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Raising the acceptance for a preference-based design methodology in the context of urban development

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By

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Preface

Before I present my master thesis, I want to reflect on the road I took towards the final step in my studies. My academic journey at the TU Delft started at the Civil Engineering bachelor programme. In this period, I learned much about engineering in general and what it means to be an engineer. This bachelor led me to the Construction Management & Engineering (CME) master in which I developed an interest in urban development, systems engineering and stakeholder management. Combining these subjects enabled me to develop a graduation project which I worked on with great enthusiasm and a result of which I can say I am truly proud.

Of course, I could not have achieved this on my own. Firstly, I would like to express my gratitude to my graduation committee. The chair of my committee, Ruud Binnekamp, helped me understand the benefits as well as the challenges of the Preferendus. This has been a great help towards finding my thesis topic on top of guiding me through the whole graduation process. Next, I want to sincerely thank Teun Janssen for our meetings in which we went through the inner workings of the genetic algorithm and tried to find improvements. This, besides of course the mathematical insights, really helped in achieving my results. Finally, I want to thank Omar Kammouh. Even though you joined the committee a little later than the others, you immediately had a positive impact by providing your insights in stakeholder engagement. Also, your academic contributions when I was finalizing my thesis really improved the result.

Throughout the whole graduation process I was also supported by the people working for Planmaat. I would like to thank them for their insights in urban development and applying optimization to this field and I would also like to sincerely thank them for allowing me to work at their office, the endless games of table football and making me feel part of their company. I especially want to thank Patrick Nan, who supported me throughout the entire graduation process by taking the time to meet with me every two weeks to discuss my process and by helping me by providing me with his experiences in the field of urban development.

I also want to thank the people from my case study group. They allowed me to use one of their current projects to apply the methodology to. The meetings often went on longer than I expected of them, because of the amount of insights they came with.

Lastly, I want to show my appreciation to my family, friends and girlfriend for their unconditional support during my graduation. I had moments where there seemed to be no end in sight, but you helped me though those.

Now that I have reflected on my road to this thesis and the people supporting me throughout the process have been acknowledged, I want to invite you to read my thesis on raising the acceptance for a preference-based design methodology in the context of urban development.

T. Raaphorst
Delft, March 2024

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Summary

In the field of urban development few challenges are as tough as the housing problem. The rapid expansion of urban populations combined with slow construction processes have caused this issue. The shortcomings in traditional design processes confirm the necessity for optimization. A design methodology using optimization called preference-based design for the construction management industry was introduced by (Binnekamp, 2010). This methodology utilizes stakeholder preference as key value on which urban development projects are designed and evaluated. This methodology uses the so-called Preferendus tool to generate, optimize and evaluate design solutions. Preference-based design models optimize towards the most preferred solution by all stakeholders. Central to the success of preference-based design is the attitude of stakeholders towards using the methodology. A positive attitude towards using the methodology is defined as system acceptance. This master thesis aims to explore the challenges of stakeholders with accepting preference-based design models and to develop modifications to a preference-based design methodology that increase the stakeholder acceptance. The main question in this research is therefore: *How can the acceptability of stakeholders on the results of preference-based design be improved in the context of urban development?*

The approach to validate the effect of the modifications on the system acceptance is to apply the technology acceptance model (TAM) introduced by (Davis, 1987). This model states that the attitude towards system use, and therewith system acceptance, is based on perceived usefulness and the perceived ease of use of the users. Both the perceived usefulness and perceived ease of use result from the response to the system design features of the methodology. The system design features of preference-based design are determined to be categorized into three categories: the "Use", "Functionality" and "Presentation". The "Use" category consists of attributes of the methodology that have to do with how, when and by whom the methodology is used. For this research, this category consists of the choice of design phase in which to apply the methodology and the involvement of the various stakeholders. Furthermore, the "Functionality" category describes attributes that determine how well the technical aspects of the methodology function. The system design features in this category were determined to be the result reliability and the running time of the model. Lastly, the "Presentation" category consists of features regarding to how the methodology is presented to the users. Within this category the model interface and the distinction between group and individual sessions were the system design features. This research proposes modifications to system design features in these three categories and evaluates their effect on the system acceptance. To verify the effectiveness of the modifications on the acceptance, two case studies were conducted. These case studies were conducted with a group of stakeholders currently involved in an urban development project.

The first case study represents a fictional area with a limited level of complexity. The goal was to show the stakeholders the essentials of the preference-based design methodology and to get a first impression evaluation. The fictional case study was used for one session: the introductory session. This session introduced the stakeholders to preference-based design with the aid of a modified interface made in Excel. The reactions of the stakeholders were generally positive towards the methodology and agreed about the added value of using the Preferendus tool for urban development. This was verified by conducting a questionnaire regarding the response to the perceived usefulness and perceived ease of use, which also showed a mainly positive response. The results from this questionnaire are taken into account in the remainder of the research and will be used to compare with the response at the end of the second case study.

The second case study explores a real life ongoing urban development project. This project had a significantly higher level of complexity than the fictional case study. The goal of the real-life case study was to demonstrate the added value of the methodology to a project the participating stakeholders were personally involved in. This was done in multiple sessions, namely, individual sessions with each stakeholder, a first group session and a concluding session. The increased

complexity resulted in necessary modifications to the functionality to be able to use the Preferendus tool to evaluate the most preferred solution. It was determined that modifications to the generation of starting points and the mutation would improve the functionality. The effect of the modifications was confirmed by the increased number of feasible solutions in the first population and an improvement in result reliability. However, after the first group session an additional constraint to the minimum of houses in the area was added, which resulted in a significantly decreased solution space. Thereafter, the results of the optimization showed a decreased result reliability which showed that more research is necessary to increase this even further. The first group session and the concluding session also included a discussion on the use of the methodology. The focus of the discussion was on the design phase in which to apply the methodology and stakeholder involvement. The conclusion on the design phase was to apply the methodology in an early stage, but after the boundaries of the project were determined. Regarding the stakeholder involvement, the participating stakeholders concluded that a substantial deviation from the current power structure in the urban development when deciding which stakeholders to involve would have a crucial effect on their perceived usefulness of the methodology. They feared participatory involvement of all stakeholders would lead to exploitative or parasitical behaviour. This research therefore proposed to introduce a distinction between participatory and indirect stakeholder involvement in the preference-based design methodology. The decision on which stakeholders to involve participatory and which to involve indirect can be done using theory from process management theory. This theory relies on the process to be centralized, therefore the Urban Systems Engineer (USE) role can be introduced in preference-based design to ensure this.

The final part of the concluding session was to evaluate the response towards the usefulness and ease of use of the methodology with the modifications or proposed modifications mentioned above. The response was again evaluated using the same questionnaire. The results showed mostly an increased likelihood to perceive the methodology as useful and easy to use. This increased likelihood, according to the TAM, leads to a positive attitude towards using the methodology. This, in turn, has a causal relationship toward actual system use. Therefore, it can be concluded the methodology with the proposed modification has a raised acceptance.

This research also provides recommendations to raise the acceptance of preference-based design even more. The first recommendation is to investigate the benefits or drawbacks of participatory involvement of non-professional stakeholders in the methodology. Moreover, the weight distribution between stakeholders has a large effect on the level of realism in the model and it is recommended to research how to make this distribution closer to reality. Furthermore, it is suggested to improve the technical modifications made in this research to increase the result reliability. Lastly, converting the Excel interface, created for this research, to a software tool that is also applicable to other construction management sectors would also be beneficial for the acceptance of preference-based design.

1 Introduction

In the field of urban development few challenges are as tough as the housing problem. The rapid expansion of urban populations (CBS, 2022) combined with slow construction processes have caused this issue. This leads to a growing need for innovative solutions. However, traditional design approaches within urban planning often fall short, resulting in sub-optimal outcomes that fail to address the complexities of modern urban environments. “Other methodologies are needed as well as these traditional planning methods” (van Loon, Heurkens, & Bronkhorst, 2008). Urban development projects have many involved stakeholders that all have a view on the optimal design of the area. The design needs to comply to laws and regulations, needs to be financially attractive and be a pleasant, sustainable living environment. Municipalities play a major role in accomplishing these goals, but also require cooperation from other parties that are professionally involved in the development or have a personal interest with the result. Managing this complex environment is a major difficulty in projects. A group of stakeholders have to agree upon a shared solution which usually does not satisfy all the goals that they established at the start of a project. To eventually reach a shared solution, decisions need to be made taking these early established goals into account. The currently sequential design process to reach these solutions more than often leads to suboptimal solutions as is determined by the following statement: “The project development and design processes in the construction industry are still often disconnected and based on individualistic principles where each involved party seeks to maximize their own local gains and optimize their own part of the project development chain, which can result in suboptimal performance on the project level.” (Zhilyaev, Binnekamp, & Wolfert, 2022)

The shortcomings in traditional design processes confirm the necessity for optimization. New modelling techniques have therefore been developed to help with the complexity of decision-making in engineering. The field of urban development could undoubtably also benefit from these techniques. Planmaat has been using linear programming (LP) techniques to evaluate and optimize area development plans, however, this technique optimizes on a single objective. This results, for example, in the most profitable or most sustainable solution. As urban development continues to evolve, there is a need for design methods that not only optimize on a single objective, but a method that finds an overall best solution for all stakeholders involved and therewith enhance the overall quality of urban life. A design method for the construction management industry that fits this description is preference-based design as introduced by (Zhilyaev, Binnekamp, & Wolfert, 2022). This method utilizes stakeholder preference as key value on which urban development projects are designed and evaluated. The preference-based design model, called the Preferendus, optimizes for the most preferred solution by each stakeholder.

Central to the success of new information systems such as the preference-based design model is their acceptance by stakeholders, including municipalities, urban planners, developers, and the local residents. People, especially those at the top of an organisation, need to be able to trust the innovation to be useful and usable. (van Loon, Heurkens, & Bronkhorst, 2008). Preference-based design models require stakeholders to determine their preferences for the project in an early phase, which requires collaboration and openness on what they desire to achieve in the project. This also induces stakeholders to establish their goals early in the process and share these goals in the form of preferences.

This master thesis aims to explore the challenges of stakeholders with accepting a preference-based design methodology and to develop modifications to this preference-based design methodology that increase the stakeholder acceptance. To achieve this, firstly a research analysis is done to study previous literature on the topics of preference-based design, collaboration in urban design and system acceptance. This research analysis also includes the proposed approach to answer the research questions. After the research analysis is concluded, 2 case studies were conducted. The case studies are performed with a group of stakeholders working in the field of urban development.

The first case study is about a fictional area designed for educating the group about preference-based design and to explore the acceptance difficulties. The second case study is a real ongoing project to apply the methodology including modifications to the functionality and the presentation and to have a dialogue about the use of the methodology in urban design. With this, this research strives to pave the way for more effective and sustainable urban development practices.

PART I: Research analysis

2 Literature study

This research on the acceptance for preference-based design starts with a literature study on three key topics, preference-based design, collaboration in urban design and system acceptance. The first section elaborates on what preference-based design is and how it utilizes stakeholder preference to optimize solutions. Furthermore, preference-based design in the context of urban development requires collaboration between multiple stakeholders, therefore the next section elaborates on collaboration in urban design. Thirdly, a method to evaluate acceptance for information systems is discussed.

2.1 Preference-based design

In order to define preference-based design firstly engineering design needs to be defined. "Engineering design is a systematic, intelligent process in which engineers generate, evaluate, and specify solutions for devices, systems, or processes whose form(s) and function(s) achieve 'stakeholder' objectives and users' needs while satisfying a specified set of constraints." (Dym, Little, & Orwin, 2013). When breaking down this definition, three phases of engineering design can be determined. Namely, generating, evaluating and specifying solutions. The process of engineering design loops through these phases until a satisfactory result has been achieved. The methodology proposed by (Wolfert, 2023), called the Open Design Systems (Odesys) methodology, also follows these phases. This methodology, however, uses innovative techniques to generate, evaluate and specify solutions. The design optimization tool used in the Odesys methodology using preference-based design is called the Preferendus, which was first introduced in (Zhilyaev, Binnekamp, & Wolfert, 2022).

Generating solutions in the Preferendus methodology is done by a-priori optimization. A-priori design means the best solution is created based on pre-determined criteria, as opposed to a-posteriori design where multiple possible solutions are firstly created and evaluated on certain criteria afterwards. "While a posteriori approaches have their advantages, they imply that stakeholders and their preferences come at the end of the optimization process. In contrast, the real-world design process starts from stakeholders and their preferences and it is, thus, inherently an a priori preferences-first process. In addition, a posteriori optimizations can become very complex and hard for stakeholders to understand as the number of objectives increases." (Zhilyaev, Binnekamp, & Wolfert, 2022).

The next step in the Preferendus methodology is evaluating the generated solutions. Many methods of decision-making have been introduced over the years. Many are analyses with all criteria defined on a monetary basis. Some aspects, however, are hard or impossible to define by a financial result. Many aspects regarding urban development have a cultural or ecological value. Methods to accommodate for non-monetary values do exist in the form of Multi Criteria Decision Making (MCDM) methods. MCDM attempts to represent imprecise goals in terms of a number of individual criteria. (Stewart, 1992). That number can be compared between solutions to determine the best solution. While these MCDM methods could prove useful, they should be mathematically correct. "When it comes to studies utilizing MCDMs, most are based on methods that, as was shown by (Barzilai, 2010), do not measure and aggregate preferences in a mathematically correct way and utilize the operations of addition and multiplication on scales where those operations are not defined." (Zhilyaev, Binnekamp, & Wolfert, 2022). Therefore, (Barzilai, 2010) introduced Preference Function Modelling (PFM). This method of calculating scores given to multiple criteria uses a least-square method, which is mathematically valid for relative terms like preference. (Binnekamp, 2010) was able to integrate preference correctly into a decision-making system by using Barzilai's theory on preference measurement. This resulted in the preference-based design methodology, the Preferendus.

The Preferendus methodology, following a-priori design, firstly gathers the criteria on which a solution will be evaluated on. These criteria are the preferences of the relevant decision-makers for different objectives. Possible alternatives are then created based on these preferences. The final solution is specified by which alternative matches the pre-determined preferences of the group of decision-makers the best.

2.1.1 Preference

The scientific foundation of the Preferendus methodology is preference measurement. "Preferences are central to design/decision theory because of the relation to human behaviour." (Wolfert, 2023). In this research, preference is defined as the measure of desirability of one alternative over another. Preference in this research is quantified as a score of desirability. That score is a variable that describes psychological or subjective properties. Preference is a relative term that can not only define an alternative as better or worse than another alternative, but also find a preference score for in-between alternatives when more than 2 alternatives are compared. This preference score is defined as a real number on a scale of 0 to 100, where the most preferred solution is given a score of 100 and the least preferred solution is given a score of 0. Any solutions in between are scored relatively to these most and least preferred solutions. This relativity is in line with PFM method by (Barzilai, 2010) that only allows for preference to be measured on affine scales. For more details regarding the measurement of preferences the reader is referred to (Barzilai, 2010).

2.1.2 Preference functions

As mentioned above, possible solutions are created based on pre-determined preferences of decision-makers. These pre-determined preferences are defined by the means of non-linear preference functions. Decision-makers define their boundaries for each design criteria. These boundaries are the maximally and minimally acceptable value of that criterium for the project. Furthermore, the decision-makers also define the progression of the curve between these boundaries. This results in a preference function on which all alternatives can be scored on. An example of a preference function is found in Figure 1. This function shows the preference of a decision-maker on the profit of project. This decision-maker minimally accepts a break-even scenario and ultimately prefers a profit of 3 million euros, however, when a project alternative solution has a profit of 1 million the decision-maker scores that project with a preference score of 80. The fitting curve is determined by the Piecewise Cubic Hermite Interpolating Polynomial (PCHIP) method. This particular method is used to prevent "overshooting", since the preference score cannot go lower than 0 or higher than 100. With these preference curves decision-makers can determine how all alternative designs score relatively to each other for each design criterion.

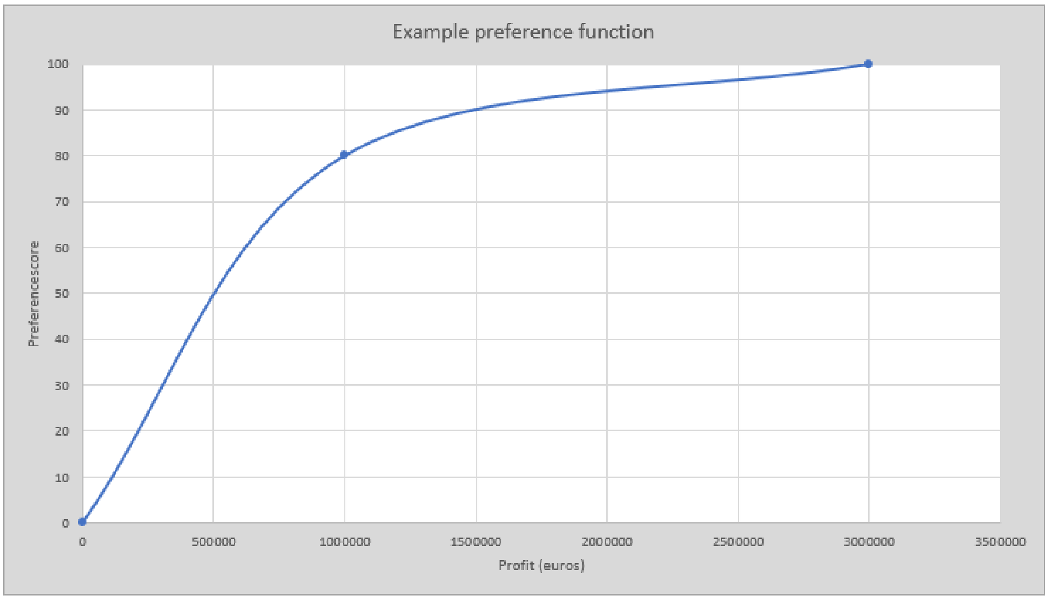

Figure 1: Example preference function

2.1.3 Preference score aggregation

With the preference functions projects can be scored individually on various criteria, but to actually compare alternative solutions the preference scores need to be aggregated to determine the preferred group solution. To determine the overall preferred solution, firstly weights between decision-makers and objectives are introduced. Thereafter, an aggregation method and accompanying tool are introduced: the Integrative Maximized Aggregated Preference (IMAP) method and the Tetra tool.

2.1.3.1 Weights

When making a decision regarding multiple objectives not all objectives are weighted the same by decision-makers. A decision-maker might value the quality of the project much more than the profit or the other way around. This difference in value can be determined by objective weights. Decision-makers have to define weights for each of the objectives in the form of a numerical value. The Preferendus tool demands the sum off all objective weights to be equal to 1.

There is not only a difference in objective weights, but also different decision-makers do not all have the same influence on a project. One decision-maker might have more power in a project than the other. These differences can also be expressed in the form of numerical weights among decision-makers. The sum of all decision-maker weights should also be equal to 1 for the Preferendus tool.

The objective weights and the decision-maker weights multiplied define the project weight for a certain objective to a certain decision-maker. These total project weights automatically total to 1 as well. The decision-maker and objective weights are defined as local weights, whereas the project weights are the global weights. An example weight distribution for a project with 3 decision-makers and 3 objectives is shown in Figure 2.

	Decision-maker weight		Objective weight	Project weight
Decision-maker 1	0,5	Objective 1	0,10	0,05
		Objective 2	0,50	0,25
		Objective 3	0,40	0,20
Decision-maker 2	0,2	Objective 1	0,50	0,10
		Objective 2	0,50	0,10
		Objective 3	0,00	0,00
Decision-maker 3	0,3	Objective 1	0,33	0,10
		Objective 2	0,33	0,10
		Objective 3	0,33	0,10
Sum	1,0		3 x 1,0	1,0

Figure 2: Example weight distribution

2.1.3.2 IMAP/Tetra

To determine a group preferred solution from all project weights and preference functions a method called the IMAP is introduced by (van Heukelum, Binnekamp, & Wolfert, 2023) and (Wolfert, 2023). The aggregated preference scores used in the IMAP are determined by a solver called Tetra, which uses the PFM principles by (Barzilai, 2010) and project weights to find the best solution. The tool that combines the Tetra solver with an inter-generational genetic algorithm (GA) is called the Preferendus. The Preferendus tool follows the three engineering design phases introduced in section 2.1; generating, evaluating and specifying solutions. The generating of solutions is done a-priori, based on the project bounds, by the GA. The GA computes a so-called first population of a pre-determined number of solutions. Thereafter it evaluates these solutions using Tetra and combines the best solutions to form a new population for a next generation. The Preferendus tool repeats this process until no better solution can be specified for a pre-determined number of generations. This iterative process imitates the classical design process in a structured way. The final solution of this optimization is not a global optimum, but a local optimum. This means there is no certainty the optimized solution is the overall best solution, but it determines the best of the evaluated solutions according to the principles of preference measurement. This optimal group solution is the solution that best fits the decision-makers preferences while also satisfying the project constraints and bounds.

2.2 Collaboration in urban design

Collaboration is essential in any urban design methodology because it allows for the integration of diverse perspectives and expertise. By involving various decision-makers in the design process, collaboration can help identify potential conflicts early on and generate innovative solutions that better reflect the preferences of the users. However, collaboration in urban design can be challenging due to power dynamics, conflicting interests, and communication barriers. (Edelenbos & Klijn, 2006). The decision-makers in urban development are usually referred to as 'stakeholders'. "This term refers to persons, groups or organizations that must somehow be taken into account by leaders, managers and front-line staff." (Bryson, 2007). The preference-based design methodology by (Wolfert, 2023) as introduced in section 2.1 provides a structured framework for collaboration in urban design by incorporating stakeholder preferences early into the decision-making process. This approach recognizes that all stakeholders possess valuable insights into their needs, desires, and concerns, which can inform design decisions. One of the predecessors of this design methodology is interorganisational design (van Loon P. P., 1998). Interorganisational design suggests that the individual points of view of all involved stakeholders should be involved in the design process. The preference-based design methodology developed in (Wolfert, 2023) incorporated this by involving all individual preferences of the stakeholders to evaluate the most preferred solution. A practical drawback of involving all individual stakeholders is the possibility of exploitative and parasitical behaviour (van Loon P. P., 1998). This behaviour can happen in the form of stakeholders providing preferences on another stakeholder's expertise, or by demanding other stakeholders to change their preferences without being open to concede in their own preferences. Another example of parasitical behaviour would be to unnecessarily keep a tight solution space and therewith create many unfeasible solutions. Avoiding exploitative and parasitical behaviour is critical for a positively experienced collaboration by all involved stakeholders.

2.2.1 Determining stakeholder involvement

To have an effective collaboration in urban design it is essential to determine which stakeholders to involve in the project and how these stakeholders should be involved. "Deciding who should be involved, how and when in doing stakeholder analyses is a key strategic choice." (Bryson, 2007). This is key since too much or too little participation of certain stakeholders can influence the outcome. Furthermore, "most of the studies on building design optimization that can be found in the literature focus on the technical aspect of the process, ignoring the stakeholders' involvement component and the group dynamics of the real-world design process." (Zhilyaev, Binnekamp, & Wolfert, 2022).

To determine the participation of stakeholders the theory on process management can be used. Process management theory focusses on stakeholder involvement in construction projects and how complex projects with multiple stakeholders are managed. An analysis in the context of process management by (Bryson, 2007) suggested a five-step process to approach the task of determining the involvement of stakeholders for a project. In short, these five steps are as follows:

1. Someone or some small planning group initiates the process by doing a preliminary stakeholder analysis. This can be done by some basic analysis techniques like the power interest grid shown in Figure 3.
2. With the results of the analysis a larger group of stakeholders can be assembled. This group should be asked to brainstorm on extending the list of stakeholders who might also need to participate in the process.
3. The original group analyses the positive and negative consequences of involving – or not – other stakeholders or their representatives, and in what ways to do so.
4. After this analysis, the extended participating group of stakeholders is assembled.
5. Last, after the full group has met, it should be possible to finalize the various groups who will have some role to play in the change effort.

“The process is designed to gain needed information, build political acceptance and address some important questions about legitimacy, representation and credibility. Stakeholders are included when there are good and prudent reasons to do so, but not when their involvement is impractical, unnecessary or imprudent.” (Bryson, 2007). To investigate the acceptability, these steps can be used to determine the involvement of stakeholders for the preference-based design methodology.

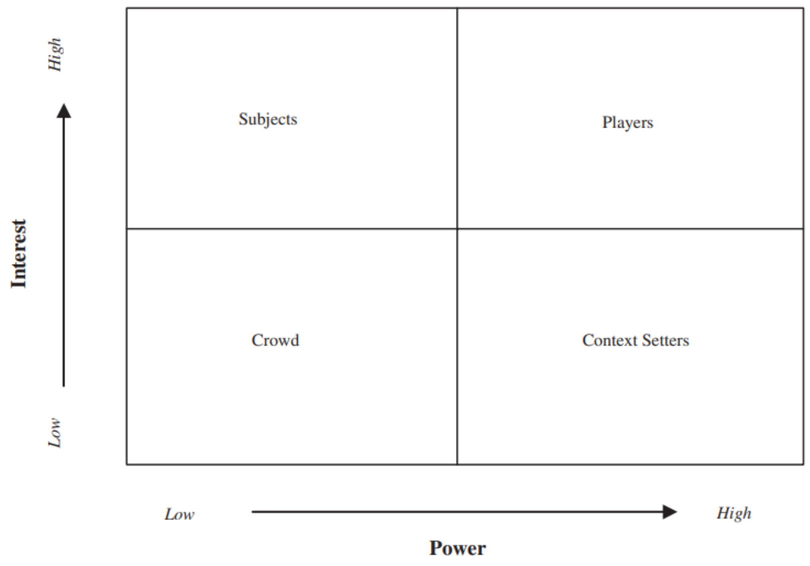

Figure 3: Power versus interest grid (Bryson, 2007)

2.3 System acceptance

Acceptance towards technological advancements has historically been difficult. The first reactions to cellular phones were not as positive as people feel about them now. The first people hearing about the concept considered it useless. “Lack of user acceptance has long been a major roadblock to the success of information systems efforts.” (Davis, 1987)

2.3.1 Technology Acceptance Model (TAM)

To address the lack of user acceptance (Davis, 1987) introduced the Technology Acceptance Model (TAM). This model explains the attitude towards using an information system as a combination of the perceived usefulness and the perceived ease of use. These two responses, in turn, are determined by the system design features. The model, including arrows for the causal relationships, can be found in Figure 4. Although the model may seem outdated it is still often used to determine user acceptance for new technologies. For example, Sagnier, Loup-Escande, Lourdeaux, Thouvenin, & Vallery (2020) and Elshafey, Saar, Aminudin, Gheisari, & & Usmani (2020) more recently applied the TAM to virtual reality and augmented reality for the construction industry.

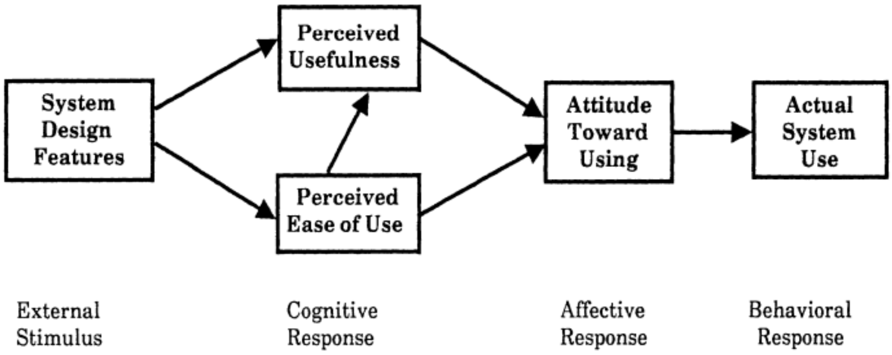

Figure 4: Technology Acceptance Model (TAM) (Davis, 1987)

The TAM is designed to address the impact of design features on user acceptance. Questioning the usefulness as well as the ease of use can be used to determine how to increase the attitude towards using a certain system. A positive attitude towards using the system can be described as system acceptance which leads to actual system use. This model can be used by determining the system design features and determining if these features contribute to the usefulness or the ease of use as perceived by the system users.

“The TAM is built upon regularities discovered in many previous studies, recognizing that variables and relationships repeatedly observed to be significant across several studies are more likely to be fundamental, and that, in turn, a model composed of such variables and relationships is likely to be more general across a range of systems and user populations.” (Davis, 1987)

The paper by (Davis, 1987) introducing the TAM describes the cognitive responses as follows:

Perceived usefulness – “the degree to which an individual believes that using a particular system would enhance their performance.”

Perceived ease of use – “the degree to which an individual believes that using a particular system would be free of physical and mental effort.”

The cognitive response towards a new technology system can be evaluated by questioning if the system design features contribute to either the perceived usefulness or the perceived ease of use following the above definitions. If a system is perceived useful and easy to use the attitude to using the system, or system acceptance, will be positive which, in turn, leads to actual system use.

3 Research question and development statement

The aim of this research is defined by the main research question and the development statement. To determine these, firstly the development gap in the literature needs to be defined. Thereafter, the main research question is formulated with the means of several sub-questions. Lastly the development statement describes what needs to be developed in order to answer the main research question.

3.1 Development gap

The Preferendus methodology proposed by (Zhilyaev, Binnekamp, & Wolfert, 2022) has been tested for multiple applications. A study by (Nannes & Eijck, 2022) applied the methodology to an urban development project. They found, however, that the methodology was not easily accepted by the users. Therefore, the gap this research fills is the lack of knowledge regarding what factors have an influence on the acceptability of preference-based design models and how the methodology could be modified for users to be able to accept the results.

3.2 Main research question

To fill the development gap mentioned above the following main research question was formulated:

How can the acceptability of stakeholders on the results of preference-based design be improved in the context of urban development?

The main research question can be answered by firstly answering the following sub-questions:

1. *How do the system design features affect the acceptability?*
2. *What modifications would improve the preference-based design methodology?*

From section 2.3.1 is learned that the perceived usefulness and perceived ease of use of the system design features of a new technology, like preference-based design, determine the attitude towards using this technology and thus the acceptability. Therefore, the first sub-question investigates what the system design features of preference-based design are and what their effect on the acceptability is. When these system design features are determined the second sub-question relates to modifications to improve the current methodology. This research will attempt to answer these questions using the approach as described in Chapter 4.

3.3 Development statement

To answer above questions a modified methodology needs to be developed that incorporates modifications to the methodology that would benefit the acceptability. This improved methodology includes technical modifications and changes to the use. Therefore, the development statement reads as follows:

It is necessary to develop modifications to the Preferendus methodology that enable stakeholders of urban development projects to better understand the use of preference-based design in their projects and thus create an increased acceptance of the results.

4 Approach

To answer the main research question, this chapter introduces the used approach. This research aims to raise the acceptance for a preference-based design methodology in the context of urban development. To raise this acceptance the preference-based design methodology introduced in section 2.1 is applied in two urban development case studies. These case studies serve to determine the key system design features of preference-based design and to determine the required modifications to these system design features to improve the acceptability. Additionally, the responses of the stakeholders involved in the case studies towards the modified methodology are evaluated. In this chapter, firstly, the case studies to which the preference-based design methodology is applied to are introduced. Furthermore, the tools used in this research are elaborated on and finally the validation method is introduced.

4.1 Case studies

This research introduces two urban redevelopment case studies. Both case studies are performed with a group of participating stakeholders from a Dutch municipality. The group of participating stakeholders consists of:

- Project manager (Municipality)
- Urban planner (External bureau)
- Financial manager (Municipality)

These stakeholders were determined to be the key stakeholders for this case study and following the first step of the stakeholder involvement decision approach by (Bryson, 2007) these stakeholders should initially be involved. The other steps of the approach are elaborated on in the case studies.

The first case study is a fictional case study with a limited level of complexity to introduce the methodology to the participating stakeholders. The second case study is the real-life area located in the Dutch municipality in which the participating stakeholders are currently involved. These case studies are used in multiple sessions with the stakeholders to demonstrate the methodology and discuss the modifications and the use of the methodology for their profession. All sessions were facilitated by the researcher. These case studies are used to validate the benefits of the modifications to the Preferendus methodology and therewith the acceptance for preference-based design.

4.2 Tools

For using the Preferendus model the project specifications and objectives have to be integrated in the programming of the Preferendus. The coding language used for the Preferendus model is Python version 3.8. The platform to edit and view the code is Spyder which is an open-source cross-platform integrated development environment for scientific programming in the Python language. For the input and presentation of the results Microsoft Excel is used. To cross reference from and to Microsoft Excel the xlwings library was used. Xlwings is a library that enables users to interact with Excel from Python. Additionally, it enables users to write User Defined Functions (UDFs) in Python that can be used in Excel. This feature made it possible to use the IMAP evaluation in Excel.

4.3 Validation approach

The method to determine the effect of the modifications to the methodology is the TAM. This model is used to validate the effect of the modifications on the stakeholder acceptance. The reason to apply this specific model is because of all the models that have been proposed for user technology acceptance, the Technology Acceptance Model (TAM) has been the most influential. (Moody, 2003). Furthermore, the TAM has a strong theoretical basis and empirical support.

To effectively apply the TAM for evaluating the acceptance for the methodology the system design features have to be determined. The design features for an urban development project have been grouped into three categories: use, functionality and presentation. The attributes within these three categories contribute to either the usefulness or ease of use of the system which, in turn, lead to an increase attitude toward using and actual system use. The 'Use' category consists of attributes of the methodology that have to do with how, when and by whom the methodology is used. The attributes in this category are directly linked to the perceived usefulness. The 'Functionality' category consists of attributes of the methodology that are related to how well the technical aspects of the methodology function. These attributes directly contribute to perceived usefulness as well as the ease of use. The 'Presentation' category is related to how the methodology is presented to the users, who are in this research the participating stakeholders of the case study introduced in section 4.1. The presentation is linked to the perceived ease of use. The TAM including the system design features relevant to this research and their relations to either the perceived usefulness or perceived ease of use can be found in Figure 5. The attributes in each category and their effect on the either the perceived usefulness or perceived ease of use are further elaborated on in this research.

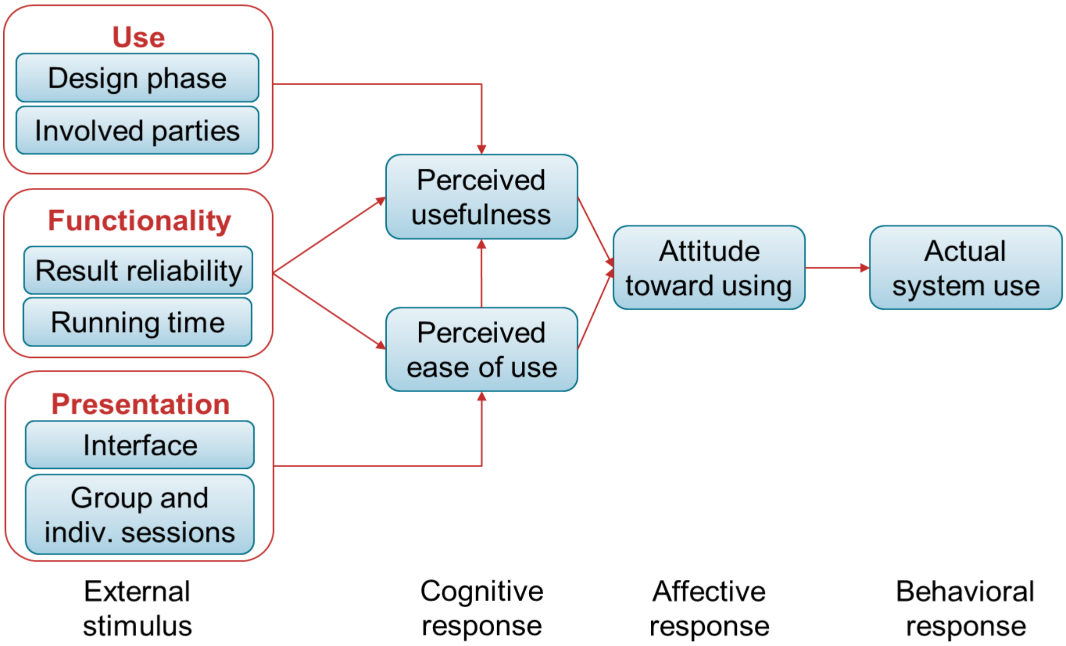

Figure 5: Applied TAM

4.3.1 Application of TAM

With the specified system design features the TAM can be applied for determining the cognitive response to the modifications to the preference-based design methodology as described in (Wolfert, 2023). To verify that the modifications contribute to an increased acceptance these modifications will be evaluated for the effect on the perceived usefulness or perceived ease of use of the methodology. The participating stakeholders are questioned on their experience of the methodology with a focus on the usefulness and the ease of use on two occasions. The first occasion is at the end of the introductory session to evaluate their first impression of the methodology. This moment was chosen since the participating stakeholders have then experienced the methodology for the fictional project and had a sense for the possibilities and risks of using the methodology for their profession. The second occasion is at the end of the concluding session to evaluate the change in response towards the methodology in regard to the first occasion. On both occasions the participating stakeholders will be questioned following the questions in Appendix 16.1. These questions evaluate the response to the usefulness and the ease of use of the modified preference-based design methodology.

PART II: Fictional case study

5 Introduction to fictional case study

To introduce the participating stakeholders to the Preferendus tool, a fictional case study was created. This fictional case study regards a simple rectangular fictional area with dimensions shown in Figure 6. This case study is a simplified urban development project with only 3 different housing types and the option to build a parking garage of various layers. Only 3 stakeholders were chosen to be involved in the fictional project, namely the project manager, city planner and a local residents representative. These 3 stakeholders needed to come to a decision for the fictional area taking into account the financial result, nitrogen emission, a social and a middle housing percentage. All project settings can be found in Figure 7. This fictional case study was used for the try-out session and the introductory session.

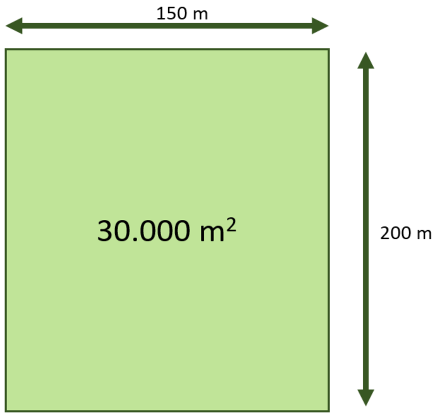

Figure 6: Fictional area

Stakeholders	3
Description	**Function**
Stakeholder 1	Municipality
Stakeholder 2	Urban planner
Stakeholder 3	Local residents

Objectives	4
Description	**Unit**
Financial result	euro
Nitrogen emission	kg
Social housing	%
Middle rent housing	%

Design variables	4
Description	**Unit**
Social house	Houses
Middle rent house	Houses
Expensive house	Houses
Parking garage levels	Levels

Constraints		1
Description	**Min**	**Max**
Total area	0	30.000

Figure 7: Fictional case study settings

5.1 Stakeholders

The stakeholders in the fictional case study are assigned certain goals for the project. These goals will later be translated into preferences curves by the participating stakeholders. These goals are based on real life goals that are common in the field of urban development. The overall goal of the municipality is to create a liveable, sustainable and resilient urban environment taking the wishes of all users into account. Simplified this leads to a fair distribution of affordable and profitable houses in a high-quality area. They also have to ensure that national or provincial rules are upheld. To create a high-quality area, the municipality hires an urban planner. The urban planner's goal is to create a vibrant and inclusive environment that preserves the integrity of the natural and built environment. The local residents are also involved in this case study. They want the project to align with their vision for a liveable, equitable and sustainable community that meets their needs and enhances overall well-being.

Social and middle rent housing are usually desired by municipalities to accommodate people with less to spend with proper housing. However, houses of these types generate fewer financial resources, which are needed for the development of the public space among other expenses. Municipalities are also faced with rules regarding nitrogen emissions and therefore desire to limit these as much as possible. The urban planner's goal is to create a liveable space for all users of the area. In this fictional project the urban planner desires to reach this goal by building as many middle-rent housing as possible. The local residents in this fictional project live close to the project area and are scared the value of their houses decreases when a neighbourhood with much social and middle rent housing is realised and therefore desire a minimum of these houses. In a real-life project these goals are significantly more complex, however, the goals are simplified to avoid adding to the complexity to the first impression of the participating stakeholders.

The specific (over)simplified goals that translate to the overall goals of the involved stakeholders are listed below:

Municipality:

- Desires 30% social housing;
- Desires 40% middle rent housing, but is flexible;
- Wants to minimize the nitrogen emissions;
- Can not have a negative financial result.

Urban planner:

- Has seen the design of the middle rent houses and wants to build as many as possible.

Local residents:

- Desires the minimum of social housing;
- Desires the minimum of middle rent housing;
- Do not want a parking garage.

6 Model development

The goal of the fictional project was to introduce the Preferendus model to the participating stakeholders. This chapter firstly introduces the functionality of the model and what settings were chosen for the GA. This was initially done without any modifications to GA. Furthermore, to be able to present the Preferendus model, an interface for the model was developed. The most important aspects of this interface are elaborated on.

6.1 Functionality

One of the categories from the applied TAM is the functionality. The functionality is defined as the technical factors that are related to the main function of the Preferendus model, which is to optimize the group preference score. Firstly, the input of the model in the form of how the objectives are defined, the given weights to these objectives and the stakeholder preferences. Furthermore, the project constraints and bounds are elaborated on. Lastly, the settings of the IMAP are stated.

6.1.1 Objectives

As mentioned, the fictional case study has 4 objectives. The financial result, nitrogen emissions, social and middle rent housing percentages. The financial result was calculated by using the land development calculation model of Planmaat which takes all costs regarding land acquisition, preparation and planning into account. The revenues from the sale of the land to developers for housing were used to cover the costs. All costs and revenues were also indexed over time to adjust for inflation. The nitrogen emissions were calculated by defining the emissions for each housing type on top of emissions related to the construction of infrastructure and the parking solution.

6.1.2 Preferences and weights

To find the optimal solution for the land use of the fictional case study with the Preferendus model, preferences and objective weights needed to be defined. The stakeholder weights were pre-determined as equally divided among all three stakeholders. The participating stakeholders were asked to produce the preferences and objective weights based on some information on their role in the fictional case study. The way this input was gathered will be elaborated on in section 7.2.

6.1.3 Constraints and bounds

Constraints are user defined project boundaries, i.e. the maximum available area. The bounds are boundaries related to design variables. Each design variable has a lower and upper bound. The constraints and bounds for the fictional case study were relatively simple. The only constraint was the total area available for development. All generated solutions have to fit in the area. If a generated solution exceeds the maximal area that solution is considered unfeasible. The bounds of the housing design variables were also determined by the maximum number of houses that would fit in the area, given that the minimal requirements for infrastructure, greenery, parking and water area per house were met. The upper bound for the number of layers of parking garage was arbitrarily set to 5 layers.

6.1.4 IMAP

The Preferendus tool requires more than preferences and weights as input. The settings of the GA also need to be defined. A general explanation of GA's can be found in Appendix 16.3. Highlighted for this research are the population size, maximum stall, the starting points and the mutation rate. The population size (*n_pop*) is the number of solutions that is generated per generation. The *n_pop* was set to 100 for the fictional case study. The maximum stall (*max_stall*) is the number of unsuccessful generations before the algorithm is stopped. Where an unsuccessful generation is defined as a generation where no solution is scored better than the current best solution from a previous generation. The *max_stall* for this research was set to 20. Two other important aspects of the GA are the generation of starting points and the principle of mutation. They are described in the next sections.

6.1.4.1 Starting points

One of the aspects of the GA is determining the starting points. The starting point is a set of possible solutions used for the first population. The algorithm uses this first population to start the genetic process of determining the optimal solution. How this starting point is formed has a large effect on the running time for the model to produce reliable results, because the generated solutions will be used for determining new and improved solutions. These new and improved solutions are formed by combining the best feasible solutions from the starting point. The feasibility of a solution is determined by the constraints of the project. When a generated solution does not fall within the given constraints, the solution is considered unfeasible and the unfeasible solution will not be used for generating new solutions. Having as many feasible solutions as possible in the starting point is therefore essential for the GA to be able to have a larger number of solutions to “choose” the best solutions from.

The original first population as used in the model described by (van Heukelum, Binnekamp, & Wolfert, 2023) consists of randomly generated design variables between the upper and lower bound of each design variable. This population is then used for an optimization using the min-max aggregation method, which is a different less time-consuming optimization method. The optimal result of this method is used as starting point for the IMAP optimization. This method of determining the starting point is also used for the fictional case study.

6.1.4.2 Mutation

To prevent the genetic algorithm from generating non-diverse solutions, genetic mutation is applied. Mutation randomly changes one or multiple design variables in solutions to diversify the evaluated solutions. How often mutation takes place is determined by a mutation rate factor. A higher value of this factor ensures that mutation takes place more often. The value for the mutation rate was set to the default value of 2.0 for the fictional project. When a mutation occurs, the design variable changes to a random value between the lower and upper bound of that design variable.

6.1.5 Running time

The running time of the current model can vary depending on the settings in the *n_pop* and *max_stall*, but for the given settings the running time was approximately 5 minutes. This is a relatively short period of time, and the optimization could therefore be run live during the sessions described in Chapter 7. This running time and all further runs in this research was determined with a PC with the following specifications:

Processor: Intel(R) Core(TM) i3-6006U CPU @ 2.00GHz   2.00 GHz
RAM: 8,00 GB (7,90 GB available)

6.2 Presentation

Besides calculating the results, results of the model also have to be presented to the stakeholders in a comprehensible manner. The Preferendus tool is programmed in Python and does not have an interface that is useable for stakeholders. To accommodate the stakeholders, it was chosen to build an interface in Microsoft Excel since this is a program stakeholder in urban development use regularly. The Excel interface for the fictional case study contained multiple sheets that were used chronologically in a session. The first sheet shows the characteristics of the area and the housing types, the second sheet is an input sheet for determining the preferences and weights, the third a manual design sheet, followed by an optimization design sheet and finalized with a result comparison. Some specific attributes of these sheets are elaborated on in the upcoming sections.

6.2.1 Preferences and weights

The input sheet for preferences and weights allowed the stakeholders to easily provide their preferences for the project. To aid the stakeholders, the ultimate boundaries of all objectives were shown. These were determined by a single-objective optimization on the project. For the fictional project, these boundaries can be found in Figure 8. An example of provided preferences by the municipality can be found in Figure 9. The “Min waarde” and “Max waarde” columns represent the ultimately acceptable values per objective of the respective stakeholder. The “Vormingswaarde” column represents the shape value that forms the curve. The “Pref.” columns are the corresponding preference value for the objective. The final column, “Weging”, is to provide the objectives weights. Besides the preference tables the corresponding preference functions are shown.

Grenswaarden	Minimaal	Beschrijving	Maximaal	Beschrijving
Saldo (€)	-6.000.000	Geen woningbouw	6.052.800	Slechts dure won.
Uitstoot (kg)	0	Geen woningbouw	1.261.800	Slechts dure won.
Percentage sociaal (%)	0	Geen sociale won.	100	Slechts sociale won.
Percentage betaalbaar (%)	0	Geen betaalbare won.	100	Slechts betaalbare won.

Figure 8: Objective boundaries

Preferenties Gemeente	Min waarde	Vormingswaarde	Max waarde	Pref. min waarde	Pref. Vormingswaarde	Pref. max waarde	Weging
Saldo	-500.000	0	6.052.800	0	100	30	0,30
Uitstoot	500.000	1.000.000	1.261.800	100	50	0	0,20
Percentage sociaal	20	30	40	0	100	70	0,40
Percentage betaalbaar	30	40	50	40	100	30	0,10
						Som:	1,00

Figure 9: Preferences and weights municipality

6.2.2 Manual design sheet

The goal of the Preferendus tool is to optimize the combination of design variables to find a most preferred solution. However, this process is often viewed as black box. One of the factors for this phenomenon is the lack of insight in the relation between the input and the output of the model. To increase the insight in this relation, the interface includes a manual design sheet. In this sheet, users can manually determine the design variables and see the how their design solution scores in regard to the provided preferences. The model interface has the option to add 6 different manual designs. These designs are also evaluated using the IMAP evaluation and can thus be compared to each other by their individual and group preference score. The preference scores are also colour coded from green to red, with dark green being the most preferred solution and red for the least preferred. This provided a better overview when comparing solutions. An example of this preference score representation is found in Figure 10. Calculating manual solutions does not require optimization and running time for the calculations is therefore negligible. Having a manual design sheet proved useful for the participating stakeholders to gain confidence in the model calculations and the IMAP evaluation method.

Groepspreferentie						
Preferentiescore	20,3	99,7	100,0	0,0	91,7	15,6

Figure 10: Preference score of 6 solutions

6.2.3 Optimization design sheet and comparison

When stakeholders have a better understanding of the Preferendus tool and the interface by using the manual design sheet the optimization design sheet is introduced. The interface of the optimization sheet is similar to the manual design sheet, but instead of manually determining the design variables these variables can be optimized using the Preferendus tool. The optimization design sheet can show up to 6 different optimized solutions and evaluate them relative to each other with the preference score. This evaluation determines the group most preferred solution, but also the preferred solution per stakeholder is shown. The final sheet is the comparison sheet, which compares the manual solutions with the optimized solutions. The interface of the fictional case study’s manual and comparison sheet can be found in Appendix 16.2.

7 Case study stakeholder sessions

The fictional case study was used for two stakeholder sessions. As mentioned in section 4.1 these sessions were to introduce the preference-based design methodology to the participating stakeholders. The first session was a try-out session with experts at Planmaat. The second session was the introductory session with the participating stakeholders introduced in section 4.1.

7.1 Try-out session

The goal of the first session was to have a try-out session for the introductory session. Unlike further sessions, the first session was not held with the participating stakeholders, but with the experts at Planmaat. The experts from Planmaat provided helpful feedback that was taken into account for the introductory session. Since the contents of the try-out session were similar to the introductory session the contents will be elaborated on in the next section.

7.2 Introductory session

The first meeting with the participating stakeholders was the introductory session. The aim of this session was to get the stakeholders familiar with preference-based design, the interface of the model and to get a first impression evaluation by the means of the TAM.

The first part of the session was dedicated to familiarizing the stakeholders with preference-based design. This was firstly done by the means of a relatable example of the consideration made when buying a new phone. This example was a simplification of preference-based decision-making. Shortly after, the connection to urban development was made by introducing the fictional case study with a limited level of complexity. Together with the introduction to the fictional area the model interface was introduced. During the session, the stakeholders were tasked with representing one of the fictional stakeholders from the example area by providing their preferences and objective weights for the fictional area. Providing these preferences and weights was done by physically filling in a table similar to the one shown in Appendix 16.2.1. The participating stakeholder were also given the option to draw their preference functions next to the table. This option was added for more visually oriented stakeholders. The provided preferences and objective weights can be found in Appendix 16.2.1. With these preferences the area was optimized and the optimized result for the group as well as the optimized result per stakeholder were presented. Finally, the first impressions of the stakeholders regarding the usefulness and the ease of use of the methodology were evaluated using the TAM questionnaire in Appendix 16.1. The results of the first TAM are described in Chapter 8.

7.2.1 Resulting design

The first results of the fictional case study are the results of the manual solutions that were designed by the participating stakeholders. The manual solutions can be found in Appendix 16.2.2. The stakeholders tried five combinations of the 4 design variables to see how the model evaluated these solutions. When the stakeholder acquired a sense of the effect of the input on the output, the optimization sheet was introduced. The optimization was run once which resulted in the design found in Figure 11.

Expensive houses	33
Affordable houses	33
Social houses	0
Parking garage layers	2
Running time	00:04:07

Figure 11: Optimized solution fictional case study

When discussing the design with the participating stakeholders they were moderately surprised by the absence of social housing in the design. However, when examining the cause of this design they quickly came to the conclusion that the solution suited the given preferences and weights. The municipality as well as the local residents had assigned a weight to a social housing preference function. However, these preferences had no overlapping values which resulted in a stalemate situation. The project weight for social housing was higher for the local residents, who had a maximum preference for 0 social houses, and therefore the GA resulted in a solution that was in accordance with the local residents' preferences. The absence of social housing also allowed for the solution to increase the number of expensive and affordable houses, which fit the preferences of the municipality and urban planner. The running time for the optimization was approximately 4 minutes as is also seen in Figure 11.

8 Findings

The end of the introductory session also marked the end of the fictional case study. The aim was to introduce the participating stakeholders to preference-based design and to familiarize them with the methodology. The reactions of the stakeholders were generally positive towards the methodology and agreed about the added value of using the Preferendus tool for urban development.

To validate these first reactions, the participating stakeholders were asked to complete the TAM questionnaire regarding the usefulness and ease of use of the modified Preferendus tool. The results of the TAM questionnaire for the usefulness and ease of use are found in Figure 12 and Figure 13. The high frequency of "quite likely" and "slightly likely" confirmed the positive reactions, but the results also show opportunities for improvement. These results will be taken into consideration for the real-life case study and the TAM questionnaire will be conducted again at the end of the concluding session to evaluate any improvements or decline in perceived usefulness or perceived ease of use of the modified Preferendus tool.

Extremely likely	Quite likely	Slightly likely	Neutral	Slightly unlikely	Quite unlikely	Extremely unlikely

Usefulness	Projectmanager municipality	City planner	Financial manager
1. The Preferendus would help me complete tasks faster	Quite likely	Slightly likely	Quite likely
2. The Preferendus would help me get better results from my job	Slightly likely	Quite likely	Slightly likely
3. The use of the Preferendus would increase my productivity	Quite likely	Quite likely	Slightly likely
4. I am able to present my view with the use of preference curves	Quite likely	Extremely likely	Quite likely
5. The use of the Preferendus would make my job easier	Neutral	Slightly likely	Slightly likely
6. I would find the Preferendus useful in my job	Quite likely	Quite likely	Slightly likely

Figure 12: TAM results fictional case study, usefulness

Ease of use	**Project manager municipality**	**City planner**	**Financial manager**
1. I would know how to express my preferences in the model	Quite likely	Slightly unlikely	Quite likely
2. Due to the interface of the model I can easily follow where to look	Quite likely	Neutral	Quite likely
3. I understand how the model input influences the outcome	Quite likely	Slightly likely	Quite likely
4. The graphic visualisations (preference curves) help understand the Preferendus	Quite likely	Extremely likely	Quite likely
5. The results are easy to interpret	Slightly likely	Quite likely	Quite likely
6. I would easily be able to learn how to work with the Preferendus	Quite likely	Quite likely	Quite likely

Figure 13: TAM Results fictional case study, ease of use

PART III: Real-life case study

9 Introduction to the real-life case study

The main function of the fictional case study was to introduce the participating stakeholders to preference-based design. The main function of the real-life case study is to apply the modified preference-based design methodology to a real-life project and evaluate the response. This project is regarding a 3.5 hectare project area in a Dutch municipality. The current function of the area is partly industrial, partly a water treatment plant and there is also a building from the local scouting association. The surrounding area is a residential area on one side and agricultural fields on the other. The project development is in an early stage as is recommended in earlier research by (Nannes & Eijck, 2022). In Figure 14 a picture of the area is shown. Figure 15 shows an overview of all involved stakeholders, objectives, design variables and constraints of the project.

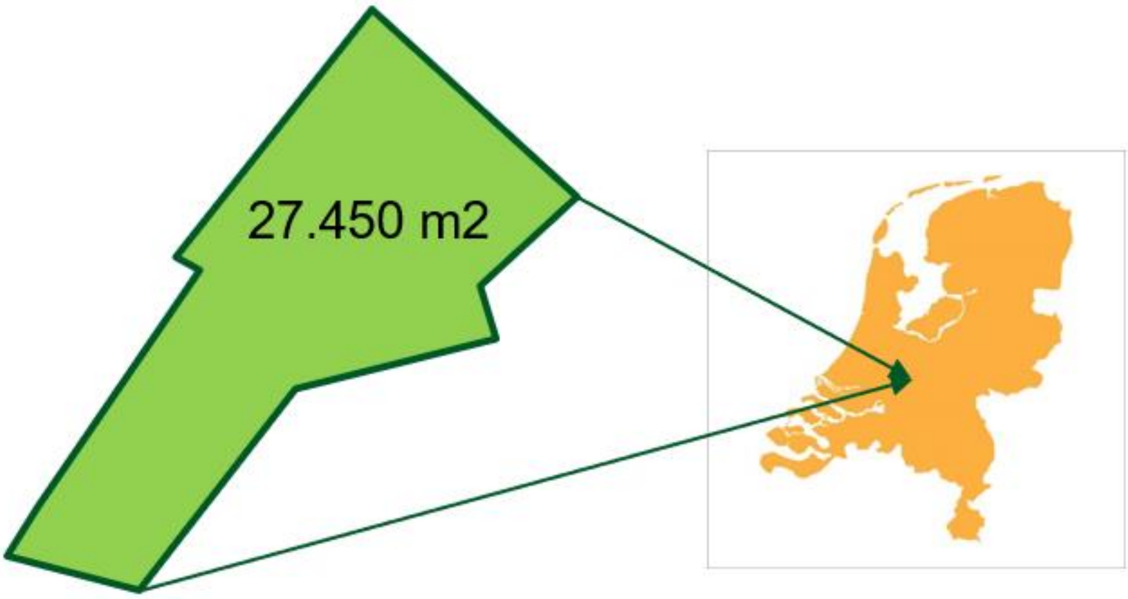

Figure 14: Real-life area in the Netherlands

Stakeholders	6
Description	**Function**
Stakeholder 1	Project manager
Stakeholder 2	Urban planner
Stakeholder 3	Local residents
Stakeholder 4	Financial manager
Stakeholder 5	Scouting association
Stakeholder 6	Developer

Objectives	15
Description	**Unit**
Financial result	euro
Social housing	%
Middle rent housing	%
Affordable housing	%
Expensive housing	%
Total houses	(-)
Appartments	%
Extra greenery	%
Extra cycling road	%
Playing areas	(-)
Extra sidewalk	%
Sustainable design	%
Building height	Layers
Keep RWZI	%
Keep scouting	0/1

Design variables	18
Description	**Unit**
Social housing	(-)
Middle rent housing	(-)
Affordable housing	(-)
Expensive housing	(-)
2/1 roof	(-)
Detached houses	(-)
Social housing (app)	(-)
Middle rent housing (app)	(-)
Affordable housing (app)	(-)
Expensive housing (app)	(-)
Extra greenery	% extra greenery
Extra cycling path	% extra cycling road
Playing areas	(-)
Extra sidewalk	% extra sidewalk
Sustainable design	% extra costs
Building height	Layers
Keep RWZI	% of current area
Keep scouting	0/1

Constraints		4
Description	**Min**	**Max**
Total area	0	27.450
Social housing	30%	100%
Middle rent housing	30%	100%
Total houses	100	-

Figure 15: Real-life case study settings

9.1 Stakeholders

The real-life case study has multiple stakeholders that are involved in the project with each certain preferences for the to be redeveloped area. The stakeholders involved in this project are:

- Project manager *(participating)*
- Urban planner *(participating)*
- Financial manager *(participating)*
- Local residents
- Scouting association
- Developers

From these stakeholders the project manager, urban planner and financial manager are participating in this research by providing insight in their preferences for the area and by evaluating the methodology. These were chosen following the first step of the stakeholder involvement decision approach by (Bryson, 2007) described in section 2.2.1. The second step of this approach is to determine the other involved stakeholders. These were determined to be the local residents, developers and scouting association, since they all had an interest in the outcome of the design. The third step was to determine the way these stakeholders should be involved. For this project it was chosen to not directly involve the other stakeholders since they are not professionally involved in the process and to have a connection to the existing plan formation structure. However, their preferences were estimated and have been taken into account in this research. All stakeholders were initially given an equal decision-maker weight.

10 Model development

For the real-life case study the Preferendus model needed to be modified, since the model used for the fictional case study proved not to be sufficient for the increased complexity of the real-life project. To address this increased complexity, modifications to the functionality and the presentation are proposed in this chapter.

10.1 Functionality

In this section the factors regarding the functionality that have an impact on the cognitive response to the Preferendus model are discussed and the modifications to the Preferendus model are stated and tested. For this research. The increased number of stakeholders, objectives, design variables and constraints increased the complexity of the project. This increased complexity caused the Preferendus to nearly never find a feasible solution. Finding feasible solutions is essential for the GA to produce new solutions, which can be optimized into the most preferred solution. More information on the inner workings of the GA used in the Preferendus model can be found in Appendix 16.3. In this section, 2 modifications to the GA used for the fictional case study are proposed to find more feasible solutions: modifications to the starting points and to the mutation. Furthermore, the running time of the model is addressed.

10.1.1 Starting points

The first modification to the Preferendus model is a change in generating starting points for the GA. The starting point is a set of design solutions for the first generation.

10.1.1.1 Problem definition

The previous method to generate a starting point, as described in section 6.1.4.1, was considered sufficient for the fictional case study, however in the context of real urban development projects this method leads to mostly unfeasible solutions. The reason for these unfeasible solutions is the number of objectives necessary for the complex problems and constraints of urban development. As an example, the real-life case study has 10 different housing types for which a combination needed to be found together with values for the other design variables. The upper bounds for the design variables related to the various houses were determined by the amount of a certain housing type that would maximally fit in the area. These upper bounds were taking the project constraints into account. The randomly generated solutions for the first population therefore were a combination of ten housing types between these bounds, which has an incredibly low chance of not exceeding the maximum area constraint. This almost always resulted in starting points with exclusively unfeasible solutions, because the maximum area constraint was exceeded. Having a starting point with exclusively unfeasible solutions results in that the GA cannot find solutions to optimize, which, in turn, leads to the GA failing to produce any final solutions.

To attempt to solve this a test with a starting point of zero for each design variable was also tested. The solutions in the first population therewith were also all unfeasible. This was a result of the social and middle rent housing constraints. These constraints were to ensure a minimum of 30% of all houses to be social and 30% to be middle rent. In order to find feasible solutions that would comply with these constraints, this method relied on mutations to produce next populations. This often did result in a final solution, however, the result reliability was not sufficient.

10.1.1.2 Proposed modification

To solve this problem a new method of generating starting points is proposed. The starting population should take the project constraints into account when generating solutions. This provides the GA with more feasible solutions in the initial population, since the feasibility is tested to these constraints. The project constraints for the case study of this research were:

- Project area: [0, 29450] (m^2)
- Housing percentage of social housing: [30, 100] (%)
- Housing percentage of middle rent housing: [30, 100] (%)

In the proposed new method of generating the starting point, firstly the amount of non-social and non-middle rent houses is determined by Equation 1. This function semi-randomly assigns one of two methods of determining the value of the housing design variable. The randomness is created with a random variable r_1 for housing type *i* being larger or smaller than a threshold value (*f*). When r_{1i} is smaller than f the first method is used. This method is similar to the original method with the exception of another random variable (r_{2i}) to reduce the chance on a high number of houses that would surpass the maximum area constraint. The second method, when r_{1i} is larger than *f*, sets the design variable of housing type *i* to 0. The combination of these methods results in the values for the design variables related to non-social and non-middle rent housing in a solution. This method significantly reduces the number of houses in the starting point and thus reduces the chance that the maximum area constraint is exceeded.

$$v_i = \begin{cases} x_i * r_{2i} & if\ r_{1i} < f \\ 0 & if\ r_{1i} \geq f \end{cases}$$

Equation 1

Where:

v_i	=	*amount of non-social and non-middle rent housing type i*
x_i	=	*random number between lower and upper bound of housing type i*
r_{1i}	=	*random number between 0 and 1*
r_{2i}	=	*random number between 0 and 1*
f	=	*threshold value between 0 and 1*

The threshold value is the determining factor and will be different for each project. The threshold value for the case study of this research was determined to be 0.60. This value resulted from using the Monte Carlo simulation seen in Appendix 16.6. According to the trend in the simulation this threshold value results in the most feasible solutions in the first generation. The number of feasible solutions, with a threshold value close to 0.60, was in the range of 10-20 on a population size of 200. This results therefore in a success percentage between 5%-10%. The threshold value can however be different for every project and should therefore be determined for any new project.

In the next step, the amount of social and middle rent houses is determined. As opposed to the non-social and non-middle rent houses these design variables are not defined randomly. The social and middle rent houses are directly based on the constraints regarding the social and middle rent housing. The sum of all non-social and non-middle rent houses (v_i) determined in Equation 1 are multiplied with a factor consisting of the constraints of the minimum social and middle rent housing (b_{soc} and b_{mid}) as decimals as shown in Equation 2 and Equation 3. This results in a solution with a combination of all housing types with at least 30% of all houses in that solution of the social type and at least 30% of the middle rent type. When the project consists of multiple social housing types the resulting number of houses should be randomly divided among the social housing types. The same applies to middle rent houses.

$$v\_soc_j = \sum(v_i) * \frac{b_{\mathrm{soc}}}{1 - b_{soc} - b_{mid}}$$

Equation 2

$$v\_mid_j = \sum(v_i) * \frac{b_{\mathrm{mid}}}{1 - b_{soc} - b_{mid}}$$

Equation 3

Where:
v_soc_j = *amount of social housing type j*
v_mid_j = *amount of middle rent housing type j*
b_soc = *constraint of minimum social housing as decimal*
b_mid = *constraint of minimum middle rent housing as decimal*

Every solution also needs non-housing design variables. The starting points of the non-housing variables are set to a value of 0 in the initial population. This is because these design variables are significantly less dependent on the project constraints and therefore can be determined by the mutation of the GA.

With this method of generating starting points more feasible solutions are initially generated which results in more reliable results. Nevertheless, the success percentage is determined to be only 5%-10%. This percentage is already an improvement as opposed to 0% for the original method of starting point generation, however more research is recommended to other methods of generating these starting points to increase the success percentage even further. The full python script can be found in Appendix 16.7.1.

10.1.2 Mutation

Another modification to the Preferendus model is a change in mutation. A mutation is when at a random time during the optimization a solution is altered to create variance in the solutions.

10.1.2.1 Problem definition

The method of mutation as described in section 6.1.4.2, where a design variable in a solution is randomly altered to a value between the lower and upper bound of that design variable does not suit the nature of urban development, especially for the design variables regarding housing types and percentages. The differences in the lower and upper bounds for the housing types and percentages are too large which lead to large changes to a solution when a mutation occurs. However, a small change would often be preferred to not exceed the project constraints. The project constraints for this case study project consisted of a maximum available area and a minimum percentage of social and middle rent housing. When a design variable is mutated to a random value between the bounds the new solution is likely to be unfeasible due to the constraints.

10.1.2.2 Proposed modification

From the problem definition it can be concluded that small mutation is preferred for certain types of design variables. The proposed modification enables users to choose the type of mutation for each design variable. For design variables that represent housing types the mutation only in- or decreases the solutions value by a certain pre-determined mutation range instead of replacing the solutions value by a random value. This mutation range is a customizable percentage multiplied by the upper bound of that design variable. For the real-life project this mutation range was set to 0.10 for housing type design variables and 0.03 for percentage type design variables. Determining the optimal mutation ranges for different types requires further research. The proposed new method of mutation uses this mutation range together with the original value to find a new value for the design variable. A possible problem with this new method is that the GA only considers solutions close to a generated original solution. To solve this problem, the mutation rate is raised from 2.0 to 4.0. This increases the amount of times mutation occurs. This causes the GA to execute more mutations, but in smaller steps which enables the GA to still mutate towards completely different solutions than the originally generated solutions. A schematic overview of the proposed new method of mutation compared to the original method can be found in Figure 16. The blue cross represents the value of the mutated design variable and can be plotted randomly on the red line.

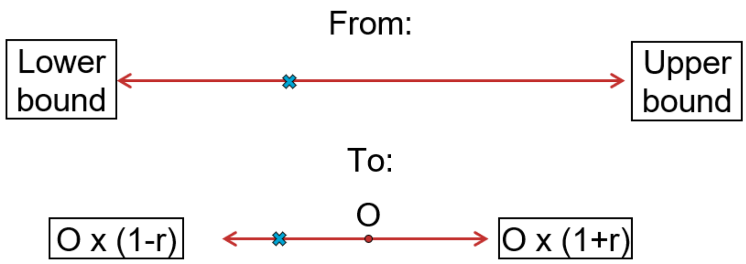

Figure 16: Proposed mutation method

Where:
O = Original value
r = Mutation range

Another aspect that contributes to solve the problem of a lack of variance in solutions in the proposed modification is to include a random chance to mutate following the traditional method. The chance of this happening is 0.10 for housing types and 0.30 for percentage types. The value is higher for percentage types since the starting points of these design variables are set to 0 and therefore large mutations are more preferable than for housing type design variables. This feature enables the GA to still consider random solutions completely out of the current path. The Python code can be found in Appendix 16.7.2.

10.1.3 Running time

The running time of an optimization model is the time it takes for the GA to find an optimized solution. The running time in this research is dependent on many factors such as the determined starting point and mutation, the GA settings and the internet connection. The modifications to the starting points generation and the mutation significantly decreased the running time. How much time is variable per optimization, but further research could be done on the effect. The GA settings also have a large effect on the running time. Especially the *max_stall* and the *n_pop*, both introduced in section 6.1.4, determine the running time. The larger the population, the more calculations the GA has to perform. The same is true for the *max_stall*, a higher *max_stall* leads to the GA taking longer since it is harder to be satisfied with the best solution and it takes more time to try to find a more preferred solution. The last factor is the internet connection. Tetra, the solver that evaluates all possible solutions and scores them relatively, has an external server. This leads to constant traffic over the internet. Therefore, a stable internet connection is necessary to run the Preferendus model. The external server also brings other issues. Even with a stable internet connection the constant traffic to and from the server takes a lot of time. To verify this, the running time of the Preferendus tool was tested with and without the use of Tetra as evaluation method. For reference, an evaluation method called Minmax was used as replacement since this method does not require an external server. The running time proved to be approximately 2.6 times as long with the Tetra tool compared to the Minmax tool for different population sizes. The results of the tests can be found in Appendix 16.8.

10.2 Presentation

For the real-life case study modifications have been made to the interface of the model by adding dynamic preference functions and the addition of the land development calculation model.

10.2.1 Preference functions

Since the participating stakeholders were familiar with the interface from the introductory session, only small modifications have been made to the interface for the further sessions. Due to the increased number of involved stakeholders and objectives the number of preference functions also increased. The 6 stakeholders and 15 objectives result in a possible 90 different preference functions. This is too many to show all, therefore a dynamic preference function was added that could show 4 different preference functions next to each other which could be changed to show the desired preference functions. This enables stakeholders to easily compare preferences on objectives. The preference functions can be found in Figure 17.

10.2.2 Land development calculation model

The most complex calculation in urban development is often considered the financial calculation. This applies to the real-life case study as well. The financial result is dependent on all design variables in the project. Furthermore, the financial result is also weighted highly by particular stakeholders and thus has a great effect on the optimally preferred result. To ensure the financial calculations were done accurately the land development calculation model that was created by Planmaat was used. The calculations done in the Planmaat model were translated to Python to avoid constantly having to make the connection between Excel and Python. This would drastically increase the running time of the Preferendus tool. Additionally, the land development calculation model was added as a sheet in the Excel interface to be able to verify the financial calculations for optimized solutions. This also avoided the financial calculations to be a black box for the participating stakeholders.

Preferentiecurves				
Keuze preferentiecurve	**Curve 1**	**Curve 2**	**Curve 3**	**Curve 4**
Belanghebbende	Project manager	Urban planner	Local residents	Project manager
Doelvariabele	Sustainable design	Sustainable design	Extra greenery	Extra greenery

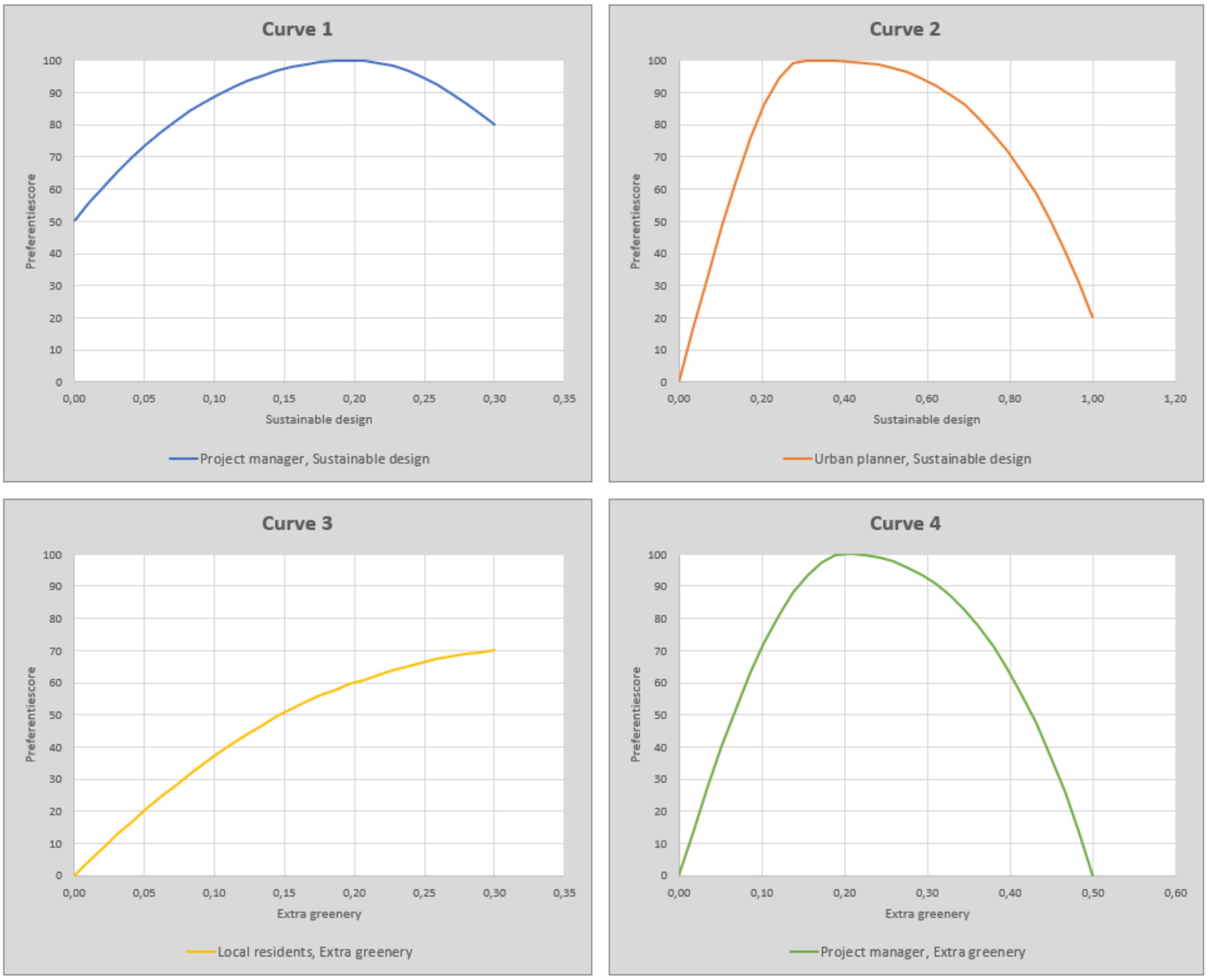

Figure 17: Preference functions

11 Case study stakeholder sessions

The real-life case study consists of an individual session with each participating stakeholder and 2 group sessions with all participating stakeholders. The aim for these sessions was to apply the preference-based design methodology with the proposed modifications to the real-life case study, to have a dialogue on the results and on the use of the methodology and evaluate the response of the participating stakeholders.

11.1 Individual sessions

The real-life case study started with individual sessions with each of the participating stakeholders. The aim of the individual sessions was to further familiarize the stakeholders with the methodology, to show how the model interpreted the specifications of the area and to obtain the preferences of the stakeholders for the objectives. The stakeholders were first presented with a recap of the introductory session to avoid confusion and confirm they were confident of their understanding of preference-based design. Thereafter, the interpretation of the project objectives was shown. The objectives required some simplification in order to be able to quantify the objectives. For example, the objective to have a green neighbourhood were simplified to the area and costs needed to realize extra greenery on top of the minimally required greenery by municipal guidelines. The second part of the individual sessions was to explain the necessary objective simplifications to the stakeholders. The final and most time-consuming part of the individual sessions was to gather the preferences and weights to the objectives. The stakeholders were first asked to assign weights to each objective or to deem objectives irrelevant to their field of work by assigning a weight of 0 to certain objectives. Thereafter, they were asked to provide the lowest and highest value of each weighted objective they could accept. Additionally, they had to provide a single in-between point to finalize the three-point preference curve.

The expected preferences for the non-participating stakeholders, namely the local residents, developers and scouting association, were also discussed with each of the participating stakeholders. The main benefit of the individual sessions as opposed to a group session was for stakeholders not to influence each other when discussing their preferences for the project. This is an aspect of the individual sessions that the participating stakeholders appreciated.

11.2 First group session

The aim of the first result session was to present the results of the first optimization and discuss any required adjustments for the next session. The results of the first optimization can be found in Appendix 16.3.

11.2.1 Resulting design

The sessions started by showing the stakeholders what their individual preferred solution would be based on their preferences. Afterwards the results of the group optimization were shown. The stakeholders were not surprised with the results, since the individual preference scores per objective were all high for their result. After the individual results, the results based on a group preference optimization were shown. These results can be found in 16.4.5. The optimization was run six times to show the variance in results and therewith the result reliability. The running times for each optimization were between 10 and 15 minutes. The second optimization, “Optimalisatie 2”, is considered the best solution according to the preference scores produced by the IMAP. This result is shown in Figure 18. The six results were all different, but definitely showed similarities. All had a reasonably high number of detached houses (‘EG Vrijstaand’) which made sense since that housing type had the highest profit per m^2 and were therefore suggested to maximize the profit of the project which had preference for multiple stakeholders. All results showed that keeping the scouting building was preferred. This likely resulted from the scouting association being a one-issue stakeholder and having the same stakeholder-weight as the other stakeholders. They noticed, however, that the number of houses in the area did not manage to reflect their preference for the area. They expected approximately 100 houses, but all optimized solutions resulted in approximately 60 houses.

	Optimalisatie 2
EG sociale huur	3
EG middenhuur	15
EG betaalbaar	0
EG rij duur	0
EG 2/1 kap	2
EG vrijstaand	20
MG sociale huur	15
MG middenhuur	3
MG betaalbaar	1
MG duur	1
Extra groen	30%
Extra aandacht fiets	68%
Speelplekken	4
Extra wandelpaden	30%
Duurzame inrichting	29%
Bouwhoogte	4
Behoud RWZI	9%
Behoud groenstrook	72%
Behoud scouting	1

Resultaten	Waarde
Handhaven overige functies	1.888
Uitgeefbaar	8.120
Parkeerplekken	36
Parkeeroppervlak	432
Weg	3.318
Fietspad	1.394
Trottoir	2.399
Water	2.267
Groen	5.850
RWZI (overgebleven opp)	932
Groenstrook (overgebleven opp)	4.320
Ongebruikt oppervlak (groen)	6
Totaal oppervlak	33.450
Saldo geïndexeerd (€)	€ 1.278.241
Woningaantal	60
Perc. sociaal (%)	30,0%
Perc. middenhuur (%)	30,0%
Perc. betaalbaar (%)	1,7%
Perc. duur (%)	38,3%
Gestapeld (%)	33,3%
Grondgebonden (%)	66,7%

Figure 18: Best optimized solution first result session

When looking at the individual scores for the best solution from the optimization, “Optimalisatie 2”, it can be seen that this solution is the best for both the municipality, local residents and the scouting association. It is also the second-best solution for the city planner and financial manager. For the developers, however, this solution was the second to worst solution out of these six. From these results, the participating stakeholders concluded that the number of houses was a more critical objective which resulted in an additional constraint of minimally 100 houses for the next session.

11.2.2 Dialogue on use of methodology

The first system design feature from the applied TAM is described as the use of the methodology. The real-life case study also consisted of a discussion regarding the use of the model. The ‘use’ is described as the setting in which to apply the methodology. The participating stakeholders reflected on the use of the methodology by the means of stakeholder involvement and stakeholder weights.

11.2.2.1 Stakeholder involvement

One of the system design features was determined to be the stakeholder involvement. This feature regards the question of which stakeholders should be directly or indirectly involved and which not at all? The vision of the participating stakeholders on this was that the ‘participatory’ or ‘direct’ involvement of stakeholders should be limited to the municipality internally. Involvement of stakeholders such as local residents and scouting associations could, in their opinion, however, be involved in an indirect manner by gathering their preferences. The main reason was creating ‘false hope’ for these type of stakeholders by showing optimized results to their preferences. Expectation management is an important factor when involving outside stakeholders like local residents and possibly giving them ‘false hope’ would be unacceptable. The participating stakeholders expected the residents would be less interested in a group optimum but more in a personal optimum. Nevertheless, local residents are always indirectly involved through the municipal council. This council is democratically chosen and therefore chosen by the residents of the municipality. The opinion of the participating stakeholders was to not deviate from the existing power structure in order for them to be able to accept the methodology for their design process.

11.2.2.2 Stakeholder weights

The Preferendus tool requires stakeholder weights to be assigned to each stakeholder. This weight represents the power of this stakeholder in the decision-making process. The stakeholder weights for the fictional project were set to all equal weights between stakeholders. The participating stakeholders agreed on that those weights did not reflect the power differences between the involved stakeholders. The power for the first results sessions was also equally divided among all stakeholders, which is not representative of the reality. The stakeholders suggested different weights per stakeholder for the next session that would be more representative of reality. They confirmed that this division of power would be hard to quantify, but they did a suggestion for this project that can be seen in Table 1. One of the noticeable changes is that they decided to set the weight of the developers to 0. The participating stakeholders concluded they do not have any power in this phase of design and that their main objective would be similar to the financial manager. These adjusted weights would be used for the concluding session.

Table 1: Newly suggested stakeholder weights

Stakeholder	Weight
Municipality	0.25
Urban planner	0.25
Financial manager	0.25
Local residents	0,20
Scouting association	0,05
Developers	0,00

11.3 Concluding session

The aim of the concluding session was to show the newly optimized solutions with the determined adjustments from the first group session and to have a further dialogue on the use of the methodology in the field of urban development.

11.3.1 Resulting design

The concluding session started with showing the final results from the adjusted preferences, weights and constraints. The new preferences, weights and constraints can be found in Appendix 16.5.1. These adjustments led to new optimized solutions found in Appendix 16.5.2. The noticeable differences with the results from the first group session were the number of houses and the increased variance in design between optimized solutions. Both differences are due to the newly added constraint of minimally 100 houses. When observing the GA during the optimization, the generating of the starting points resulted in many unfeasible solutions. The addition of the minimal number of houses in combination with the constraint of the maximum project area caused the solution space to reduce significantly. The large variance of the results shows a low result reliability, which is essential for system acceptance.

	Optimalisatie 3
Social housing	1
Middle rent housing	1
Affordable housing	0
Expensive housing	0
2/1 roof	1
Detached houses	8
Social housing (app)	31
Middle rent housing (app)	31
Affordable housing (app)	23
Expensive housing (app)	10
Extra greenery	0%
Extra cycling road	0%
Playing areas	0
Extra sidewalk	0%
Sustainable design	0%
Building height	4
Keep RWZI	0%
Keep scouting	1

Resultaten	Waarde
Handhaven overige functies	1.888
Uitgeefbaar	7.493
Parkeerplekken	77
Parkeeroppervlak	925
Weg	2.589
Fietspad	647
Trottoir	3.235
Water	1.739
Groen	7.950
RWZI (overgebleven opp)	0
Ongebruikt oppervlak (groen)	60
Totaal oppervlak	27.450
Saldo geïndexeerd (€)	€ 479.391
Woningaantal	106
Perc. sociaal (%)	30,2%
Perc. middenhuur (%)	30,2%
Perc. betaalbaar (%)	21,7%
Perc. duur (%)	17,9%
Gestapeld (%)	89,6%
Grondgebonden (%)	10,4%

Figure 19: Best optimized solution concluding session

11.3.2 Further dialogue on use of methodology

For the methodology to be useful, determining the design phase in which the methodology is applied is essential. This aspect of the methodology was discussed with the participating stakeholders.

11.3.2.1 Design phase

The process of (re)developing an urban area goes through multiple design phases before realisation. Decisions need to be made regarding land use, planning, infrastructure and public spaces. This section discusses how and when the Preferendus tool could be incorporated in the design process.

The research by (Nannes & Eijck, 2022) suggested the methodology should start during the phase in which a cooperation agreement is discussed. During this phase stakeholders negotiate boundaries for the project. These boundaries are necessary for the Preferendus tool as well for determining the constraints for the model.

The case study for this research had slightly surpassed the suggested phase since the boundaries for the project were set, nevertheless the number of boundaries was reasonably low and were not definite. When discussing the phase in which to use the methodology the participating stakeholder of this research concluded that an earlier phase would indeed be more useful. The methodology can help determine the boundaries of the project by showing results optimized on their preferences. As an example, the results of the first group session showed the stakeholders that the number of houses they aspired for the area was higher than the optimized amount by the Preferendus model.

12 Findings

With all sessions completed, the final findings from the real-life case study can be evaluated. The goal of this case study was to apply the modified preference-based design methodology to a real-life project and evaluate the response. Firstly, modifications to the functionality were necessary to be able to run the model for the case study, secondly some slight additions to the proposed presentation of the model were implemented. The individual sessions and 2 group sessions were held to decide on the input for the model and present the output. To validate the effectiveness of the modification to the methodology on the acceptance for preference-based design the TAM was introduced. At the end of the concluding session a final TAM questionnaire was conducted with the participating stakeholders. The questionnaire consisted of the same questions regarding their response to the usefulness and the ease of use of the methodology. This allowed for the results to be comparable and see if the methodology gained acceptance after the modifications. The results of the second TAM questionnaire can be found in Figure 20 and Figure 21. Unfortunately, the final response of the financial manager was not evaluated due to unforeseen circumstances. Together with the results from the questionnaire conducted after the first case study, conclusions can be made regarding the response to the usefulness and ease of use of the methodology. The TAM results of the concluding sessions confirmed an increased or stable perceived usefulness and perceived ease of use on many of the responses as shown in Figure 20 and Figure 21. The only decrease was by the project manager regarding question 2 and 6 from the ease of use questionnaire.

Extremely likely	Quite likely	Slightly likely	Neutral	Slightly unlikely	Quite unlikely	Extremely unlikely

Usefulness	Projectmanager municipality	City planner	Financial manager
1. The Preferendus would help me complete tasks faster	Quite likely	Slightly likely	Quite likely
2. The Preferendus would help me get better results from my job	Slightly likely -> Quite likely	Quite likely	Slightly likely
3. The use of the Preferendus would increase my productivity	Quite likely	Quite likely	Slightly likely
4. I am able to present my view with the use of preference curves	Quite likely	Extremely likely	Quite likely
5. The use of the Preferendus would make my job easier	Neutral -> Quite likely	Slightly likely -> Quite likely	Slightly likely
6. I would find the Preferendus useful in my job	Quite likely	Quite likely -> Extremely likely	Slightly likely

Figure 20: Comparison TAM results, usefulness

Ease of use	Project manager municipality	City planner	Financial manager
1. I would know how to express my preferences in the model	Quite likely	Slightly unlikely -> Quite likely	Quite likely
2. Due to the interface of the model I can easily follow where to look	Quite likely -> Slightly likely	Neutral -> Slightly likely	Quite likely
3. I understand how the model input influences the outcome	Quite likely	Slightly likely -> Extremely likely	Quite likely
4. The graphic visualisations (preference curves) help understand the Preferendus	Quite likely -> Extemely likely	Extremely likely	Quite likely
5. The results are easy to interpret	Slightly likely -> Quite likely	Quite likely	Quite likely
6. I would easily be able to learn how to work with the Preferendus	Quite likely -> Slightly likely	Quite likely	Quite likely

Figure 21: Comparison TAM result, ease of use

PART IV: Discussion and conclusion

13 Discussion on findings

This research aimed to explore the challenges of stakeholders with accepting preference-based design models and to develop modifications to a preference-based design methodology that increase the stakeholder acceptance. The used approach to answer the main question of this research was to conduct two urban development case studies with a modified preference-based design methodology and evaluate the response to the usefulness and ease of use of the methodology. The first case study was a fictional case study to introduce the participating stakeholders to preference-based design. The second case study was a real-life ongoing case study to apply the methodology with the real complexities in urban development and discover required modification necessary for this application. To evaluate the effect of the modifications to the methodology on the system acceptance, the TAM was introduced. This model offered a structure to evaluate a technological advancement on the acceptance by users. The essence of this model was that system design features that contribute to either the perceived usefulness or the perceived ease of use lead to a positive attitude towards using a system and therewith increase the acceptance. The system design features of the Preferendus methodology were determined to be categorized as the "Use", "Functionality" and "Presentation". The findings regarding these three categories are discussed in this chapter. Thereafter, it is discussed how these findings lead to system acceptance by the means of the TAM.

13.1 Use

The first category of the applied TAM is the use of the methodology. The use is defined as the setting in which to apply the methodology. This has to do with how, when and by whom the methodology is used. The use is split in two sub-categories for this research: the design phase and the stakeholder involvement.

13.1.1 Design phase

Determining the phase of design in which to apply the Preferendus tool has an effect on the perceived usefulness of the methodology. Using the Preferendus tool in a too early phase would prove to have too many unknowns to even begin modelling the project. Moreover, using the Preferendus tool in a phase where stakeholders already have a set vision for the project and therefore have less flexibility would be too late. When discussing the preferred design phase in which to use the methodology, the participating stakeholder of this research concluded that an early phase would indeed be more useful. Earlier research by (Nannes & Eijck, 2022) confirmed this as well, therefore no modifications to the design phase are recommended.

13.1.2 Stakeholder involvement

Deciding which stakeholders to involve is a difficult decision in traditional urban development design methods. For a preference-based design methodology this is not different. The methodology as proposed by (Wolfert, 2023), however, limitedly delves into the question on who to involve as stakeholder and how this involvement is defined in the decision-making process. During the sessions with the participating stakeholders a dialogue was initiated to discuss the effect of stakeholder involvement on the acceptability of the preference-based design methodology. This section discusses their view and how this relates to the literature on collaboration in design.

Firstly, this research makes a distinction between two forms of stakeholder involvement participatory and indirect involvement. Participatory involvement means the stakeholder participates in the sessions and contributes their preferences for the project, their objective weights and the project constraints. Whereas indirect involvement of a stakeholder means they are not present at sessions. They are, however, asked to contribute their preferences and objective weights by the means of consultation sessions or questionnaires. Furthermore, they do not have a contribution in the stakeholder weight assignment. The vision of the participating stakeholders from the case studies was that stakeholders like local residents and a scouting association should be seen as indirectly involved stakeholders. The participating stakeholders expected the residents would be less interested in a group optimum but more in their personal optimum. The participatory involvement of these stakeholders was believed to lead to behaviour that can be explained as exploitative or parasitical as defined by (van Loon P. P., 1998). This behaviour is critical to avoid as mentioned in section 2.2. For this reason, the participating stakeholders deemed a participatory involvement of stakeholders, like for example local residents, as unacceptable. The participatory involvement of these stakeholder would be a substantial deviation from the current process. They believed that a deviation from the current power structure within a municipality would be a crucial factor for the usefulness of the methodology. The participating stakeholders suggested to involve the municipal council as participatory stakeholder. The municipal council is a democratically chosen group of people that also look after the interests of local stakeholders. This is believed to reduce the chance of exploitative or parasitical behaviour and increase the chance of a constructive collaboration.

Another way to avoid exploitative or parasitical behaviour is to include aspects of process management theory in the preference-based methodology. One of the aspects of effective process management is the presence of a process manager. A process manager brings participating parties (stakeholders) together to reach a common solution and centralizes the process. However, the process manager is often too far removed from the urban development expertise. Therefore, the research by (van Loon, Heurkens, & Bronkhorst, 2008) introduced the role of Urban Systems Engineer (USE). This person could fulfil the role of process manager while also control the technological aspects of preference-based design. The addition of the USE role into the preference-based design methodology would be to adjust the Preferendus model to the specific project, to apply process management techniques described by (Bryson, 2007) to determine the stakeholder involvement and to lead the sessions with these stakeholders in a constructive manner. The introduction of process management techniques and the introduction of an USE to the preference-based design methodology contributes to the complex decision-making on who to involve as a participatory stakeholder, indirect stakeholder or not at all. This would allow for the process to be centralized and come closer to the current power structure and therewith raise the acceptability of the participating stakeholders.

13.2 Functionality

This research introduced several modifications to the functionality of the Preferendus tool. The functionality is defined as the technical factors that are related to the main function of the Preferendus model, which is to optimize the group preference score. The functionality of the model is evaluated by two factors, the reliability of the results and the running time for finding an optimized solution.

13.2.1 Result reliability

The complexities of urban development projects lead to many design variables in a project. With every added design variable, the complexity rises considerably. A high number of design variables therefore results in an incredibly large number of possible solutions. The determined bounds of the design variables do limit the number of possible solutions but the number of possible solutions is too large to evaluate them all. Having a non-integer design variable even leads to an infinite number of possible solutions. Therefore, the GA gradually refines the possible solutions to eventually result in the most-preferred solution that it evaluated. This solution is what is called a local optimum, since there is no absolute certainty this is the best solution possible. Result reliability is therefore defined as the reliability that designs found by the GA with the same settings are similar. Running a GA multiple times and finding the same solution or similar solutions can determine if the results are reliable.

Improving the result reliability can be done by providing the GA with a high number of feasible solutions in the first population. The solutions in the first population are called the starting points. Generating these starting points was done in the fictional case study by randomly generating a value per design variable between the bounds of that variable. This method, however, did not suffice for the increased complexity of the real-life case study. Using this method for the real-life case study led to no feasible starting points and therewith the GA had no feasible solutions to refine. Therefore, modifications were proposed to the generation of starting points that incorporated the project constraints. Using the project constraints to generate more feasible starting points lead to more feasible starting points and more reliable results.

Another method to improve the result reliability is an improved mutation. Mutation is a method of the GA to avoid refining only one solution by randomly altering some design variables in a solution. This increases the probability that multiple options are evaluated. The mutation in the fictional case study was done by altering one or more design variables to a random value between the bounds of that variable. Since solutions can often be improved by just a small change of a design variable, another method was proposed. This method reduced the range to which a design variable could mutate to a percentage of the maximum bound. This modification resulted in more detailed mutations and therewith a higher probability of improving the solution.

Even though the modifications created feasible solutions, whereas the GA without modification did not, the final results of the concluding session were deemed unreliable by the participating stakeholders. Therefore, further research is required to investigate if other modifications could be implemented to increase the result reliability.

13.2.2 Running time

The running time of the model and result reliability are directly related to each other. Increasing the running time by changing the GA settings increases the probability of approximating the global optimum. The most important factors for the running time were determined to be the starting points generation and mutation, the GA settings and the internet connection. The starting points generation and mutation modifications discussed above also contribute to a reduced running time. With the GA settings the running time can be estimated by changing the *max_stall* and *n_pop* settings. These were set to respectively 5 and 500 for the real-life case study. This led to a running time of approximately 15 minutes. This duration was also determined by the participating stakeholders to be the maximum duration to be able to run an optimization during a live session. This is preferable since the effect of a change in for example stakeholder preferences could then be evaluated during a meeting.

13.3 Presentation

The last category contributing to system acceptance is the presentation of the methodology. The methodology was presented using a newly created interface. This interface was used in multiple sessions that each had a different function. The interface and the different sessions are discussed in this section.

13.3.1 Interface

As part of this research, a new interface for the Preferendus model was created. This interface was developed in Microsoft Excel since this is a program that is often used by stakeholders in the urban development sector and therefore easier to interpret. The interface consisted of several sheets that were showed chronologically. The most notable sheets were the manual design, optimization design and comparison sheet. The aim of the manual design sheet was to increase the insight in the relation of the model input to the model output. Stakeholders could manually design the project with the design variables and see the results. The sheet allowed to evaluate and compare 6 different solutions to discover differences between them. The solutions could be evaluated by the Tetra method due to a Xlwings UDF which allowed excel to access Python functions. The results were colour-coded to quickly compare solutions. The interface for the optimization sheet was similar to the manual design sheet, but instead of manual designs the designs were determined by the Preferendus tool. This sheet also allowed to evaluate and compare 6 different solutions to also be able to determine the result reliability. The final sheet allowed for stakeholder to compare the manual design with the optimization designs. The interface was considered beneficial for the understanding of the methodology by the participating stakeholders. The colours enabled them to quickly see the most preferred solution.

13.3.2 Group and individual sessions

Another part of the presentation of the methodology were the various sessions with the stakeholders. How these sessions are built up is essential to increase the ease of use for the stakeholders. The various sessions chronologically were the introductory session, individual sessions, the first group session and finally the concluding session. Each session was planned with a goal. The goal of the introductory session was to introduce preference-based design to the stakeholders with less complex examples. The relatively high evaluation of the first TAM questionnaire proved the effectiveness of the introductory session in regard to the ease of use.

The second part were the individual sessions with each of the participating stakeholders. The goal of the individual sessions was to revisit the essentials of preference-based design and to gather preferences and weights for the real-life case study. The reason for these sessions to be individual instead of with the group was to avoid stakeholders being influenced by the preferences of other stakeholders. The methodology, however, is built on transparency and openness and these preferences and weights were visible to all stakeholders in the following group sessions. This allows for stakeholders to see each other’s goals. The participating stakeholder all agreed on the benefit of the methodology motivating them to establish these goals early in the process. The following group session was to present the first optimized results based on their provided preferences and to determine whether changes to the input of the model were necessary. The goal of the concluding session was to show the effect of these changes on the results and to discuss the use of the methodology in the urban development sector.

13.4 TAM

To validate the effectiveness of the modification to the methodology on the acceptance for preference-based design the TAM was introduced and applied in section 4.3. The system design features categorized by the “Use”, “Functionality” and “Presentation” affect either the perceived usefulness or the perceived ease of use. The responses of the participating stakeholders to the usefulness and ease of use were evaluated using a TAM questionnaire at the end of the introductory sessions and at the end of the concluding session. The results of the first questionnaire showed a promising response with all participating stakeholder determining to be either slightly or quite likely to agree to most statements. These results were used as base response to see the difference at the end of the case studies. The final TAM questionnaire mostly showed an increase in perceived usefulness and perceived ease of use, nevertheless, the response of the project manager regarding the questions knowing where to look and being easy to learn how to work with the model had a decreased result. The explanation for the decrease in likelihood to knowing where to look in the interface of the model and for being able to easily learn to work with the Preferendus model both resulted from the difference in complexity between the case studies. The increased number of design variables, objectives and involved stakeholders made the interface “busy.” Further research to developing an interface for the Preferendus is therefore advised to limit the amount of information on the interface. The other decrease in response also resulted from the increased complexity, since this also led to the project manager feeling less likely to be able to learn how to work with the Preferendus.

The overall conclusion from the results of the TAM questionnaire is considered an increased perceived usefulness and perceived ease of use. According to the TAM this has a causal relationship to the attitude towards using the methodology, which results in an increased acceptance for preference-based design.

14 Conclusion

To conclude this research the main question and development statement are revisited and conclusion are drawn from the findings from this research. The main question of this research is: "*How can the acceptability of stakeholders on the results of preference-based design be improved in the context of urban development?*" To answer this main question, two other questions were introduced in section 3.2. Furthermore, the generalizability, limitations and recommendations are discussed.

The first sub-question was: "*How do the system design features affect the acceptability?"* These system design features were categorized as the 'Use', 'Functionality' and the 'Presentation' of the preference-based design methodology as proposed by (Binnekamp, 2010). The 'Use' category consisted of aspects that determine how, when and by whom the methodology is used defined by the design phase and the involvement of stakeholders. The 'Functionality' category regarded the question how well the technical aspects of the methodology function. This was evaluated by result reliability and the running time. The final category, 'Presentation', related to how the methodology was presented to the users. This included the interface of the model and the group and individual sessions. These three categories were determined to be the most influential system design features that affect the perceived usefulness and perceived ease of use. The TAM introduces these two responses to have a causal relationship with the acceptance for a new technology, which in this research is preference-based design.

The second sub-question was: "*What modifications would improve the preference-based design methodology?"* The research proposed several modifications that would have an effect on the perceived usefulness and the ease of use.

Modifications regarding the use of the methodology were discussed with a group of participating stakeholders in the field of urban development and they concluded that a substantial deviation from the current power structure in the urban development sector when deciding which stakeholders to involve would have a crucial effect on their perceived usefulness of the methodology. They feared participatory involvement of all stakeholders would lead to exploitative or parasitical behaviour. This research therefore proposes to introduce a distinction between participatory and indirect stakeholder involvement in the preference-based design methodology. The decision on which stakeholders to involve participatory and which to involve indirect can be done using theory from process management theory. This theory relies on the process to be centralized, therefore the Urban Systems Engineer (USE) role can be introduced in preference-based design to ensure this.

Modifications related to the functionality of the GA used in the Preferendus model were done in the form of starting points generation and mutation. These modifications substantially improved the Preferendus' ability to generate feasible solutions which is essential to finding an optimized solution. However, the reliability of the optimized solutions was deemed insufficient and therefore more modifications are needed to be able to effectively use the Preferendus tool for the complexity of similar projects.

The last modifications were regarding the presentation of the methodology. The modifications involved a newly developed interface in Excel to familiarize the stakeholders with the methodology. The participating stakeholders responded positive to the interface, but proposed some changes to the amount of information shown on the interface by reducing it to the essential. Another modification to the presentation was the addition of individual sessions besides the group sessions. This avoided stakeholders from influencing each other when providing their preferences and weights for the Preferendus model. All provided preferences were, however, shown during the session after the individual sessions to have transparency which is one of the key elements of the preference-based methodology. The transparency was an aspect which was perceived as positive by the stakeholder group.

14.1 Generalizability

This research was set in the context of urban development, however, preference-based design can be used in wider range of applications in the construction industry. This section will elaborate on the generalizability of the findings of this research for these applications. This research included two case studies with a similar area size. The modifications proposed in this research are applicable for any urban development project of a resembling size with the comparable objectives. Not all modifications, however, are applicable when projects of a different size or with different objectives are designed. Modifications regarding the functionality are primarily based on the constraints of this case study. Other projects might have completely different constraints, which would require other modifications for the GA to optimally function. Nevertheless, the suggested modifications regarding the use and presentation are generally very applicable for urban development projects of various sizes or projects with other stakeholders.

The generalizability of the findings of this research in other engineering fields should also be discussed. Close to all engineering projects deal with decision-making in some way. Part of preference-based design is the decision-making process, which makes it applicable in many different engineering sectors. Acceptability is also essential to be able to apply the method in these sectors. Key to this acceptability are the use, functionality and presentation for any application.

14.2 Limitations

While the findings of this study offer valuable insights into the acceptance of stakeholders towards preference-based design it is essential to acknowledge and address the limitations inherent in the research process. It is important to note that while limitations may introduce uncertainties or constraints, they do not invalidate the significance or contributions of the research. Rather, they serve as points of reflection and opportunities for refinement, ultimately enhancing the robustness and applicability of the findings.

The first limitation is the duration of the research. This research was conducted in a period of 6 months, while urban development project generally has a duration of years. This would have allowed to conduct more sessions with the participating stakeholders to refine the provided stakeholder preferences and weights even more and reflect a more realistic representation of the project.

The second limitation was the limited variation in stakeholders. For this research three involved stakeholders were invited to participate in this research. All three were directly or indirectly working for the municipality. This caused the views on the usefulness and ease of use one sided. The stakeholders were experienced and have worked on many projects with other stakeholders and could therefore confidently say they had the ability to predict their reactions to certain aspects of the methodology. Nevertheless, input from stakeholders outside the municipality would have been preferable.

Another limitation of this research was the running time of the Preferendus tool. As discussed in section 10.1.3, the main cause of this running time was the time to run the Tetra solver many times over during a optimization. This technical limitation caused a slower process developing the modifications and limited possibility to run optimizations live with stakeholders.

14.3 Recommendations

In this chapter, we present four key recommendations based on the findings of our study. These recommendations aim to provide practical guidance for addressing the issues identified in previous chapters.

14.3.1 Stakeholder involvement

This research makes a distinction between indirect and participating stakeholders for their involvement. One of the crucial recommendations of the participating stakeholders was to avoid the participatory involvement of non-professional stakeholders to not deviate from the current power structure in urban development projects. This research also refrained from the participatory involvement of non-professional stakeholders, however, it is recommended to further investigate the benefits or drawbacks of participatory involvement of non-professional stakeholders.

14.3.2 Stakeholder weights

One of the characteristics of a functioning model is to reflect reality as close as possible. Not all stakeholders in an urban development project have equal influence on the outcome. This influence is represented by the stakeholder weights in the preference-based methodology. The fictional case study and the first iteration of the real-life case study were both optimized using equal weights among stakeholders. The effect of this became clear in the real-life case study and the participating stakeholders decided to change the weights to more realistic values. Despite the new values being more realistic, they were chosen rather arbitrarily. It is suggested to further investigate how to decide on stakeholder weights that would reflect reality as close as possible.

14.3.3 Preferendus algorithm

One of the integral parts of the Preferendus tool was the Tetra solver. This solver determines the preference scores for each solution. One disadvantage of the solver is the required external server. Constantly connecting to this server over the internet caused the running time for optimization to be longer than necessary. Creating a solver that would not need an external server would significantly reduce running time and increase the possibilities of the Preferendus tool. Additionally, it is also recommended to research alternative algorithms to the genetic algorithm. Algorithms like simulated annealing (SA) could prove to show a better result reliability. A comparative study would be useful.

14.3.4 Sensibility analysis

The GA in this research has many settings that determine how the GA generates solutions. These settings have an influence on the final result. Especially, the population size and maximum stall proved to be influential. In the development of the model for this research many settings have been tested which resulted in the eventual used settings. Nevertheless, it is recommended to perform a sensibility analysis on these settings to find the values that generate the best results.

14.3.5 Method of starting point generation

This research proposed a new method for generating starting points for the GA. This method proved successful in producing more feasible solutions in the initial population. The original method resulted in a success percentage of 0.0% for creating feasible solutions in the context of the second case study. The proposed new method raised this success percentage to approximately 5%-10%, which resulted in more reliable solutions. Nevertheless, the final solutions when running the algorithm multiple times showed large differences in the optimized solutions. This shows a low result reliability. To solve this, it is recommended to raise the success percentage even further. A possible method to accomplish this could be to integrate the maximum area constraint into the function that generates the starting points. This could prevent any generated solution from exceeding the maximum area constraint while also taking the other constraints into account.

14.3.6 Excel to software tool

For the presentation of preference-based design, this research proposed an Excel interface. This interface helped the participating stakeholders to comprehend the black box of the Preferendus tool. This interface proved useful, nevertheless, Python software and knowledge were required to use the tool. When the methodology is ready for commercial use it is recommended to create a software tool that is easy to use for all users. It is also advised to make the tool as broadly applicable as possible, to be able to apply the tool for other fields of construction management.

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16 Appendix

16.1 TAM questionnaire

Questions

Usefulness
1. The Preferendus would help me complete tasks faster
2. The Preferendus would help me get better results from my job
3. The use of the Preferendus would increase my productivity
4. I am able to present my view with the use of preference curves
5. The use of the Preferendus would make my job easier
6. I would find the Preferendus useful in my job

Ease of use
1. I would know how to express my preferences in the model
2. Due to the interface of the model I can easily follow where to look
3. I understand how the model input influences the outcome
4. The graphic visualisations (preference curves) help understand the Preferendus
5. The results are easy to interpret
6. I would easily be able to learn how to work with the Preferendus

Possible answers

Extremely likely	Quite likely	Slightly likely	Neutral	Slightly unlikely	Quite unlikely	Extremely unlikely

16.2 Results fictional case study

16.2.1 Preferences

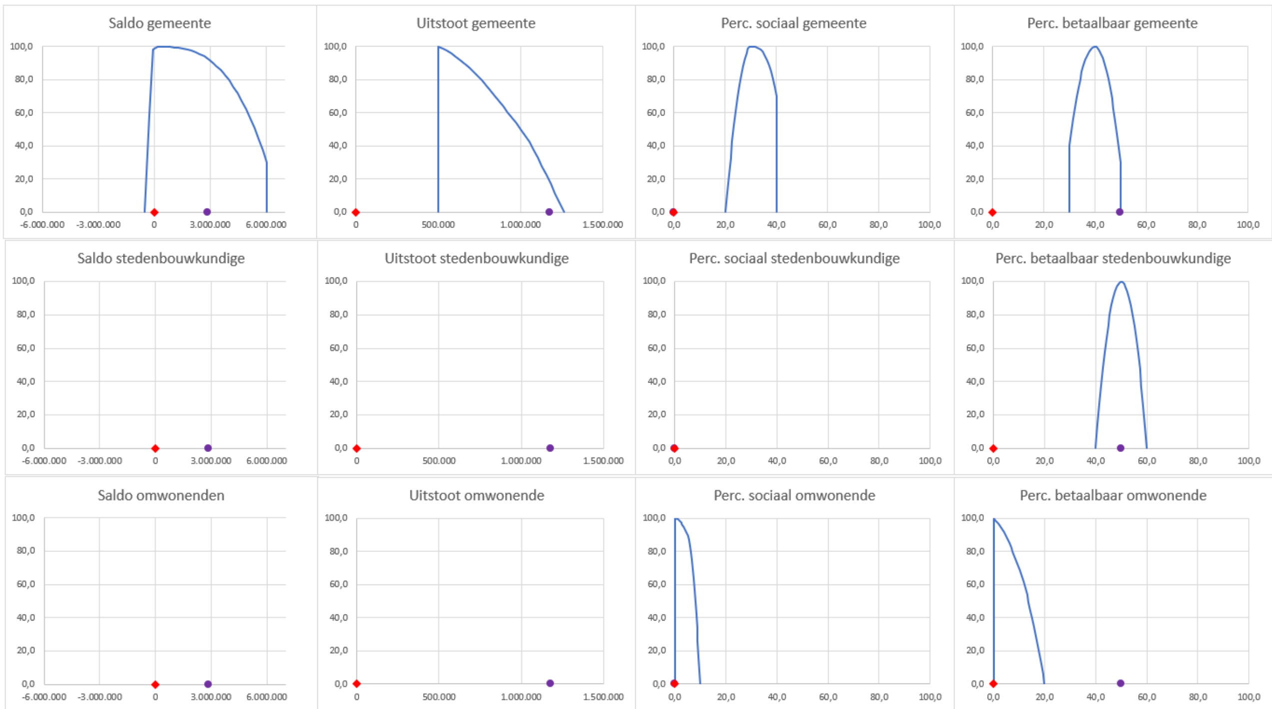
Wegingen			
Belanghebbende	**Rol weging**	**Doel**	**Weging**
Gemeente	0,33	Saldo	0,100
		Uitstoot	0,067
		Percentage sociaal	0,133
		Percentage betaalbaar	0,033
Stedenbouwkundige	0,33	Saldo	0,000
		Uitstoot	0,000
		Percentage sociaal	0,000
		Percentage betaalbaar	0,333
Omwonenden	0,33	Saldo	0,000
		Uitstoot	0,000
		Percentage sociaal	0,267
		Percentage betaalbaar	0,067

Preferenties Gemeente	**Min waarde**	**Vormingswaarde**	**Max waarde**	**Pref. min waarde**	**Pref. Vormingswaarde**	**Pref. max waarde**	**Weging**
Saldo	-500.000	0	6.052.800	0	100	30	0,30
Uitstoot	500.000	1.000.000	1.261.800	100	50	0	0,20
Percentage sociaal	20	30	40	0	100	70	0,40
Percentage betaalbaar	30	40	50	40	100	30	0,10
						Som:	1,00

Preferenties Stedenbouwkundige	**Min waarde**	**Vormingswaarde**	**Max waarde**	**Pref. min waarde**	**Pref. Vormingswaarde**	**Pref. max waarde**	**Weging**
Saldo	0	0	0	0	0	0	0,00
Uitstoot	0	0	0	0	0	0	0,00
Percentage sociaal	0	0	0	0	0	0	0,00
Percentage betaalbaar	40	50	60	0	100	0	1,00
						Som:	1,00

Preferenties Omwonenden	**Min waarde**	**Vormingswaarde**	**Max waarde**	**Pref. min waarde**	**Pref. Vormingswaarde**	**Pref. max waarde**	**Weging**
Saldo	0	0	0	0	0	0	0,00
Uitstoot	0	0	0	0	0	0	0,00
Percentage sociaal	0	5	10	100	90	0	0,80
Percentage betaalbaar	0	10	20	100	70	0	0,20
						Som:	1,00

Beste combinatie	**Comb. 3**
Beste optimalisatie	**Resultaten 1**
Beste combinatie	●
Beste optimalisatie	◆



16.2.2 Manual design sheet

Handmatige resultaten							
Settings	**Comb. 1**	**Comb. 2**	**Comb. 3**	**Comb. 4**	**Comb. 5**	**Comb. 6**	**Maximaal**
Dure woningen	60	40	40	72	30		72
Betaalbare woningen		20	40				97
Sociale woningen	20	28					122
Garage lagen		2					5

Resultaten	**Waarde**	**Waarde**	**Waarde**	**Waarde**	**Waarde**	**Waarde**
Woonoppervlak (m2)	21.400	21.160	20.800	21.600	9.000	0
Groen (m2)	2.000	1.780	1.800	2.160	900	0
Water (m2)	660	584	600	720	300	0
Parkeerplekken totaal	140	138	140	144	60	0
Straatparkeerplekken	140	38	140	144	60	0
Parkeeroppervlak (m2)	1.680	1.956	1.680	1.728	720	0
Infra oppervlak (m2)	4.000	4.400	4.000	3.600	1.500	0
Gebruikt oppervlak (m2)	29.740	29.880	28.880	29.808	12.420	0
Ongebruikt oppervlak (m2)	260	120	1.120	192	17.580	30.000
Saldo (€)	€ 4.148.000	€ 1.302.600	€ 2.858.000	€ 6.052.800	€ -978.000	€ -
Uitstoot (kg N_2)	1.178.000	1.096.600	1.178.000	1.261.800	525.750	0
Perc. duur (%)	75,0%	45,5%	50,0%	100,0%	100,0%	0,0%
Perc. betaalbaar (%)	0,0%	22,7%	50,0%	0,0%	0,0%	0,0%
Perc. sociaal (%)	25,0%	31,8%	0,0%	0,0%	0,0%	0,0%

Groeps preferenties							
Minmax score (uit)							
Preferentie score	0,0	3,8	100,0	14,5	24,5		Voor correcte preferentiescores druk F9!

Preferentie per belanghebbende							
Gemeente	w = 0,33	Comb. 1	Comb. 2	Comb. 3	Comb. 4	Comb. 5	Comb. 6
Minmax score (uit)							
Preferentie score		67,9	100,0	50,4	0,0	20,5	
Saldo	0,30	77,5	99,3	92,6	30,0	0,0	100,0
Uitstoot	0,20	18,2	34,4	18,2	0,0	98,9	0,0
Sociaal	0,40	70,6	99,8	0,0	0,0	0,0	0,0
Betaalbaar	0,10	0,0	0,0	30,0	0,0	0,0	0,0
Stedenbouwkundige	w = 0,33						
Minmax score (uit)							
Preferentie score		0,0	0,0	100,0	0,0	0,0	
Saldo	0,00	0,0	0,0	0,0	0,0	0,0	0,0
Uitstoot	0,00	0,0	0,0	0,0	0,0	0,0	0,0
Sociaal	0,00	0,0	0,0	0,0	0,0	0,0	0,0
Betaalbaar	1,00	0,0	0,0	100,0	0,0	0,0	0,0
Omwonenden	w = 0,33						
Minmax score (uit)							
Preferentie score		20,0	0,0	80,0	100,0	100,0	
Saldo	0,00	0,0	0,0	0,0	0,0	0,0	0,0
Uitstoot	0,00	0,0	0,0	0,0	0,0	0,0	0,0
Sociaal	0,80	0,0	0,0	100,0	100,0	100,0	100,0
Betaalbaar	0,20	100,0	0,0	0,0	100,0	100,0	100,0

16.2.3 Comparison results fictional case

Preferentie vergelijking						
Ontwerp	**Comb. 1**	**Comb. 2**	**Comb. 3**	**Comb. 4**	**Comb. 5**	**Resultaten 1**
Dure woningen	60	40	40	72	30	33
Betaalbare woningen	0	20	40	0	0	33
Sociale woningen	20	28	0	0	0	0
Garage lagen	0	2	0	0	0	2
Saldo (€)	€ 4.148.000	€ 1.302.600	€ 2.858.000	€ 6.052.800	€ -978.000	€ 687.850
Uitstoot (kg N2)	1.178.000	1.096.600	1.178.000	1.261.800	525.750	951.850
Perc. duur (%)	75,0%	45,5%	50,0%	100,0%	100,0%	50,0%
Perc. betaalbaar (%)	0,0%	22,7%	50,0%	0,0%	0,0%	50,0%
Perc. sociaal (%)	25,0%	31,8%	0,0%	0,0%	0,0%	0,0%
Groeps preferenties						
Ontwerp	**Comb. 1**	**Comb. 2**	**Comb. 3**	**Comb. 4**	**Comb. 5**	**Resultaten 1**
Minmax score (uit)						
Preferentie score	**0,0**	**4,6**	**91,3**	**15,6**	**26,8**	**100,0**
Preferentie per belanghebbende						
Gemeente w = 0,33	**Comb. 1**	**Comb. 2**	**Comb. 3**	**Comb. 4**	**Comb. 5**	**Resultaten 1**
Minmax score (uit)						
Preferentie score	**67,9**	**100,0**	**47,2**	**0,0**	**21,7**	**64,2**
Saldo 0,30	77,5	99,3	92,6	30,0	0,0	99,9
Uitstoot 0,20	18,2	34,4	18,2	0,0	98,9	56,5
Sociaal 0,40	70,6	99,8	0,0	0,0	0,0	0,0
Betaalbaar 0,10	0,0	0,0	30,0	0,0	0,0	30,0
Stedenbouwkundige w = 0,33						
Minmax score (uit)						
Preferentie score	**0,0**	**0,0**	**100,0**	**0,0**	**0,0**	**100,0**
Saldo 0,00	0,0	0,0	0,0	0,0	0,0	0,0
Uitstoot 0,00	0,0	0,0	0,0	0,0	0,0	0,0
Sociaal 0,00	0,0	0,0	0,0	0,0	0,0	0,0
Betaalbaar 1,00	0,0	0,0	100,0	0,0	0,0	100,0
Omwonenden w = 0,33						
Minmax score (uit)						
Preferentie score	**19,1**	**0,0**	**80,9**	**100,0**	**100,0**	**80,9**
Saldo 0,00	0,0	0,0	0,0	0,0	0,0	0,0
Uitstoot 0,00	0,0	0,0	0,0	0,0	0,0	0,0
Sociaal 0,80	0,0	0,0	100,0	100,0	100,0	100,0
Betaalbaar 0,20	100,0	0,0	0,0	100,0	100,0	0,0
Gegevens ontwerp						
Ontwerp	**Comb. 1**	**Comb. 2**	**Comb. 3**	**Comb. 4**	**Comb. 5**	**Resultaten 1**
Woonoppervlak (m2)	21.400	21.160	20.800	21.600	9.000	17.160
Groen (m2)	2.000	1.780	1.800	2.160	900	1.485
Water (m2)	660	584	600	720	300	495
Parkeerplekken totaal	140	138	140	144	60	116
Straatparkeerplekken	140	38	140	144	60	16
Parkeeroppervlak (m2)	1.680	1.956	1.680	1.728	720	1.686
Infra oppervlak (m2)	4.000	4.400	4.000	3.600	1.500	3.300
Gebruikt oppervlak (m2)	29.740	29.880	28.880	29.808	12.420	24.126
Ongebruikt oppervlak (m2)	260	120	1.120	192	17.580	5.874

16.3 Genetic algorithm in the Preferendus model

Genetic algorithms (GAs) are a class of optimization algorithms inspired by the principles of natural selection and genetics. Developed by John Holland in the 1960s, genetic algorithms have found applications in various fields, including computer science, engineering, economics, biology, and more. The core concept behind genetic algorithms is to mimic the process of natural evolution to find solutions to complex optimization and search problems. This is done by steps following 6 basic principles: initialization, fitness evaluation, selection, reproduction, replacement and termination. These 6 principles will be elaborated on in this section.

"GAs search by simulating evolution, starting from an initial set of solutions or hypotheses, and generating successive "generations" of solutions." (Mathew, 2012). This initial set of solutions or hypotheses is called the starting point of the GA in the Preferendus model. The size of this initial set can be determined to best fit the requirements of the application. The generating of this starting point is the first basic principle of genetic algorithms; initialization. The second step of the algorithm is the fitness evaluation. All solutions in the starting point are evaluated by a fitness function. This function evaluates all solutions and scores them. The scoring in the GA used by the Preferendus is done by the Tetra tool. Thirdly, the "selection" principle of the GA consists of selecting the "fittest" or best solutions from the starting points and mark them as "parents" for new solutions. Next, the selected parents are combined to create "offspring" in a process called "crossover". This offspring, therewith, is a set of solutions based on the best solutions from the previous set. To create variance, the concept of mutation is also performed in this step. Mutation is introducing random changes to solutions. This process is called the reproduction principle. The fifth principle, replacement, is replacing the starting points with the newly generated set of solutions. This set is a combined set of the parent solutions and the, possibly mutated, offspring of the last iteration. After this step, step 2-5 are repeated until termination. The final principle of termination is a criterion on when the GA should stop repeating the previous steps. The GA used in the Preferendus tool incorporates this with by a maximum stall variable that determines after how many unsuccessful iterations termination should follow. An unsuccessful iteration is when no new best solution is found. The full process of a GA is shown in Figure 22. GAs are used regularly due to its versatility in applications and its robustness in that it can handle problems of a complex nature.

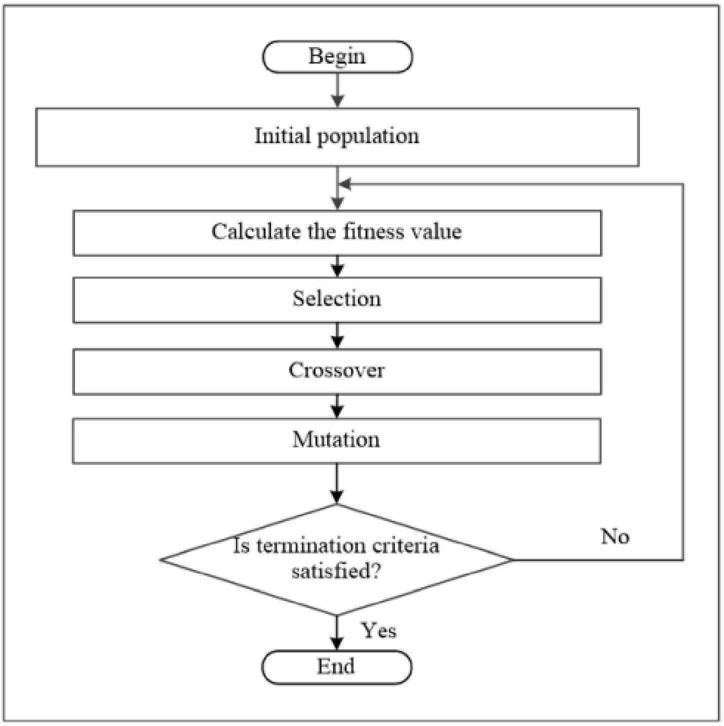


Figure 22: GA process (Albadr, Tiun, Ayob, & Al-Dhief, 2020)

16.4 Results first result session

16.4.1 Characteristics area

Woningeigenschappen											
Woningtypes	**Grondoppervlak (m^2)***	**Residuele grondwaarde (€)**	**Parkeren (m2)**	**Weg (m2)**	**Fietspad (m2)**	**Trottoir (m2)**	**Groen (m2)**	**Water (m2)**	**Ttl. benodigd opp (m^2)***	**Max woningen (-)**	**Max woningen (incl harde eisen)**
Social housing	100	€ 20.000	7	53	13	25	75	20	293	87	67
Middle rent housing	160	€ 35.000	9,6	56	14	35	75	27	377	67	58
Affordable housing	160	€ 68.801	9,6	56	14	35	75	27	377	67	40
Expensive housing	300	€ 138.020	12	56	14	35	75	42	534	47	32
2/1 roof	400	€ 211.419	18	60	15	35	75	53	656	38	28
Detached houses	600	€ 317.152	4	96	24	35	75	76	909	28	22
Social housing (app)	30	€ 14.250	7	12	3	20	75	7	154	165	106
Middle rent housing (app)	50	€ 30.000	10	20	5	35	75	12	207	123	94
Affordable housing (app)	50	€ 60.364	10	20	5	35	75	12	207	123	54
Expensive housing (app)	90	€ 109.409	12	20	5	35	75	16	253	100	49

*Op basis van een maximale bouwhoogte van 3 verdiepingen

Oppervlakte gegevens		
Beschrijving	**Waarde**	**Eenheid**
Gebied	27.450	m^2
RWZI	10.350	m^2
Handhaven overige functies	1888	m^2
Scoutinggebouw	925	m^2
Speelplaats	400	m^2

16.4.2 Preferences and weights

Wegingen belanghebbende		
Belanghebbende	**Weging**	**Eigen invul**
Gemeente	0,17	0,17
Stedenbouwkundige	0,17	0,17
Omwonenden	0,17	0,17
Planeconoom	0,17	0,17
Scouting	0,17	0,17
Portaal	0,17	0,17
	0,00	0,00
	0,00	0,00
	0,00	0,00
	0,00	0,00
	0,00	0,00
Som:	1,00	1,00

Preferenties Gemeente	Min waarde	Vormingswaarde	Max waarde	Pref. min waarde	Pref. Vormingswaa	Pref. max waarde	Weging	Totale weging
Saldo	I -	I 1.000.000	I 4.054.690	10	90	100	0,15	0,026
Sociale huur	30%	35%	40%	100	50	0	0,15	0,026
Middenhuur	30%	35%	40%	100	50	0	0,08	0,013
Betaalbare koop	20%	25%	30%	100	50	0	0,08	0,013
Woningaantal	100	110	150	50	100	50	0,08	0,013
Extra groen	0%	20%	50%	0	100	0	0,08	0,013
Speelplekken	2	3	5	80	100	100	0,08	0,013
Behoud RWZI	0%	10%	30%	0	100	0	0,15	0,026
Behoud groenstrook	0%	50%	100%	0	100	0	0,08	0,013
Behoud scouting	0		1	100		0	0,08	0,013
						Som:	1,00	

Preferenties Stedenbouwkun	Min waarde	Vormingswaarde	Max waarde	Pref. min waarde	Pref. Vormingswaa	Pref. max waarde	Weging	Totale weging
Saldo	I -	I 200.000	I 4.054.690	0	80	100	0,08	0,013
Sociale huur	30%	35%	100%	100	0	0	0,04	0,006
Middenhuur	30%	35%	100%	100	0	0	0,04	0,006
Betaalbare koop	0%	10%	100%	0	100	0	0,04	0,006
Dure koop	0%	30%	100%	0	100	0	0,04	0,006
Woningaantal	100	110	130	50	100	50	0,15	0,026
Gestapeld	50%	65%	70%	50	100	80	0,12	0,019
Extra groen	0%	50%	100%	90	100	100	0,08	0,013
Extra aandacht fiets	30%	50%	100%	60	90	100	0,08	0,013
Speelplekken	2	3	4	50	100	50	0,04	0,006
Extra wandelpaden	30%	50%	100%	90	100	100	0,04	0,006
Duurzame inrichting	0%	30%	100%	0	100	20	0,08	0,013
Bouwhoogte	3		4	100		60	0,04	0,006
Behoud RWZI	0%	30%	100%	100	10	0	0,08	0,013
Behoud groenstrook	50%	70%	100%	0	80	100	0,04	0,006
Behoud scouting	0		1	0		100	0,04	0,006
						Som:	1,00	

Preferenties Omwonenden	Min waarde	Vormingswaarde	Max waarde	Pref. min waarde	Pref. Vormingswaa	Pref. max waarde	Weging	Totale weging
Sociale huur	30%	31%	32%	100	50	40	0,25	0,042
Extra groen	10%	20%	30%	50	60	70	0,15	0,025
Speelplekken	3	4	5	30	80	100	0,10	0,017
Extra wandelpaden	10%	20%	30%	50	60	70	0,10	0,017
Bouwhoogte	3		4	100		0	0,10	0,017
Behoud groenstrook	0%	80%	100%	0	80	100	0,20	0,033
Behoud scouting	0		1	40		100	0,10	0,017
						Som:	1,00	

Preferenties Planeconoom	Min waarde	Vormingswaarde	Max waarde	Pref. min waarde	Pref. Vormingswaa	Pref. max waarde	Weging	Totale weging
Saldo	I -	I 1.000.000	I 4.054.690	10	90	100	0,30	0,050
Sociale huur	30%	31%	32%	100	50	10	0,20	0,033
Middenhuur	30%	32%	35%	100	50	10	0,20	0,033
Dure koop	30%	35%	40%	10	40	100	0,20	0,033
Woningaantal	125	130	135	50	100	80	0,10	0,017
						Som:	1,00	

Preferenties Scouting	Min waarde	Vormingswaarde	Max waarde	Pref. min waarde	Pref. Vormingswaa	Pref. max waarde	Weging	Totale weging
Behoud scouting	0		1	0		100	1,00	0,167
						Som:	1,00	

Preferenties Portaal	Min waarde	Vormingswaarde	Max waarde	Pref. min waarde	Pref. Vormingswaa	Pref. max waarde	Weging	Totale weging
Sociale huur	30%	40%	50%	60	100	60	0,30	0,050
Middenhuur	10%	15%	20%	100	50	0	0,10	0,017
Woningaantal	100	130	150	0	60	100	0,50	0,083
Gestapeld	30%	40%	50%	60	100	60	0,10	0,017
						Som:	1,00	

- The black and white striped cells are not fillable since those variables are boolean and can therefore only be 2 values.

16.4.3 Manual results

Handmatige resultaten						
Settings	**Handmatig 1**	**Handmatig 2**	**Handmatig 3**	**Handmatig 4**	**Handmatig 5**	**Handmatig 6**
EG sociale huur	0	0	2	0	5	
EG middenhuur	0	0	2	0	4	
EG betaalbaar	0	0	0	0	0	
EG rij duur	0	0	0	0	0	
EG 2/1 kap	0	0	0	0	0	
EG vrijstaand	24	0	19	0	23	
MG sociale huur	25	38	16	3	22	
MG middenhuur	25	38	16	7	23	
MG betaalbaar	0	25	3	0	0	
MG duur	9	24	2	0	12	
Extra groen	0%	20%	60%	30%	0%	
Extra aandacht fiets	0%	0%	83%	25%	0%	
Speelplekken	0	4	3	5	0	
Extra wandelpaden	0%	0%	50%	30%	0%	
Duurzame inrichting	0%	0%	39%	93%	0%	
Bouwhoogte	4	4	4	3	4	
Behoud RWZI	25%	10%	0%	7%	9%	
Behoud groenstrook	2%	50%	66%	100%	0%	
Behoud scouting	0	0	1	1	0	
Resultaten	**Waarde**	**Waarde**	**Waarde**	**Waarde**	**Waarde**	**Waarde**
Handhaven overige functies	1.888	1.888	1.888	1.888	1.888	1.888
Uitgeefbaar	12.908	5.017	9.020	440	13.373	0
Parkeerplekken	51	97	35	7	57	0
Parkeeroppervlak	614	1.166	424	89	680	0
Weg	3.284	2.196	2.654	176	3.660	0
Fietspad	821	549	1.214	55	915	0
Trottoir	2.530	3.805	2.760	397	2.735	0
Water	2.446	1.417	1.911	105	2.582	0
Groen	6.225	11.250	7.200	975	6.675	0
RWZI (overgebleven opp)	2.588	1.035	0	725	932	0
Groenstrook (overgebleven opp)	120	3.000	3.960	6.000	0	0
Ongebruikt oppervlak (groen)	27	527	295	19.676	11	31.562
Totaal oppervlak	33.450	33.450	33.450	33.450	33.450	33.450
Saldo geïndexeerd (€)	€ 4.054.690	€ -771.160	€ 506.880	€ -6.333.595	€ 3.558.809	€ -
Woningaantal	83	125	60	10	89	0
Perc. sociaal (%)	30,1%	30,4%	30,0%	30,0%	30,3%	0,0%
Perc. middenhuur (%)	30,1%	30,4%	30,0%	70,0%	30,3%	0,0%
Perc. betaalbaar (%)	0,0%	20,0%	5,0%	0,0%	0,0%	0,0%
Perc. duur (%)	39,8%	19,2%	35,0%	0,0%	39,3%	0,0%
Gestapeld (%)	71,1%	100,0%	61,7%	100,0%	64,0%	0,0%
Grondgebonden (%)	28,9%	0,0%	38,3%	0,0%	36,0%	0,0%
Binnen harde grenzen	Feasible	Feasible	Feasible	Feasible	Feasible	
Groepspreferentie						
Preferentiescore	0,0	48,9	100,0	70,7	0,1	

- “Handmatig 1” is an optimization based on financial result.

Stakeholder	Individual optimized run
Municipality	‘Handmatig 2’
City planner	‘Handmatig 3’
Local residents	‘Handmatig 4’
Financial manager	‘Handmatig 5’
Scouting association	‘Handmatig 3’/ ‘Handmatig 4’
Developers	None

16.4.4 Individual manual results

Preferentie per belanghebbende

Gemeente	w = 0,17	Handmatig 1	Handmatig 2	Handmatig 3	Handmatig 4	Handmatig 5	Handmatig 6
Preferentiescore		27,8	100,0	8,6	0,0	19,4	
Saldo	0,15	100,0	0,0	62,1	0,0	99,8	10,0
Sociale huur	0,15	98,8	96,0	100,0	100,0	96,6	0,0
Middenhuur	0,08	98,8	96,0	100,0	0,0	96,6	0,0
Betaalbare koop	0,08	0,0	100,0	0,0	0,0	0,0	0,0
Woningaantal	0,08	0,0	97,4	0,0	0,0	0,0	0,0
Extra groen	0,08	0,0	100,0	0,0	92,6	0,0	0,0
Speelplekken	0,08	0,0	100,0	100,0	100,0	0,0	0,0
Behoud RWZI	0,15	57,8	100,0	0,0	87,9	98,6	0,0
Behoud groenstrook	0,08	7,8	100,0	89,8	0,0	0,0	0,0
Behoud scouting	0,08	100,0	100,0	0,0	0,0	100,0	100,0

Stedenbouwkundige	w = 0,17	Handmatig 1	Handmatig 2	Handmatig 3	Handmatig 4	Handmatig 5	Handmatig 6
Preferentiescore		0,0	35,2	100,0	27,5	22,3	
Saldo	0,08	100,0	0,0	84,1	0,0	99,9	0,0
Sociale huur	0,04	97,4	90,9	100,0	100,0	92,4	0,0
Middenhuur	0,04	97,4	90,9	100,0	0,0	92,4	0,0
Betaalbare koop	0,04	0,0	99,9	63,9	0,0	0,0	0,0
Dure koop	0,04	99,7	82,3	100,0	0,0	99,8	0,0
Woningaantal	0,15	0,0	78,9	0,0	0,0	0,0	0,0
Gestapeld	0,12	0,0	0,0	98,8	0,0	99,9	0,0
Extra groen	0,08	90,0	95,7	100,0	97,9	90,0	90,0
Extra aandacht fiets	0,08	0,0	0,0	98,8	0,0	0,0	0,0
Speelplekken	0,04	0,0	50,0	100,0	0,0	0,0	0,0
Extra wandelpaden	0,04	0,0	0,0	100,0	90,0	0,0	0,0
Duurzame inrichting	0,08	0,0	0,0	99,8	41,7	0,0	0,0
Bouwhoogte	0,04	60,0	60,0	60,0	100,0	60,0	0,0
Behoud RWZI	0,08	15,1	60,2	100,0	72,1	64,1	100,0
Behoud groenstrook	0,04	0,0	0,0	72,0	100,0	0,0	0,0
Behoud scouting	0,04	0,0	0,0	100,0	100,0	0,0	0,0

Omwonenden	w = 0,17	Handmatig 1	Handmatig 2	Handmatig 3	Handmatig 4	Handmatig 5	Handmatig 6
Preferentiescore		14,3	28,2	49,0	100,0	0,0	
Sociale huur	0,25	91,7	73,9	100,0	100,0	77,7	0,0
Extra groen	0,15	0,0	60,0	0,0	70,0	0,0	0,0
Speelplekken	0,10	0,0	80,0	30,0	100,0	0,0	0,0
Extra wandelpaden	0,10	0,0	0,0	0,0	70,0	0,0	0,0
Bouwhoogte	0,10	0,0	0,0	0,0	100,0	0,0	0,0
Behoud groenstrook	0,20	2,0	50,0	66,0	100,0	0,0	0,0
Behoud scouting	0,10	40,0	40,0	100,0	100,0	40,0	40,0

Planeconoom	w = 0,17	Handmatig 1	Handmatig 2	Handmatig 3	Handmatig 4	Handmatig 5	Handmatig 6
Preferentiescore		100,0	16,2	76,1	0,0	78,5	
Saldo	0,30	100,0	0,0	62,1	0,0	99,8	10,0
Sociale huur	0,20	93,4	78,7	100,0	100,0	82,0	0,0
Middenhuur	0,20	96,4	88,3	100,0	0,0	90,1	0,0
Dure koop	0,20	96,4	0,0	40,0	0,0	90,1	0,0
Woningaantal	0,10	0,0	50,0	0,0	0,0	0,0	0,0

Scouting	w = 0,17	Handmatig 1	Handmatig 2	Handmatig 3	Handmatig 4	Handmatig 5	Handmatig 6
Preferentiescore		0,0	0,0	100,0	100,0	0,0	
Behoud scouting	1,00	0,0	0,0	100,0	100,0	0,0	0,0

Ontwikkelaar	w = 0,17	Handmatig 1	Handmatig 2	Handmatig 3	Handmatig 4	Handmatig 5	Handmatig 6
Preferentiescore		11,1	100,0	0,0	0,0	30,7	
Sociale huur	0,30	61,0	63,1	60,0	60,0	62,7	0,0
Middenhuur	0,10	0,0	0,0	0,0	0,0	0,0	0,0
Woningaantal	0,50	0,0	50,0	0,0	0,0	0,0	0,0
Gestapeld	0,10	0,0	0,0	0,0	0,0	0,0	0,0

16.4.5 Optimization results

Optimalisatie resultaten							
Settings		Optimalisatie 1	Optimalisatie 2	Optimalisatie 3	Optimalisatie 4	Optimalisatie 5	Optimalisatie 6
Maximale stall	3	Click to run	Click to run	Click to run	Click to run	Click to run	Click to run
Grootte populaties	200						
Methode	Tetra						
EG sociale huur		2	3	6	2	0	8
EG middenhuur		2	15	8	2	1	7
EG betaalbaar		0	0	0	0	0	0
EG rij duur		6	0	0	0	0	0
EG 2/1 kap		5	2	0	0	1	0
EG vrijstaand		13	20	21	20	21	22
MG sociale huur		17	15	10	13	17	9
MG middenhuur		17	3	8	13	16	10
MG betaalbaar		1	1	0	0	0	0
MG duur		0	1	0	0	0	0
Extra groen		22%	30%	30%	23%	30%	30%
Extra aandacht fiets		71%	68%	67%	73%	86%	80%
Speelplekken		4	4	4	0	4	4
Extra wandelpaden		28%	30%	15%	30%	30%	30%
Duurzame inrichting		13%	29%	24%	25%	28%	27%
Bouwhoogte		4	4	4	3	4	4
Behoud RWZI		10%	9%	8%	7%	9%	10%
Behoud groenstrook		73%	72%	84%	60%	75%	78%
Behoud scouting		1	1	1	1	1	1

Resultaten	Waarde	Waarde	Waarde	Waarde	Waarde	Waarde
Handhaven overige functies	1.888	1.888	1.888	1.888	1.888	1.888
Uitgeefbaar	9.020	8.120	7.590	13.560	9.647	7.945
Parkeerplekken	45	36	29	27	32	30
Parkeeroppervlak	538	432	344	324	379	365
Weg	2.666	3.318	3.061	2.554	2.656	3.234
Fietspad	1.140	1.394	1.278	1.104	1.235	1.455
Trottoir	2.470	2.399	1.892	1.996	2.217	2.269
Water	1.933	2.267	2.100	1.861	1.987	2.204
Groen	5.765	5.850	5.168	4.613	5.460	5.460
RWZI (overgebleven opp)	1.035	932	828	725	932	1.035
Groenstrook (overgebleven opp)	4.380	4.320	5.040	3.600	4.500	4.680
Ongebruikt oppervlak (groen)	91	6	1.737	301	25	390
Totaal oppervlak	33.450	33.450	33.450	33.450	33.450	33.450
Saldo geïndexeerd (€)	€ 796.800	€ 1.278.241	€ 1.111.950	€ 1.193.883	€ 1.425.512	€ 1.381.023
Woningaantal	63	60	53	50	56	56
Perc. sociaal (%)	30,2%	30,0%	30,2%	30,0%	30,4%	30,4%
Perc. middenhuur (%)	30,2%	30,0%	30,2%	30,0%	30,4%	30,4%
Perc. betaalbaar (%)	1,6%	1,7%	0,0%	0,0%	0,0%	0,0%
Perc. duur (%)	38,1%	38,3%	39,6%	40,0%	39,3%	39,3%
Gestapeld (%)	55,6%	33,3%	34,0%	52,0%	58,9%	33,9%
Grondgebonden (%)	44,4%	66,7%	66,0%	48,0%	41,1%	66,1%
Groepspreferentie						
Preferentiescore	0,0	100,0	59,1	70,5	65,0	60,2

16.4.6 Individual optimization results

Preferentie per belanghebbende

Gemeente	w = 0,17	Optimalisatie 1	Optimalisatie 2	Optimalisatie 3	Optimalisatie 4	Optimalisatie 5	Optimalisatie 6
Preferentiescore		32,6	100,0	0,0	45,3	16,7	16,7
Saldo	0,15	83,7	91,9	90,8	91,4	92,9	92,6
Sociale huur	0,15	98,4	100,0	98,1	100,0	96,4	96,4
Middenhuur	0,08	98,4	100,0	98,1	100,0	96,4	96,4
Betaalbare koop	0,08	0,0	0,0	0,0	0,0	0,0	0,0
Woningaantal	0,08	0,0	0,0	0,0	0,0	0,0	0,0
Extra groen	0,08	99,8	92,6	92,6	99,5	92,6	92,6
Speelplekken	0,08	100,0	100,0	100,0	0,0	100,0	100,0
Behoud RWZI	0,15	100,0	98,6	94,4	87,9	98,6	100,0
Behoud groenstrook	0,08	78,8	80,6	53,8	96,0	75,0	68,6
Behoud scouting	0,08	0,0	0,0	0,0	0,0	0,0	0,0

Stedenbouwkundige	w = 0,17	Optimalisatie 1	Optimalisatie 2	Optimalisatie 3	Optimalisatie 4	Optimalisatie 5	Optimalisatie 6
Preferentiescore		0,0	73,4	26,2	63,1	100,0	44,9
Saldo	0,08	87,5	91,9	90,5	91,2	93,0	92,7
Sociale huur	0,04	96,5	100,0	95,8	100,0	91,9	91,9
Middenhuur	0,04	96,5	100,0	95,8	100,0	91,9	91,9
Betaalbare koop	0,04	19,2	20,3	0,0	0,0	0,0	0,0
Dure koop	0,04	99,8	99,8	99,7	99,7	99,8	99,8
Woningaantal	0,15	0,0	0,0	0,0	0,0	0,0	0,0
Gestapeld	0,12	85,0	0,0	0,0	65,7	95,0	0,0
Extra groen	0,08	96,2	97,9	97,9	96,4	97,9	97,9
Extra aandacht fiets	0,08	96,6	95,9	95,6	97,1	99,2	98,4
Speelplekken	0,04	50,0	50,0	50,0	0,0	50,0	50,0
Extra wandelpaden	0,04	0,0	90,0	0,0	90,0	90,0	90,0
Duurzame inrichting	0,08	59,6	99,8	94,1	95,8	99,3	98,5
Bouwhoogte	0,04	60,0	60,0	60,0	100,0	60,0	60,0
Behoud RWZI	0,08	60,2	64,1	68,1	72,1	64,1	60,2
Behoud groenstrook	0,04	83,5	82,3	93,8	50,3	85,6	88,7
Behoud scouting	0,04	100,0	100,0	100,0	100,0	100,0	100,0

Omwonenden	w = 0,17	Optimalisatie 1	Optimalisatie 2	Optimalisatie 3	Optimalisatie 4	Optimalisatie 5	Optimalisatie 6
Preferentiescore		0,0	100,0	55,9	0,6	16,1	29,2
Sociale huur	0,25	89,1	100,0	87,1	100,0	76,5	76,5
Extra groen	0,15	62,0	70,0	70,0	63,0	70,0	70,0
Speelplekken	0,10	80,0	80,0	80,0	0,0	80,0	80,0
Extra wandelpaden	0,10	68,0	70,0	55,0	70,0	70,0	70,0
Bouwhoogte	0,10	0,0	0,0	0,0	100,0	0,0	0,0
Behoud groenstrook	0,20	73,0	72,0	84,0	60,0	75,0	78,0
Behoud scouting	0,10	100,0	100,0	100,0	100,0	100,0	100,0

Planeconoom	w = 0,17	Optimalisatie 1	Optimalisatie 2	Optimalisatie 3	Optimalisatie 4	Optimalisatie 5	Optimalisatie 6
Preferentiescore		0,0	74,4	60,0	100,0	39,3	37,8
Saldo	0,30	83,7	91,9	90,8	91,4	92,9	92,6
Sociale huur	0,20	91,4	100,0	89,8	100,0	80,9	80,9
Middenhuur	0,20	95,3	100,0	94,4	100,0	89,6	89,6
Dure koop	0,20	73,2	76,3	94,4	100,0	89,5	89,5
Woningaantal	0,10	0,0	0,0	0,0	0,0	0,0	0,0

Scouting	w = 0,17	Optimalisatie 1	Optimalisatie 2	Optimalisatie 3	Optimalisatie 4	Optimalisatie 5	Optimalisatie 6
Preferentiescore		50,0	50,0	50,0	50,0	50,0	50,0
Behoud scouting	1,00	100,0	100,0	100,0	100,0	100,0	100,0

Ontwikkelaar	w = 0,17	Optimalisatie 1	Optimalisatie 2	Optimalisatie 3	Optimalisatie 4	Optimalisatie 5	Optimalisatie 6
Preferentiescore		35,2	20,8	63,4	0,0	78,4	100,0
Sociale huur	0,30	61,3	60,0	61,5	60,0	62,8	62,8
Middenhuur	0,10	0,0	0,0	0,0	0,0	0,0	0,0
Woningaantal	0,50	0,0	0,0	0,0	0,0	0,0	0,0
Gestapeld	0,10	0,0	82,2	85,4	0,0	0,0	85,3

16.5 Results concluding session

16.5.1 Preferences and weights

Wegingen belanghebbende		
Belanghebbende	**Weging**	**Eigen invul**
Project manager	0,25	0,25
Urban planner	0,25	0,25
Local residents	0,20	0,20
Financial manager	0,25	0,25
Scouting association	0,05	0,05
Developer	0,00	0,00
	0,00	
	0,00	
	0,00	
	0,00	
Som:	1,00	1,00

Preferenties Project manage	Min waarde	Vormingswaarde	Max waarde	Pref. min waarde	Pref. Vormingswaa	Pref. max waarde	Weging	Totale weging
Financial result	I 300.000	I 500.000	I 1.000.000	80	90	100	0,27	0,067
Social housing	30%	50%	100%	100	95	0	0,13	0,033
Middle rent housing	30%	50%	100%	100	95	0	0,07	0,017
Affordable housing	20%	25%	30%	100	50	0	0,07	0,017
Total houses	80	110	150	0	100	50	0,20	0,050
Extra greenery	0%	20%	50%	0	100	0	0,07	0,017
Playing areas	2	3	5	80	100	100	0,07	0,017
Sustainable design	0%	20%	30%	50	100	80	0,07	0,017
Keep RWZI	0%	10%	20%	100	20	0	0,07	0,017
						Som:	1,00	

Preferenties Urban planner	Min waarde	Vormingswaarde	Max waarde	Pref. min waarde	Pref. Vormingswaa	Pref. max waarde	Weging	Totale weging
Expensive housing	0%	30%	100%	0	100	0	0,06	0,014
Total houses	80	110	130	0	100	50	0,28	0,069
Appartments	50%	65%	70%	50	100	80	0,17	0,042
Extra greenery	0%	50%	100%	90	100	100	0,11	0,028
Extra cycling road	30%	50%	100%	60	90	100	0,11	0,028
Playing areas	2	3	4	50	100	50	0,06	0,014
Extra sidewalk	30%	50%	100%	90	100	100	0,06	0,014
Sustainable design	0%	30%	100%	0	100	20	0,06	0,014
Building height	3		4	100		60	0,06	0,014
Keep RWZI	0%	10%	20%	80	100	0	0,06	0,014
						Som:	1,00	

Preferenties Local residents	Min waarde	Vormingswaarde	Max waarde	Pref. min waarde	Pref. Vormingswaa	Pref. max waarde	Weging	Totale weging
Social housing	30%	31%	35%	100	70	0	0,25	0,050
Extra greenery	0%	20%	30%	0	60	70	0,15	0,030
Playing areas	3	4	5	30	80	100	0,15	0,030
Extra sidewalk	10%	20%	30%	50	60	70	0,10	0,020
Building height	3		4	100		0	0,25	0,050
Keep scouting	0		1	0		100	0,10	0,020
						Som:	1,00	

Preferenties Financial manag	Min waarde	Vormingswaarde	Max waarde	Pref. min waarde	Pref. Vormingswaa	Pref. max waarde	Weging	Totale weging
Financial result	I 300.000	I 500.000	I 1.000.000	80	90	100	0,70	0,175
Social housing	30%	31%	32%	100	50	10	0,10	0,025
Middle rent housing	30%	32%	35%	100	50	10	0,10	0,025
Expensive housing	30%	35%	40%	10	40	100	0,10	0,025
						Som:	1,00	

Preferenties Scouting associ	Min waarde	Vormingswaarde	Max waarde	Pref. min waarde	Pref. Vormingswaa	Pref. max waarde	Weging	Totale weging
Keep scouting	0		1	0		100	1	0,050
						Som:	1,00	

16.5.2 Optimization results

	Groen variant	ptimalisatie 2	ptimalisatie 3	ptimalisatie 4	ptimalisatie 5	ptimalisatie 6
Social housing	12	0	1	19	0	11
Middle rent housing	7	2	1	11	2	14
Affordable housing	0	0	0	0	0	0
Expensive housing	0	0	0	0	0	0
2/1 roof	0	0	1	0	0	0
Detached houses	0	2	8	0	2	0
Social housing (app)	20	36	31	15	36	20
Middle rent housing (app)	25	34	31	19	34	18
Affordable housing (app)	0	2	23	0	2	0
Expensive housing (app)	36	44	10	36	44	37
Extra greenery	13%	0%	0%	12%	0%	19%
Extra cycling road	54%	0%	0%	30%	0%	55%
Playing areas	3	0	0	1	0	0
Extra sidewalk	1%	0%	0%	0%	0%	0%
Sustainable design	20%	14%	0%	24%	0%	24%
Building height	4	4	4	4	4	4
Keep RWZI	1%	0%	0%	1%	0%	0%
Keep scouting	1	1	1	1	1	1
Duur optimalisatie						
Resultaten	**Waarde**	**Waarde**	**Waarde**	**Waarde**	**Waarde**	**Waarde**
Handhaven overige functies	1.888	1.888	1.888	1.888	1.888	1.888
Uitgeefbaar	5.822	6.270	7.493	6.225	6.270	6.285
Parkeerplekken	81	97	77	80	97	81
Parkeeroppervlak	970	1.159	925	965	1.159	974
Weg	2.486	2.336	2.589	2.899	2.336	2.705
Fietspad	957	584	647	942	584	1.048
Trottoir	3.111	3.660	3.235	3.085	3.660	3.090
Water	1.457	1.610	1.739	1.597	1.610	1.562
Groen	8.475	9.000	7.950	8.400	9.000	8.925
RWZI (overgebleven opp)	104	0	0	104	0	0
Ongebruikt oppervlak (groen)	0	0	60	20	18	49
Totaal oppervlak	27.393	27.432	27.450	27.450	27.450	27.450
Saldo geïndexeerd (I)	I -1.213.869	I 812.700	I 479.391	I -1.211.579	I 946.936	I -1.049.169
Woningaantal	100	120	106	100	120	100
Perc. sociaal (%)	32,0%	30,0%	30,2%	34,0%	30,0%	31,0%
Perc. middenhuur (%)	32,0%	30,0%	30,2%	30,0%	30,0%	32,0%
Perc. betaalbaar (%)	0,0%	1,7%	21,7%	0,0%	1,7%	0,0%
Perc. duur (%)	36,0%	38,3%	17,9%	36,0%	38,3%	37,0%
Gestapeld (%)	81,0%	96,7%	89,6%	70,0%	96,7%	75,0%
Grondgebonden (%)	19,0%	3,3%	10,4%	30,0%	3,3%	25,0%

16.5.3 Individual optimization results

Groepspreferentie							
Preferentiescore		20,3	99,7	100,0	0,0	91,7	15,6

Preferentie per belanghebbende

Project manager	w = 0,25	Groen variant	Optimalisatie 2	Optimalisatie 3	Optimalisatie 4	Optimalisatie 5	Optimalisatie 6
Preferentiescore		24,4	100,0	95,5	0,0	90,5	27,7
Financial result	0,27	0,0	98,2	89,3	0,0	99,8	0,0
Social housing	0,13	99,9	100,0	100,0	99,7	100,0	100,0
Middle rent housing	0,07	99,9	100,0	100,0	100,0	100,0	99,9
Affordable housing	0,07	0,0	0,0	83,0	0,0	0,0	0,0
Total houses	0,20	85,8	99,2	97,6	85,8	99,2	85,8
Extra greenery	0,07	85,1	0,0	0,0	80,8	0,0	99,7
Playing areas	0,07	100,0	0,0	0,0	0,0	0,0	0,0
Sustainable design	0,07	100,0	96,1	50,0	96,3	50,0	96,3
Keep RWZI	0,07	89,1	100,0	100,0	89,1	100,0	100,0

Urban planner	w = 0,25	Groen variant	Optimalisatie 2	Optimalisatie 3	Optimalisatie 4	Optimalisatie 5	Optimalisatie 6
Preferentiescore		82,0	7,3	56,1	100,0	0,0	67,6
Expensive housing	0,06	99,9	99,8	78,3	99,9	99,8	99,9
Total houses	0,28	89,3	87,1	98,3	89,3	87,1	89,3
Appartments	0,17	0,0	0,0	0,0	80,0	0,0	0,0
Extra greenery	0,11	93,8	90,0	90,0	93,5	90,0	95,4
Extra cycling road	0,11	91,5	0,0	0,0	60,0	0,0	91,9
Playing areas	0,06	100,0	0,0	0,0	0,0	0,0	0,0
Extra sidewalk	0,06	0,0	0,0	0,0	0,0	0,0	0,0
Sustainable design	0,06	84,5	63,6	0,0	94,1	0,0	94,1
Building height	0,06	60,0	60,0	60,0	60,0	60,0	60,0
Keep RWZI	0,06	85,4	80,0	80,0	85,4	80,0	80,0

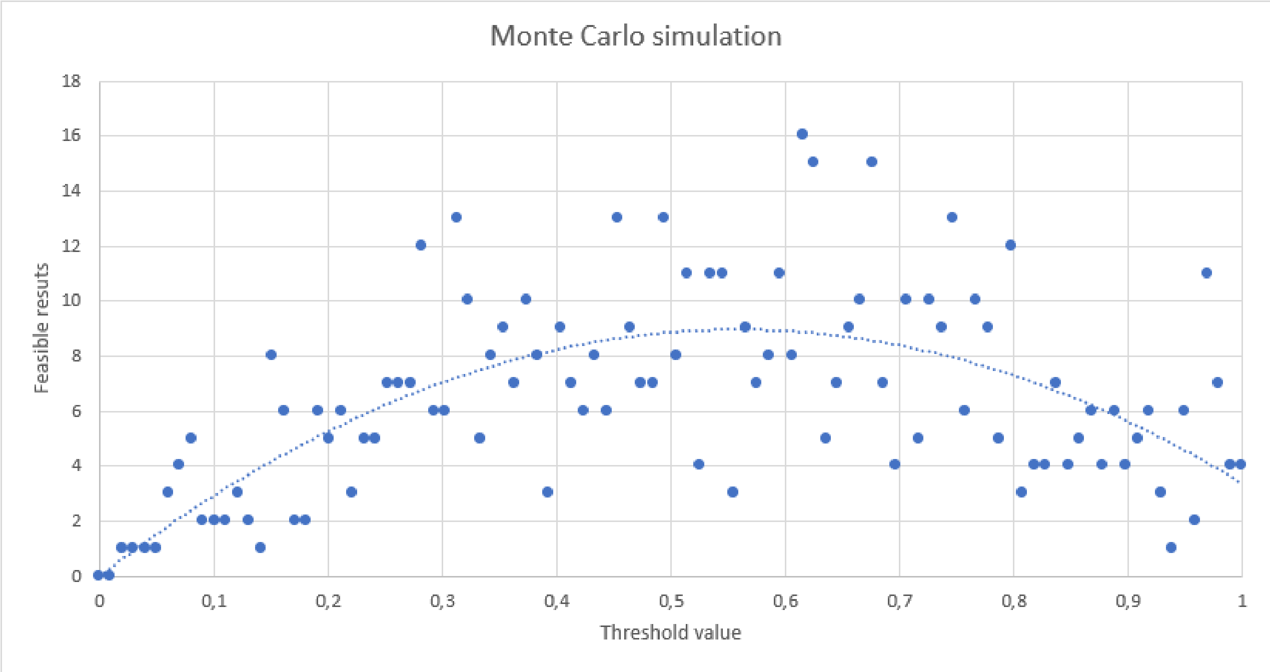
Local residents	w = 0,2	Groen variant	Optimalisatie 2	Optimalisatie 3	Optimalisatie 4	Optimalisatie 5	Optimalisatie 6
Preferentiescore		100,0	60,8	54,1	0,0	60,8	78,1
Social housing	0,25	47,3	100,0	93,8	10,8	100,0	70,0
Extra greenery	0,15	45,8	0,0	0,0	43,1	0,0	58,5
Playing areas	0,15	30,0	0,0	0,0	0,0	0,0	0,0
Extra sidewalk	0,10	0,0	0,0	0,0	0,0	0,0	0,0
Building height	0,25	0,0	0,0	0,0	0,0	0,0	0,0
Keep scouting	0,10	100,0	100,0	100,0	100,0	100,0	100,0

Financial manager	w = 0,25	Groen variant	Optimalisatie 2	Optimalisatie 3	Optimalisatie 4	Optimalisatie 5	Optimalisatie 6
Preferentiescore		0,0	98,8	75,0	9,7	100,0	6,9
Financial result	0,70	0,0	98,2	89,3	0,0	99,8	0,0
Social housing	0,10	10,0	100,0	89,8	0,0	100,0	50,0
Middle rent housing	0,10	50,0	100,0	94,4	100,0	100,0	50,0
Expensive housing	0,10	49,0	76,3	0,0	49,0	76,3	59,7

Scouting association	w = 0,05	Groen variant	Optimalisatie 2	Optimalisatie 3	Optimalisatie 4	Optimalisatie 5	Optimalisatie 6
Preferentiescore		50,0	50,0	50,0	50,0	50,0	50,0
Keep scouting	1,00	100,0	100,0	100,0	100,0	100,0	100,0

16.6 Monte Carlo simulation effect threshold value on feasible results

The threshold value (f) determines the amount of housing design variables that are set to 0 to avoid exceeding the maximum area constraint. The threshold value is a value between 0 and 1. A low value would ensure many housing design variables to be set to 0, which results in many unfeasible solutions because of the minimal amount of houses constraint. A high value would result in solutions with many houses, which also results in many unfeasible solutions due to the maximum area constraint. The best value for f is therefore somewhere in between to get the most feasible solutions in the starting point. The graph below shows the number of feasible solutions in 100 different starting points with a population size of 200 against the threshold value used to create the starting point. The trend line shows the most feasible results with a threshold value of approximately 0.6.



16.7 Python script

16.7.1 Starting points

```python
"""Start point maker"""

def make_start_point(n = int(n_pop), rand_factor = f):
    start_point = []
    for j in range(n):
        rand1 = []
        for i in range(n_ontwerpvariabelen):
            if i<10 and np.random.rand()<rand_factor and i not in index_soc+index_mid:
                rand1.append(int(np.random.randint(np.array(bounds)[:, 0][i], np.array(bounds)[:, 1][i]+1)*np.random.rand()))
            else:
                rand1.append(0)
        n_soc = np.ceil(np.sum(rand1[:10])*(harde_randvw_min[1]/(1-harde_randvw_min[1]-harde_randvw_min[2])))
        n_mid = np.ceil(np.sum(rand1[:10])*(harde_randvw_min[2]/(1-harde_randvw_min[1]-harde_randvw_min[2])))
        r_soc = np.random.rand()
        r_mid = np.random.rand()
        rand1[index_soc[0]] = int(np.ceil(r_soc * n_soc))
        rand1[index_soc[1]] = int(np.ceil((1-r_soc) * n_soc))
        rand1[index_mid[0]] = int(np.ceil(r_mid * n_mid))
        rand1[index_mid[1]] = int(np.ceil((1-r_mid) * n_mid))

        start_point.append(rand1)

    return start_point
```

16.7.2 Mutation

```python
for i in range(len(member)):
    if approach[i] == 'int':
        # check for a mutation
        if rand() < r_mut:
            member[i] = randint(bounds[i][0], bounds[i][1]+1)
    elif approach[i] == 'int_house':
        # check for mutation
        if rand() < r_mut:
            if rand() < 0.1:
                member[i] = randint(bounds[i][0], bounds[i][1]+1)
            else:
                member[i] += randint(-house_mutation_range*bounds[i][1], house_mutation_range*bounds[i][1]+1)
                member[i] = np.min([bounds[i][1], np.max([bounds[i][0], member[i]])])
    elif approach[i] == 'int_perc':
        # check for mutation
        if rand() < r_mut:
            if rand() < 0.3:
                member[i] = randint(bounds[i][0], bounds[i][1]+1)
            else:
                member[i] += randint(-perc_mutation_range*bounds[i][1], perc_mutation_range*bounds[i][1]+1)
                member[i] = np.min([bounds[i][1], np.max([bounds[i][0], member[i]])])
    elif approach[i] == 'bool':
        # check for a mutation
        if rand() < r_mut:
            member[i] = 1 - member[i]  # flip the boolean
    else:
        for j in range(len(member[i])):
            # check for a mutation
            if rand() < r_mut:
                # flip the bit
                member[i][j] = 1 - member[i][j]
```

16.8 Comparison running time Tetra and Minmax

To find the effect of the Tetra evaluation on the running time, the model is simulated with 2 evaluation methods: Tetra and Minmax. The Tetra evaluation is performed at an external server, whereas the Minmax result is calculated locally. The graph below is the result of 10 runs for each of 5 different population sizes. The average running times of these 10 runs for each population size is shown for the 2 methods of evaluation. The runs were limited to 1 generation to ensure the GA computes the same amount of data for both methods. The Tetra evaluation takes 2.6 times as long as the Minmax evaluation.