensive houses
    Tot_betaalbaar =  xbest(:,2) + xbest(:,3) +xbest(:,8) +xbest(:,12) +xbest(:,15) + xbest(:,16); % Total affordable houses
    Tot_sociaal =   xbest(:,1) +xbest(:,10) +xbest(:,11) +xbest(:,14)+ xbest(:,17) ;  % Total social houses

    Tot_rij = xbest(:,1) + xbest(:,2) + xbest(:,3) +xbest(:,4) +xbest(:,8) +xbest(:,9)+ xbest(:,17); % Total number of terraced houses
    Tot_2kap = xbest(:,5); % Total number of semidetached houses
    Tot_vrij = xbest(:,6) +xbest(:,7); % Total number of detached houses
    Tot_MG = xbest(:,10) +xbest(:,11) +xbest(:,12) + xbest(:,13) +xbest(:,14) +xbest(:,15) + xbest(:,16);  % Total number of appartments
    Tot_EG = Tot_rij + Tot_2kap + Tot_vrij; % Total number of single-family houses
    won_bebouwdpark = xbest(:,13) +xbest(:,14) +xbest(:,15) + xbest(:,16); % Total number of houses where there are build parking spaces

    P_bebouwdpark = won_bebouwdpark./Tot_woningen; % Percentage of houses with build parking spaces from total number of houses

%loop zorgcomplex
    if (xbest(:,18) >= 0.5) & (xbest(:,18)  < 1.5)  % Option 1 (between 0.5 and 1.4): 31 units
        zorgopp = 31*21 +66;                        % Total area needed for option 1, build in 4 layers
        zorgwinst = 31* 17500;                      % Profit for 31 units
        zorgextrapark = 0;                          % No extra parking spaces needed
        Rustwonenb =  0.3 ;                         % Percentage houses that can be labeled as 'quiet living'
        zorgoptie = 31;                             %  Amount of units with the corresponding option
    elseif (xbest(:,18)  >= 1.5) & (xbest(:,18)  < 2.5) % Option 2 (between 1.5 and 2.5): 62 units
        zorgopp = 1366;                             % Standard area usage, build in 4 layers
        zorgwinst = 62*17500;                       % Profit for 62 units
        zorgextrapark = 0 ;                         % No extra parkingspaces needed
        Rustwonenb =  0.2 ;                         % Percentage houses that can be labeled as 'quiet living'
        zorgoptie = 62;                             %  Amount of units with the corresponding option
    elseif (xbest(:,18)  >= 2.5) & (xbest(:,18)  < 3.5) % Option 3 (between 2.5 and 3.4): 93 units
        zorgopp = 93*18 +66;                        % Total area needed, build in 6 layers
        zorgwinst = 93*17500;                       % Profit for 93 units
        zorgextrapark = 31*0.7*12.5;                % Area for extra parking spaces (m2)
        Rustwonenb =  0.0 ;                         % Percentage houses that can be labeled as 'quiet living'
        zorgoptie = 93;                             % Amount of units with the corresponding option
    else                                            % Option 0: 0 units
        zorgopp = 0 ;                               % No area needed
        zorgwinst = 0;                              % No profit
        zorgextrapark = 0;                          % No area for extra parking spaces
        Rustwonenb =  0.5 ;                         % Percentage houses that can be labeled as 'quiet living'
        zorgoptie = 0;                              % Amount of units with the corresponding option
    end

    % Area usage

    Tot_uitgeefbaar =  sum(Uitgeef(1:17)'.*xbest(:,1:17),2);   % Total plot area
    Minimaal_groen = min_Groen .* Tot_woningen ; % Minimal total area for greenery
    Tot_spelen =  sum(Spelen(1:17)'.*xbest(:,1:17),2)  ; % Total area for a playground, dependent on total plot area

    Minimaal_parkeren =min_parkafw.*(sum(Parkeren(1:17)'.*xbest(:,1:17),2)) + zorgextrapark; % Minimal total area for parking, based on the minimum obtained
    Norm_parkeren = (sum(Parkeren(1:17)'.*xbest(:,1:17),2)); % Total area for parking, based on standard norm (=1)

    Tot_rijbaan =  sum(Straat(1:17)'.*xbest(:,1:17),2); % Total area for road
    Tot_stoep =  sum(Stoep(1:17)'.*xbest(:,1:17),2);  % Total area for sidewalk
    Tot_verharding = Tot_parkeren + Tot_rijbaan +Tot_stoep ; % Total pavement area

    Tot_oppervlak =  Tot_uitgeefbaar + Minimaal_parkeren + Tot_rijbaan +Tot_stoep... % Total area for the number of houses
                    + Tot_spelen + Minimaal_groen +zorgopp ;                          % This should be equal to the total plan area

    Opvulling = Opp_gebied -(Tot_uitgeefbaar + Minimaal_parkeren + Tot_rijbaan...     % Area that is 'not used' in the plans and
                +Tot_stoep + Tot_spelen + Minimaal_groen +zorgopp +Opp_parkeeropl);   % will be divided between extra green and extra parkingspaces

    Tot_groen = min_Groen .* Tot_woningen + Opvulling.*xbest(:,19); % Total area for greenery

    Tot_parkeren = min_parkafw .* sum(Parkeren(1:17)'.*xbest(:,1:17),2)...  % Total area for parking, including parking spaces for
                 + zorgextrapark + Opvulling.*(1-xbest(:,19));              % the healtchare center and extra parking from division factor

    Tot_parkerenwon = min_parkafw .*sum(Parkeren(1:17)'.*xbest(:,1:17),2) + ... % Total area for parking for the houses
                      Opvulling .*(1-xbest(:,19));                              % (without healthcare complex parking spaces)
```

```
Tot_verharding = Tot_parkeren + Tot_rijbaan +Tot_stoep ;                % Total pavement area

Weglengte = Tot_verharding/Verhardingb; % Road length and sewer length depending on total paved area

groendek = xbest(:,20).*12.5;                  % Area greenery on roof of parking spaces (in m2)
Tot_groen_dek = groendek + Tot_groen;      % Total greenert in the area (on parking deck and in the rest of the area)
groenwon = Tot_groen_dek./Tot_woningen;    % Total area of green per house in m2
parkafw = Tot_parkerenwon./Norm_parkeren;  % Deviation from (the standard) parking norm

P_parkeerdek = (xbest(:,20).*12.5 ./ Tot_parkerenwon)*100 ; % Pecentage parkeren onder een dek van
```

Final Costs to develop the area

```
%Opr        Opruimingswerkzaamheden
Opr1        =       Opp_gebied .*kopr(1);   %       Clearing agricultural land, incl. dumping costs
Opr2        =       Opp_gebied .*kopr(2);   %       Milling terrain
Opr3        =       Opp_gebied .*kopr(3);   %       Leveling terrain
Tot_Opr     =       Opr1 + Opr2 + Opr3;         %   Total costs clearing operations


% Oph       Elevation of the site
Oph1        =   H_oph_verharding .* Tot_verharding .*koph(1);       %       Adding sand in front of paving (delivery)
Oph2        =   H_oph_uitg .* Tot_uitgeefbaar .*koph(2);        %    Soil supply in front of the plot area (release)
Oph3        =       H_oph_groen .* Tot_groen .*koph(3);                 %       Soil supply from green space (release)

balans  = (Gr_vrij_ag+ (Weglengte .* 8.75 .* 0.4)) - (Gr_verwerken_ag + (H_oph_uitg .* Tot_uitgeefbaar) + (H_oph_groen .* Tot_groen));
tekort  = (Gr_tekort_ag+ (Weglengte .* 8.75 .* 0.4)+ (H_oph_uitg .* Tot_uitgeefbaar)+ (H_oph_groen .* Tot_groen));
verdeling = ((Weglengte .* 8.75 .* 0.4) - (H_oph_uitg .* Tot_uitgeefbaar)- (H_oph_groen .* Tot_groen));
Oph4     = - ((balans ./ tekort).*verdeling).*koph(4);   %    Delivering soil shortage


Oph5        =       (Opp_gebied ./ 6 .* Lv_drain) .*koph(5);        %       Apply vertical drainage
Oph6        =       (Opp_gebied ./ 10 ) .*koph(6);              %    Apply horizontal drainage
Oph7        =       (Opp_gebied ./ 500) .*koph(7);              %    Applying sack beacons
Oph8        =       (Opp_gebied ./ 500)  .*koph(8);             %    Monitor sack beacons
Oph9        =       Opp_gebied  .*koph(9);                      %    Covering embankment
Tot_Oph     =       Oph1 + Oph2 + Oph3 + Oph4 + Oph5 + Oph6 + Oph7 + Oph8 + Oph9;    %       Total costs elevation of the site

%Gv  Soil transportation
Gv1     =   (Weglengte .* 8.75 .* 0.4) .*kgv(1);    %       Transport of soil within sub-area
Gv2     =   0 .*kgv(2);                                 %    Transport soil to other sub-area
Tot_Gv      = Gv1 + Gv2     ;                                   %    Total costs transport of soil

%Bm         Site preparation (Bouwrijp maken)
Bm1     =   (Weglengte .* 8.75 .* 0.4) .*kbm(1);    %       Excavated sewer trench (soil)
Bm2     =   Weglengte.*8.75.*0.6 .*kbm(2);          %       Excavated sewer trench (sand, reuse)
Bm3     =   Weglengte .*kbm(3);                         %    Applying drainage
Bm4     =   Weglengte .*kbm(4);                         %    Laying sewer DWA including manholes
Bm5     =   Tot_woningen .*kbm(5);                  %       Installation of house connections DWA
Bm6     =   0 .*kbm(6);                                 %    Connecting DWA to existing sewer
Bm7     =   Weglengte .*kbm(7);                         %    Installation of sewer HWA including manholes
Bm8     =   Tot_woningen .*kbm(8);                  %       Installation of house connections HWA
Bm9     =   0 .*kbm(9);                                 %    Connecting HWA to existing sewer
Bm10        =       (Tot_verharding ./ 100) .*kbm(10);          %    Installing gully connections
Bm11        =       Weglengte .*kbm(11);                    %       Installing drainage p90 incl. manholes
Bm12        =       ((Weglengte .* 8.75 .* 0.4)+ (Weglengte.*8.75.*0.6)) .*kbm(12);         %       Fill up sewer trench with sand incl. compaction
Bm13        =       (Weglengte.*8.75.* 0.4) .*kbm(13);          %    Delivering missing sand
Bm14        =       0.02 .* (Bm1+ Bm2+ Bm3+ Bm4+ Bm5+ Bm6+ Bm7+ Bm8+ Bm9+ Bm10+ Bm11+ Bm12+ Bm13); %        Temporary provisions sewerage
Bm15        =       2 .* Weglengte .*kbm(15);                   %    Overhaul and inspection sewers
Bm16        =       Weglengte .* 6  .*kbm(16);                  %    Construction of granulate road
Bm17        =       Weglengte .* 6 *kbm(17);                    %    Maintenance construction road granulate
Bm18        =       (0.05 .* Weglengte .* 6) .*kbm(18);         %    Temporary pavements
Bm19        =       300 .* 2 .*kbm(19)-44010;                   %    Installation of shoring equipment
Tot_Bm      =       Bm1 + Bm2 + Bm3 + Bm4 + Bm5 + Bm6 + Bm7 + Bm8 + Bm9 + Bm10 +...
            Bm11 + Bm12 + Bm13 + Bm14 + Bm15 + Bm16 + Bm17 + Bm18 +Bm19;        %    Total costs site preparation

%Wm   Hard and soft landscaping (Woonrijp maken)
Wm1     =   (Weglengte .* 6)  .*kwm(1);                 %    Filling out foundation construction roads
Wm2     =   (Weglengte .* 6 .* 0.05) .*kwm(2);          %    Removing temporary pavements
Wm3     =   H_zand .* Tot_verharding  .*kwm(3);         %    Adding sand in front of pavement

Wm5     =   Tot_verharding .* p_rij .*kwm(5);       %       Installing baked pavement and edge protections (traffic lane)
Wm6     =   Tot_verharding .* p_park .*kwm(6);          %    Install concrete pavement and edge closures (parking)
Wm7     =   Tot_verharding .* p_stoep .*kwm(7);         %    Install concrete pavers edging (sidewalk)
Wm4     =   (Tot_verharding .* p_rij + Tot_verharding .* p_park + Tot_verharding .* p_stoep ) .*kwm(4);     %       Apply street layer

Wm8     =   ( Tot_verharding .* p_rij).* 0.05 .*kwm(8);     %       Apply traffic calming mat measures
Wm9     =   ( Tot_verharding .* p_rij + Tot_verharding .* p_park + Tot_verharding .* p_stoep ) .*kwm(9);    %       Maintain pavements
Wm10        =       ((2.* Weglengte) ./ 35) .*kwm(10);          %    Leveling manhole cover edges
Wm11        =       (Tot_verharding ./ 100) .*kwm(11);          %    Installing gullies
Wm12        =       (Weglengte./ Af_Lm) .*kwm(12);          %       Installing lighting incl. cable
Wm13        =       Opp_gebied .*kwm(13);                   %       Adding traffic signs/street name signs
Wm14        =       Opp_gebied .*kwm(14);                   %       Installation of street furniture
Wm15        =       H_teelaarde .* Tot_groen .*kwm(15);         %    Applying soil in green areas
Wm16        =       0.3 .* Tot_groen .*kwm(16);                 %    Applying planting
Wm17        =       (Weglengte ./ Af_bomen)  .*kwm(17);     %       Applying avenue tree in pavement incl. soil improvement
Wm18        =       (Weglengte ./ Af_bomen  .* 10   ) .*kwm(18) ;       %       Applying root guide trees in pavement
Wm19        =       0.7 .* Tot_groen *kwm(19);                          %       Fertilize and sow lawns
Wm20        =       ( 0.3 .* Tot_groen +0.7 .* Tot_groen) .*kwm(20);    %       Maintenance of green spaces
Wm21        =       (Weglengte ./ Af_bomen) .*kwm(21);                  %       Maintenance trees
Tot_Wm      =       Wm1 + Wm2 + Wm3 + Wm4 + Wm5 + Wm6 + Wm7 + Wm8 + Wm9 + Wm10+...
            Wm11 + Wm12 + Wm13 + Wm14 + Wm15 + Wm16 + Wm17 + Wm18 + Wm19 + Wm20 + Wm21;         %    Total costs hard and soft landscaping

%Awe         Additional work elements
Awe1        = 2 .*kawe(1);          %       Outflow basins culverts
Awe2        = 1 .*kawe(2);          %       Culverts within development fields
Awe3        = 1 .*kawe(3);          %       Constructing play facility
Tot_Awe     =       Awe1 + Awe2 + Awe3;     %       Total costs additional work elements

% Costs parking deck (parkingspaces with a roof)
Tot_pdek = xbest(:,20) * K_parkeerdek; %  Total cost for parking spaces with parking deck

Tot_kos = Tot_Opr + Tot_Oph + Tot_Gv + Tot_Bm + Tot_Wm + Tot_Awe + Tot_pdek ; %Totale kosten voor ontwikkelen/aanleggen gebied

%Ik  (In)directe kosten
Ik1 =       Tot_kos;                                %       Direct costs
Ik2 =       Tot_kos.*0.07;                      %    Non-recurring costs, construction site costs, implementation costs
Ik3 =       (Tot_kos + Tot_kos.*0.07).*0.115;       %       AK, WR. Contributions (e.g. RAW/FCO)
```

```
Ik4 =       0.*Tot_kos;                          %       Contingencies
Tot_Ik      =       Ik1 + Ik2 + Ik3 + Ik4;          %       Total costs Including indirect costs

Tot_kosten = Tot_Ik/1000000; % Total costs including indirect costs

% Revenues
Tot_opbrengst = ((sum(profx(1:17)'.*xbest(:,1:17),2)) + zorgwinst + 681000)/1000000; %Total revenues

%Result
Tot_Saldo = (Tot_opbrengst-Tot_kosten); % Result after optimalisation
```

Final preference based on optimization values (xbest)

```
% Preference Stakeholder F (Financial director)
Preffun_f1 = pchip(Valf1, Preff1, Tot_opbrengst); %Preference function over objective F1
Preffun_f2 = pchip(Valf2, Preff2, groenwon); %Preference function over objective F2
Preffun_f3 = pchip(Valf3, Preff3, Tot_betaalbaar); %Preference function over objective F3
Preffun_f4 = pchip(Valf4, Preff4, Tot_duur); %Preference function over objective F4
Preffun_f5 = pchip(Valf5, Preff5, Tot_EG); %Preference function over objective F5
Preffun_f6 = pchip(Valf6, Preff6, Tot_woningen); %Preference function over objective F6
Preffun_f7 = pchip(Valf7, Preff7, Tot_sociaal); %Preference function over objective F7
Preffun_f8 = pchip(Valf8, Preff8, Tot_MG); %Preference function over objective F8

Preffun_fbest = [Preffun_f1 Preffun_f2 Preffun_f3 Preffun_f4 Preffun_f5...    % Preferences for all objectives of stakeholder F in one array
                 Preffun_f6 Preffun_f7 Preffun_f8];

% Preference Stakeholder G (Municipality)
Preffun_g1 = pchip(Valg1, Prefg1, Tot_opbrengst); %Preference function over objective G1
Preffun_g2 = pchip(Valg2, Prefg2, groenwon); %Preference function over objective G2
Preffun_g3 = pchip(Valg3, Prefg3, parkafw); %Preference function over objective G3
Preffun_g4 = pchip(Valg4, Prefg4, Tot_schuur); %Preference function over objective G4
Preffun_g5 = pchip(Valg5, Prefg5, Tot_EG); %Preference function over objective G5
Preffun_g6 = pchip(Valg6, Prefg6, Tot_duur); %Preference function over objective G6
Preffun_g7 = pchip(Valg7, Prefg7, Tot_betaalbaar); %Preference function over objective G7
Preffun_g8 = pchip(Valg8, Prefg8, Tot_MG); %Preference function over objective G8
Preffun_g9 = pchip(Valg9, Prefg9, Tot_woningen); %Preference function over objective G9
Preffun_g10 = pchip(Valg10, Prefg10, Tot_sckoop); %Preference function over objective G10
Preffun_g11 = pchip(Valg11, Prefg11, xbest(:,18)); %Preference function over objective G11

Preffun_gbest = [Preffun_g1 Preffun_g2 Preffun_g3 Preffun_g4 Preffun_g5 Preffun_g6...  % Preferences for all objectives of stakeholder G in one array
                 Preffun_g7 Preffun_g8 Preffun_g9 Preffun_g10 Preffun_g11];

% Preference Stakeholder S (Urban planner)
Preffun_s1 = pchip(Vals1, Prefs1, Tot_opbrengst); %Preference function over objective S1
Preffun_s2 = pchip(Vals2, Prefs2, groenwon); %Preference function over objective S2
Preffun_s3 = pchip(Vals3, Prefs3, parkafw); %Preference function over objective S3
Preffun_s4 = pchip(Vals4, Prefs4, P_bebouwdpark); %Preference function over objective S4
Preffun_s5 = pchip(Vals5, Prefs5, Rustwonenb); %Preference function over objective S5
Preffun_s6 = pchip(Vals6, Prefs6, Tot_betaalbaar); %Preference function over objective S6
Preffun_s7 = pchip(Vals7, Prefs7, Tot_EG); %Preference function over objective S7
Preffun_s8 = pchip(Vals8, Prefs8, Tot_MG); %Preference function over objective S8
Preffun_s9 = pchip(Vals9, Prefs9, Tot_sociaal); %Preference function over objective S9
Preffun_s10 = pchip(Vals10, Prefs10, Tot_woningen); %Preference function over objective S10
Preffun_s11 = pchip(Vals11, Prefs11, Tot_duur); %Preference function over objective S11
Preffun_s12 = pchip(Vals12, Prefs12, xbest(:,18)); %Preference function over objective S12

Preffun_sbest = [Preffun_s1 Preffun_s2 Preffun_s3 Preffun_s4 Preffun_s5 Preffun_s6 ...  % Preferences for all objectives of stakeholder S in one array
                 Preffun_s7 Preffun_s8 Preffun_s9 Preffun_s10 Preffun_s11 Preffun_s12];

Pbest = [Preffun_fbest Preffun_gbest Preffun_sbest]; %All preferences together in an array
```

Second optimization: 1 solution in Tetra (using xbest)

```
PrefbestT = [Pbest];
Tetrabest = Tetra_solver2(Wtot_tot1,PrefbestT);
```

Distance from goal

To compare with the goal attainment method

```
D_fin= 100 - Preffun_fbest; % distance from goal (a 100 preference score) per objective for Financial director
D_gemeente = 100- Preffun_gbest;  % distance from goal (a 100 preference score) per objective for Urban planner
D_steden = 100- Preffun_sbest;  % distance from goal (a 100 preference score) per objective for Municipality

Dist_fin = W_f .* D_fin; % distance from goal (a 100 preference score) per objective times the weight per objective for Financial director
Dist_gemeente = W_g .* D_gemeente;  % distance from goal (a 100 preference score) per objective times the weight per objective for Urban planner
Dist_steden= W_s .* D_steden; % distance from goal (a 100 preference score) per objective times the weight per objective for Municipality

maxDist = max([Dist_fin,Dist_gemeente,Dist_steden]); % the maximal distance of 1 objective of the three staekholders
maxdist_fin = max(Dist_fin); % the maximal distance of 1 objective of Financial director
maxdist_gemeente = max(Dist_gemeente); % the maximal distance of 1 objective of Municipality
maxdist_steden = max(Dist_steden); % the maximal distance of 1 objective of Urbanp lanner
sumdist_fin = sum(Dist_fin); %Total (all objectives) distance for Financial director
sumdist_gemeente = sum(Dist_gemeente); %Total (all objectives) distance for Municipality
sumdist_steden = sum(Dist_steden); %Total (all objectives) distance for Urban planner
```

Display

Several values that are displayed after running the model. The purple text indicatates what value is displayed

```
display(Duurrun,'Elapsed time in seconds');
display(Tot_oppervlak, 'Total plan area in m2');
display(Opvulling, 'm2 unused land');
display(Opp_gebied, 'Total area in m2');
display((Tot_uitgeefbaar+ Tot_spelen +Tot_rijbaan + Tot_stoep), 'Total plan area without green and parking');
display( (Tot_kosten), 'General costs');
display( (Tot_opbrengst), 'General revenues');
display((Tot_groen), 'Total area for greenery and parkingdeck');
display((Tot_groen_dek), 'Area for greenery');
display((Tot_parkeren), 'Total area for parking');
display((xbest(:,20)), 'Parking spaces with a roof (parkingdeck)');
display((groenwon), 'Area green per house');
display((parkafw), 'Deviation from parking norm');
display((Tot_parkeren/Tot_woningen), 'Area parking per house');
```

```
display((xbest(:,19)), 'Ratio Parking/Green');
display((Tot_woningen), 'Total number of houses');
display((Tot_sociaal), 'Social houses');
display((Tot_schuur), 'Social rental houses');
display((Tot_sckoop), 'Social owner-occupied houses');
display((Tot_betaalbaar), 'Affordable houses');

display((Tot_spelen), 'Area for playground next to greenery (1,5%)');

display((Tot_duur), 'Expensive houses');
display(xbest(1:17), 'Number of houses per type');
display(zorgoptie, 'Option healthcare center');

display((Wm16 +Wm19 +Wm20), 'Costs greenery');

display(Preffun_fbest,'Preference per objective stakeholder F (Financial director)'); % Preference
display(Preffun_gbest,'Preference per objective stakeholder G (Municipality)'); % Preference
display(Preffun_sbest(1:11),'Preference per objective stakeholder S (Urban planner)'); % Preference
display(-fbest,'Optimisation value'); %Overall preference

display(exitflag,'exitflag'); %exitflag
display(Tot_Saldo, 'Saldo (negative is deficit)'); % Result
display( (Tot_opbrengst), 'General revenues'); %Final values of design variables
display(-Tetrabest,'alter Tetra'); %Overall preference in Tetra
```

Save output to the Excel output file

Several values that are displayed after running the model. The purple text indicatates what value is displayed.

```
datum = string(datetime('now'));
filename = 'Output Waelpolder.xlsx'; % Name output Excel file

% Design outcome for Excel file
waardes = [Tot_Saldo (Tot_oppervlak+ Opp_parkeeropl)  Tot_kosten Tot_opbrengst Tot_groen (Tot_groen/Tot_woningen)  Tot_parkeren parkafw (P_bebouwdpark*100) P_parkeerdek  Tot_spelen Tot_wor
desfinaf = round(waardes,4);

% Show personal preference scores:
overallaf = [nan nan nan nan nan nan nan nan nan nan nan nan nan nan]; %let one column empty between every personal preference scores per design

% Minucipality preference and distance from goal for Excel file
Gemeente = [Preffun_g1 Preffun_g2 Preffun_g3 nan Preffun_g9 nan Preffun_g4 Preffun_g10 Preffun_g7 Preffun_g6 Preffun_g5 Preffun_g8 Preffun_g11 nan ];
gemeenteaf = round(Gemeente,4);
gemeentegem = sum(W_g.*Preffun_gbest);
distGemeente = [Dist_gemeente(1) Dist_gemeente(2) Dist_gemeente(3) nan Dist_gemeente(9) nan Dist_gemeente(4) Dist_gemeente(10) Dist_gemeente(7) Dist_gemeente(6) Dist_gemeente(5) Dist_gemee
distgemeenteaf = round(distGemeente,4);

% Financial director preference and distance from goal for Excel file
Financieel = [Preffun_f1 Preffun_f2 nan nan Preffun_f6 Preffun_f7 nan nan Preffun_f3 Preffun_f4 Preffun_f5 Preffun_f8 nan nan ];
financieelaf = round(Financieel,4);
finangem = sum(W_f.*Preffun_fbest);
distFinancieel = [Dist_fin(1) Dist_fin(2) nan nan Dist_fin(6) Dist_fin(7) nan nan Dist_fin(3) Dist_fin(4) Dist_fin(5) Dist_fin(8) nan nan ];
distfinaf = round(distFinancieel,4);

% Urban planner preference and distance from goal for Excel file
Stedenbouw= [Preffun_s1 Preffun_s2 Preffun_s3 Preffun_s4 Preffun_s10 Preffun_s9 nan nan Preffun_s6 Preffun_s11 Preffun_s7 Preffun_s8 Preffun_s12 Preffun_s5 ];
stedenbouwaf = round(Stedenbouw,4);
stedengem = sum(W_s.*Preffun_sbest);
distStedenbouw= [Dist_steden(1) Dist_steden(2) Dist_steden(3) Dist_steden(4) Dist_steden(10) Dist_steden(9) nan nan Dist_steden(6) Dist_steden(11) Dist_steden(7) Dist_steden(8) Dist_steder
diststedenbouwaf = round(distStedenbouw,4);


% Values for the preference sheet in Excel: Overall preference, and per stakeholder; Municiapilty, Financial director, Urban planner
OverallPref = [ name, -fbest, "Totaal" overallaf nan datum nan nan nan maxDist ];
GemeentePref = [ nan nan "Gemeente" gemeenteaf gemeentegem nan nan nan nan nan maxdist_gemeente distgemeenteaf sumdist_gemeente ];
FinanPref = [ nan nan  "Financieel" financieelaf finangem nan nan nan nan nan maxdist_fin distfinaf sumdist_fin];
StedenPref = [ nan nan  "Stedenbouwkundige" stedenbouwaf stedengem nan nan nan nan nan maxdist_steden diststedenbouwaf sumdist_steden];

% Values of total design and extra information in one 'Design' sheet in Excel:
outputb = [ name, "Ontwerp", -fbest, desfinaf, datum, Duurrun, Opvulling];

% Values of xbest of design variables in 'xwaardes' sheet in Excel:
xwaardes = [name, xbest, datum];

% Writing the values to the design and x-values sheet of the Excel file
writematrix(outputb,filename, 'Sheet', 'ML Ontwerp', 'WriteMode','append')
writematrix(xwaardes, filename, 'Sheet', 'X-values', 'WriteMode','append')

% Writing the values to the preference sheet of the Excel file
writematrix(OverallPref, filename, 'Sheet', 'ML preferentie', 'WriteMode','append')
writematrix(FinanPref, filename, 'Sheet', 'ML preferentie', 'WriteMode','append')
writematrix(StedenPref, filename, 'Sheet', 'ML preferentie', 'WriteMode','append')
writematrix(GemeentePref, filename, 'Sheet', 'ML preferentie', 'WriteMode','append')
```

```
end
```

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I.2 MATLAB Script goal attainment Waelpolder

The MATLAB script for the goal attainment method used in Waelpolder is shown on the following pages.

Contents

- Design variables:
- Loading data
- Bounds for design variables
- Data house types
- Fixed values
- Data preference curve
- Weights of objectives
- Constraints
- Objective function
- Relations
- Preference scores
- Optimisation value
- Options
- Optimisation
- Calculations of the relations with xbest
- Final Costs to develop the area
- Final preference based on optimization values (xbest)
- Second optimization: 1 solution in Tetra (using xbest)
- Distance from goal
- Display
- Save output to the Excel output file


```
function PFM_Waelpolder_V6opbr_goalatt_w211
```

```
clc, clear, close all
```

Design variables:

```
% Design variables x(1)-x(17) refer to the house types
% x(1)  - EG soc kp < €194.000
% x(2)  - EG bereikb kp < €231.500
% x(3)  - EG betaalb kp < €310.000
% x(4)  - EG rijwoning €375.000
% x(5)  - EG 2/1kap €542.500
% x(6)  - EG vrijstaand klein €585.900
% x(7)  - EG vrijstaand groot €672.300
% x(8)  - EG verandawoning €328.000
% x(9)  - EG drive-in €355.000+€25.000
% x(10) - MG sociale huur
% x(11) - MG sociale kp < €194.000
% x(12) - MG kp €291.000
% x(13) - MG duur geb P
% x(14) - MG sociale kp < €194.000 geb P
% x(15) - MG kp betaalbaar, geb P onder dek
% x(16) - MG kp €291.000+€20.000 alles geb P
% x(17) - EG sociale huur

% x(18) - Zorgcomplex --> 4 options for the healthcare center: 0, 31, 62 or 93 units

% x(19) - Division factor. Factor indicating how the division of the unused area will be, between green and parking (dependent on both preferences).
%         Extra space for greenery = x(19) and extra space for parking = (1-x(19)).

% x(20) - Number of parking spaces with a roof (12.5 m2 per parking space).
```

Loading data

Loading data to use in the model

```
Dv = readtable("Database Waelpolder.xlsx", 'Sheet', 'Vaste waarden', 'PreserveVariableNames', true); % Data regarding fixed values
Dk = readtable("Database Waelpolder.xlsx", 'Sheet', 'Financieel'   , 'PreserveVariableNames', true); % Data of costs and revenues for area development
Dg = readtable("Database Waelpolder.xlsx", 'Sheet', 'gegevens'     , 'PreserveVariableNames', true); % Data regarding the house types
```

Bounds for design variables

Surrogate optimization requires that the lower- & upperbound and integer variables are listed.

```
Lowerbound = [Dg.Lowerbound(1:18); 0; 0];   % Defining the lowerbound of the design variables, the last two variables are not defined in the database
Upperbound = [Dg.Upperbound(1:18); 1; 500]; % Defining the upperbound of the design variables, the last two variables are not defined in the database

lb = Lowerbound';                           % Translating the lower bounds
ub = Upperbound';                           % Translating the upper bounds

IntCon = [1:18 20];                         % Defining the design variables that are integer
```

Data house types

Defining variables that represent different properties of the house types and will be calulated with in the model

```
Uitgeef = Dg.("Uitgeefbaar (m² kavel)");    % Plot area per house type in m2
Straat = Dg.("Straat (m²)");                % Area for street per house type in m2
Stoep = Dg.("Trottoir (m²)");               % Area for sidewalk per house type in m2
Parkeren = Dg.("Parkeren (m²)");            % Area for parking per house type in m2 (parking norm * 12.5 per parking space)
Spelen = Dg.("Spelen (m²)");                % Area for playground per house type in m2

min_Groen = 7.0;                            % Minimal green norm (in m2) that needs to be maintained per house type
min_parkafw = 0.9;                          % Minimal deviation from parking norm that needs to be maintained per house type
```

Fixed values

Defining variables that are fixed and will be calulated with in the model

```
V_waarde = Dv.Waarde;               % Defining a variable that is loading the fixed values from the database Excel

Opp_gebied = V_waarde(1);           % Total plan area in m2

% Inflation
Startjaar= V_waarde(2);             % Base year of unit prices
Boekjaar =V_waarde(3);              % Year on which the costs should be based
Kostenstijging = V_waarde(4);       % Cost increase of unit prices per year
f_Prijsstijging = 1+Kostenstijging.^(Boekjaar-Startjaar); % Factor price increase

Opp_parkeeropl  = 0;                % V_waarde(7); % Area parking solution in subarea 5 , Oppervlakte parkeer oplossing in deelgebied 5 --> Kan weg?

% Pavement and elevation
Verhardingb = V_waarde(8);          % Pavement width in meters
H_oph_verharding= V_waarde(9);      % Elevation of pavement in meters
H_oph_uitg = V_waarde(10);          % Elevation plot area in meters
H_oph_groen = V_waarde(10);         % Elevation green in meters
H_teelaarde =V_waarde(12);          % Height of soil in green area in meters
H_zand = V_waarde(13);              % Height of sand with pavement in meters
Af_Lm = V_waarde(14);               % Distance between lampposts in meters
Af_bomen= V_waarde(15);             % Distance between trees long avenue in meters
Lv_drain = V_waarde(16);            % Length of vertical drainage in meters

p_rij = V_waarde(17);               % Percentage of pavement that is carriageway
p_park = V_waarde(18);              % Percentage of pavement that is parking
p_stoep = V_waarde(19);             % Percentage of pavement that is sidewalk

% Soil
Gr_vrij_ag =V_waarde(20);           % Land/Soil cleared from other areas
Gr_verwerken_ag = V_waarde(21);     % Soil to be processed from other areas
Gr_tekort_ag = V_waarde(22);        % Shortage of soil in other areas

% Revenues
profx = Dg.("Grondwaarde Patrick"); % Defining a variable that is loading the land vlaue from the database Excel

% Costs per actitivity
kopr = Dk.Kostopr .*f_Prijsstijging;    % Clearing operations
koph = Dk.Kostoph .*f_Prijsstijging;    % Elevation of the site
kgv      = Dk.Kostgv .*f_Prijsstijging;     % Soil transportation
kbm  = Dk.Kostbm .*f_Prijsstijging;     % Site preparation (Bouwrijp maken)
kwm      = Dk.Kostwm  .*f_Prijsstijging;    % Hard and soft landscaping (Woonrijp maken)
kawe = Dk.Kostawe .*f_Prijsstijging;    % Additional work elements

K_parkeerdek = 1250*12.5;               % Costs of a roof above parking space
```

Data preference curve

Preference curves of stakeholders loaded from the preferences Excel

```
PrefF= readtable("Preferenties Waelpolder aangepast w211.xlsx", 'Sheet', 'PreferentiesF','PreserveVariableNames',true); %Loading data preference stakeholder F
PrefS= readtable("Preferenties Waelpolder aangepast w211.xlsx", 'Sheet', 'PreferentiesS','PreserveVariableNames',true); %Loading data preference stakeholder S
PrefG= readtable("Preferenties Waelpolder aangepast w211.xlsx", 'Sheet', 'PreferentiesG','PreserveVariableNames',true); %Loading data preference stakeholder G

%Preference curves Financial director (Financieel) (F):
Preff1 = PrefF.f1pref(~isnan(PrefF.f1pref));    % Stakeholder F - Preference for objective number 1: Revenue
Valf1 = PrefF.f1val(~isnan(PrefF.f1val));       % Stakeholder F - Values for objective number 1: Revenue
Preff2 = PrefF.f2pref(~isnan(PrefF.f2pref));    % Stakeholder F - Preference for objective number 2: Tot green per house
Valf2 = PrefF.f2val(~isnan(PrefF.f2val));       % Stakeholder F - Values for objective number 2: Tot green per house
Preff3 = PrefF.f3pref(~isnan(PrefF.f3pref));    % Stakeholder F - Preference for objective number 3: Total affordable houses
Valf3 = PrefF.f3val(~isnan(PrefF.f3val));       % Stakeholder F - Values for objective number 3 : Total affordable houses
Preff4 = PrefF.f4pref(~isnan(PrefF.f4pref));    % Stakeholder F - Preference for objective number 4: Total expensive houses
Valf4 = PrefF.f4val(~isnan(PrefF.f4val));       % Stakeholder F - Values for objective number 4: Total expensive houses
Preff5 = PrefF.f5pref(~isnan(PrefF.f5pref));    % Stakeholder F - Preference for objective number 5: Houses EG (single-family)
Valf5 = PrefF.f5val(~isnan(PrefF.f5val));       % Stakeholder F - Values for objective number 5 : Houses EG (single-family)
Preff6 = PrefF.f6pref(~isnan(PrefF.f6pref));    % Stakeholder F - Preference for objective number 6:  Total number of houses
Valf6 = PrefF.f6val(~isnan(PrefF.f6val));       % Stakeholder F - Values for objective number 6: Total number of houses
Preff7 = PrefF.f7pref(~isnan(PrefF.f7pref));    % Stakeholder F - Preference for objective number 7: Total social houses
Valf7 = PrefF.f7val(~isnan(PrefF.f7val));       % Stakeholder F - Values for objective number 7: Total social houses
Preff8 = PrefF.f8pref(~isnan(PrefF.f8pref));    % Stakeholder F - Preference for objective number 8: Houses MG (multi-family)
Valf8 = PrefF.f8val(~isnan(PrefF.f8val));       % Stakeholder F - Values for objective number 8: Houses MG (multi-family)

%Preference curves Urban planner (Stedenbouwekundig) (S):
Prefs1 = PrefS.s1pref(~isnan(PrefS.s1pref));    % Stakeholder S - Preference for objective number 1: Revenue
Vals1 = PrefS.s1val(~isnan(PrefS.s1val));       % Stakeholder S - Values for objective number 1: Revenue
Prefs2 = PrefS.s2pref(~isnan(PrefS.s2pref));    % Stakeholder S - Preference for objective number 2: Tot green per house
Vals2 = PrefS.s2val(~isnan(PrefS.s2val));       % Stakeholder S - Values for objective number 2: Tot green per house
Prefs3 = PrefS.s3pref(~isnan(PrefS.s3pref));    % Stakeholder S - Preference for objective number 3: Deviation from parking norm
Vals3 = PrefS.s3val(~isnan(PrefS.s3val));       % Stakeholder S - Values for objective number 3: Deviation from parking norm
Prefs4 = PrefS.s4pref(~isnan(PrefS.s4pref));    % Stakeholder S - Preference for objective number 4: Build parking spaces
Vals4 = PrefS.s4val(~isnan(PrefS.s4val));       % Stakeholder S - Values for objective number 4: Build parking spaces
Prefs5 = PrefS.s5pref(~isnan(PrefS.s5pref));    % Stakeholder S - Preference for objective number 5: Quiet neighbourhood
Vals5 = PrefS.s5val(~isnan(PrefS.s5val));       % Stakeholder S - Values for objective number 5: Quiet neighbourhood
Prefs6 = PrefS.s6pref(~isnan(PrefS.s6pref));    % Stakeholder S - Preference for objective number 6: Total affordable houses
Vals6 = PrefS.s6val(~isnan(PrefS.s6val));       % Stakeholder S - Values for objective number 6: Total affordable houses
Prefs7 = PrefS.s7pref(~isnan(PrefS.s7pref));    % Stakeholder S - Preference for objective number 7: Houses EG (single-family)
Vals7 = PrefS.s7val(~isnan(PrefS.s7val));       % Stakeholder S - Values for objective number 7: Houses EG (single-family)
Prefs8 = PrefS.s8pref(~isnan(PrefS.s8pref));    % Stakeholder S - Preference for objective number 8: Houses MG (multi-family)
Vals8 = PrefS.s8val(~isnan(PrefS.s8val));       % Stakeholder S - Values for objective number 8: Houses MG (multi-family)
Prefs9 = PrefS.s9pref(~isnan(PrefS.s9pref));    % Stakeholder S - Preference for objective number 9: Total social houses
Vals9 = PrefS.s9val(~isnan(PrefS.s9val));       % Stakeholder S - Values for objective number 9: Total social houses
Prefs10 = PrefS.s10pref(~isnan(PrefS.s10pref)); % Stakeholder S - Preference for objective number 10: Total number of houses
Vals10 = PrefS.s10val(~isnan(PrefS.s10val));    % Stakeholder S - Values for objective number 10: Total number of houses
Prefs11 = PrefS.s11pref(~isnan(PrefS.s11pref)); % Stakeholder S - Preference for objective number 11: Total expensive houses
Vals11 = PrefS.s11val(~isnan(PrefS.s11val));    % Stakeholder S - Values for objective number 11: Total expensive houses
Prefs12 = PrefS.s12pref(~isnan(PrefS.s12pref)); % Stakeholder S - Preference for objective number 12: Healthcare center
Vals12 = PrefS.s12val(~isnan(PrefS.s12val));    % Stakeholder S - Values for objective number 12: Healthcare center

%Preference curves Municipality (Gemeente) (G):
Prefg1 = PrefG.g1pref(~isnan(PrefG.g1pref));    % Stakeholder G - Preference for objective number 1: Revenue
Valg1 = PrefG.g1val(~isnan(PrefG.g1val));       % Stakeholder G - Values for objective number 1: Revenue
Prefg2 = PrefG.g2pref(~isnan(PrefG.g2pref));    % Stakeholder G - Preference for objective number 2:  Tot green per house
Valg2 = PrefG.g2val(~isnan(PrefG.g2val));       % Stakeholder G - Values for objective number 2:  Tot green per house
Prefg3 = PrefG.g3pref(~isnan(PrefG.g3pref));    % Stakeholder G - Preference for objective number 3: Deviation from parking norm
Valg3 = PrefG.g3val(~isnan(PrefG.g3val));       % Stakeholder G - Values for objective number 3: Deviation from parking norm
Prefg4 = PrefG.g4pref(~isnan(PrefG.g4pref));    % Stakeholder G - Preference for objective number 4: Houses social (rental)
Valg4 = PrefG.g4val(~isnan(PrefG.g4val));       % Stakeholder G - Values for objective number 4: Houses social (rental)
Prefg5 = PrefG.g5pref(~isnan(PrefG.g5pref));    % Stakeholder G - Preference for objective number 5: Houses EG (single-family)
```

```
Valg5 = PrefG.g5val(~isnan(PrefG.g5val));       % Stakeholder G - Values for objective number 5: Houses EG (single-family)
Prefg6 = PrefG.g6pref(~isnan(PrefG.g6pref));    % Stakeholder G - Preference for objective number 6: Total expensive houses
Valg6 = PrefG.g6val(~isnan(PrefG.g6val));       % Stakeholder G - Values for objective number 6: Total expensive houses
Prefg7 = PrefG.g7pref(~isnan(PrefG.g7pref));    % Stakeholder G - Preference for objective number 7: Total affordable houses
Valg7 = PrefG.g7val(~isnan(PrefG.g7val));       % Stakeholder G - Values for objective number 7: Total affordable houses
Prefg8 = PrefG.g8pref(~isnan(PrefG.g8pref));    % Stakeholder G - Preference for objective number 8: Houses MG (multi-family)
Valg8 = PrefG.g8val(~isnan(PrefG.g8val));       % Stakeholder G - Values for objective number 8: Houses MG (multi-family)
Prefg9 = PrefG.g9pref(~isnan(PrefG.g9pref));    % Stakeholder G - Preference for objective number 9: Total number of houses
Valg9 = PrefG.g9val(~isnan(PrefG.g9val));       % Stakeholder G - Values for objective number 9: Total number of houses
Prefg10 = PrefG.g10pref(~isnan(PrefG.g10pref)); % Stakeholder G - Preference for objective number 10: Houses social (buy)
Valg10 = PrefG.g10val(~isnan(PrefG.g10val));    % Stakeholder G - Values for objective number 10: Houses social (buy)
Prefg11 = PrefG.g11pref(~isnan(PrefG.g11pref)); % Stakeholder G - Preference for objective number 11: Healthcare center
Valg11 = PrefG.g11val(~isnan(PrefG.g11val));    % Stakeholder G - Values for objective number 11: Healthcare center
```

Weights of objectives

Defining the relative weights that are used in the model, defined by the stakeholder over his objectives

```
Gewichten= readtable("Preferenties Waelpolder aangepast w211.xlsx", 'Sheet', 'Gewichten','PreserveVariableNames', true); % Loading weights data

W_f  = Gewichten.("Relative weight")(1:8)';     % Relative weights for stakeholder F, adds upto 1 per stakeholder
W_g  = Gewichten.("Relative weight")(9:19)';    % Relative weights for stakeholder G, adds upto 1 per stakeholder
W_s  = Gewichten.("Relative weight")(20:31)';   % Relative weights for stakeholder S, adds upto 1 per stakeholder

W_f_tot1 = W_f ./3;     % Relative weights for stakeholder F, adds upto 1 for the 3 stakeholders together
W_g_tot1 = W_g ./3;     % Relative weights for stakeholder G, adds upto 1 for the 3 stakeholders together
W_s_tot1 = W_s ./3;     % Relative weights for stakeholder S, adds upto 1 for the 3 stakeholders together

Wtot_tot1 = [W_f_tot1 W_g_tot1 W_s_tot1];       % All relative weights for all stakeholders, adds upto 1 for the 3 stakeholders together
```

Constraints

```
%Standard Matlab form is A*x <= b.
%Examples:
%For minimal number of houses x(1)+x(2)+x(3)+x(4)+x(5)>=600

function [c,ceq] = Constraints(x)

    %loop zorgcomplex
    if (x(:,18) >= 0.5) & (x(:,18)  < 1.5)      % Option 1 (between 0.5 and 1.4): 31 units
        zorgopp = 31*21 +66;                    % Total area needed for option 1, build in 4 layers
        zorgwinst = 31* 17500;                  % Profit for 31 units
        zorgextrapark = 0;                      % No extra parking spaces needed
        Rustwonen =  repmat(0.3,size(x,1),1);   % Percentage houses that can be labeled as 'quiet living'
    elseif (x(:,18)  >= 1.5) & (x(:,18)  < 2.5) % Option 2 (between 1.5 and 2.5): 62 units
        zorgopp = 1366;                         % Standard area usage, build in 4 layers
        zorgwinst = 62*17500;                   % Profit for 62 units
        zorgextrapark = 0 ;                     % No extra parkingspaces needed
        Rustwonen = repmat(0.2,size(x,1),1);    % Percentage houses that can be labeled as 'quiet living'
    elseif (x(:,18)  >= 2.5) & (x(:,18)  < 3.5) % Option 3 (between 2.5 and 3.4): 93 units
        zorgopp = 93*18 +66;                    % Total area needed, build in 6 layers
        zorgwinst = 93*17500;                   % Profit for 93 units
        zorgextrapark = 31*0.7*12.5;            % Area for extra parking spaces (m2)
        Rustwonen =  repmat(0.0,size(x,1),1);   % Percentage houses that can be labeled as 'quiet living'
    else                                        % Option 0: 0 units
        zorgopp = 0 ;                           % No area needed
        zorgwinst = 0;                          % No profit
        zorgextrapark = 0;                      % No area for extra parking spaces
        Rustwonen = repmat(0.5,size(x,1),1);    % Percentage houses that can be labeled as 'quiet living'
    end


    %Houses
    Tot_woningen = x(:,1)+ x(:,2)+x(:,3)+x(:,4)+x(:,5)+x(:,6)+x(:,7)+x(:,8)+x(:,9)+x(:,10)...
                  +x(:,11)+x(:,12)+x(:,13)+x(:,14)+x(:,15)+x(:,16)+x(:,17); % Total number of houses

    Tot_schuur = x(:,10)+x(:,17);                                       % Total number of social (rental) houses
    Tot_sckoop = x(:,1)+x(:,11)+x(:,14);                                % Total number of social (owner-occupied) houses

    % Area usage
    Tot_uitgeefbaar = sum(Uitgeef(1:17)'.*x(:,1:17),2) ;                           % Total plot area
    Minimaal_groen = min_Groen .* Tot_woningen;                                     % Minimal total area for greenery

    Tot_spelen =  sum(Spelen(1:17)'.*x(:,1:17),2);                                  % Total area for a playground, dependent on total plot area

    Minimaal_parkeren =min_parkafw*(sum(Parkeren(1:17)'.*x(:,1:17),2)) +zorgextrapark;  % Minimal total area for parking, based on the minimum obtained
    Norm_parkeren = (sum(Parkeren(1:17)'.*x(:,1:17),2));                            % Total area for parking, based on standard norm (=1)
    Tot_rijbaan =  sum(Straat(1:17)'.*x(:,1:17),2);                                 % Total area for road
    Tot_stoep =  sum(Stoep(1:17)'.*x(:,1:17),2);                                    % Total area for sidewalk


        Tot_oppervlak =  Tot_uitgeefbaar + Minimaal_parkeren + Tot_rijbaan +Tot_stoep +...  % Total area for the number of houses
                     Tot_spelen + Minimaal_groen +zorgopp ;                         % This should be equal to the total plan area

    Opvulling =  Opp_gebied -(Tot_uitgeefbaar + Minimaal_parkeren + Tot_rijbaan + ...   % Area that is 'not used' in the plans and
                Tot_stoep + Tot_spelen + Minimaal_groen +zorgopp +Opp_parkeeropl);      % will be divided between extra green and extra parkingspaces

    Tot_groen = min_Groen .* Tot_woningen + Opvulling.*x(:,19);                     % Total area for greenery

    Tot_parkeren =min_parkafw .* sum(Parkeren(1:17)'.*x(:,1:17),2)...               % Total area for parking, including parking spaces for
                 +zorgextrapark + Opvulling .*(1-x(:,19));                          % the healtcare center and extra parking from division factor

    Tot_parkerenwon = min_parkafw .* sum(Parkeren(1:17)'.*x(:,1:17),2) + ...        % Total area for parking for the houses
                     Opvulling .*(1-x(:,19));                                       % (without healthcare complex parking spaces)

    Tot_verharding = Tot_parkeren + Tot_rijbaan +Tot_stoep  ;                       % Total pavement area

    Weglengte = Tot_verharding./Verhardingb;                                        % Road length and sewer length depending on total paved area

    groendek = x(:,20).*12.5;                   % Area greenery on roof of parking spaces (in m2)
    Tot_groen_dek = groendek + Tot_groen;       % Total greenert in the area (on parking deck and in the rest of the area)
    groenwon = Tot_groen_dek./Tot_woningen;     % Total area of green per house in m2

    parkafw = Tot_parkerenwon./Norm_parkeren;  % Deviation from (the standard) parking norm

  % Common constraints
    calg(:,1) =  + ( Tot_oppervlak +Opp_parkeeropl + Opvulling ) -  Opp_gebied  -0.001;     %Maximal area of Waelpolder design should be equal to this
```

```
calg(:,2) = - (Tot_oppervlak+Opp_parkeeropl  +Opvulling )+  Opp_gebied  -0.001;        %Maximal area of Waelpolder design should be equal to this
calg(:,3) = - Opvulling + 0.001;                                                       % the 'opvulling'of area that is not in fuction, cannot be negative
ca = [calg];

%Constraints greenery and parking
 cgroen(:,1) =    (groenwon) -50;       %Maximal greenery per house in m2
 cgroen(:,2) =    (parkafw) -1.5;       %Maximaal deviation of parking norm
 cgroen(:,3) =    -(groenwon) +5;       %Minimal greenery per house in m2
 cgroen(:,4) =    -(parkafw) +0.8;      %Minimaal deviation of parking norm

 cgroen = [cgroen];


%Constraints living
cwon(:,1) = x(:,1) + x(:,2) + x(:,3) +x(:,4) +x(:,5) +x(:,6) +x(:,7) +x(:,8) +x(:,9) +x(:,10) +x(:,11) +x(:,12) + x(:,13)...
                +x(:,14) +x(:,15) + x(:,16)+ x(:,17)- 217 ;                 % Maximum total number of houses

cwon(:,2) = - ( x(:,1) +x(:,10) +x(:,11) +x(:,14) +x(:,17)) +144;           % Minimal  total number of social houses
cwon(:,3) = -( x(:,2) + x(:,3) +x(:,8) +x(:,12) +x(:,15) + x(:,16)) + 34 ;  % Minimaal total number of affordable houses
cwon(:,4) = - ( x(:,10)+ x(:,17) ) + 102;                                   % Minimaal  total number of social rental houses
cwon = [cwon];


c = [ca, cwon,cgroen];
ceq=[];    %Equality constraints

end
nonlcon = @Constraints;

A=[];

b=[];

Aeq = []; beq= [];
```

Objective function

```
function   Opt1 = ObjFunction1(x) % Optimisation fuction
```

```
% In Matlab optimization problems are always defined as minimization
% problems. Thus, the sign of the objective function was changed to "-"
```

Relations

```
%Houses
Tot_woningen = x(:,1)+ x(:,2)+x(:,3)+x(:,4)+x(:,5)+x(:,6)+x(:,7)+x(:,8)+x(:,9)+x(:,10)...
               +x(:,11)+x(:,12)+x(:,13)+x(:,14)+x(:,15)+x(:,16)+x(:,17); % Total number of houses
Tot_schuur = x(:,10)+x(:,17);                                            % Total number of social (rental) houses
Tot_sckoop = x(:,1)+x(:,11)+x(:,14);                                     % Total number of social (owner-occupied) houses
Tot_duur = x(:,4)+x(:,5)+x(:,6)+x(:,7)+x(:,9)+x(:,13);                   % Total expensive houses
Tot_betaalbaar = x(:,2)+ x(:,3)+x(:,8)+x(:,12)+x(:,15)+x(:,16);          % Total affordable houses
Tot_sociaal = x(:,1)+x(:,10)+x(:,11)+x(:,14)+x(:,17) ;                   % Total social houses

Tot_rij = x(:,1) + x(:,2) + x(:,3) +x(:,4) +x(:,8) +x(:,9)+ x(:,17);     % Total number of terraced houses
Tot_2kap = x(:,5);                                                       % Total number of semidetached houses
Tot_vrij = x(:,6) +x(:,7);                                               % Total number of detached houses
Tot_MG = x(:,10) +x(:,11) +x(:,12) + x(:,13) +x(:,14)+x(:,15) +x(:,16);  % Total number of appartments
Tot_EG = Tot_rij + Tot_2kap + Tot_vrij;                                  % Total number of single-family houses
won_bebouwdpark = x(:,13) +x(:,14) +x(:,15) + x(:,16);                   % Total number of houses where there are build parking spaces

P_bebouwdpark = won_bebouwdpark./Tot_woningen;                           % Percentage of houses with build parking spaces from total number of houses

% Loop for the different options of the healthcare center (x(18)) and the associated values
if (x(:,18) >= 0.5) & (x(:,18)  < 1.5)      % Option 1 (between 0.5 and 1.4): 31 units
    zorgopp = 31*21 +66;                    % Total area needed for option 1, build in 4 layers
    zorgwinst = 31* 17500;                  % Profit for 31 units
    zorgextrapark = 0;                      % No extra parking spaces needed
    Rustwonen =  repmat(0.3,size(x,1),1);   % Percentage houses that can be labeled as 'quiet living'
elseif (x(:,18)  >= 1.5) & (x(:,18)  < 2.5) % Option 2 (between 1.5 and 2.5): 62 units
    zorgopp = 1366;                         % Standard area usage, build in 4 layers
    zorgwinst = 62*17500;                   % Profit for 62 units
    zorgextrapark = 0 ;                     % No extra parkingspaces needed
    Rustwonen = repmat(0.2,size(x,1),1);    % Percentage houses that can be labeled as 'quiet living'
elseif (x(:,18)  >= 2.5) & (x(:,18)  < 3.5) % Option 3 (between 2.5 and 3.4): 93 units
    zorgopp = 93*18 +66;                    % Total area needed, build in 6 layers
    zorgwinst = 93*17500;                   % Profit for 93 units
    zorgextrapark = 31*0.7*12.5;            % Area for extra parking spaces (m2)
    Rustwonen =  repmat(0.0,size(x,1),1);   % Percentage houses that can be labeled as 'quiet living'
else                                        % Option 0: 0 units
    zorgopp = 0 ;                           % No area needed
    zorgwinst = 0;                          % No profit
    zorgextrapark = 0;                      % No area for extra parking spaces
    Rustwonen = repmat(0.5,size(x,1),1);    % Percentage houses that can be labeled as 'quiet living'
end

% Area usage
Tot_uitgeefbaar = sum(Uitgeef(1:17)'.*x(:,1:17),2) ;                            % Total plot area
Minimaal_groen = min_Groen .* Tot_woningen;                                     % Minimal total area for greenery

Tot_spelen =  sum(Spelen(1:17)'.*x(:,1:17),2);                                  % Total area for a playground, dependent on total plot area

Minimaal_parkeren =min_parkafw*(sum(Parkeren(1:17)'.*x(:,1:17),2)) +zorgextrapark;  % Minimal total area for parking, based on the minimum obtained
Norm_parkeren = (sum(Parkeren(1:17)'.*x(:,1:17),2));                            % Total area for parking, based on standard norm (=1)
Tot_rijbaan =  sum(Straat(1:17)'.*x(:,1:17),2);                                 % Total area for road
Tot_stoep =  sum(Stoep(1:17)'.*x(:,1:17),2);                                    % Total area for sidewalk

Tot_oppervlak =  Tot_uitgeefbaar + Minimaal_parkeren + Tot_rijbaan +Tot_stoep +...  % Total area for the number of houses
                 Tot_spelen + Minimaal_groen +zorgopp ;                          % This should be equal to the total plan area

Opvulling =  Opp_gebied -(Tot_uitgeefbaar + Minimaal_parkeren + Tot_rijbaan + ...  % Area that is 'not used' in the plans and
             Tot_stoep + Tot_spelen + Minimaal_groen +zorgopp +Opp_parkeeropl);   % will be divided between extra green and extra parkingspaces

Tot_groen = min_Groen .* Tot_woningen + Opvulling.*x(:,19);                     % Total area for greenery

Tot_parkeren =min_parkafw .* sum(Parkeren(1:17)'.*x(:,1:17),2)...               % Total area for parking, including parking spaces for
```

```
              +zorgextrapark + Opvulling .*(1-x(:,19));                              % the healthcare center and extra parking from division factor

Tot_parkerenwon = min_parkafw .* sum(Parkeren(1:17)'.*x(:,1:17),2) + ...           % Total area for parking for the houses
                  Opvulling .*(1-x(:,19));                                         % (without healthcare complex parking spaces)

Tot_verharding = Tot_parkeren + Tot_rijbaan +Tot_stoep  ;                           % Total pavement area

Weglengte = Tot_verharding./Verhardingb;                                            % Road length and sewer length depending on total paved area

groendek = x(:,20).*12.5;                 % Area greenery on roof of parking spaces (in m2)
Tot_groen_dek = groendek + Tot_groen;     % Total greenert in the area (on parking deck and in the rest of the area)
groenwon = Tot_groen_dek./Tot_woningen;   % Total area of green per house in m2

parkafw = Tot_parkerenwon./Norm_parkeren; % Deviation from (the standard) parking norm

% Revenues
Tot_opbrengst = ((sum(profx(1:17)'.*x(:,1:17),2))+ zorgwinst + 681000)/1000000;      % Total revenues


% Costs to develop the area
% Opr        Clearing operations
Opr1        =       Opp_gebied .*kopr(1);   %       Clearing agricultural land, incl. dumping costs
Opr2        =       Opp_gebied .*kopr(2);   %       Milling terrain
Opr3        =       Opp_gebied .*kopr(3);   %       Leveling terrain
Tot_Opr     =       Opr1 + Opr2 + Opr3;         %   Total costs clearing operations

% Oph       Elevation of the site
Oph1        =   H_oph_verharding .* Tot_verharding .*koph(1);       %       Adding sand in front of paving (delivery)
Oph2        =   H_oph_uitg .* Tot_uitgeefbaar .*koph(2);        %   Soil supply in front of the plot area (release)
Oph3        =       H_oph_groen .* Tot_groen .*koph(3);                 %   Soil supply from green space (release)

balans  = (Gr_vrij_ag+ (Weglengte .* 8.75 .* 0.4)) - (Gr_verwerken_ag + (H_oph_uitg .* Tot_uitgeefbaar) + (H_oph_groen .* Tot_groen));
tekort  = (Gr_tekort_ag+ (Weglengte .* 8.75 .* 0.4) + (H_oph_uitg .* Tot_uitgeefbaar)+ (H_oph_groen .* Tot_groen));
verdeling = ((Weglengte .* 8.75 .* 0.4) - (H_oph_uitg .* Tot_uitgeefbaar)- (H_oph_groen .* Tot_groen));
Oph4    = - ((balans ./ tekort).*verdeling).*koph(4);   %   Delivering soil shortage

Oph5        =       (Opp_gebied ./ 6 .* Lv_drain) .*koph(5);        %       Apply vertical drainage
Oph6        =       (Opp_gebied ./ 10 ) .*koph(6);              %   Apply horizontal drainage
Oph7        =       (Opp_gebied ./ 500) .*koph(7);              %   Applying sack beacons
Oph8        =       (Opp_gebied ./ 500)  .*koph(8);             %   Monitor sack beacons
Oph9        =       Opp_gebied  .*koph(9);                      %   Covering embankment
Tot_Oph     =       Oph1 + Oph2 + Oph3 + Oph4 + Oph5 + Oph6 + Oph7 + Oph8 + Oph9;  %       Total costs elevation of the site

%Gv  Soil transportation
Gv1     =   (Weglengte .* 8.75 .* 0.4) .*kgv(1);    %       Transport of soil within sub-area
Gv2     =   0 .*kgv(2);                                 %   Transport soil to other sub-area
Tot_Gv      = Gv1 + Gv2     ;                               %   Total costs transport of soil

%Bm         Site preparation (Bouwrijp maken)
Bm1     =   (Weglengte .* 8.75 .* 0.4) .*kbm(1);    %       Excavated sewer trench (soil)
Bm2     =   Weglengte.*8.75.*0.6 .*kbm(2);          %       Excavated sewer trench (sand, reuse)
Bm3     =   Weglengte .*kbm(3);                         %   Applying drainage
Bm4     =   Weglengte .*kbm(4);                         %   Laying sewer DWA including manholes
Bm5     =   Tot_woningen .*kbm(5);                  %       Installation of house connections DWA
Bm6     =   0 .*kbm(6);                                 %   Connecting DWA to existing sewer
Bm7     =   Weglengte .*kbm(7);                         %   Installation of sewer HWA including manholes
Bm8     =   Tot_woningen .*kbm(8);                  %       Installation of house connections HWA
Bm9     =   0 .*kbm(9);                                 %   Connecting HWA to existing sewer
Bm10        =       (Tot_verharding ./ 100) .*kbm(10);          %   Installing gully connections
Bm11        =       Weglengte .*kbm(11);                    %       Installing drainage p90 incl. manholes
Bm12        =       ((Weglengte .* 8.75 .* 0.4)+ (Weglengte.*8.75.*0.6)) .*kbm(12);         %       Fill up sewer trench with sand incl. compaction
Bm13        =       (Weglengte.*8.75.* 0.4) .*kbm(13);          %   Delivering missing sand
Bm14        =       0.02 .* (Bm1+ Bm2+ Bm3+ Bm4+ Bm5+ Bm6+ Bm7+ Bm8+ Bm9+ Bm10+ Bm11+ Bm12+ Bm13); %        Temporary provisions sewerage
Bm15        =       2 .* Weglengte .*kbm(15);                   %   Overhaul and inspection sewers
Bm16        =       Weglengte .* 6  .*kbm(16);                  %   Construction of granulate road
Bm17        =       Weglengte .* 6 *kbm(17);                    %   Maintenance construction road granulate
Bm18        =       (0.05 .* Weglengte .* 6) .*kbm(18);         %   Temporary pavements
Bm19        =       300 .* 2 .*kbm(19)-44010;                   %   Installation of shoring equipment
Tot_Bm      =       Bm1 + Bm2 + Bm3 + Bm4 + Bm5 + Bm6 + Bm7 + Bm8 + Bm9 + Bm10 +...
            Bm11 + Bm12 + Bm13 + Bm14 + Bm15 + Bm16 + Bm17 + Bm18 +Bm19;        %    Total costs site preparation

%Wm   Hard and soft landscaping (Woonrijp maken)
Wm1     =   (Weglengte .* 6)  .*kwm(1);                 %   Filling out foundation construction roads
Wm2     =   (Weglengte .* 6 .* 0.05) .*kwm(2);          %   Removing temporary pavements
Wm3     =   H_zand .* Tot_verharding  .*kwm(3);         %   Adding sand in front of pavement

Wm5     =   Tot_verharding .* p_rij .*kwm(5);       %       Installing baked pavement and edge protections (traffic lane)
Wm6     =   Tot_verharding .* p_park .*kwm(6);          %   Install concrete pavement and edge closures (parking)
Wm7     =   Tot_verharding .* p_stoep .*kwm(7);         %   Install concrete pavers edging (sidewalk)
Wm4     =   (Tot_verharding .* p_rij + Tot_verharding .* p_park + Tot_verharding .* p_stoep ) .*kwm(4);     %       Apply street layer

Wm8     =   ( Tot_verharding .* p_rij).* 0.05 .*kwm(8);     %       Apply traffic calming mat measures
Wm9     =   ( Tot_verharding .* p_rij + Tot_verharding .* p_park + Tot_verharding .* p_stoep ) .*kwm(9);    %       Maintain pavements
Wm10        =       ((2.* Weglengte) ./ 35) .*kwm(10);          %   Leveling manhole cover edges
Wm11        =       (Tot_verharding ./ 100) .*kwm(11);          %   Installing gullies
Wm12        =       (Weglengte./ Af_Lm) .*kwm(12);          %       Installing lighting incl. cable
Wm13        =       Opp_gebied .*kwm(13);                   %       Adding traffic signs/street name signs
Wm14        =       Opp_gebied .*kwm(14);                   %       Installation of street furniture
Wm15        =       H_teelaarde .* Tot_groen .*kwm(15);         %   Applying soil in green areas
Wm16        =       0.3 .* Tot_groen .*kwm(16);                 %   Applying planting
Wm17        =       (Weglengte ./ Af_bomen)  .*kwm(17);     %       Applying avenue tree in pavement incl. soil improvement
Wm18        =       (Weglengte ./ Af_bomen  .* 10   ) .*kwm(18) ;       %   Applying root guide trees in pavement
Wm19        =       0.7 .* Tot_groen *kwm(19);                          %       Fertilize and sow lawns
Wm20        =       ( 0.3 .* Tot_groen +0.7 .* Tot_groen) .*kwm(20);    %       Maintenance of green spaces
Wm21        =       (Weglengte ./ Af_bomen) .*kwm(21);                  %       Maintenance trees
Tot_Wm      =       Wm1 + Wm2 + Wm3 + Wm4 + Wm5 + Wm6 + Wm7 + Wm8 + Wm9 + Wm10+...
            Wm11 + Wm12 + Wm13 + Wm14 + Wm15 + Wm16 + Wm17 + Wm18 + Wm19 + Wm20 + Wm21;         %    Total costs hard and soft landscaping

%Awe         Additional work elements
Awe1        = 2 .*kawe(1);          %       Outflow basins culverts
Awe2        = 1 .*kawe(2);          %       Culverts within development fields
Awe3        = 1 .*kawe(3);          %       Constructing play facility
Tot_Awe     =       Awe1 + Awe2 + Awe3;     %       Total costs additional work elements

% Costs parking deck (parkingspaces with a roof)
Tot_pdek = x(:,20) * K_parkeerdek; %  Total cost for parking spaces with parking deck

Tot_kos = Tot_Opr + Tot_Oph + Tot_Gv + Tot_Bm + Tot_Wm + Tot_Awe + Tot_pdek ; % Total cost to develop/build area
```

```
%Ik  (In)directe kosten
Ik1 =       Tot_kos;                            %       Direct costs
Ik2 =       Tot_kos.*0.07;                  %    Non-recurring costs, construction site costs, implementation costs
Ik3 =       (Tot_kos + Tot_kos.*0.07).*0.115;       %       AK, WR. Contributions (e.g. RAW/FCO)
Ik4 =       0.*Tot_kos;                         %       Contingencies
Tot_Ik      =       Ik1 + Ik2 + Ik3 + Ik4;          %       Total costs Including indirect costs

Tot_kosten = Tot_Ik/1000000;                %    Total costs including indirect costs expressed in millions

Tot_Saldo = (Tot_opbrengst- Tot_kosten);    %    Result after optimalisation
```

Preference scores

```
% Preference Stakeholder F
Preffun_f1 = pchip(Valf1, Preff1, Tot_opbrengst);  % Preference function over objective F1
Preffun_f2 = pchip(Valf2, Preff2, groenwon);       % Preference function over objective F2
Preffun_f3 = pchip(Valf3, Preff3, Tot_betaalbaar); % Preference function over objective F3
Preffun_f4 = pchip(Valf4, Preff4, Tot_duur);       % Preference function over objective F4
Preffun_f5 = pchip(Valf5, Preff5, Tot_EG);         % Preference function over objective F5
Preffun_f6 = pchip(Valf6, Preff6, Tot_woningen);   % Preference function over objective F6
Preffun_f7 = pchip(Valf7, Preff7, Tot_sociaal);    % Preference function over objective F7
Preffun_f8 = pchip(Valf8, Preff8, Tot_MG);         % Preference function over objective F8

Preffun_f = [Preffun_f1 Preffun_f2 Preffun_f3 Preffun_f4 Preffun_f5 Preffun_f6 Preffun_f7 Preffun_f8]; % Preferences for all objectives of stakeholder F
                                                                                                        % in one array

% Preference Stakeholder G
Preffun_g1 = pchip(Valg1, Prefg1, Tot_opbrengst);  % Preference function over objective G1
Preffun_g2 = pchip(Valg2, Prefg2, groenwon);       % Preference function over objective G2
Preffun_g3 = pchip(Valg3, Prefg3, parkafw);        % Preference function over objective G3
Preffun_g4 = pchip(Valg4, Prefg4, Tot_schuur);     % Preference function over objective G4
Preffun_g5 = pchip(Valg5, Prefg5, Tot_EG);         % Preference function over objective G5
Preffun_g6 = pchip(Valg6, Prefg6, Tot_duur);       % Preference function over objective G6
Preffun_g7 = pchip(Valg7, Prefg7, Tot_betaalbaar); % Preference function over objective G7
Preffun_g8 = pchip(Valg8, Prefg8, Tot_MG);         % Preference function over objective G8
Preffun_g9 = pchip(Valg9, Prefg9, Tot_woningen);   % Preference function over objective G9
Preffun_g10 = pchip(Valg10, Prefg10, Tot_sckoop);  % Preference function over objective G10
Preffun_g11 = pchip(Valg11, Prefg11, x(:,18));     % Preference function over objective G11

Preffun_g = [Preffun_g1 Preffun_g2 Preffun_g3 Preffun_g4 Preffun_g5 Preffun_g6 Preffun_g7 Preffun_g8 Preffun_g9 Preffun_g10 Preffun_g11]; % Preferences
                                                                                                    % for all objectives of stakeholder G in one array

% Preference Stakeholder S
Preffun_s1 = pchip(Vals1, Prefs1, Tot_opbrengst);  % Preference function over objective S1
Preffun_s2 = pchip(Vals2, Prefs2, groenwon);       % Preference function over objective S2
Preffun_s3 = pchip(Vals3, Prefs3, parkafw);        % Preference function over objective S3
Preffun_s4 = pchip(Vals4, Prefs4, P_bebouwdpark);  % Preference function over objective S4
Preffun_s5 = pchip(Vals5, Prefs5, Rustwonen);      % Preference function over objective S5
Preffun_s6 = pchip(Vals6, Prefs6, Tot_betaalbaar); % Preference function over objective S6
Preffun_s7 = pchip(Vals7, Prefs7, Tot_EG);         % Preference function over objective S7
Preffun_s8 = pchip(Vals8, Prefs8, Tot_MG);         % Preference function over objective S8
Preffun_s9 = pchip(Vals9, Prefs9, Tot_sociaal);    % Preference function over objective S9
Preffun_s10 = pchip(Vals10, Prefs10, Tot_woningen);% Preference function over objective S10
Preffun_s11 = pchip(Vals11, Prefs11, Tot_duur);    % Preference function over objective S11
Preffun_s12 = pchip(Vals12, Prefs12, x(:,18));     % Preference function over objective S12

Preffun_s = [Preffun_s1 Preffun_s2 Preffun_s3 Preffun_s4 Preffun_s5 Preffun_s6 Preffun_s7 Preffun_s8 Preffun_s9 Preffun_s10 Preffun_s11 Preffun_s12];
                                                                                      % Preferences for all objectives of stakeholder S in one array

P = [Preffun_f Preffun_g Preffun_s];               % All preferences together
```

Optimisation value

distance from goal

```
%Stakeholder Financial (F)
P_Fin=Preffun_f;                                % Preferences per objective for Financial director
d_Fin=100-P_Fin;                                % distance from goal (a 100 preference score) per objective for Financial director
W_Fin=repmat(W_f,size(d_Fin,1),1);              % Reshape the weights (of Financial director) to be able to use them in the optimisation solver
w_d_Fin=W_Fin.*d_Fin;                           % distance from goal (a 100 preference score) per objective times the weight per objective for Financial director
w_d_Fin_sum=sum(w_d_Fin);                       % Total (all objectives) distance for Financial director

%Stakeholder Municipality (G)
P_gemeente= Preffun_g ;                         % Preferences per objective for Municipality
d_gemeente=100-P_gemeente;                      % distance from goal (a 100 preference score) per objective for Municipality
W_gemeente=repmat(W_g,size(d_gemeente,1),1);    % Reshape the weights (of Municipality) to be able to use them in the optimisation solver
w_d_gemeente=W_gemeente.*d_gemeente;            % distance from goal (a 100 preference score) per objective times the weight per objective for Municipality
w_d_gemeente_sum=sum(w_d_gemeente);             % Total (all objectives) distance for Municipality

%Stakeholder urban developer (S)
P_steden= Preffun_s;                            % Preferences per objective for Urban planner
d_steden=100-P_steden;                          % distance from goal (a 100 preference score) per objective for Urban planner
W_steden=repmat(W_s,size(d_steden,1),1);        % Reshape the weights (of Urban Planner) to be able to use them in the optimisation solver
w_d_steden=W_steden.*d_steden;                  % distance from goal (a 100 preference score) per objective times the weight per objective for Urban planner
w_d_steden_sum=sum(w_d_steden);                 % Total (all objectives) distance for Urban planner


%Minmax objective: To minimize the total distance per stakeholder
Opt1=max([w_d_Fin_sum w_d_gemeente_sum w_d_steden_sum],[],2);
```

```
end


% Fill in a title for the run that will be showed above the design in the output Excel
name = "V6 W211 surrogate, goal attainment, gr7 pp0.9, ";
```

Options

Set of options for the problem definition

```
opts = optimoptions(@fmincon,'Algorithm','sqp','FunctionTolerance', 1e-10, 'ConstraintTolerance', 1e-10);
```

Optimisation

optimization will be run with Multistart

```
tic;                    % Start moment to Calculate the runtime
rng('shuffle');


x0=(ub+lb)/2;           %In initial point, estimation in between lower and upper bound
problem = createOptimProblem('fmincon','objective',...          %Formulation of the objective problem to solve for multistart
    @ObjFunction1,'x0',x0,'lb',lb,'ub',ub,'Aineq',A,'bineq',b,'Aeq',Aeq,'beq',beq,'nonlcon',nonlcon,'options',opts);

% multistart options used for the Multisatrt solver
ms = MultiStart;
ms.Display='iter';
ms.UseParallel=true;
ms.FunctionTolerance=1e-10;
ms.XTolerance=1e-10;
ms.PlotFcn=@gsplotbestf;


% optimisation fuction
[xbest, fbest] = run(ms,problem,2500)
% xbest = retuns 20 best values of x (design variables)
% fbest = optimisation value


x_out=[xbest,fbest]
assignin('base','x_out',x_out) % Assigns X-values to the workspace in MATLAB (not used)

Duurrun = toc;          % Calculates the runtime;
```

Calculations of the relations with xbest

Filling in the xbest values in the relation

```
%Houses
    Tot_woningen = xbest(:,1) + xbest(:,2) + xbest(:,3) +xbest(:,4) +xbest(:,5) +xbest(:,6) +xbest(:,7) +xbest(:,8) +xbest(:,9) +xbest(:,10)...
                 +xbest(:,11) +xbest(:,12) + xbest(:,13) +xbest(:,14) +xbest(:,15) + xbest(:,16)+ xbest(:,17); % Total number of houses
    Tot_schuur = xbest(:,10)+ xbest(:,17); % Total number of social (rental) houses
    Tot_sckoop = xbest(:,1) + xbest(:,11) + xbest(:,14); % Total number of social (owner-occupied) houses
    Tot_duur = xbest(:,4) +xbest(:,5) +xbest(:,6) +xbest(:,7) +xbest(:,9) +xbest(:,13); % Total expensive houses
    Tot_betaalbaar =  xbest(:,2) + xbest(:,3) +xbest(:,8) +xbest(:,12) +xbest(:,15) + xbest(:,16); % Total affordable houses
    Tot_sociaal =   xbest(:,1) +xbest(:,10) +xbest(:,11) +xbest(:,14)+ xbest(:,17) ;  % Total social houses

    Tot_rij = xbest(:,1) + xbest(:,2) + xbest(:,3) +xbest(:,4) +xbest(:,8) +xbest(:,9)+ xbest(:,17); % Total number of terraced houses
    Tot_2kap = xbest(:,5); % Total number of semidetached houses
    Tot_vrij = xbest(:,6) +xbest(:,7); % Total number of detached houses
    Tot_MG = xbest(:,10) +xbest(:,11) +xbest(:,12) + xbest(:,13) +xbest(:,14) +xbest(:,15) + xbest(:,16);  % Total number of appartments
    Tot_EG = Tot_rij + Tot_2kap + Tot_vrij; % Total number of single-family houses
    won_bebouwdpark = xbest(:,13) +xbest(:,14) +xbest(:,15) + xbest(:,16); % Total number of houses where there are build parking spaces

    P_bebouwdpark = won_bebouwdpark./Tot_woningen; % Percentage of houses with build parking spaces from total number of houses


%loop zorgcomplex
    if (xbest(:,18) >= 0.5) & (xbest(:,18)  < 1.5)  % Option 1 (between 0.5 and 1.4): 31 units
        zorgopp = 31*21 +66;                        % Total area needed for option 1, build in 4 layers
        zorgwinst = 31* 17500;                      % Profit for 31 units
        zorgextrapark = 0;                          % No extra parking spaces needed
        Rustwonenb =  0.3 ;                         % Percentage houses that can be labeled as 'quiet living'
        zorgoptie = 31;                             %  Amount of units with the corresponding option
    elseif (xbest(:,18)  >= 1.5) & (xbest(:,18)  < 2.5) % Option 2 (between 1.5 and 2.5): 62 units
        zorgopp = 1366;                             % Standard area usage, build in 4 layers
        zorgwinst = 62*17500;                       % Profit for 62 units
        zorgextrapark = 0 ;                         % No extra parkingspaces needed
        Rustwonenb =  0.2 ;                         % Percentage houses that can be labeled as 'quiet living'
        zorgoptie = 62;                             %  Amount of units with the corresponding option
    elseif (xbest(:,18)  >= 2.5) & (xbest(:,18)  < 3.5) % Option 3 (between 2.5 and 3.4): 93 units
        zorgopp = 93*18 +66;                        % Total area needed, build in 6 layers
        zorgwinst = 93*17500;                       % Profit for 93 units
        zorgextrapark = 31*0.7*12.5;                % Area for extra parking spaces (m2)
        Rustwonenb =  0.0 ;                         % Percentage houses that can be labeled as 'quiet living'
        zorgoptie = 93;                             % Amount of units with the corresponding option
    else                                            % Option 0: 0 units
        zorgopp = 0 ;                               % No area needed
        zorgwinst = 0;                              % No profit
        zorgextrapark = 0;                          % No area for extra parking spaces
        Rustwonenb =  0.5 ;                         % Percentage houses that can be labeled as 'quiet living'
        zorgoptie = 0;                              % Amount of units with the corresponding option
    end


    % Area usage
    Tot_uitgeefbaar =  sum(Uitgeef(1:17)'.*xbest(:,1:17),2);   % Total plot area
    Minimaal_groen = min_Groen .* Tot_woningen ; % Minimal total area for greenery
    Tot_spelen =  sum(Spelen(1:17)'.*xbest(:,1:17),2)   ; % Total area for a playground, dependent on total plot area

    Minimaal_parkeren =min_parkafw.*(sum(Parkeren(1:17)'.*xbest(:,1:17),2)) + zorgextrapark; % Minimal total area for parking, based on the minimum obtained
    Norm_parkeren = (sum(Parkeren(1:17)'.*xbest(:,1:17),2)); % Total area for parking, based on standard norm (=1)

    Tot_rijbaan =  sum(Straat(1:17)'.*xbest(:,1:17),2); % Total area for road
    Tot_stoep =  sum(Stoep(1:17)'.*xbest(:,1:17),2);  % Total area for sidewalk
    Tot_verharding = Tot_parkeren + Tot_rijbaan +Tot_stoep ; % Total pavement area

    Tot_oppervlak =  Tot_uitgeefbaar + Minimaal_parkeren + Tot_rijbaan +Tot_stoep... % Total area for the number of houses
                   + Tot_spelen + Minimaal_groen +zorgopp ;                          % This should be equal to the total plan area

    Opvulling = Opp_gebied -(Tot_uitgeefbaar + Minimaal_parkeren + Tot_rijbaan...    % Area that is 'not used' in the plans and
               +Tot_stoep + Tot_spelen + Minimaal_groen +zorgopp +Opp_parkeeropl);   % will be divided between extra green and extra parkingspaces

    Tot_groen = min_Groen .* Tot_woningen + Opvulling.*xbest(:,19); % Total area for greenery

    Tot_parkeren = min_parkafw .* sum(Parkeren(1:17)'.*xbest(:,1:17),2)...  % Total area for parking, including parking spaces for
                 + zorgextrapark + Opvulling.*(1-xbest(:,19));             % the healtchare center and extra parking from division factor

    Tot_parkerenwon = min_parkafw .*sum(Parkeren(1:17)'.*xbest(:,1:17),2) + ... % Total area for parking for the houses
                    Opvulling .*(1-xbest(:,19));                               % (without healthcare complex parking spaces)
    Tot_verharding = Tot_parkeren + Tot_rijbaan +Tot_stoep ;                 % Total pavement area
```

```
Weglengte = Tot_verharding/Verhardingb; % Road length and sewer length depending on total paved area

groendek = xbest(:,20).*12.5;                  % Area greenery on roof of parking spaces (in m2)
Tot_groen_dek = groendek + Tot_groen;      % Total greenert in the area (on parking deck and in the rest of the area)
groenwon = Tot_groen_dek./Tot_woningen;    % Total area of green per house in m2
parkafw = Tot_parkerenwon./Norm_parkeren;  % Deviation from (the standard) parking norm

P_parkeerdek = (xbest(:,20).*12.5 ./ Tot_parkerenwon)*100 ; % Pecentage parkeren onder een dek van
```

Final Costs to develop the area

```
%Opr        Opruimingswerkzaamheden
Opr1        =       Opp_gebied .*kopr(1);   %       Clearing agricultural land, incl. dumping costs
Opr2        =       Opp_gebied .*kopr(2);   %       Milling terrain
Opr3        =       Opp_gebied .*kopr(3);   %       Leveling terrain
Tot_Opr     =       Opr1 + Opr2 + Opr3;         %    Total costs clearing operations


% Oph       Elevation of the site
Oph1        =   H_oph_verharding .* Tot_verharding .*koph(1);       %       Adding sand in front of paving (delivery)
Oph2        =   H_oph_uitg .* Tot_uitgeefbaar .*koph(2);        %    Soil supply in front of the plot area (release)
Oph3        =       H_oph_groen .* Tot_groen .*koph(3);                %    Soil supply from green space (release)

balans  = (Gr_vrij_ag+ (Weglengte .* 8.75 .* 0.4)) - (Gr_verwerken_ag + (H_oph_uitg .* Tot_uitgeefbaar) + (H_oph_groen .* Tot_groen));
tekort  = (Gr_tekort_ag+ (Weglengte .* 8.75 .* 0.4) + (H_oph_uitg .* Tot_uitgeefbaar)+ (H_oph_groen .* Tot_groen));
verdeling = ((Weglengte .* 8.75 .* 0.4) - (H_oph_uitg .* Tot_uitgeefbaar)- (H_oph_groen .* Tot_groen));
Oph4    = - ((balans ./ tekort).*verdeling).*koph(4);   %    Delivering soil shortage


Oph5        =       (Opp_gebied ./ 6 .* Lv_drain) .*koph(5);        %       Apply vertical drainage
Oph6        =       (Opp_gebied ./ 10 ) .*koph(6);              %    Apply horizontal drainage
Oph7        =       (Opp_gebied ./ 500) .*koph(7);              %    Applying sack beacons
Oph8        =       (Opp_gebied ./ 500)  .*koph(8);             %    Monitor sack beacons
Oph9        =       Opp_gebied  .*koph(9);                      %    Covering embankment
Tot_Oph     =       Oph1 + Oph2 + Oph3 + Oph4 + Oph5 + Oph6 + Oph7 + Oph8 + Oph9;   %       Total costs elevation of the site

%Gv  Soil transportation
Gv1     =   (Weglengte .* 8.75 .* 0.4) .*kgv(1);    %       Transport of soil within sub-area
Gv2     =   0 .*kgv(2);                                 %    Transport soil to other sub-area
Tot_Gv      = Gv1 + Gv2     ;                               %    Total costs transport of soil

%Bm         Site preparation (Bouwrijp maken)
Bm1     =   (Weglengte .* 8.75 .* 0.4) .*kbm(1);    %       Excavated sewer trench (soil)
Bm2     =   Weglengte.*8.75.*0.6 .*kbm(2);          %       Excavated sewer trench (sand, reuse)
Bm3     =   Weglengte .*kbm(3);                         %    Applying drainage
Bm4     =   Weglengte .*kbm(4);                         %    Laying sewer DWA including manholes
Bm5     =   Tot_woningen .*kbm(5);                  %       Installation of house connections DWA
Bm6     =   0 .*kbm(6);                                 %    Connecting DWA to existing sewer
Bm7     =   Weglengte .*kbm(7);                         %    Installation of sewer HWA including manholes
Bm8     =   Tot_woningen .*kbm(8);                  %       Installation of house connections HWA
Bm9     =   0 .*kbm(9);                                 %    Connecting HWA to existing sewer
Bm10        =       (Tot_verharding ./ 100) .*kbm(10);          %    Installing gully connections
Bm11        =       Weglengte .*kbm(11);                %       Installing drainage p90 incl. manholes
Bm12        =       ((Weglengte .* 8.75 .* 0.4)+ (Weglengte.*8.75.*0.6)) .*kbm(12);         %       Fill up sewer trench with sand incl. compaction
Bm13        =       (Weglengte.*8.75.* 0.4) .*kbm(13);          %    Delivering missing sand
Bm14        =       0.02 .* (Bm1+ Bm2+ Bm3+ Bm4+ Bm5+ Bm6+ Bm7+ Bm8+ Bm9+ Bm10+ Bm11+ Bm12+ Bm13); %       Temporary provisions sewerage
Bm15        =       2 .* Weglengte .*kbm(15);                   %    Overhaul and inspection sewers
Bm16        =       Weglengte .* 6  .*kbm(16);                  %    Construction of granulate road
Bm17        =       Weglengte .* 6 *kbm(17);                    %    Maintenance construction road granulate
Bm18        =       (0.05 .* Weglengte .* 6) .*kbm(18);         %    Temporary pavements
Bm19        =       300 .* 2 .*kbm(19)-44010;                   %    Installation of shoring equipment
Tot_Bm      =       Bm1 + Bm2 + Bm3 + Bm4 + Bm5 + Bm6 + Bm7 + Bm8 + Bm9 + Bm10 +...
            Bm11 + Bm12 + Bm13 + Bm14 + Bm15 + Bm16 + Bm17 + Bm18 +Bm19;        %    Total costs site preparation

%Wm   Hard and soft landscaping (Woonrijp maken)
Wm1     =   (Weglengte .* 6)  .*kwm(1);                 %    Filling out foundation construction roads
Wm2     =   (Weglengte .* 6 .* 0.05) .*kwm(2);          %    Removing temporary pavements
Wm3     =   H_zand .* Tot_verharding  .*kwm(3);         %    Adding sand in front of pavement

Wm5     =   Tot_verharding .* p_rij .*kwm(5);       %       Installing baked pavement and edge protections (traffic lane)
Wm6     =   Tot_verharding .* p_park .*kwm(6);          %    Install concrete pavement and edge closures (parking)
Wm7     =   Tot_verharding .* p_stoep .*kwm(7);         %    Install concrete pavers edging (sidewalk)
Wm4     =   (Tot_verharding .* p_rij + Tot_verharding .* p_park + Tot_verharding .* p_stoep ) .*kwm(4);     %       Apply street layer

Wm8     =   ( Tot_verharding .* p_rij).* 0.05 .*kwm(8);     %       Apply traffic calming mat measures
Wm9     =   ( Tot_verharding .* p_rij + Tot_verharding .* p_park + Tot_verharding .* p_stoep ) .*kwm(9);    %       Maintain pavements
Wm10        =       ((2.* Weglengte) ./ 35) .*kwm(10);          %    Leveling manhole cover edges
Wm11        =       (Tot_verharding ./ 100) .*kwm(11);          %    Installing gullies
Wm12        =       (Weglengte./ Af_Lm) .*kwm(12);          %       Installing lighting incl. cable
Wm13        =       Opp_gebied .*kwm(13);                   %       Adding traffic signs/street name signs
Wm14        =       Opp_gebied .*kwm(14);                   %       Installation of street furniture
Wm15        =       H_teelaarde .* Tot_groen .*kwm(15);         %    Applying soil in green areas
Wm16        =       0.3 .* Tot_groen .*kwm(16);                 %    Applying planting
Wm17        =       (Weglengte ./ Af_bomen)  .*kwm(17);     %       Applying avenue tree in pavement incl. soil improvement
Wm18        =       (Weglengte ./ Af_bomen  .* 10   ) .*kwm(18) ;       %    Applying root guide trees in pavement
Wm19        =       0.7 .* Tot_groen *kwm(19);                      %       Fertilize and sow lawns
Wm20        =       ( 0.3 .* Tot_groen +0.7 .* Tot_groen) .*kwm(20);        %       Maintenance of green spaces
Wm21        =       (Weglengte ./ Af_bomen) .*kwm(21);              %       Maintenance trees
Tot_Wm      =       Wm1 + Wm2 + Wm3 + Wm4 + Wm5 + Wm6 + Wm7 + Wm8 + Wm9 + Wm10+...
            Wm11 + Wm12 + Wm13 + Wm14 + Wm15 + Wm16 + Wm17 + Wm18 + Wm19 + Wm20 + Wm21;         %    Total costs hard and soft landscaping

%Awe         Additional work elements
Awe1        = 2 .*kawe(1);          %       Outflow basins culverts
Awe2        = 1 .*kawe(2);          %       Culverts within development fields
Awe3        = 1 .*kawe(3);          %       Constructing play facility
Tot_Awe     =       Awe1 + Awe2 + Awe3;     %       Total costs additional work elements

% Costs parking deck (parkingspaces with a roof)
Tot_pdek = xbest(:,20) * K_parkeerdek; %  Total cost for parking spaces with parking deck

Tot_kos = Tot_Opr + Tot_Oph + Tot_Gv + Tot_Bm + Tot_Wm + Tot_Awe + Tot_pdek ; %Totale kosten voor ontwikkelen/aanleggen gebied

%Ik  (In)directe kosten
Ik1 =       Tot_kos;                        %       Direct costs
Ik2 =       Tot_kos.*0.07;                      %    Non-recurring costs, construction site costs, implementation costs
Ik3 =       (Tot_kos + Tot_kos.*0.07).*0.115;       %       AK, WR. Contributions (e.g. RAW/FCO)
Ik4 =       0.*Tot_kos;                         %       Contingencies
```

```
Tot_Ik      =       Ik1 + Ik2 + Ik3 + Ik4;          %       Total costs Including indirect costs

Tot_kosten = Tot_Ik/1000000; % Total costs including indirect costs

% Revenues
Tot_opbrengst = ((sum(profx(1:17)'.*xbest(:,1:17),2)) + zorgwinst + 681000)/1000000; %Total revenues

%Result
Tot_Saldo = (Tot_opbrengst-Tot_kosten); % Result after optimalisation
```

Final preference based on optimization values (xbest)

```
% Preference Stakeholder F (Financial director)
Preffun_f1 = pchip(Valf1, Preff1, Tot_opbrengst); %Preference function over objective F1
Preffun_f2 = pchip(Valf2, Preff2, groenwon); %Preference function over objective F2
Preffun_f3 = pchip(Valf3, Preff3, Tot_betaalbaar); %Preference function over objective F3
Preffun_f4 = pchip(Valf4, Preff4, Tot_duur); %Preference function over objective F4
Preffun_f5 = pchip(Valf5, Preff5, Tot_EG); %Preference function over objective F5
Preffun_f6 = pchip(Valf6, Preff6, Tot_woningen); %Preference function over objective F6
Preffun_f7 = pchip(Valf7, Preff7, Tot_sociaal); %Preference function over objective F7
Preffun_f8 = pchip(Valf8, Preff8, Tot_MG); %Preference function over objective F8

Preffun_fbest = [Preffun_f1 Preffun_f2 Preffun_f3 Preffun_f4 Preffun_f5...    % Preferences for all objectives of stakeholder F in one array
                 Preffun_f6 Preffun_f7 Preffun_f8];

% Preference Stakeholder G (Municipality)
Preffun_g1 = pchip(Valg1, Prefg1, Tot_opbrengst); %Preference function over objective G1
Preffun_g2 = pchip(Valg2, Prefg2, groenwon); %Preference function over objective G2
Preffun_g3 = pchip(Valg3, Prefg3, parkafw); %Preference function over objective G3
Preffun_g4 = pchip(Valg4, Prefg4, Tot_schuur); %Preference function over objective G4
Preffun_g5 = pchip(Valg5, Prefg5, Tot_EG); %Preference function over objective G5
Preffun_g6 = pchip(Valg6, Prefg6, Tot_duur); %Preference function over objective G6
Preffun_g7 = pchip(Valg7, Prefg7, Tot_betaalbaar); %Preference function over objective G7
Preffun_g8 = pchip(Valg8, Prefg8, Tot_MG); %Preference function over objective G8
Preffun_g9 = pchip(Valg9, Prefg9, Tot_woningen); %Preference function over objective G9
Preffun_g10 = pchip(Valg10, Prefg10, Tot_sckoop); %Preference function over objective G10
Preffun_g11 = pchip(Valg11, Prefg11, xbest(:,18)); %Preference function over objective G11

Preffun_gbest = [Preffun_g1 Preffun_g2 Preffun_g3 Preffun_g4 Preffun_g5 Preffun_g6...  % Preferences for all objectives of stakeholder G in one array
                 Preffun_g7 Preffun_g8 Preffun_g9 Preffun_g10 Preffun_g11];

% Preference Stakeholder S (Urban planner)
Preffun_s1 = pchip(Vals1, Prefs1, Tot_opbrengst); %Preference function over objective S1
Preffun_s2 = pchip(Vals2, Prefs2, groenwon); %Preference function over objective S2
Preffun_s3 = pchip(Vals3, Prefs3, parkafw); %Preference function over objective S3
Preffun_s4 = pchip(Vals4, Prefs4, P_bebouwdpark); %Preference function over objective S4
Preffun_s5 = pchip(Vals5, Prefs5, Rustwonenb); %Preference function over objective S5
Preffun_s6 = pchip(Vals6, Prefs6, Tot_betaalbaar); %Preference function over objective S6
Preffun_s7 = pchip(Vals7, Prefs7, Tot_EG); %Preference function over objective S7
Preffun_s8 = pchip(Vals8, Prefs8, Tot_MG); %Preference function over objective S8
Preffun_s9 = pchip(Vals9, Prefs9, Tot_sociaal); %Preference function over objective S9
Preffun_s10 = pchip(Vals10, Prefs10, Tot_woningen); %Preference function over objective S10
Preffun_s11 = pchip(Vals11, Prefs11, Tot_duur); %Preference function over objective S11
Preffun_s12 = pchip(Vals12, Prefs12, xbest(:,18)); %Preference function over objective S12

Preffun_sbest = [Preffun_s1 Preffun_s2 Preffun_s3 Preffun_s4 Preffun_s5 Preffun_s6 ...  % Preferences for all objectives of stakeholder S in one array
                 Preffun_s7 Preffun_s8 Preffun_s9 Preffun_s10 Preffun_s11 Preffun_s12];

Pbest = [Preffun_fbest Preffun_gbest Preffun_sbest]; %All preferences together in an array
```

Second optimization: 1 solution in Tetra (using xbest)

```
PrefbestT = [Pbest];
Tetrabest = Tetra_solver2(Wtot_tot1,PrefbestT);
```

Distance from goal

To compare with the goal attainment method

```
D_fin= 100 - Preffun_fbest; % distance from goal (a 100 preference score) per objective for Financial director
D_gemeente = 100- Preffun_gbest;  % distance from goal (a 100 preference score) per objective for Urban planner
D_steden = 100- Preffun_sbest;  % distance from goal (a 100 preference score) per objective for Municipality

Dist_fin = W_f .* D_fin; % distance from goal (a 100 preference score) per objective times the weight per objective for Financial director
Dist_gemeente = W_g .* D_gemeente;  % distance from goal (a 100 preference score) per objective times the weight per objective for Urban planner
Dist_steden= W_s .* D_steden; % distance from goal (a 100 preference score) per objective times the weight per objective for Municipality

maxDist = max([Dist_fin,Dist_gemeente,Dist_steden]); % the maximal distance of 1 objective of the three staekholders
maxdist_fin = max(Dist_fin); % the maximal distance of 1 objective of Financial director
maxdist_gemeente = max(Dist_gemeente); % the maximal distance of 1 objective of Municipality
maxdist_steden = max(Dist_steden); % the maximal distance of 1 objective of Urbanp lanner
sumdist_fin = sum(Dist_fin); %Total (all objectives) distance for Financial director
sumdist_gemeente = sum(Dist_gemeente); %Total (all objectives) distance for Municipality
sumdist_steden = sum(Dist_steden); %Total (all objectives) distance for Urban planner
```

Display

Several values that are displayed after running the model. The purple text indicatates what value is displayed

```
display(Duurrun,'Elapsed time in seconds');
display(Tot_oppervlak, 'Total plan area in m2');
display(Opvulling, 'm2 unused land');
display(Opp_gebied, 'Total area in m2');
display((Tot_uitgeefbaar+ Tot_spelen +Tot_rijbaan + Tot_stoep), 'Total plan area without green and parking');
display( (Tot_kosten), 'General costs');
display( (Tot_opbrengst), 'General revenues');
display((Tot_groen), 'Total area for greenery and parkingdeck');
display((Tot_groen_dek), 'Area for greenery');
display((Tot_parkeren), 'Total area for parking');
display((xbest(:,20)), 'Parking spaces with a roof (parkingdeck)');
display((groenwon), 'Area green per house');
display((parkafw), 'Deviation from parking norm');
display((Tot_parkeren/Tot_woningen), 'Area parking per house');
display((xbest(:,19)), 'Ratio Parking/Green');
```

```
display((Tot_woningen), 'Total number of houses');
display((Tot_sociaal), 'Social houses');
display((Tot_schuur), 'Social rental houses');
display((Tot_sckoop), 'Social owner-occupied houses');
display((Tot_betaalbaar), 'Affordable houses');

display((Tot_spelen), 'Area for playground next to greenery (1,5%)');

display((Tot_duur), 'Expensive houses');
display(xbest(1:17), 'Number of houses per type');
display(zorgoptie, 'Option healthcare center');

display((Wm16 +Wm19 +Wm20), 'Costs greenery');

display(Preffun_fbest,'Preference per objective stakeholder F (Financial director)'); % Preference
display(Preffun_gbest,'Preference per objective stakeholder G (Municipality)'); % Preference
display(Preffun_sbest(1:11),'Preference per objective stakeholder S (Urban planner)'); % Preference
display(-fbest,'Optimisation value'); %Overall preference

display(Tot_Saldo, 'Saldo (negative is deficit)'); % Result
display( (Tot_opbrengst), 'General revenues'); %Final values of design variables
display(-Tetrabest,'alter Tetra'); %Overall preference in Tetra
```

Save output to the Excel output file

Several values that are displayed after running the model. The purple text indicatates what value is displayed.

```
datum = string(datetime('now'));
filename = 'Output Waelpolder.xlsx'; % Name output Excel file

% Design outcome for Excel file
waardes = [Tot_Saldo (Tot_oppervlak+ Opp_parkeeropl)  Tot_kosten Tot_opbrengst Tot_groen (Tot_groen/Tot_woningen)  Tot_parkeren parkafw (P_bebouwdpark*100) P_parkeerdek  Tot_spelen Tot_wor
desfinaf = round(waardes,4);

% Show personal preference scores:
overallaf = [nan nan nan nan nan nan nan nan nan nan nan nan nan nan]; %let one column empty between every personal preference scores per design

% Minucipality preference and distance from goal for Excel file
Gemeente = [Preffun_g1 Preffun_g2 Preffun_g3 nan Preffun_g9 nan Preffun_g4 Preffun_g10 Preffun_g7 Preffun_g6 Preffun_g5 Preffun_g8 Preffun_g11 nan ];
gemeenteaf = round(Gemeente,4);
gemeentegem = sum(W_g.*Preffun_gbest);
distGemeente = [Dist_gemeente(1) Dist_gemeente(2) Dist_gemeente(3) nan Dist_gemeente(9) nan Dist_gemeente(4) Dist_gemeente(10) Dist_gemeente(7) Dist_gemeente(6) Dist_gemeente(5) Dist_gemee
distgemeenteaf = round(distGemeente,4);

% Financial director preference and distance from goal for Excel file
Financieel = [Preffun_f1 Preffun_f2 nan nan Preffun_f6 Preffun_f7 nan nan Preffun_f3 Preffun_f4 Preffun_f5 Preffun_f8 nan nan ];
financieelaf = round(Financieel,4);
finangem = sum(W_f.*Preffun_fbest);
distFinancieel = [Dist_fin(1) Dist_fin(2) nan nan Dist_fin(6) Dist_fin(7) nan nan Dist_fin(3) Dist_fin(4) Dist_fin(5) Dist_fin(8) nan nan ];
distfinaf = round(distFinancieel,4);

% Urban planner preference and distance from goal for Excel file
Stedenbouw= [Preffun_s1 Preffun_s2 Preffun_s3 Preffun_s4 Preffun_s10 Preffun_s9 nan nan Preffun_s6 Preffun_s11 Preffun_s7 Preffun_s8 Preffun_s12 Preffun_s5 ];
stedenbouwaf = round(Stedenbouw,4);
stedengem = sum(W_s.*Preffun_sbest);
distStedenbouw= [Dist_steden(1) Dist_steden(2) Dist_steden(3) Dist_steden(4) Dist_steden(10) Dist_steden(9) nan nan Dist_steden(6) Dist_steden(11) Dist_steden(7) Dist_steden(8) Dist_steder
diststedenbouwaf = round(distStedenbouw,4);


% Values for the preference sheet in Excel: Overall preference, and per stakeholder; Municiapilty, Financial director, Urban planner
OverallPref = [ name, -fbest, "Totaal" overallaf nan datum nan nan nan maxDist ];
GemeentePref = [ nan nan "Gemeente" gemeenteaf gemeentegem nan nan nan nan nan maxdist_gemeente distgemeenteaf sumdist_gemeente ];
FinanPref = [ nan nan  "Financieel" financieelaf finangem nan nan nan nan nan maxdist_fin distfinaf sumdist_fin];
StedenPref = [ nan nan  "Stedenbouwkundige" stedenbouwaf stedengem nan nan nan nan nan maxdist_steden diststedenbouwaf sumdist_steden];

% Values of total design and extra information in one 'Design' sheet in Excel:
outputb = [ name, "Ontwerp", -fbest, desfinaf, datum, Duurrun, Opvulling];

% Values of xbest of design variables in 'xwaardes' sheet in Excel:
xwaardes = [name, xbest, datum];

% Writing the values to the design and x-values sheet of the Excel file
writematrix(outputb,filename, 'Sheet', 'ML Ontwerp', 'WriteMode','append')
writematrix(xwaardes, filename, 'Sheet', 'X-values', 'WriteMode','append')

% Writing the values to the preference sheet of the Excel file
writematrix(OverallPref, filename, 'Sheet', 'ML preferentie', 'WriteMode','append')
writematrix(FinanPref, filename, 'Sheet', 'ML preferentie', 'WriteMode','append')
writematrix(StedenPref, filename, 'Sheet', 'ML preferentie', 'WriteMode','append')
writematrix(GemeentePref, filename, 'Sheet', 'ML preferentie', 'WriteMode','append')
```

```
end
```

Published with MATLAB® R2021b

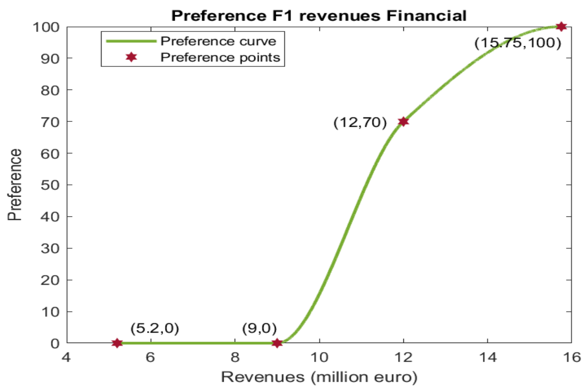
I.3 Outcome stakeholder sessions 1 & 2

In this appendix, there will be elaborated on the preference curves that were conducted by the stakeholders during the first and second stakeholder session.

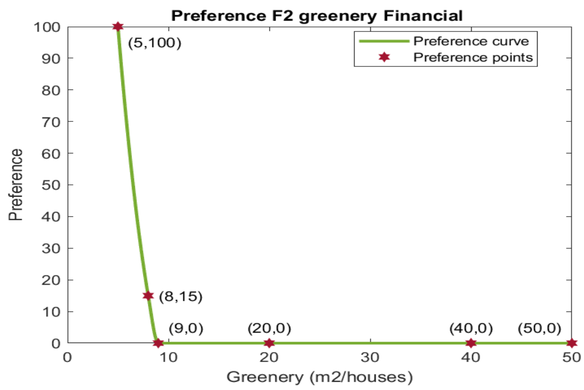
I.3.1 Financial director

In short, what can be seen in the curves of the financial director for housing is that he wants to maximize the number of houses that generate revenues. He prefers expensive houses over affordable and social houses and single-family houses over multi-family houses. Therefore, the curves for expensive houses, total number of houses and single-family houses increase slowly in preference, until a certain point close to the maximum is reached. After that point, the preference will increase quickly. The other curves concerning houses have an opposite shape, where the preference is the highest at the minimal number of houses. The preference decreases fast when a little more than the minimum is built.

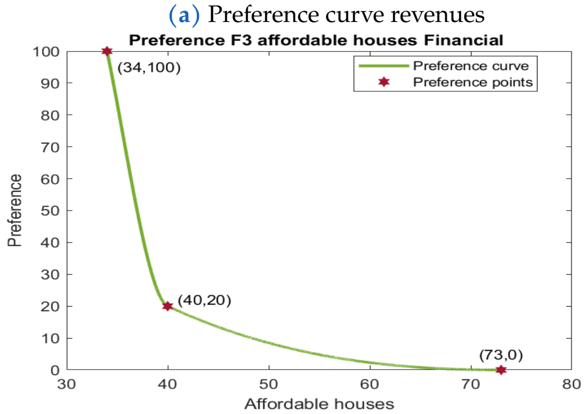
The curve for the revenues (fig. I.1a) gets a preference higher than zero, only after reaching a minimum of 9 million euros. This has to do with the fact that the financial director wants to compensate for the other subareas with subarea 5. In addition, there is already a design for subarea 5 in which the revenues are around 9-10 million euros. So, a next design should at least be better than that according to the financial director.
The amount of green (fig. I.1b) in subarea 5 can be as low as possible according to the financial director since he assumes there is already an ecozone planned, which is directly next to subarea 5 for the entire area. His preference drops soon after the minimal amount of green is met.



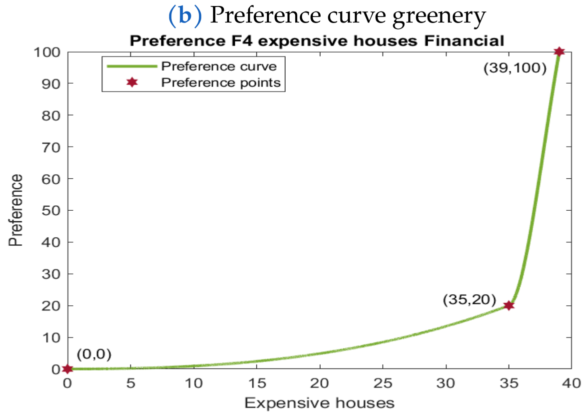
(a) Preference curve revenues



(b) Preference curve greenery

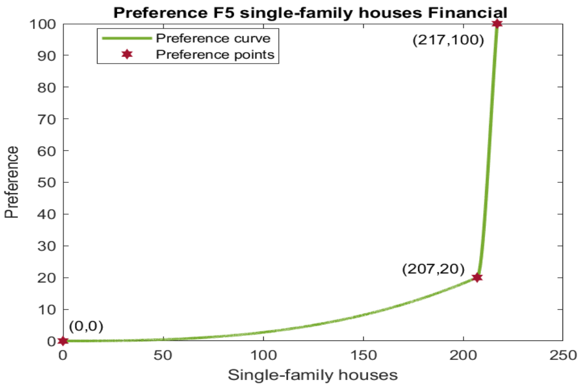


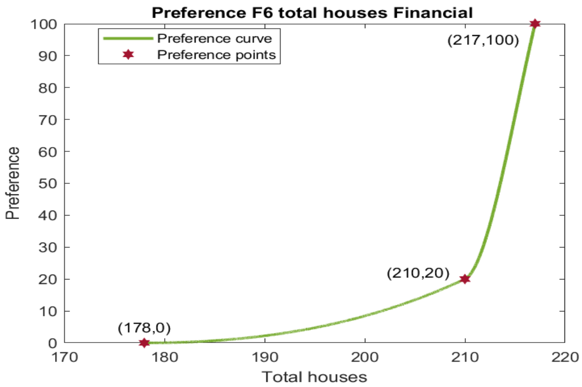
(c) Preference curve affordable houses



(d) Preference curve expensive houses

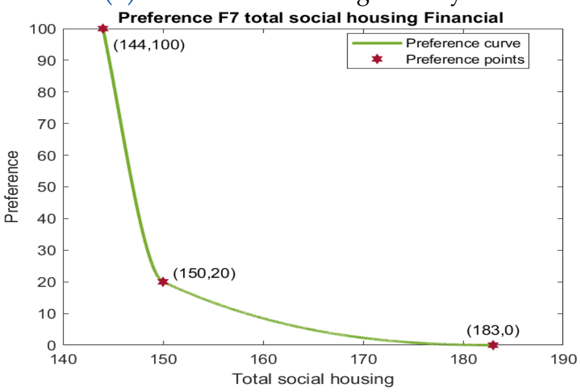
Figure I.1: Preference curves after individual sessions financial director ONW part 1

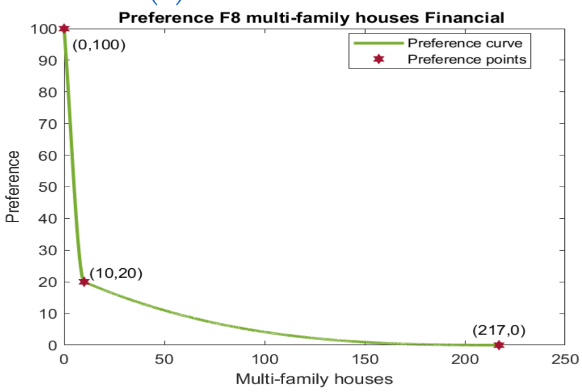




(a) Preference curve single-family houses

(b) Preference curve total houses





(c) Preference curve social housing

(d) Preference curve multi-family houses

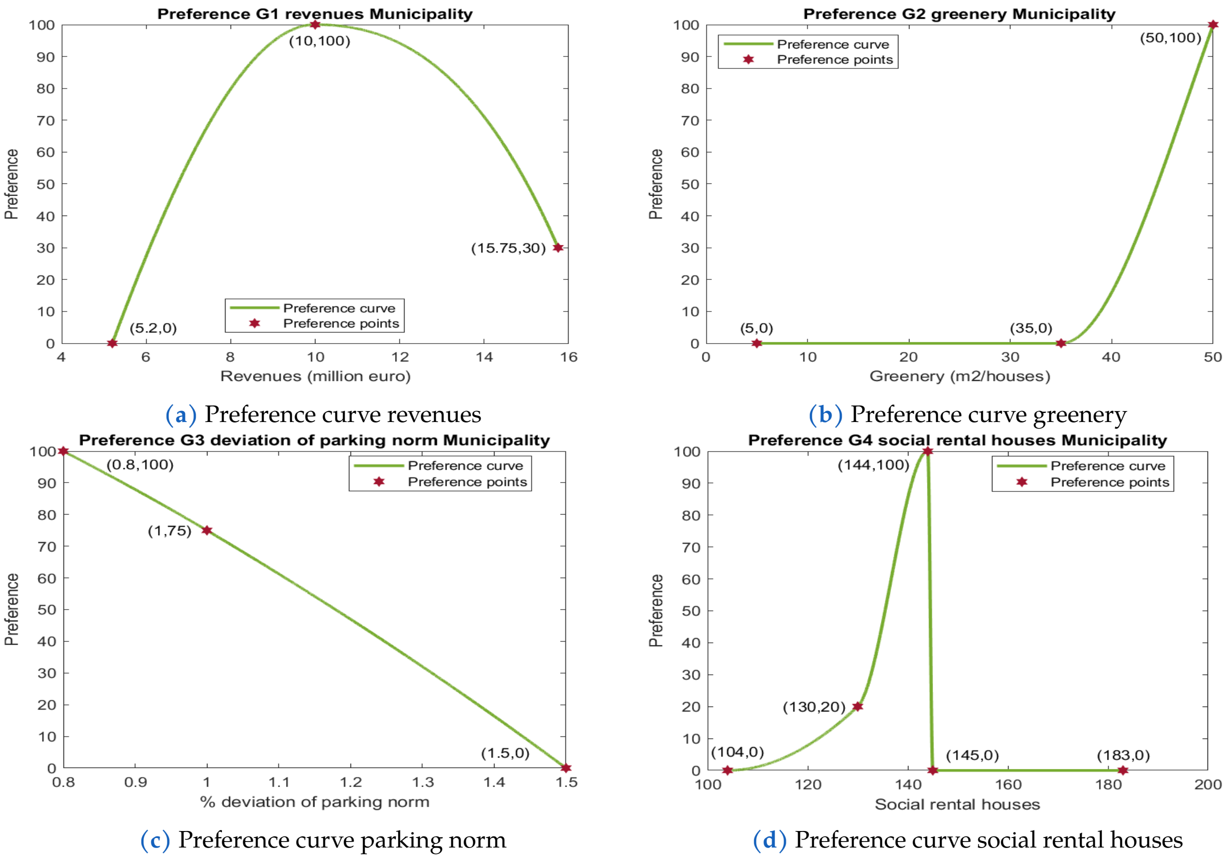
Figure I.2: Preference curves after individual sessions financial director ONW part 2

I.3.2 Municipality

Regarding the preference curve for revenues (fig. I.3a), the municipality wants to reach the amount of 10 million euros since that amount is needed to compensate for the losses in the rest of Waelpolder. However, more than 10 million revenues can only be reached, looking at the space in the area, with expensive houses. That is something the municipality does not want and therefore their curve drops again after 10 million revenues.

The municipality does not want the maximum number of houses since she will be interested in having enough space for green. Therefore, the curve for total number of houses will decrease fast. The same shape holds for the expensive houses and the owner-occupied social houses. The owner-occupied social houses are less preferred than the social (rented) houses, because of the size and the attached strict rules for resale of the owner-occupied houses. The curve of the rented social houses therefore has a top at the minimal amount of total social houses (144), since the municipality prefers all social houses to be rented ones. The single-family and multi-family houses both have a top in the curve around 100 houses. As there should be a balance between the two types according to the municipality. In addition, the number of multi-family houses cannot be too high since that would cause problems for parking (paved surface) and green in the area. This contrasts with her goal: an attractive and good living environment.

In an ideal situation, the amount of green per house (shown in fig. I.3b) should be as high as possible. The top preference point is therefore on 50 m^2/house. The curve only starts increasing at 35 m^2/house since green is one of the most important aspects for the municipality.
The preference (fig. I.3c) for the deviation from the parking norm is zero at 150% (1.5) since this will bring too much pavement in the area. Ideally, the municipality wants as little pavement as possible. Therefore, her preference at 80% (0.8) is 100. Since the municipality currently has to deal with a parking norm of 100% (1), she also has a preference of 75 at that point. The municipality is stating that the people in Westland have a lot of cars that they have to be able to park their cars in the area, if they cannot, the municipality has a problem.
Lastly, the municipality wants a large healthcare center, therefore a center with 62 or 93 units are preferred (100).



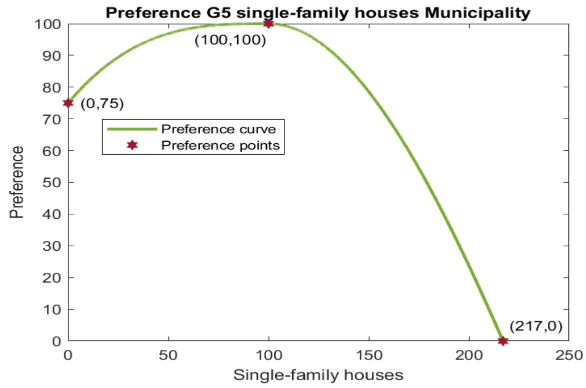
(a) Preference curve revenues

(b) Preference curve greenery

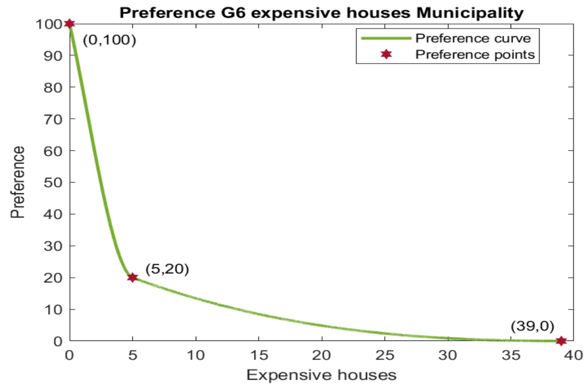
(c) Preference curve parking norm

(d) Preference curve social rental houses

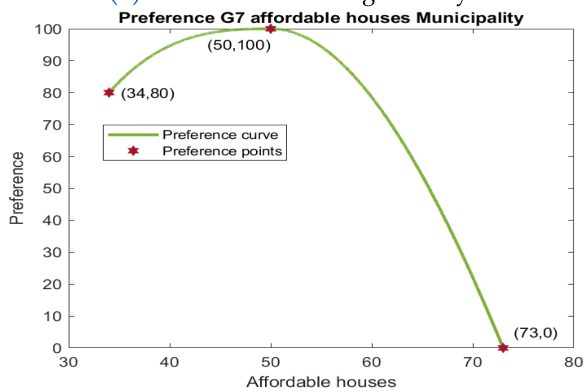
Figure I.3: Preference curves after individual sessions municipality part 1



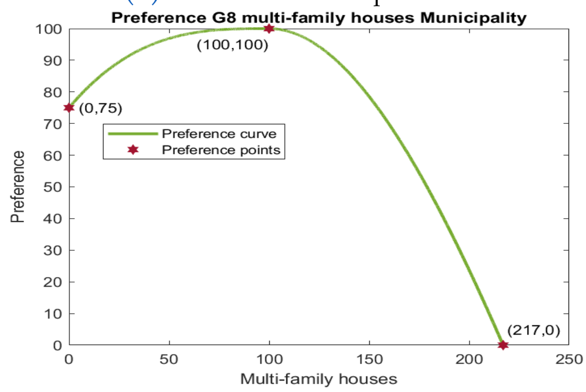
(a) Preference curve single-family houses



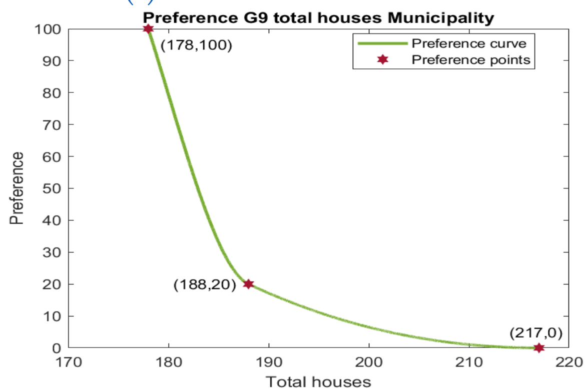
(b) Preference curve expensive houses



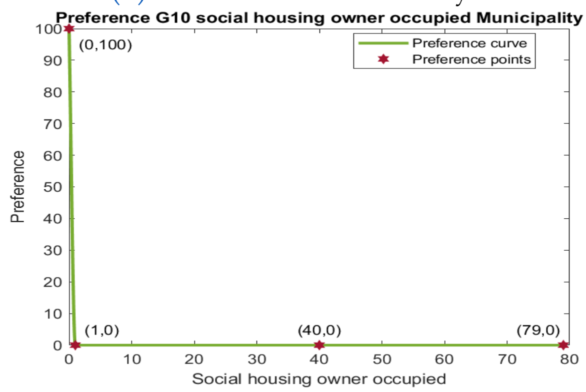
(c) Preference curve affordable houses



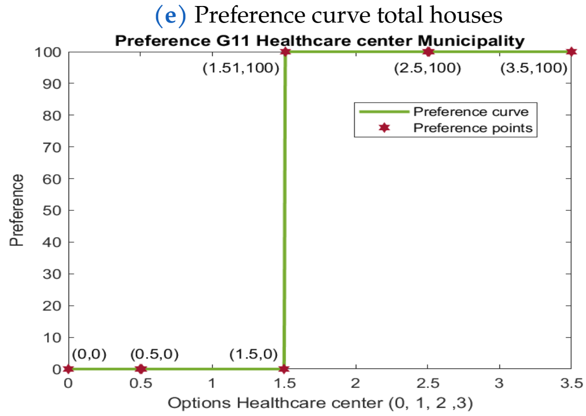
(d) Preference curve multi-family houses



(e) Preference curve total houses



(f) Preference curve social owner occupied houses



(g) Preference curve healthcare center

Figure I.4: Preference curves after individual sessions municipality part 2

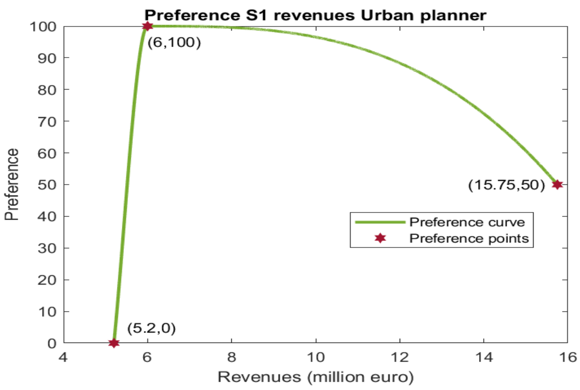
I.3.3 Urban planner

The urban planner would be satisfied with a revenue of 6 million euros, since he is in the understanding that when more revenues are generated, he can get some money to spend on quality in the area (such as a nice bridge).

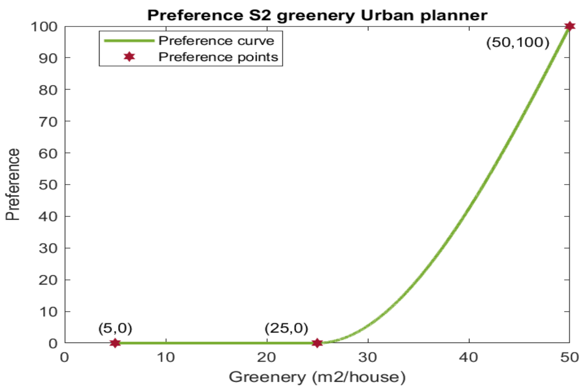
The curve for the total number of houses, total number of social houses and affordable houses have the same shape: linearly increasing. This shape does not hold for the expensive houses. The urban planner wants at least 30 expensive houses. The curve (fig. I.6g) increases slowly until 30 expensive houses are reached. The multi-family and single-family houses both have a top. The urban planner wants a mixed environment, therefore both curves get a top somewhere in the middle. A top in the end would mean that he likes to have the entire area filled with one type, and that is not what he wants.

The urban planner wants a healthcare center, but not too big (93 units) since he states that Waelpolder is not the perfect location for a healthcare center. His top preference is at 62 units and no more. The maximal percentage of houses that can be labeled as quiet living is 50%, according to the urban planner. This is the point where the preference of the urban planner is 100.

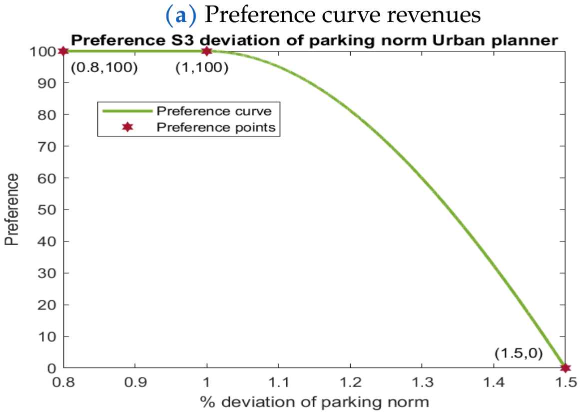
The urban planner wants as less parking as possible (as shown in fig. I.5c), so the top preference point lays between the minimal deviation and a no deviation (100%) from the parking norm. 100% (1) still gets a preference of 100 since that is the standard norm and is fine to deal with according to the urban planner. More deviation would have a negative impact on the quality of the area, so here the preference drops.
The urban planner prefers to have as much green in the area as possible, as long as agreements will be made for the maintenance of the greenery and on the type of greenery that will be created.
The total amount of houses with built-in parking spaces is also a criterion for the urban planner. His preference (fig. I.5d) increases when there is more than 0% of the total number of houses that has built-in parking space. The curve follows an almost linear line towards the maximum of 52%.



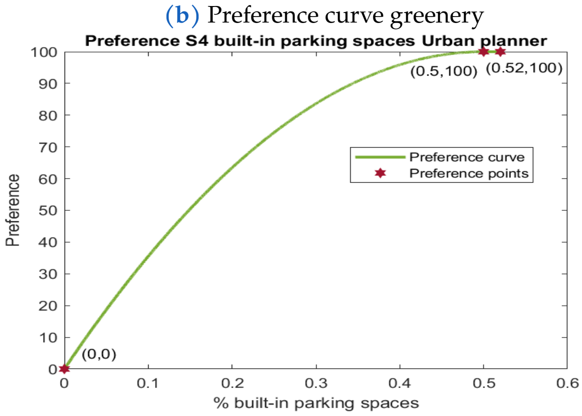
(a) Preference curve revenues



(b) Preference curve greenery

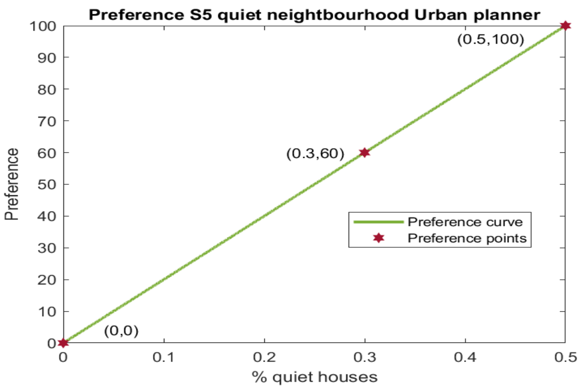


(c) Preference curve parking norm

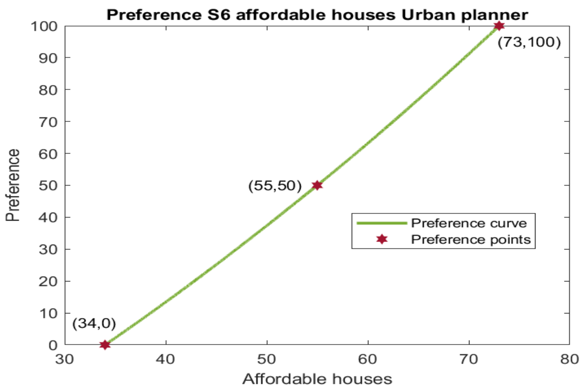


(d) Preference curve built-in parking

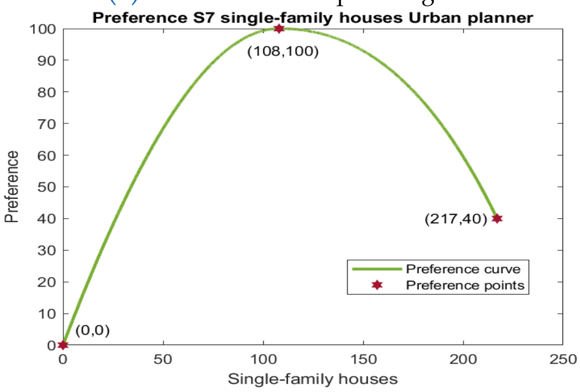
Figure I.5: Preference curves after individual sessions urban planner part 1



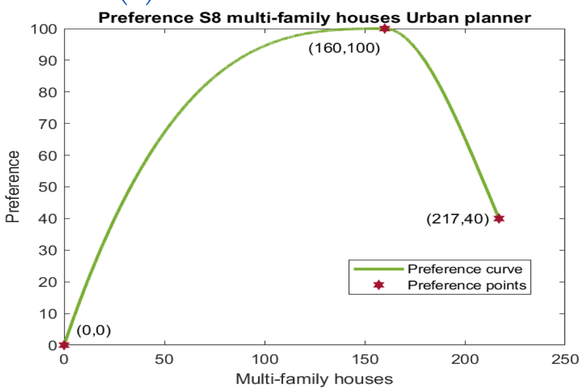
(a) Preference curve quiet neighborhood



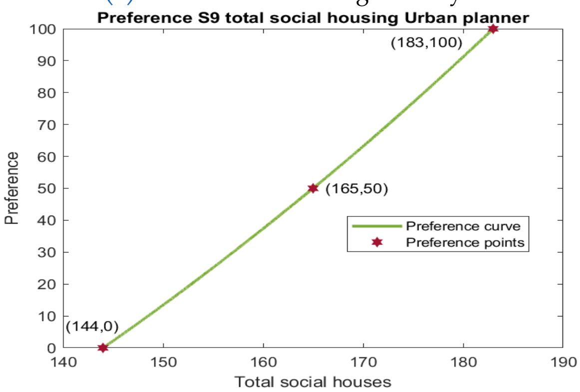
(b) Preference curve affordable houses



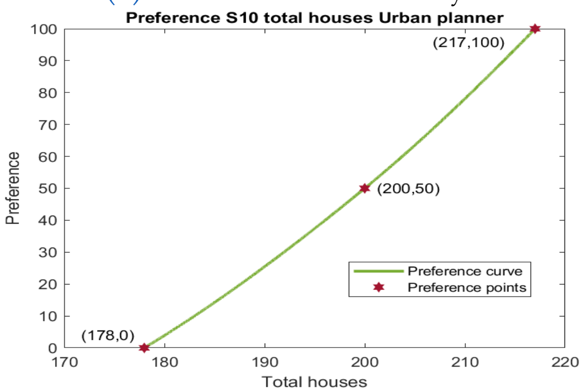
(c) Preference curve single-family houses



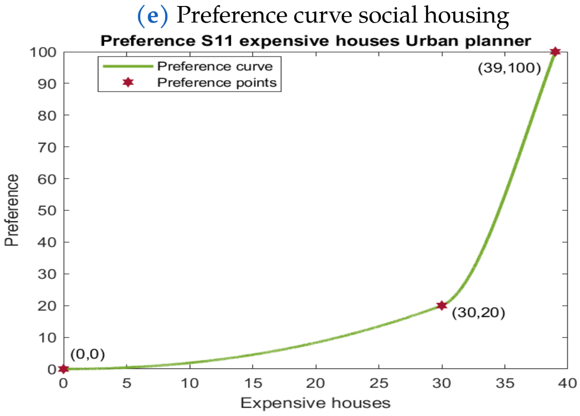
(d) Preference curve multi-family houses



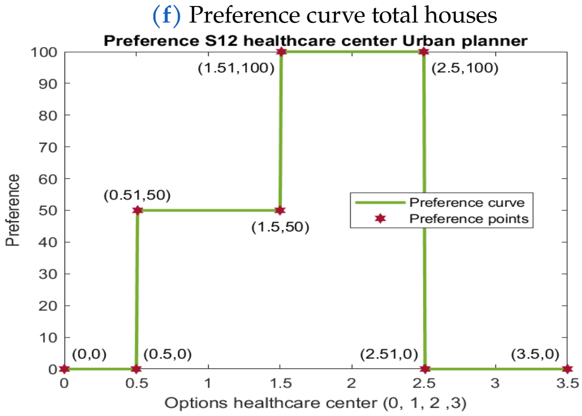
(e) Preference curve social housing



(f) Preference curve total houses



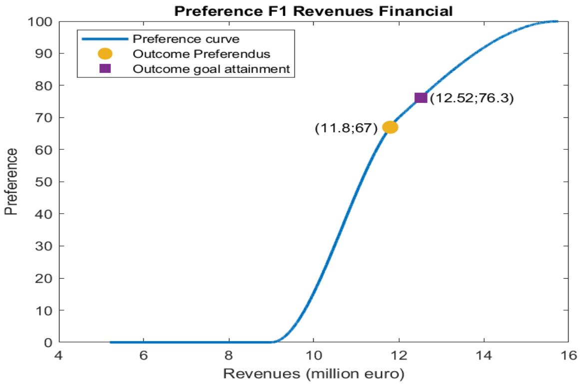
(g) Preference curve expensive houses



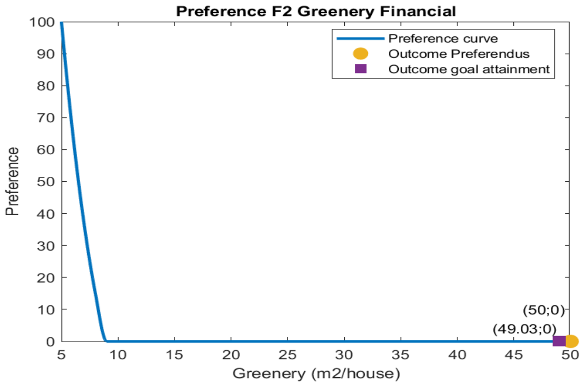
(h) Preference curve healthcare center

Figure I.6: Preference curves after individual sessions urban planner part 2

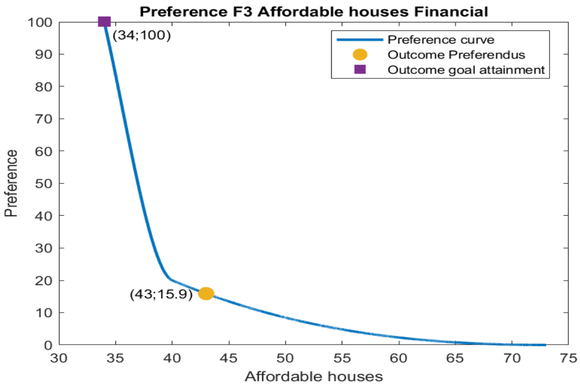
I.4 Final preference curves stakeholders Waelpolder



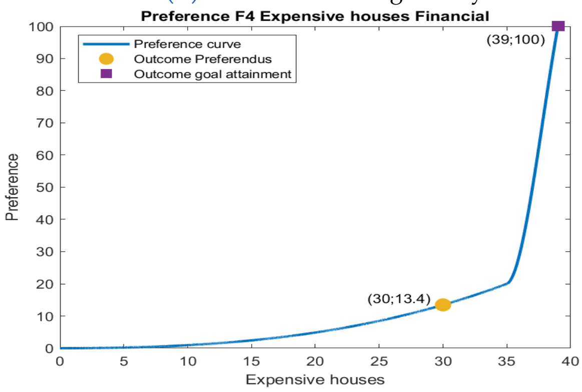
(a) Preference curve revenues



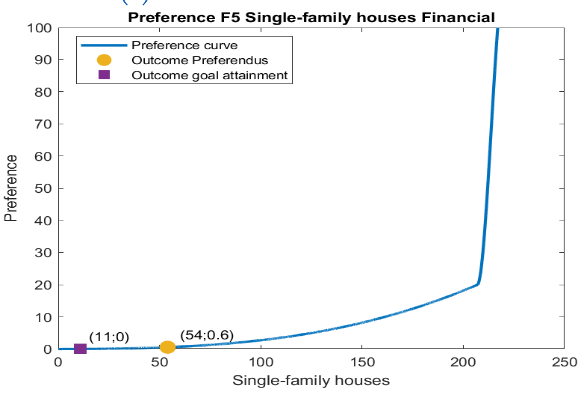
(b) Preference curve greenery



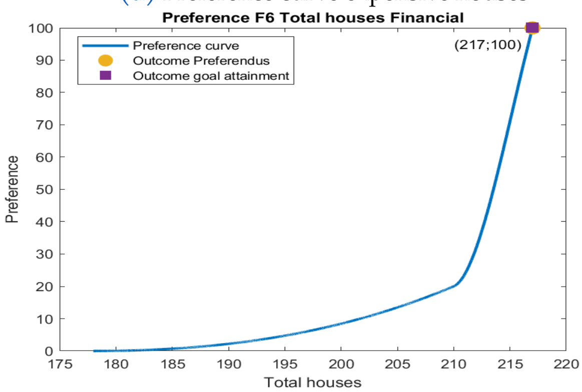
(c) Preference curve affordable houses



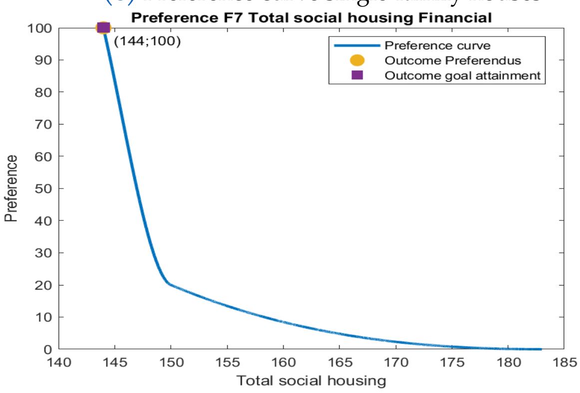
(d) Preference curve expensive houses



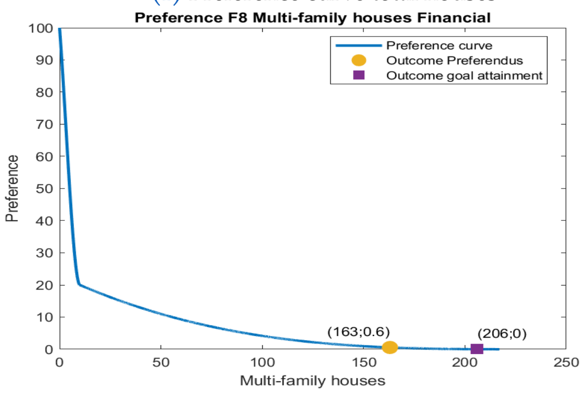
(e) Preference curve single-family houses



(f) Preference curve total houses

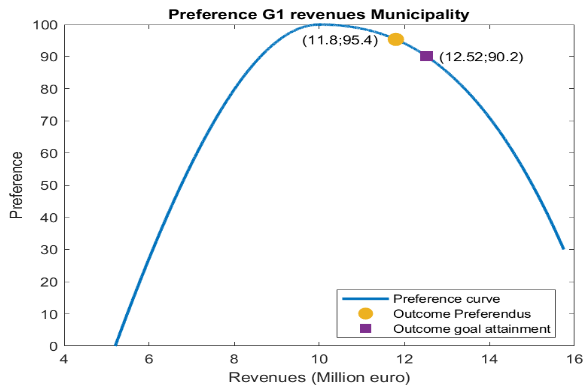


(g) Preference curve total social housing

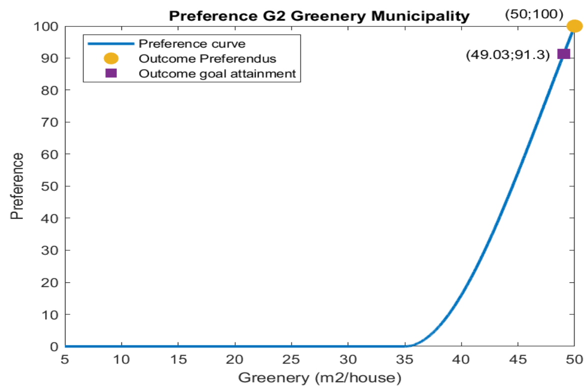


(h) Preference curve multi-family houses

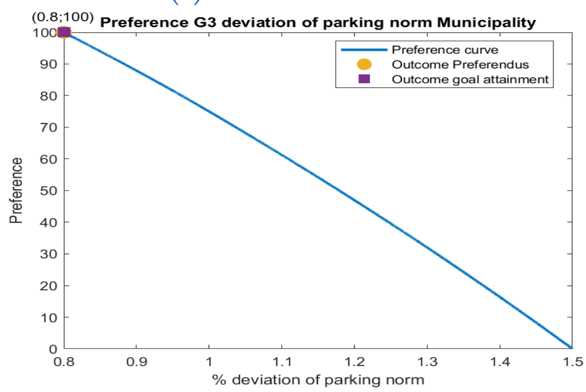
Figure I.7: Final preference curves financial director ONW



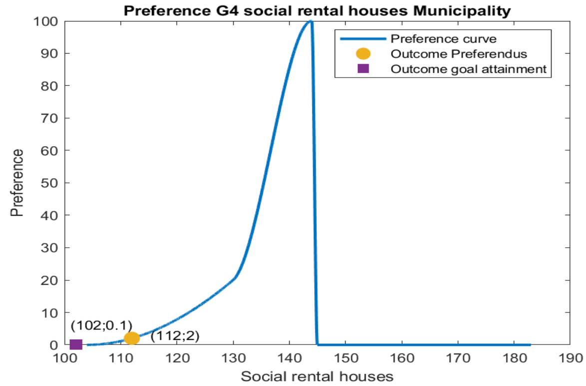
(a) Preference curve revenues



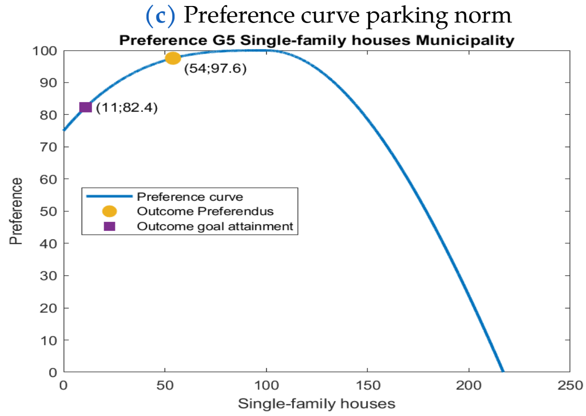
(b) Preference curve greenery



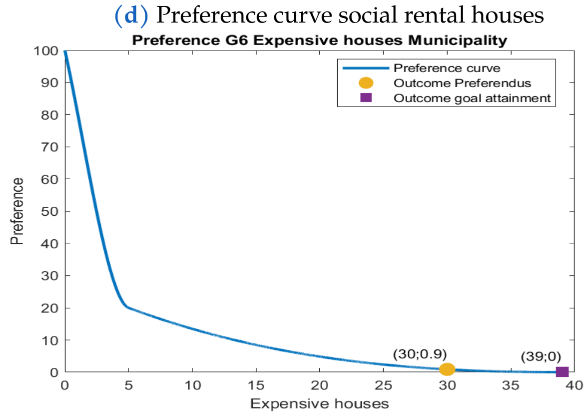
(c) Preference curve parking norm



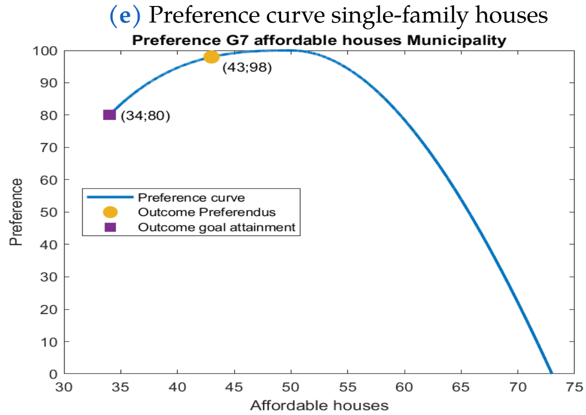
(d) Preference curve social rental houses



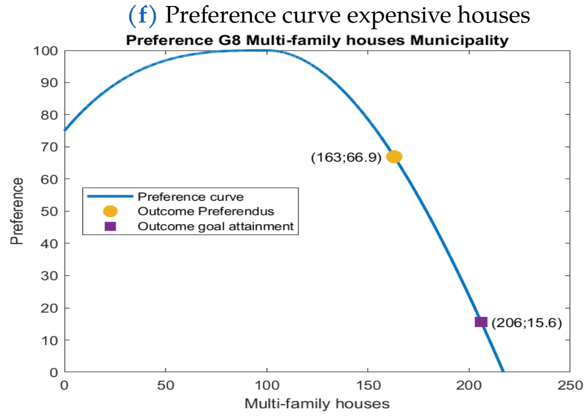
(e) Preference curve single-family houses



(f) Preference curve expensive houses

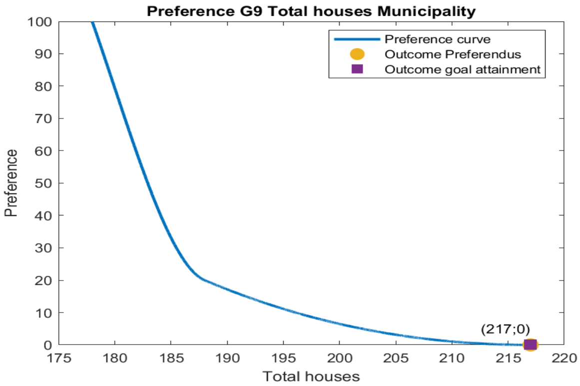


(g) Preference curve affordable houses

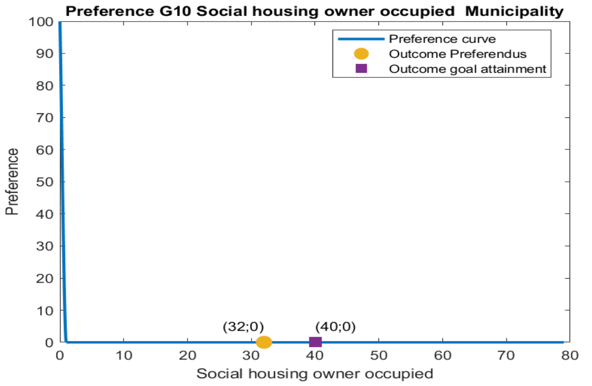


(h) Preference curve multi-family houses

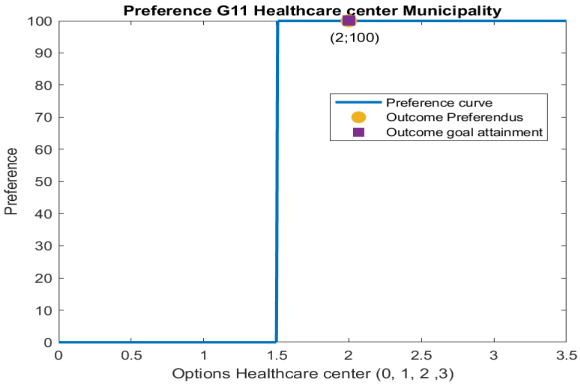
Figure I.8: Final preference curves municipality part 1



(a) Preference curve total houses

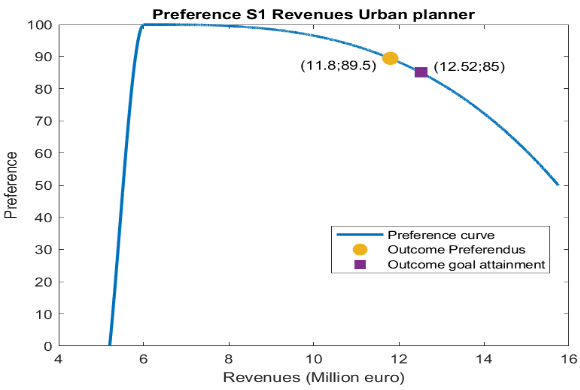


(b) Preference curve social owner occupied houses

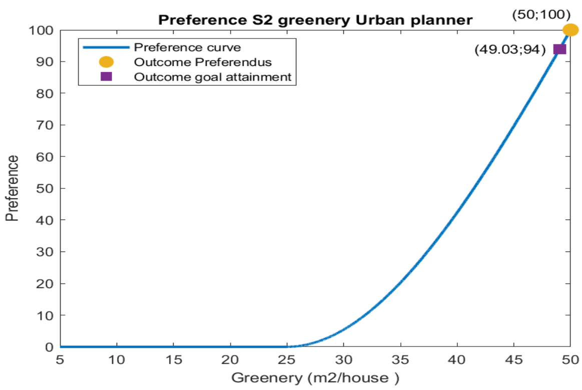


(c) Preference curve healthcare center

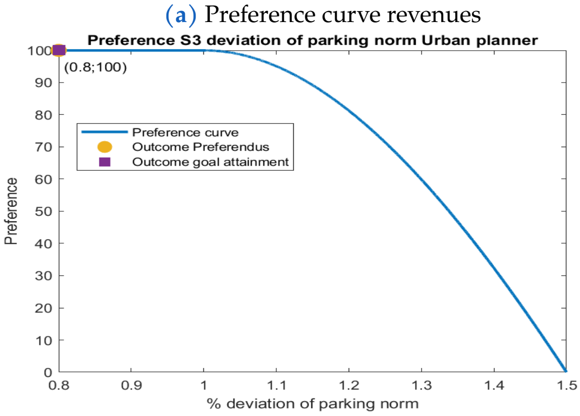
Figure I.9: Final preference curves municipality part 2



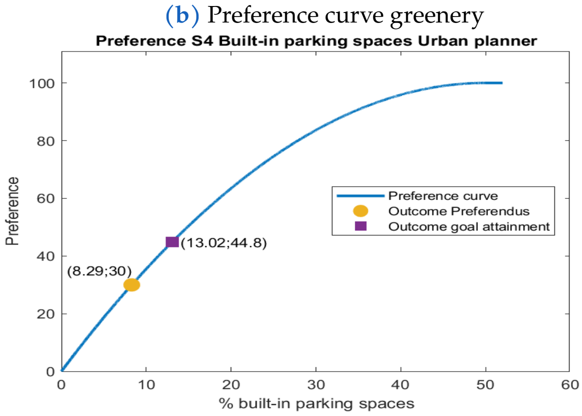
(a) Preference curve revenues



(b) Preference curve greenery

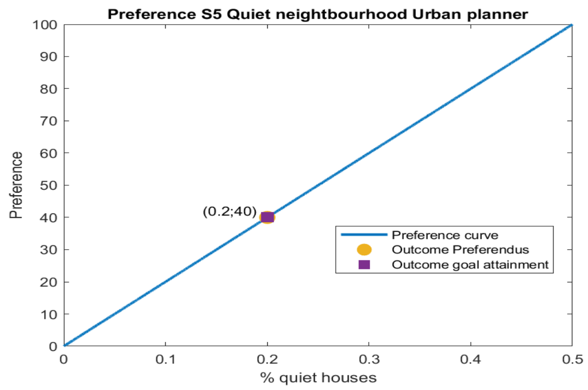


(c) Preference curve parking norm

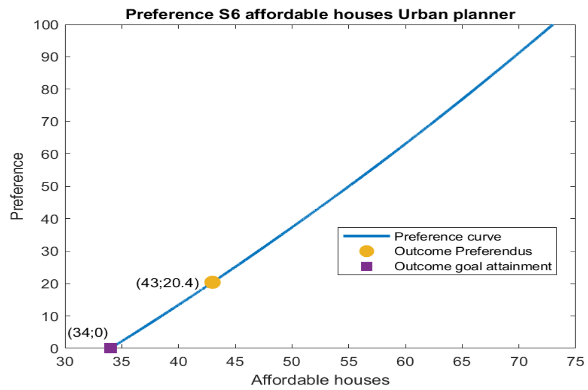


(d) Preference curve built-in parking

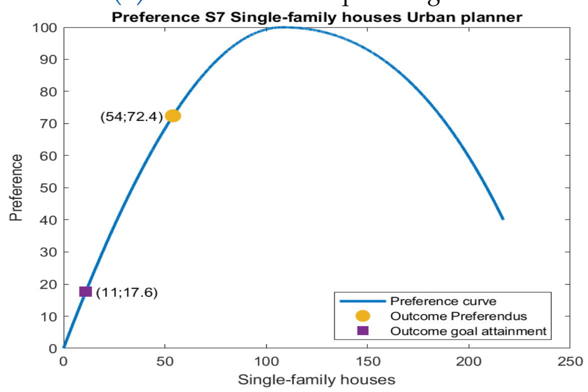
Figure I.10: Final preference curves urban planner part 1



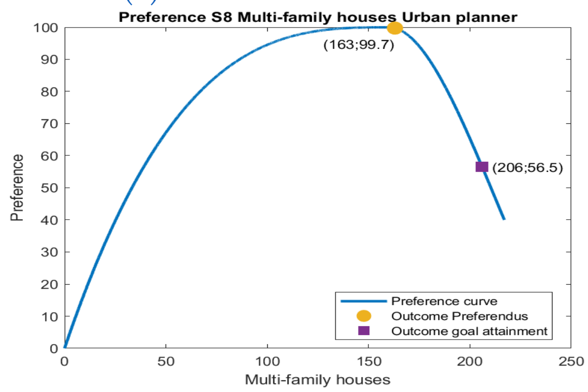
(a) Preference curve quiet neighborhood



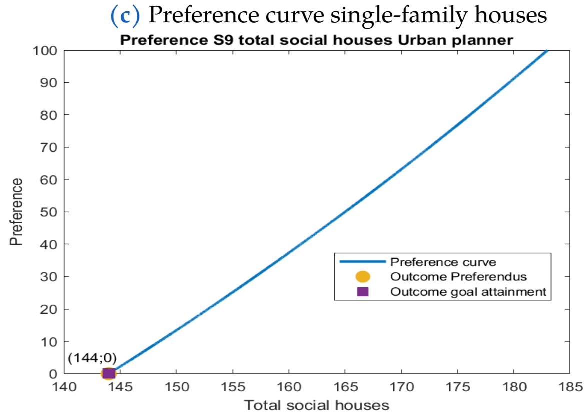
(b) Preference curve affordable houses



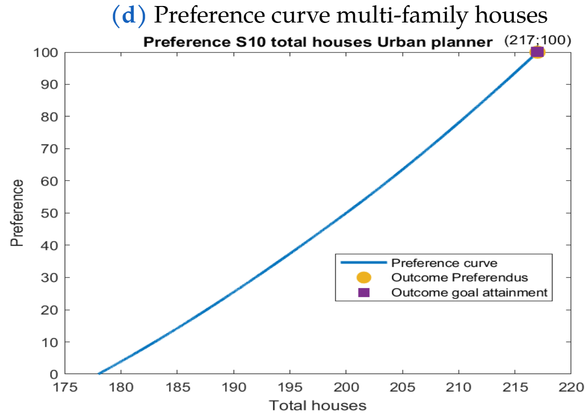
(c) Preference curve single-family houses



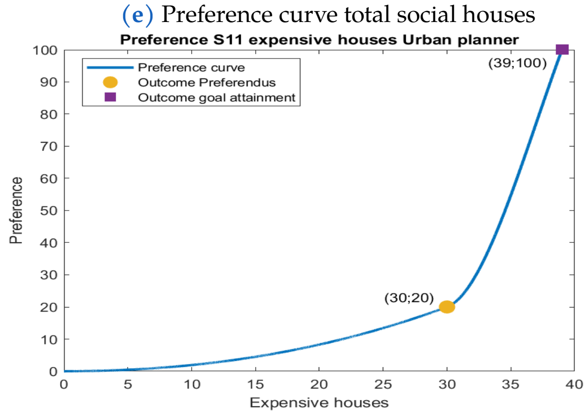
(d) Preference curve multi-family houses



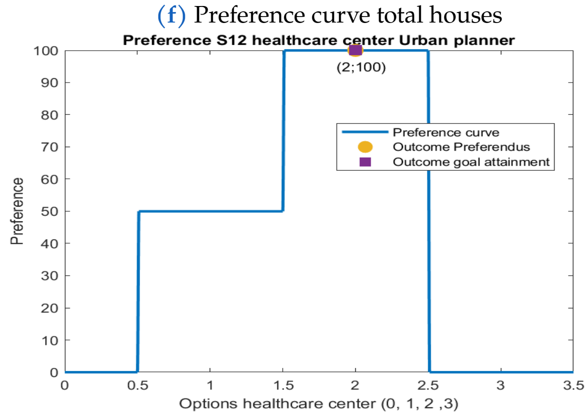
(e) Preference curve total social houses



(f) Preference curve total houses



(g) Preference curve expensive houses



(h) Preference curve healthcare center

Figure I.11: Final preference curves urban planner part 2

I.5 PoR's of other optimizations Waelpolder

Before the workshop with the stakeholders of Waelpolder, several PoR's were created upfront due to the running time of the model. The PoR's consists of other optimizations stakeholders were likely to ask for during the workshop itself. The PoR's that were created and shown to the stakeholders on request, are shown in the tables of this section including a short explanation.

In the table below (table I.1), an overview of the three different designs optimized on the overall preference (Preferendus) of one stakeholder each is given. These designs were generated to give the stakeholders insights in what would happen when a design is fully based on the wishes of one stakeholder.

Table I.1: PoR of optimizations to stakeholder preference

		Unit	Preference Urban planner	Preference Financial director	Preference Municipality
	Optimization value	**-**	**84.4094**	**89.0962**	**90.8319**
Finances	Revenues	Million €	8.0993	13.9669	9.3054
Green	Greenery per house	m²/ house	49.934	5.0567	49.9975
Parking	Deviation parking norm	-	0.8	0.8026	0.8
	Houses with built-in parking	%	23.9631	9.6774	10.5991
	Parking spaces with a roof	m²	512.5	0	87.5
Category houses	Total number of houses	Houses	217	217	217
	Affordable housing	Houses	53	40	57
	Total social housing	Houses	157	144	160
	Social rental	Houses	104	116	124
	Social owner-occupied	Houses	53	28	36
	Expensive housing	Houses	7	33	-
	Single-family housing	Houses	98	63	73
	Multi-family housing	Houses	119	154	144
Quiet neighborhood	Quiet neighborhood	-	0.5	0.2	0.2
Healthcare center	Healthcare center	Units	-	62	62
Housing differentiation	EG soc kp <€194.000	Houses	-	1	25
	EG sociale huur	Houses	66	10	29
	EG bereikb kp <€231.500	Houses	3	2	3
	EG betaalb kp <€310.000	Houses	1	16	2
	EG rijwoning €375.000	Houses	2	1	-
	EG 2/1kap €542.500	Houses	-	-	-
	EG vrijstaand klein €585.900	Houses	-	30	-
	EG vrijstaand groot €672.300	Houses	1	-	-
	EG verandawoning €328.000	Houses	23	2	14
	EG drive-in €355.000+€25.000	Houses	2	1	-
	MG sociale huur	Houses	38	106	95
	MG sociale kp <€194.000	Houses	28	26	11
	MG kp €291.000	Houses	1	1	15
	MG duur geb P	Houses	2	1	-
	MG sociale kp <€194.000 geb P	Houses	25	1	-
	MG kp betaalbaar, geb P onder dek	Houses	15	8	23
	MG kp €290.000+€20.000 alles geb P	Houses	10	11	-

In table I.2, the PoR's, generated with the Preferendus and goal attainment method, with constraints as currently in the cooperation agreement are shown. This means, a minimal of 7 m^2 greenery per house and no deviation of the current parking norm.

Table I.2: PoR for parking norm equal to 1 and amount of greenery 7 m^2

		Unit	Preferendus p=1 g=7	Goal attainment p=1 g=7
	Optimization value	**-**	**73.6455**	**28.5245**
Finances	Revenues	Million €	12.0395	12.459
Green	Greenery per house	m^2 / house	35.9146	34.9351
Parking	Deviation parking norm	-	1.0865	1
	Houses with built-in parking	%	23.5023	13.2301
	Parking spaces with a roof	%	69.786	70
Category houses	Total number of houses	Houses	217	217
	Affordable housing	Houses	42	34
	Total social housing	Houses	144	144
	Social rental	Houses	104	104
	Social owner-occupied	Houses	40	40
	Expensive housing	Houses	31	39
	Single-family housing	Houses	38	10
	Multi-family housing	Houses	179	207
Quiet neighborhood	Quiet neighborhood	-	0.2	0.2
Healthcare center	Healthcare center	Units	62	62
Housing differentiation	EG soc kp <€194.000	Houses	1	-
	EG sociale huur	Houses	-	-
	EG bereikb kp <€231.500	Houses	1	-
	EG betaalb kp <€310.000	Houses	18	-
	EG rijwoning €375.000	Houses	1	-
	EG 2/1kap €542.500	Houses	11	-
	EG vrijstaand klein €585.900	Houses	6	10
	EG vrijstaand groot €672.300	Houses	-	-
	EG verandawoning €328.000	Houses	-	-
	EG drive-in €355.000+€25.000	Houses	-	-
	MG sociale huur	Houses	104	104
	MG sociale kp <€194.000	Houses	3	40
	MG kp €291.000	Houses	21	34
	MG duur geb P	Houses	13	29
	MG sociale kp <€194.000 geb P	Houses	36	-
	MG kp betaalbaar, geb P onder dek	Houses	1	-
	MG kp €290.000+€20.000 alles geb P	Houses	1	-

In table I.3, the PoR's for both methods are shown, considering a minimal greenery per house of 7 m^2 and a parking norm deviation of 0.8, as discussed in the constraints in appendix G.2.

Table I.3: PoR for parking norm equal to 0.8 and amount of greenery 7 m²

		Unit	Preferendus p=0.8 g=7	Goal attainment p=0.8 g=7
	Optimization value	**-**	**63.4243**	**28.3501**
Finances	Revenues	Million €	13.1261	12.6614
Green	Greenery per house	m² / house	7.0972	38.5242
Parking	Deviation parking norm	-	0.8011	0.8
	Houses with built-in parking	%	21.659	6.8112
	Parking spaces with a roof	%	22.7729	70
Category houses	Total number of houses	Houses	217	217
	Affordable housing	Houses	34	62
	Total social housing	Houses	144	144
	Social rental	Houses	104	104
	Social owner-occupied	Houses	40	40
	Expensive housing	Houses	39	11
	Single-family housing	Houses	86	11
	Multi-family housing	Houses	131	216
Quiet neighborhood	Quiet neighborhood	-	0.2	0.2
Healthcare center	Healthcare center	Units	62	62
Housing differentiation	EG soc kp <€194.000	Houses	3	-
	EG sociale huur	Houses	55	-
	EG bereikb kp <€231.500	Houses	-	-
	EG betaalb kp <€310.000	Houses	-	-
	EG rijwoning €375.000	Houses	3	-
	EG 2/1kap €542.500	Houses	4	-
	EG vrijstaand klein €585.900	Houses	20	11
	EG vrijstaand groot €672.300	Houses	1	-
	EG verandawoning €328.000	Houses	-	-
	EG drive-in €355.000+€25.000	Houses	-	-
	MG sociale huur	Houses	49	104
	MG sociale kp <€194.000	Houses	33	25
	MG kp €291.000	Houses	2	62
	MG duur geb P	Houses	11	-
	MG sociale kp <€194.000 geb P	Houses	4	15
	MG kp betaalbaar, geb P onder dek	Houses	7	-
	MG kp €290.000+€20.000 alles geb P	Houses	25	-

Table I.4 is showing, the PoR's for both methods, considering a minimal greenery per house of 5 m^2 and a parking norm deviation of 1.

Table I.4: PoR for parking norm equal to 1 and amount of greenery 5 m²

		Unit	Preferendus p=1 g=5	Goal attainment p=1 g=5
	Optimization value	**-**	**72.3843**	**28.5245**
Finances	Revenues	Million €	11.6591	12.459
Green	Greenery per house	m² / house	45.1646	34.9351
Parking	Deviation parking norm	-	1.0004	1
	Houses with built-in parking	%	20.7373	13.2301
	Parking spaces with a roof	%	25.6455	70
Category houses	Total number of houses	Houses	217	217
	Affordable housing	Houses	34	34
	Total social housing	Houses	145	144
	Social rental	Houses	115	104
	Social owner-occupied	Houses	30	40
	Expensive housing	Houses	38	39
	Single-family housing	Houses	23	10
	Multi-family housing	Houses	194	207
Quiet neighborhood	Quiet neighborhood	-	0.2	0.2
Healthcare center	Healthcare center	Units	62	62
Housing differentiation	EG soc kp <€194.000	Houses	1	-
	EG sociale huur	Houses	-	-
	EG bereikb kp <€231.500	Houses	-	-
	EG betaalb kp <€310.000	Houses	2	-
	EG rijwoning €375.000	Houses	-	-
	EG 2/1kap €542.500	Houses	10	-
	EG vrijstaand klein €585.900	Houses	6	10
	EG vrijstaand groot €672.300	Houses	-	-
	EG verandawoning €328.000	Houses	4	-
	EG drive-in €355.000+€25.000	Houses	-	-
	MG sociale huur	Houses	115	104
	MG sociale kp <€194.000	Houses	14	40
	MG kp €291.000	Houses	20	34
	MG duur geb P	Houses	22	29
	MG sociale kp <€194.000 geb P	Houses	15	-
	MG kp betaalbaar, geb P onder dek	Houses	1	-
	MG kp €290.000+€20.000 alles geb P	Houses	7	-

The PoR shown below (table I.5) is the exact same as what is stated in the cooperation agreement and includes the maximal total number of houses (211) as stated in the zoning plan. This PoR was generated to test if the stakeholders would choose for another design, as those other designs have a higher overall preference.

Table I.5: PoR for parking norm equal to 1, amount of greenery 7 m² and number of houses 211

		Unit	**Preferendus p=1 g=7 w=211**	**Goal attainment p=1 g=7 w=211**
	Optimization value	**-**	**67.9126**	**31.1199**
Finances	Revenues	Million €	12.012	12.4894
Green	Greenery per house	m² / house	34.4387	35.1575
Parking	Deviation parking norm	-	1.0625	1
	Houses with built-in parking	%	5.6872	2.2787
	Parking spaces with a roof	%	69.2888	70
Category houses	Total number of houses	Houses	211	211
	Affordable housing	Houses	58	55
	Total social housing	Houses	144	144
	Social rental	Houses	104	104
	Social owner-occupied	Houses	40	40
	Expensive housing	Houses	9	12
	Single-family housing	Houses	63	12
	Multi-family housing	Houses	148	199
Quiet neighborhood	Quiet neighborhood	-	0	0.2
Healthcare center	Healthcare center	Units	93	62
Housing differentiation	EG soc kp <€194.000	Houses	28	-
	EG sociale huur	Houses	22	-
	EG bereikb kp <€231.500	Houses	-	-
	EG betaalb kp <€310.000	Houses	4	-
	EG rijwoning €375.000	Houses	-	-
	EG 2/1kap €542.500	Houses	6	-
	EG vrijstaand klein €585.900	Houses	3	12
	EG vrijstaand groot €672.300	Houses	-	-
	EG verandawoning €328.000	Houses	-	-
	EG drive-in €355.000+€25.000	Houses	-	-
	MG sociale huur	Houses	82	104
	MG sociale kp <€194.000	Houses	12	35
	MG kp €291.000	Houses	42	55
	MG duur geb P	Houses	-	-
	MG sociale kp <€194.000 geb P	Houses	-	5
	MG kp betaalbaar, geb P onder dek	Houses	11	-
	MG kp €290.000+€20.000 alles geb P	Houses	1	-

In the table below PoR's with different number of healthcare center units (0, 62 and 93) are given. The design with 93 is only generated using the preferendus, as this was to show the possibilities of adding extra units to the center, and not showing an average design generated with the goal attainment method.

Table I.6: PoR's for healthcare center with 0, 62 and 93 units

		Unit	Preferendus Zorg = 0	Goal attainment Zorg=0	Preferendus Zorg = 62	Goal attainment Zorg = 62	Preferendus Zorg =93
	Optimization value	**-**	**51.6071**	**50.7792**	**73.074**	**27.9082**	**61.1655**
Finances	Revenues	Million €	12.1023	11.0325	11.5666	12.5167	15.4546
Green	Greenery per house	m² / house	5.9148	5	42	49.0253	5
Parking	Deviation parking norm	-	0.8822	0.8	0.84	0.8	0.8044
	Houses with built-in parking	%	4.1475	9.8989	16.13	13.0188	18.894
	Parking spaces with a roof	%	69.8238	0.0161	47	2375	0.3713
Category houses	Total number of houses	Houses	217	217	217	217	217
	Affordable housing	Houses	55	51	56	34	36
	Total social housing	Houses	144	146	144	144	144
	Social rental	Houses	105	144	107	104	105
	Social owner-occupied	Houses	39	2	37	40	39
	Expensive housing	Houses	18	20	17	39	37
	Single-family housing	Houses	92	103	46	11	39
	Multi-family housing	Houses	125	114	171	206	178
Quiet neighborhood	Quiet neighborhood	-	0.5	0.5	0.2	0.2	0
Healthcare center	Healthcare center	Units	-	-	62	62	93
Housing differentiation	EG soc kp <€194.000	Houses	23	-	12	-	1
	EG sociale huur	Houses	28	80	20	-	-
	EG bereikb kp <€231.500	Houses	-	-	-	-	1
	EG betaalb kp <€310.000	Houses	11	3	1	-	-
	EG rijwoning €375.000	Houses	-	-	4	-	-
	EG 2/1kap €542.500	Houses	-	-	4	-	-
	EG vrijstaand klein €585.900	Houses	7	20	2	11	37
	EG vrijstaand groot €672.300	Houses	11	-	3	-	-
	EG verandawoning €328.000	Houses	12	-	-	-	-
	EG drive-in €355.000+€25.000	Houses	-	-	-	-	-
	MG sociale huur	Houses	77	64	87	104	105
	MG sociale kp <€194.000	Houses	13	-	24	40	-
	MG kp €291.000	Houses	26	29	25	34	32
	MG duur geb P	Houses	-	-	4	28	-
	MG sociale kp <€194.000 geb P	Houses	3	2	1	-	38
	MG kp betaalbaar, geb P onder dek	Houses	3	15	18	-	1
	MG kp €290.000+€20.000 alles geb P	Houses	3	4	12	-	2

The two designs that were already known by Planmaat, were generated with the Preferendus to calculate the overall preference of both designs, to be able to compare these with the final Preferendus design as shown below.

Table I.7: PoR for the already conducted studies

		Unit	Model studie GREX	Model studie 4
	Optimization value	**-**	**25.7583**	**56.3508**
Finances	Revenues	Million €	10.3762	14.3038
Green	Greenery per house	m² / house	27.7823	7
Parking	Deviation parking norm	-	1.4998	1.2331
	Houses with built-in parking	%	0	0
	Parking spaces with a roof	%	0	0
Category houses	Total number of houses	Houses	211	215
	Affordable housing	Houses	39	42
	Total social housing	Houses	144	144
	Social rental	Houses	102	102
	Social owner-occupied	Houses	42	42
	Expensive housing	Houses	28	29
	Single-family housing	Houses	85	39
	Multi-family housing	Houses	126	176
Quiet neighborhood	Quiet neighborhood	-	0.5	0.2
Healthcare center	Healthcare center	Units	-	62
Housing differentiation	EG soc kp <€194.000	Houses	42	-
	EG sociale huur	Houses	-	-
	EG bereikb kp <€231.500	Houses	-	-
	EG betaalb kp <€310.000	Houses	15	10
	EG rijwoning €375.000	Houses	28	-
	EG 2/1kap €542.500	Houses	-	14
	EG vrijstaand klein €585.900	Houses	-	8
	EG vrijstaand groot €672.300	Houses	-	7
	EG verandawoning €328.000	Houses	-	-
	EG drive-in €355.000+€25.000	Houses	-	-
	MG sociale huur	Houses	102	102
	MG sociale kp <€194.000	Houses	-	42
	MG kp €291.000	Houses	24	32
	MG duur geb P	Houses	-	-
	MG sociale kp <€194.000 geb P	Houses	-	-
	MG kp betaalbaar, geb P onder dek	Houses	-	-
	MG kp €290.000+€20.000 alles geb P	Houses	-	-

With the constraint of maximum number of total houses of 211 (as stated in the cooperation agreement), different combinations of minimal parking norm and minimal amount of greenery are considered to generate PoR's. one with a minimal deviation of the parking norm of 0.8 and greenery per house of 7 m^2. Two other PoR's are shown in the table below, respectively with 1 & 5 m^2 and 0.8 & 5 m^2.

Table I.8: PoR's for different norms for greenery and parking with a maximum of 211 houses

		Unit	Preferendus p=0.8 g=7 w=211	Preferendus p=1 g=5 w=211	Preferendus p=0.8 g=5 w=211
	Optimization value	**-**	**69.7604**	**67.3161**	**70.263**
Finances	Revenues	Million €	11.292	11.0784	11.3572
Green	Greenery per house	m² / house	37.9956	44.7659	38.1616
Parking	Deviation parking norm	-	0.805	1.0054	0.8183
	Houses with built-in parking	%	9.4787	24.2718	8.0569
	Parking spaces with a roof	%	69.9429	28.3698	69.9532
Category houses	Total number of houses	Houses	211	206	211
	Affordable housing	Houses	55	40	53
	Total social housing	Houses	144	144	144
	Social rental	Houses	109	111	104
	Social owner-occupied	Houses	35	33	40
	Expensive housing	Houses	12	22	14
	Single-family housing	Houses	64	29	76
	Multi-family housing	Houses	147	177	135
Quiet neighborhood	Quiet neighborhood	-	0.2	0.2	0.2
Healthcare center	Healthcare center	Units	62	62	62
Housing differentiation	EG soc kp <€194.000	Houses	15	-	25
	EG sociale huur	Houses	1	-	40
	EG bereikb kp <€231.500	Houses	-	-	-
	EG betaalb kp <€310.000	Houses	37	2	2
	EG rijwoning €375.000	Houses	2	1	1
	EG 2/1kap €542.500	Houses	2	4	5
	EG vrijstaand klein €585.900	Houses	6	15	3
	EG vrijstaand groot €672.300	Houses	-	-	-
	EG verandawoning €328.000	Houses	-	7	-
	EG drive-in €355.000+€25.000	Houses	1	-	-
	MG sociale huur	Houses	108	111	64
	MG sociale kp <€194.000	Houses	10	12	10
	MG kp €291.000	Houses	9	4	44
	MG duur geb P	Houses	1	2	5
	MG sociale kp <€194.000 geb P	Houses	10	21	5
	MG kp betaalbaar, geb P onder dek	Houses	7	16	1
	MG kp €290.000+€20.000 alles geb P	Houses	2	11	6

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Planmaat