MASTER

Where to build

Designing a GIS-based decision-support tool used to screen areas in the Netherlands for potential housing sites and determining their level of suitability based on stakeholder interests

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WHERE TO BUILD

Designing a GIS-based decision-support tool used to screen areas in the Netherlands for potential housing sites and determining their level of suitability based on stakeholder interests.

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Summary

Due to the large shortage of affordable housing in the Netherlands, there is a strong need for the development of new housing sites. However, limited space, long building times, and different interests make it a compilated task to find suitable locations. The question that is central to this challenge is where to build. To speed up the screening process for the selection of new housing sites, and rating their relative suitability, this research aims to develop a decision-support tool, which can be used for these purposes, and can potentially speed up the process.

First, a literature review is conducted into the underlying development process, which stakeholders are relevant in this process, and which decision-support tools currently exist. It is found that in the Netherlands, the municipality is endowed with the responsibility of solving the housing demand within their borders, but they are not the only stakeholder that can influence where new housing might be realized. The developer, and any other stakeholder for that matter, can submit a request for the change of the zoning plan. These requests must always be handled by the municipality, and when substantiated, have a real chance of being passed. It is not uncommon for developers to submit such a request when they seek to develop an area. In this research, municipalities and developers are perceived as the two main stakeholders, which represent additional societal interests from secondary stakeholders like end-users. For the two primary stakeholders, interests are identified based on policy documents and stated missions and vision. For secondary stakeholders, literature is reviewed to come up with additional interests. For these interests, relevant influencing spatial characteristics are identified via literature, and these spatial characteristics are translated into spatial criteria. It is found that sustainability is often perceived as important, together with aspects like avoiding development risk and protecting cultural or natural areas.

The literature review also reviews decision-support used in other studies. It is found that an application of Multi-Criteria Decision Analyses is a very useful tool to solve spatial challenges, since Multi-Criteria Decision Analyses help decision makers in analysing potential actions or alternatives based on multiple factors or criteria, using decision rules to aggregate those criteria, and to rate or rank the alternatives. A Multi-Criteria Decision Analysis always consists of several factors. These are the option, objective, criterion, performance score and criterion weights. Many methods are available and are applied depending on the kind of research. One of the most often used methods is the Multi-Attribute Utility Theory method, which sums the weighted scores for several attributes to come up with a general utility. In case of spatial challenges, it is very useful to couple Multi-Criteria Decision Analyses with Geographic Information Systems. This is a spatial system that creates, manages, analyses and maps all types of data. The main principle of Geographic Information Systems is that of spatial data layers that are being overlaid to analyse and augment these. There is a large magnitude of software available, but they often have similar tools aimed at augmenting and analysing data, which provides a promising perspective for answering the fifth sub-research question. An interesting development of the last ten years within the Geographic Information Systems Community is the development of open-source options as opposed to commercial ones. Some authors believe that these open sources have the potential to accommodate the needs of modern-day planners, despite the limits of open-source development software. However, this has not been proven in a real-world scenario. It is therefore interesting to test whether a suitability analysis for housing

sites can be conducted, based on real-life stakeholder interests, in the context of a country experiencing great challenges in finding suitable locations.

First, a schematic model is developed using the criteria that were identified, to serve as a general framework. This schematic model is universally applicable to Geographic Information Systems software and consists of three steps: setting up, screening and a suitability analysis. In phase one, the user sets up the tool and selects a Project Area to analyse. In the next phase, screening takes place that removes all unsuitable sites from the Project area by a Map Overlay Analysis, producing a map of all potential sites for development. For these resulting sites, a raster analysis is conducted in the second analysis phase. Here, the suitability of sites is calculated using a Multi-Attribute Utility Function, which calculates the weighted sum of suitability scores for different spatial criteria.

After completion of the schematic model, software and data sources are selected to be able to implement the model in a software-specific GIS environment. The choice is made to implement the model in QGIS, since it is freely available, gets updates regularly, has a big supporting community and, additionally, is known to be user-friendly. For data, several sources were used. The first of these is OSM, whose data can be loaded into QGIS by default. Additionally, two plugins are installed via which data can be retrieved from online databases. These are the INSPIRE, and PDOK plugins. For each criterion, the relevant data was identified. Suitable spatial data is available for almost all criteria, except for soil conditions, and VNG distances. However, for VNG distances, an alternative method is developed to still be able to partially assess this criterion. For all other criteria, data was found, but much of this data is not instantly usable and needs additional processing. The operations that are necessary to do so are defined and visualised schematically.

After automation, a demonstration is conducted. Five hypothetical stakeholder scenarios are simulated in QGIS, by implementing different weights in the raster MCDA. The weights for the first case are all set equally, to come up with a base scenario to compare the others to. For scenarios 2, 3 and 4, stakeholder weights are 'simulated' by the author, by conducting a Pairwise Comparison. In this pairwise comparison, importance is assigned to individual criteria based on how often interests were found to be mentioned in the literature. This produced three separate sets of weights for each stakeholder scenario, and the output of the model responded to these by producing three distinct outputs. In the last scenario, the average weights of the stakeholder weights are used, creating an average suitability score based on all hypothetical stakeholder inputs. The quality and face validity of the model output seem to be okay. Furthermore, it seems that the output of the model is quite different for separate stakeholder groups. Because the Pairwise Comparison was filled in according to stated interests, they are suspected to be at least partially indicative of what real-life stakeholder input would yield. However, this is not confirmed, because no real-life stakeholders were involved with this research.

The research concludes with a general conclusion and recommendations. There are assumptions and limitations associated with a lot of parts of the model. One of the main improvements is to confirm stakeholder criteria with experts and to conduct a case study with expert weight inputs to determine the validity of the model. Nevertheless, it has proven to be at least partially possible to develop a decision-support tool for the screening process, and suitability analysis of housing plots, using only open software.

Samenvatting

Door het grote tekort aan betaalbare woningen in Nederland is er een sterke behoefte aan de ontwikkeling van nieuwe woningbouwlocaties. De beperkte ruimte, lange bouwtijden en verschillende interesses maken het echter een gecompliceerde opgave om geschikte locaties te vinden. De vraag die centraal staat bij deze uitdaging is waar er gebouwd moet worden. Om het screeningproces voor de selectie van nieuwe huisvestingslocaties te versnellen en hun relatieve geschiktheid te beoordelen, heeft dit onderzoek tot doel een beslissingsondersteunend instrument te ontwikkelen dat voor deze doeleinden kan worden gebruikt en mogelijk het proces kan versnellen.

Eerst wordt er literatuuronderzoek gedaan naar het onderliggende ontwikkelingsproces, welke stakeholders relevant zijn in dit proces en welke beslissingsondersteunende instrumenten er momenteel bestaan. Het blijkt dat in Nederland, de gemeente de verantwoordelijkheid heeft om de woningvraag binnen haar grenzen op te lossen. Zij is echter niet de enige belanghebbende die invloed kunnen uitoefenen op de vraag waar nieuwe woningen kunnen worden gerealiseerd. De ontwikkelaar, en iedere andere belanghebbende, kan een verzoek tot wijziging van het bestemmingsplan indienen. Deze verzoeken moeten altijd door de gemeente worden afgehandeld en hebben, mits onderbouwd, een reële kans om te worden gehonoreerd. Het is niet ongebruikelijk dat ontwikkelaars een dergelijk verzoek indienen als ze een gebied willen ontwikkelen. In dit onderzoek worden gemeenten en ontwikkelaars gezien als de twee belangrijkste stakeholders, die aanvullende maatschappelijke belangen vertegenwoordigen van secundaire stakeholders zoals toekomstige bewoners. Voor de twee primaire stakeholders worden belangen in kaart gebracht op basis van beleidsdocumenten, geformuleerde missies en visies. Voor secundaire belanghebbenden wordt de literatuur doorgenomen om aanvullende belangen te identificeren. Voor deze belangen worden via de literatuur relevante beïnvloedende ruimtelijke karakteristieken geïdentificeerd, en deze ruimtelijke karakteristieken vertaald naar ruimtelijke criteria. Gebleken is dat sustainability vaak als belangrijk wordt gezien, samen met aspecten als het vermijden van ontwikkelingsrisico's en het beschermen gebieden van culturele of natuurlijk waarde.

In het literatuuronderzoek wordt ook gekeken naar de beslissingsondersteuning die in andere onderzoeken wordt gebruikt. Het is gebleken dat een toepassing van Multi-Criteria Decision Analyses een zeer nuttig hulpmiddel is om ruimtelijke uitdagingen op te lossen, aangezien Multi-Criteria Decision Analyses besluitvormers helpen bij het analyseren van potentiële acties of alternatieven op basis van meerdere factoren, waarbij gebruik wordt gemaakt van beslissingsregels om deze te aggregeren. Een Multi-Criteria Decision Analysis bestaat altijd uit meerdere factoren. Dit zijn de optie, doelstelling, criteria, scores en gewichten. Er zijn veel methoden beschikbaar en deze worden vaak toegepast, afhankelijk van het soort onderzoek. Een van de meest gebruikte methoden is de Multi-Attribute Utility Theory-methode, die de gewogen scores voor verschillende attributen bij elkaar optelt om tot een algemene utiliteitsscore te komen. Bij ruimtelijke uitdagingen is het zeer nuttig om Multi-Criteria Decision Analyses te koppelen aan Geographic Information Systems. Dit zijn ruimtelijke systemen die allerlei soorten van ruimtelijke data kan creëren, beheren, analyseren en in kaar brengen. Het belangrijkste principe van geografische informatiesystemen is dat van ruimtelijke gegevenslagen die over elkaar heen worden gelegd om deze te analyseren en uit te breiden. Er is een grote hoeveelheid software beschikbaar, maar deze beschikken vaak over vergelijkbare

tools die gericht zijn op het aanvullen en analyseren van gegevens, wat een veelbelovend perspectief biedt voor het beantwoorden van de vijfde deelonderzoeksvraag. Een interessante ontwikkeling van de afgelopen tien jaar binnen de Geographic Information Systems Community is de ontwikkeling van open source-opties in tegenstelling tot commerciële opties. Sommige auteurs zijn van mening dat deze open bronnen het potentieel hebben om de behoeften van moderne planners te kunnen vervullen, ondanks de beperkingen van open-source ontwikkelsoftware. Dit is echter niet bewezen in een realistisch scenario vergelijkbaar aan dat van dit onderzoek. Het is daarom interessant om te testen of een geschiktheidsanalyse voor woningbouwlocaties kan worden uitgevoerd op basis van reële belangen van belanghebbenden, in de context van de Nederlandse situatie.

Eerst wordt er een schematisch model ontwikkeld op basis van de geïdentificeerde criteria, die als algemeen raamwerk dient. Dit schematische model is universeel toepasbaar op software voor Geografische Informatiesystemen en bestaat uit drie stappen: opzetten, screenen en een geschiktheidsanalyse. In fase één stelt de gebruiker de tool in en selecteert hij een projectgebied om te analyseren. In de volgende fase vindt een screening plaats waarbij alle ongeschikte locaties uit het projectgebied worden verwijderd door middel van een Map Overlay Analysis, waardoor een kaart ontstaat met alle potentiële locaties voor ontwikkeling. Voor deze resulterende locaties wordt in de tweede analysefase een Raster Analysis. Hier wordt de geschiktheid van locaties berekend met behulp van een Multi-Attribute Utility Function, die de gewogen som van geschiktheidsscores voor verschillende ruimtelijke criteria berekent.

Na voltooiing van het schematisch model worden software en databronnen geselecteerd om het model in een softwarespecifieke GIS-omgeving te kunnen implementeren. Er is voor gekozen om het model in QGIS te implementeren, omdat deze software gratis is, regelmatig updates krijgt, een grote ondersteunende gemeenschap heeft en bovendien bekend staat als gebruiksvriendelijk. Voor de gegevens zijn verschillende bronnen gebruikt. De eerste hiervan is Open Street Map, waarvan de gegevens zonder extra plug-ins direct in QGIS kunnen worden geladen. Daarnaast zijn er twee plug-ins geïnstalleerd waarmee gegevens uit online databases kunnen worden opgehaald. Dit zijn de INSPIRE- en PDOK-plug-ins. Voor elk criterium zijn de relevante gegevens geïdentificeerd. Voor vrijwel alle criteria zijn geschikte ruimtelijke gegevens beschikbaar, behalve voor bodemgesteldheid en VNG-afstanden. Voor VNG-afstanden wordt echter een alternatieve methode ontwikkeld om dit criterium toch gedeeltelijk te kunnen beoordelen. Voor alle overige criteria zijn gegevens gevonden, maar veel van deze gegevens zijn niet direct bruikbaar en behoeven aanvullende verwerking. De handelingen die daarvoor nodig zijn, worden schematisch gedefinieerd en gevisualiseerd.

Na de automatisering wordt een demonstratie uitgevoerd. Vijf hypothetische scenario's van belanghebbenden worden gesimuleerd in QGIS, door het implementeren van verschillende gewichten in de raster-MCDA. De gewichten voor het eerste geval zijn allemaal gelijk ingesteld, zodat er een basisscenario ontstaat waarmee de andere kunnen worden vergeleken. Voor scenario's 2, 3 en 4 worden de gewichten van belanghebbenden door de auteur 'gesimuleerd' door een paarsgewijze vergelijking uit te voeren. Bij deze paarsgewijze vergelijking wordt belang toegekend aan individuele criteria op basis van hoe vaak belangen in de literatuur genoemd zijn. Dit leverde drie afzonderlijke reeksen gewichten op voor elk stakeholderscenario, en de output van het model reageerde hierop door drie verschillende outputs te produceren. In het laatste scenario worden de gemiddelde gewichten van de stakeholdergewichten gebruikt, waardoor een gemiddelde geschiktheidsscore ontstaat op basis van alle hypothetische stakeholderinputs. De kwaliteit en face validity van de modeluitvoer lijken in orde. Bovendien lijkt het erop dat de output van het model heel verschillend is voor afzonderlijke groepen belanghebbenden. Omdat de paarsgewijze vergelijking is ingevuld op basis van aangegeven belangen (uit de literatuur), wordt vermoed dat deze op zijn minst gedeeltelijk indicatief zijn voor wat de inbreng van belanghebbenden in de praktijk zou opleveren. Dit wordt echter niet bevestigd, omdat bij dit onderzoek geen belanghebbenden betrokken waren.

Het onderzoek wordt afgesloten met een algemene conclusie en aanbevelingen. Er zijn aannames en beperkingen verbonden aan veel delen van het model. Een van de belangrijkste verbeteringen is het bevestigen van de criteria van belanghebbenden met deskundigen en het uitvoeren van een casestudy met input van deskundigen om de validiteit van het model te bepalen. Niettemin is het op zijn minst gedeeltelijk mogelijk gebleken om een beslissingsondersteunend instrument voor het screeningproces en de geschiktheidsanalyse van woningbouwkavels te ontwikkelen, waarbij uitsluitend gebruik wordt gemaakt van open software- en dataopties.

Abstract

The Netherlands faces a critical shortage of affordable housing, which necessitates development on new housing sites. However, certain challenges like limited space, lengthy building times, and conflicting interests complicate the task of identifying suitable locations. This research therefore addresses the central question of ‘where to build’, by development of a decision-support tool that can automate the screening process, and suitability analysis for new housing sites. The study consists of a comprehensive literature review, identifying stakeholders, associated with these processes. Their interests are identified and spatial characteristics that are relevant for their interests are identified. By doing so, it becomes possible to come up with a list of spatial criteria for development. The review also explores existing decision-support tools, highlighting the effectiveness of Multi-Criteria Decision Analyses (MCDA) coupled with Geographic Information Systems (GIS) in addressing spatial challenges. The research proposes a schematic model for a universal GIS-based tool, consisting of three phases: setting up, screening, and a suitability analysis. The model is implemented in QGIS, utilizing open-source data from various plugins. A demonstration of the tool involves simulating five hypothetical stakeholder scenarios, revealing distinct outputs based on different stakeholder weights. While the model output appears valid and responsive to stakeholder inputs, the study acknowledges the need for expert validation and suggests improvements, including case studies with real-life stakeholders. Nevertheless, the research demonstrates the feasibility of developing a decision-support tool for housing site selection using open-source software.

Keywords

MCDA, GIS, Open-Source, Housing, Netherlands

Terminology and Abbreviations

AHP	Analytical Hierarchy Process. A MCDA coupled with a pairwise comparison.
Area	A collection of sites.
Data Area	The Area that indicates to which extent spatial data is loaded into the model.
Exclusion Area	Area that is the sum of all unsuitable areas based on Exclusion Criteria.
Exclusion Criterion	Criterion used for screening that excludes a site from analysis if not met.
GIS	Geographic Information Systems. Systems that handle spatial data.
Inclusion Area	Area that results from subtracting the Exclusion Area from the Project Area.
INSPIRE	Name of Geoportal. One of the data sources.
MAUT	Multi-Attribute Utility Theory.
MCDA	Multi Criteria Decision Analysis. Method for assessing multi-criteria problems.
MOA	Map Overlay Analysis.
OSM	Open Street Map.
Pairwise Comparison	Method to assess stakeholder weights based on comparing pairs of criteria.
PDOK	Name of Geoportal. One of the data sources.
Project Area	Area selected by the user to be analysed.
PT	Public Transport.
QGIS	GIS software in which the tool was developed.
RA	Raster Analysis.
Screening	Analysing an area and identifying potential sites by removing unsuitable ones.
Site	An uninterrupted plot of land.
Stakeholder Criterion	Criterion that is used to determine level of suitability. Does not exclude areas.
Suitability Analysis	Analysis that assesses the suitability of sites for housing development.
VNG	Association of Dutch Municipalities (Dutch: Vereniging van Nederlandse Gemeenten).

VNG Distances	Recommended distances between housing and certain functions like industry.

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1. Introduction

Urbanization is one of the defining trends of the 21st century (ESPAS, 2019). According to numbers from the Maddison project (Bolt & Luiten van Zanden, 2020), the Netherlands has been the fastest-growing, non-microstate country in Western Europe for at least 100 years and has experienced a growth rate triple the average during that time (183% as opposed to 61%). This has resulted in the Netherlands being the most densely populated country in the entirety of Europe (excluding microstates). Although growth did especially take place in the last century, the Netherlands has long been a very urbanized country. Already around 1400 around a third of the population lived in settlements, and the coastal province in Holland even reached an urbanization share of 55% after the 1600s (Paping, 2014). Since then, Holland (later divided into North-Holland and South-Holland), has kept its status as the most urbanized area of the country. Since the 20th century, the urban areas in this region, together with the urban area of Utrecht, have become known as the 'Randstad' or 'Edge City' in Dutch. This name refers to a special spatial characteristic of this area, namely that it forms a ring around a relatively under-urbanized, green region called the green heart (Dutch: Groene hart).

Since WWII, the Dutch government has actively sought to maintain the green heart as a green unurbanized area and even tried to discourage population growth in the west of the country, by stimulating economic growth in the North and South (Bruinsma & Koomen, 2018). Nevertheless, it was expected that the Randstad would have grown by one million inhabitants by 1980. To combat this, the policy focus was put on the decentralization of urban centres by the realization of growth cores around existing urban centres, supported by a dense road network. The negative effects of car use were not acknowledged yet by this time.

Multiple updates were published in the following decade, but a clear change of path can be distinguished in the Fourth Iteration (Bruinsma & Koomen, 2018). Globally, concerns regarding climate started to grow, and the existing form of urban development suburbanization got criticized increasingly. City planners around the world started rethinking the model of the city to achieve more sustainable development (Pelczynski & Tomkowicz, 2019). In line with this development, more emphasis was put on sustainable development by the Dutch government; The fourth policy document was the first one to focus on climate goals and increased emphasis on public transport as a way to decrease car usage and densification as a way to combat suburbanization. Densification of cities is a method of sustainable development that has numerous advantages (Pelczynski & Tomkowicz, 2019). However, this is more complicated than peripheral development. Since the centrally located area is already built up, the development usually must take place at locations that are already urbanized and must therefore be redeveloped. Then there are often also the increasingly strict guidelines for development to take place in terms of health, for instance, the vicinity to polluting functions.

The most recent change in spatial development took place in 2005, with the 'Nota Ruimte'. As its contents point out, the responsibilities for spatial development were redistributed. Instead of a national approach, spatial development was delegated to more regional and local governments like provinces and municipalities, and the national government now primarily focussed on the national spatial structure, with examples like urban dynamics and guarding the quality of ecological structures and landscapes.

Despite the ambition for sustainable densification as much as possible, there is considerable debate on the subject in the Netherlands, since the country has not been able to keep up with housing demand and is currently experiencing a housing crisis. Part of the problem is a lack of space, which causes considerable challenges (CBS, 2023a).

1.1 Problem Description

Due to the large shortage of affordable housing in the Netherlands, there is a strong need for the development of new housing sites (International Monetary Fund, 2022). However, limited space, long building times and different interests make it a compilated task to find suitable locations (Rijksoverheid, 2022). In the Netherlands, the municipality is endowed with the responsibility of solving the housing demand of their municipality within their borders. All spatial decisions of a municipality are included in the zoning plan (Dutch: Bestemmingsplan), and the municipality is the only stakeholder holding the power to change this. Nevertheless, municipalities are expected to consider the interests of other stakeholders, especially civilians while composing a plan, since the goal of a zoning plan is to rationally divide space for functions (Rijksoverheid, 2023). Things like health, wellbeing, and protection of heritage must be considered, while also making sure that demand for housing is met. A general definition of what constitutes a 'suitable location', based on these factors seems to be missing in literature. This probably has to do with the fact that suitability is subjectively different from the perspective of different stakeholders, and therefore a general definition that is applicable in every situation is hard to define. Although there are a lot of factors that are unanimously considered important (for instance minimizing air pollution and maximizing sustainability as elaborated in Paragraph 2.3.4, the importance, or weight of such a factor might differ per location and/or stakeholder. Additionally, it is not always clear who these stakeholders are, and what their interests are exactly. It can be expected that some interests collide, not only between stakeholders but also within stakeholder groups.

Although a structural standard procedure exists for composing a zoning plan in general (Paragraph 2.2.2), no such framework exists for conducting preliminary suitability analyses based on weighing interests against each other. More often, municipalities work together with urban planners (Dolstra & Couwenbergh, 2020) who act as advisors during this phase, but the depth of the approach differs per municipality based on internal knowledge and capacity (VNG, 2020). No standardized approach that is universally applicable currently exists in the literature. However, creating clarity in the multitude of stakeholder and their interests and translating these interests into usable criteria for new housing development sites could prove to be very useful, since there are a lot of methods available for solving multi-criteria problems. These have been applied to a magnitude of problems, not only spatial (Sousa, 2012a). In spatial problems, however, these multi-criteria analyses are often coupled with Geographic Information systems (GIS) that help in translating the 'what' of non-spatial MCAs into 'where' (Malczewski, 1999). When looking at the literature, multiple examples can be found where GIS is used for answering spatial challenges like determining the most optimal location for a wide range of functions, the assessment of natural dangers like flooding, or population research. However, when analysing the literature for suitability of sites for housing, no consensus on what constitutes a suitable site for housing can be found, because suitability is often interpreted subjectively, and not based on objective measurements. In practice, a wide range of different criteria are used to base the level of suitability on (See Paragraph 2.4.1).

GIS development has incrementally taken place since the late 1950s (Hussain, 2016), but an interesting development of the last few years is that open-source software and data have reached the point where some professionals deem open-source options an adequate alternative to commercial ones. By designing a tool that only makes use of open-source software and data, and is easy to use, it is expected that it becomes easier and more accessible for municipalities to implement integrated GIS analyses into the decision-making process, decreasing the dependence on external urban planning knowledge. Such a tool could be very promising because it can save a lot of time in the analysis phase of development and prevent miscommunication. Aside from the tool's relevance to policymakers, it can also prove of use to other stakeholders. One of these is the developer, which sometimes conducts its own screening. By also including the interests of developers in the location analysis, like ground prices and accessibility for construction, it becomes possible for developers to tweak the analysis in such a way that it not only finds the best location based on the interests of the municipality but also based on development factors. The final actor for which the tool would prove the be useful is the end-user/future resident. By including the options to input personal preferences, a future resident can locate the most suitable site for a future residence, based on individual preferences.

1.2 Objective and Scope

Based on the challenges associated with finding new housing sites, and the lack of a general and accessible approach for municipalities to tackle these challenges, this research aims to achieve clarity on the subject by the use of a scientific approach. This will be done by creating a basis to build upon for primary stakeholders in the housing site identification process, in the form of a GIS tool that is universally applicable and accessible. This tool must be built around the recently developing concept of open-source software and data to ensure this universal accessibility, which in turn could help in the implementation of more science-based approaches in the housing site identification process because it does not require an investment from stakeholders to start using it. Consequently, the main research question is as follows:

"How can a decision support tool that can be used by different stakeholders, to assess suitability for new housing development sites be designed?

The goal of this tool is to provide a universally applicable approach to the land screening process for housing development and the suitability quantification of the resulting options. This is done by automating a Multi Criteria Decision Analysis (MCDA) in a GIS environment. The input for this development consists of an extensive literature study on the development process, stakeholders, and their interests, combined with open-source spatial data. The following sub-research questions are part of the research:

1. *Who are the relevant stakeholders in the context of screening for new housing sites, and attaching relative suitability to these?*
2. *What interests do these stakeholders have in the process?*
3. *How can these interests be translated into usable criteria?*

4. *What is the best method for comparing these criteria to assess if a site is suitable, and to what degree?*
5. *How can these factors be integrated into a tool?*

First, the relevant stakeholders in the housing site identification process are identified by doing a literature study on housing development process. Although certain stakeholders are expected to yield certain power in the process, it is not clear how these relate to each other, and how interest might be shared. Creating an overview of these is an important basis for this research, as it seeks to provide a general framework from which the spatial analysis can be conducted. It must however be determined how interests are translated into usable criteria, and how these criteria should be weighted among each other. This will be done using a MCDA, but there are many methods available, and the most suitable options must be selected. Finally, it must be determined how this MCDA can be implemented and automated into a tool to create a final, usable package that can be universally applicable and is accessible to all stakeholders.

The research and sub-research questions will all be answered in the context of the Dutch situation specifically. This choice was made for several reasons. Firstly, stakeholders and their interests are expected to show significant differences between countries, because the planning system differs per country, and the housing situation might facilitate different importance of interests. Additionally, it is expected that the availability of data differs strongly, and that extensive bundling and standardizing must be done to make the data usable at all. The Dutch case presents an interesting enough subject, to the large demand for housing and the constraining spatial characteristics of the country and general interests.

1.3 Research Design

This research consists of three main phases as visualized in the Conceptual Model in Figure 1. In the first phase, preliminary literature research is conducted with several goals. The first of these is to achieve clarity about the process of housing development with an emphasis on the screening phase where new locations are identified. Then, it is determined which stakeholder are associated with this process, and what their interests are during this. It is important to also find out how these interests relate to spatial characteristics of sites and how these can be translated into usable criteria. These criteria are important because they will be used for a MCDA that will be integrated into the tool that is to be developed. Before this can be done, however, it is researched which specific approaches to MCDA exist, and how these can be coupled with GIS. For GIS, it is also researched what the current developments are in the field, and how these can be incorporated into the final tool product.

In the second phase, development of the tool takes place. Here, it is first determined what criteria are used based on findings from the first phase. Then, the specific MCDA method is selected. Here, it is decided how criteria are standardized, scored, and how to determine weights for each criterion. Once finished, it becomes possible to formulate a general equation that determines a utility for a specific site. This utility score equates to the final suitability score of the site in question. After defining this formula, it is determined how this MCDA can be integrated into a GIS environment. First, a general GIS model is developed consisting of all the general GIS operations that are necessary to execute the MCDA. Then, this general model is implemented in a specific GIS environment. This step consists of selecting a specific GIS software that is most suitable for this specific MCDA, in the context of current developments in the field, and by identifying usable data sources for the MCDA. For each criterion, spatial data must be found, and incorporated into the GIS model. Finally, it is determined how, and to what extent, the GIS model can be automated, to come up with a usable package of operations that represents the final tool.

The last phase of the research consists of testing the output of the developed tool. Several scenarios are tested by changing weights according to several stakeholder scenarios. The goal of this phase is to see what the output of the tool looks like, and whether this can be optimized. Additionally, this testing phase provides insights into possible differences among stakeholders. It is also reviewed whether the results are in line with expectations and whether the output is useful for the target group. Lastly, it is reviewed whether there is room for improvement, and how future research can build upon this.

	Action	**Goals/Results**
Literature Review	Topics of Research: - Dutch housing development process - The housing screening process - The decision process concerning the zoning of housing - Stakeholders in housing allocation - Spatial characteristics relevant to stakeholder interests - Decision-support tools in the development process	- Clear insight in the development process - Clear knowledge of the housing allocation procedure - List of stakeholders in the housing allocation process - List of stakeholder interests - A list of spatial characteristics that are relevant to stakeholder interests - An overview of decision support tools that are relevant to the housing allocation process
Tool Development	- Identify methods for screening and suitability analysis - Translate spatial aspects and interests into MCDA criteria - Choose software and data - Design schematic model - Develop schematic model and data into software-specific GIS model - Automate tool	- Elaborated method for screening and suitability analysis - General schematic GIS model - GIS-specific automated model - Format tool output
Tool Demonstration	- Determine input weights for tool demonstrations - Apply weights in number of hypothetical cases	- Maps containing potential housing locations - Different suitability map outputs according to stakeholder weights - Review of results

Figure 1. Conceptual model.

1.4 Relevance

1.4.1 Practical

The goal of this research is to develop a tool prototype that can aid decision-makers in the process of screening sites for new housing sites and to determine the relative level of suitability of these locations. Such a tool can greatly optimize the decision-making process because a general, universally applicable approach is now lacking. Such an approach can give better insight into potential locations, whether they are suitable, and how they compare to alternatives.

Aside from this, more insight is created into the specific interests of stakeholders in the process, which could also help in achieving a better understanding of mutual interests and clashing ones, which can be of great use in the current housing crisis.

1.4.2 Societal

This research also has societal relevance, from two separate perspectives. On the one hand, society will have great benefits from speeding up the housing development process. There are currently very large housing shortages, and many people struggle to find a suitable residence. An action like this focussed towards optimizing and speeding up the production of new housing stock is thus beneficial. On the other hand, the development of the tool within an open environment allows for much more transparency than is the case with commercial solutions. The Dutch government scores very poorly on transparency, and by making processes associated with matters as pressing as the housing market more transparent, the general population can be given better insight into the challenges that the government faces.

1.4.3. Academic

From the academic perspective, this research is interesting for several reasons. First of all, the majority of articles that conduct spatial analysis for housing sites pick their criteria based on arbitrary methods, instead of stakeholder interests. Additionally, it is often not investigated how interests like sustainability and inclusivity are influenced by the location of new housing when screening for potential development sites. The combination of GIS together with MCDA provides an interesting method for tackling the spatial challenges in the Netherlands, especially when the MCDA is based on stakeholder interests, and the GIS only makes use of open data, which is the concluding academic interest. Over the last 10 years, great progress has been made with the development of open-source GIS solutions, and many authors believe that it has reached a point where open-source options are a viable alternative for commercial ones. By developing the tool in such an open environment, more insight can be created about the functionality of open options, challenges, and potential for further developments.

1.5 Reading Guide

This research is focused on developing an open-source GIS-MCDA tool that can aid policymakers in the screening process of new housing sites and finding out relative suitability scores for potential new housing development sites. In Chapter 2, a literature review is conducted aimed at providing clarity on the background of housing development in the Netherlands, and the screening process that precedes it. Furthermore, stakeholders in this process and their interests are summarized. For these interests, relevant spatial characteristics are identified. Chapter 3 elaborates on how the tool is to be developed, and the MCDA that serves as the backbone of the analysis in the tool. Chapter 4 summarizes which software is chosen, which data is used, and how the data is processed to come up with a viable tool. This tool is automated in the last part of Chapter 4, after which it is tested in Chapter 5. The results that are acquired here are discussed in Chapter 5 as well, after which a general conclusion is elaborated in Chapter 6.

2. Literature Review

Before being able to develop a tool that can be used to identify sites suitable for housing development, research into several topics is conducted First, it is determined what the most suitable approach is in resolving the research question. To do so, more knowledge is needed to be acquired about the process of identifying locations for housing. The first part of this Chapter therefore focuses on elaborating on the decision-making process in the context of finding housing sites, after which additional research is conducted that builds upon the first findings. In Paragraph 2.1 the housing situation in the Netherlands is analysed, consisting of the history of planning policy, current housing market developments, and how these are related. Paragraph 2.2 analyses how the development of spatial planning works, with the allocation of power, the process of composing a zoning plan, and how criteria can be identified that are relevant in this process. The relevant stakeholders that are involved in this process are analysed in Paragraph 2.3, and their interests are established. Paragraph 2.4 builds upon these findings by identifying constraints for new housing developments that arise from these interests, and Paragraph 2.5 analyses tools that are often used in similar research that can help to weigh these constraints against each other.

2.1 Housing situation in the Netherlands

2.1.1 History of Dutch Spatial Policy

The Netherlands has known a uniform law on spatial planning since the Housing Law of 1901 (Bruinsma & Koomen, 2018). Here, universal national guidelines were defined for the first time. Together with the health law from the same year, it is seen as the starting point of spatial planning management in the country. The main goal of these laws was to end the unhealthy living circumstances of the poor. In the fast-growing industrialising cities, it was crucial to create a healthy living environment. New housing had to have certain basic services like clean water and sewage. Apart from that, conditions were set for building quality. These set the basis for the contemporary spatial management system, which would develop especially after the Second World War, when a combination of an already existing trend of urbanization, together with a reduction of the housing stock due to war damage created a large shortage of housing in the following years. Since this era, Dutch planning has been based on planning documents, that get updated or renewed regularly (Appendix I). A couple of trends can be distinguished when looking at the contents of these. The first and most noticeable is the steady aversion to uncontrolled suburbanization, starting with controlled suburbanization in planned neighbourhoods in designated areas. These days a renewed interest in suburbanization, albeit it being heavily controlled and conditioned, can be distinguished as well. This is primarily due to necessity since inner city locations are scarce. On the other hand, a shift of responsibility can be distinguished from top-down to bottom-up. Originally, plans were determined by the national government, but gradually municipalities have gotten more responsibility to fulfil their own housing demand. However, as will be discussed in Paragraph 2.1.2, there are discussions taking place about potentially shifting more responsibility to the national government again, since municipalities have not been able to keep up with housing demand.

2.1.2 Current Developments

The Netherlands is currently experiencing a large shortage of available housing. A report published by Rabobank (Lennartz, 2018) states that there was a shortage of around 100,000 to 140,000 dwellings. In 2022, the shortage was estimated at 390,000 dwellings (Atlas Research, 2022), The shortage is caused by several developments (Rijksoverheid, 2022):

1. Population increases caused by ageing, immigration and a diminishing family size.
2. Changing family composition causes a bigger demand for small and affordable housing for smaller families and singles
3. Limited space for development
4. Long bureaucratic procedures
5. Rising costs in the construction sector caused by higher interests, inflation and a shortage of men and materials
6. Limited space
7. Nitrogen crisis which limits the likelihood of a permit

The seemingly logical solution would be to develop more housing, but there are several challenges associated with the limited space mentioned in point 3. The Netherlands is one of the most densely populated countries in Europe, and the unavailability of undeveloped land causes challenges. These spatial challenges are especially felt in the urban core of the country named the 'Randstad', or 'edge city', and are caused by the following aspects (Bruinsma & Koomen, 2018; PBL, 2021)

1. Conservation of greenery: Due to the population density in the Netherlands, greenery is relatively scarce. One of the main spatial characteristics of the country is the so-called 'green heart' of the country; a large rural area sitting between the four largest cities of the country that has a protected status. Additionally, preventing the fusion of large urban areas has been a key policy in the country since the 1950s to prevent green areas from being cut off from each other.
2. Existing other functions: Not all non-urban area is used as greenery, but other functions exist as well. One example is Schiphol Airport to the south of Amsterdam, which has an area of almost 28 square kilometres. Aside from the physical space taken up by the airfield, noise and air pollution make adjoining areas unsuited for housing development as well.
3. Housing type preference: The Netherlands has a tradition of housing most of its population in detached, or semi-detached housing. According to Eurostat (2019), within the European Union, only Ireland has fewer people living in flats (the other categories being detached and semi-detached housing) than the Netherlands. This is noteworthy since at the same time, the Netherlands is only surpassed in population density by Island states like Malta and city-states by Monaco (Eurostat, 2021). It would seem logical that due to the scarcity of space, more dense housing by flats would be more prevalent. The reason for this discrepancy can only be guessed. Most likely, there is a strong cultural preference for single-family housing that is much stronger than in other European countries of similar population size.

The shortage is not equal for each municipality but differs strongly per case (Atlas Research, 2022). To better illustrate this, the research institute has developed the Housing Pressure Index (HPI), which expresses the housing pressure as the percentage of housing stock to which the existing housing stock should increase to completely fulfil demand in that municipality (i.e. the HPI of Hilversum is 150, meaning that the municipality’s stock should increase by 50% to fulfil the demand). It was found that half of the shortage of housing is concentrated in the metropolitan area of Amsterdam. This includes the municipalities of Amsterdam, Amstelveen, Hilversum, Haarlemmermeer, Haarlem, Velsen, Purmerend, Almere, and Lelystad. What can also be seen is that the second and third-largest municipalities of the country, Rotterdam and The Hague, are both within a relatively small 10% shortage to fulfil demand. Figure 2 visualizes the housing pressure indexes of Dutch municipalities on a map.

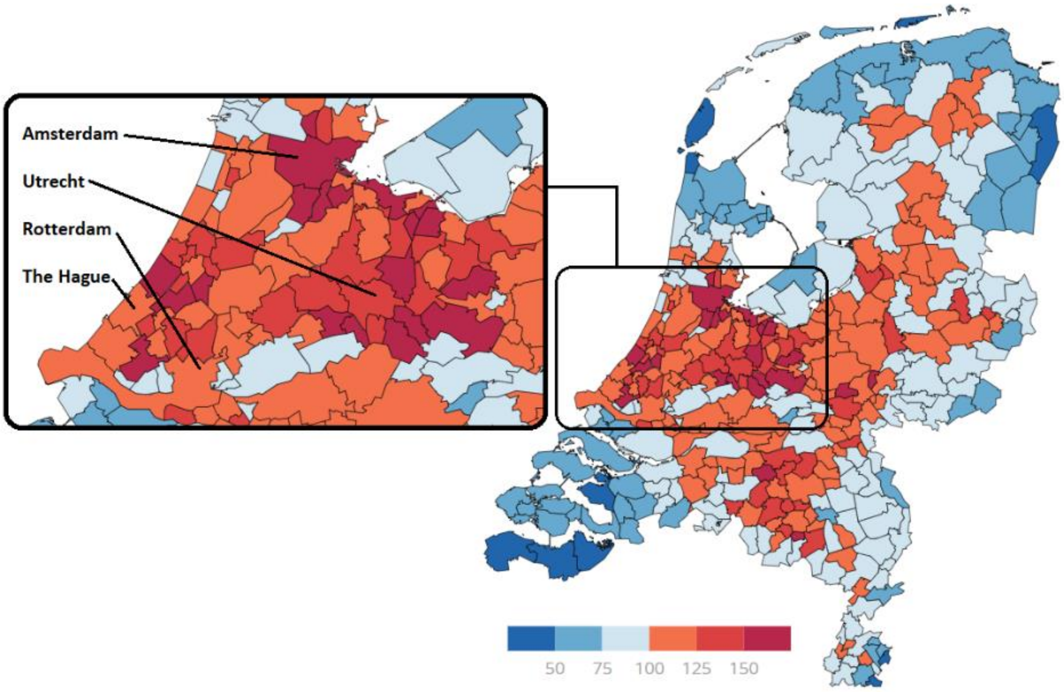

Figure 2. Housing shortage index Netherlands (adapted from CBS, 2022).

The current Dutch housing stock (CBS, 2023b)can be subdivided as is done in Table 1.

Table 1. Housing types as distinguished by CBS.

Type	**Single/multi-family building**	**Elaboration**	**Stock**
Flat/Apartment	Multi-family	A single-floor house within a multi-floor building	2,965,440
Three+ house rowhouse	Single family	A house built wall-to-wall within a row of houses of at least three	3,399,684
Two house rowhouse	Single family	Two houses that share one wall	707,902
Free standing	Single family	A free-standing house	1,048,853
Total			8,125,229

2.2 Housing Development Process

To better assess where the problem with finding housing sites comes from, it is useful to first investigate the underlying process of spatial planning, of which housing development is part, in the Dutch context.

2.2.1 Allocation of Power

As was mentioned in Paragraph 2.1, the responsibility for housing plans was originally laid with the national government, which would develop nationwide plans to implement large-scale housing developments. However, over the last few decades, responsibility has largely shifted from centralized WWII, the country had to be rebuilt, and it was thought that this could only efficiently be done by centralized management. Eventually, this demand decreased, especially after the economic crisis of the seventies (Bruinsma & Koomen, 2018). These days, the positive sides of decentralized spatial planning are more appreciated. Municipalities have better internal knowledge of local circumstances, both spatially as well as in terms of local wishes and needs of the population and can therefore fit a plan better to the local circumstances.

The tool that is used by the municipality to steer spatial planning is called a ‘zoning plan’ (Dutch: Bestemmingsplan). This is a juridically binding document for the government, inhabitants, and companies, that is most often composed by the city planning department (Kenniscentrum InfoMil, 2023b). In a zoning plan, the use and construction possibilities are determined for an area (Rijksoverheid, 2023c).

Although municipalities are the sole governing body responsible for developing such a plan, this does not mean that they do not have to adhere to certain rules. For consistent and coordinated spatial management, the bodies of government (national and provincial), have instruments at their disposal to steer spatial development, called ‘structure visions’ (Dutch: Structuurvisies). This cooperation between different bodies of government is essential to achieve a durable and balanced development of housing and infrastructure. In a structure vision, the vision of spatial policy by the municipality, province or the national government for (parts of) the territory or for certain aspects is described (Kenniscentrum InfoMil, 2023c). A zoning plan is thus always based on the principles of these structure visions. Three types of zoning plans can be developed, as detailed in Table 2.

Table 2. Types of zoning plans (Kenniscentrum InfoMil, 2023b).

Development Plan Type	**Explanation**
Detailed	Most often used for existing sites. Goes into much detail about functions and development.
Global	Most often used for new developments, with optional mandatory future elaboration. If this elaboration is mandatory, the plan must first be worked out in detail before permits can be granted.
Combination	A combination of the above.

A zoning plan always consists of three basic elements as detailed in Table 3.

Table 3. Elements of zoning plan. (Kenniscentrum InfoMil, 2023b).

Development Plan Element	Explanation
Explanation	The explanation forms the substantiation of the zoning plan. Here, the goal, the relevant policies, and a description of the plan area, the relevant physical aspects and the feasibility are elaborated.
Visualisation	A digital map using colours to indicate certain (future) functions. Must be published every 10 years or made available online in interactive or pdf format.
Rules	Definitions, methods of measurements, allowed functions, building heights, etc.

2.2.2 Process of Composing a Zoning Plan

The process of composing a zoning plan consists of several fixed (iterative) steps, and the process can be started by not only the municipality but also by developers who want to acquire new land for development or other parties of interest like civilians (Government, 2021). The municipality can decide whether or not there is a need for a new plan based on these initiatives. When a decision is made on the former, the first step of developing a zoning plan is the publishing of a ‘starting note’ (Dutch: Startnotitie), where the motive for developing a new zoning plan is elaborated thoroughly. In a starting note, frameworks, assumptions, and research questions are made concrete. This makes it clear where the future plan and vision should at least adhere to (e,g. Municipality of Arnhem, 2023). The next steps are elaborated in Table 4.

Table 4. Stages of implementation of a zoning plan (Kenniscentrum InfoMil, 2023a).

Stage	Elaboration
Preliminary Research	After publishing the starting note, research starts into the current situation of the site that is to be redeveloped. The research is about a lot of subjects like soil, archaeology, and ecology. In general, this is about asserting the suitability of a plot for the development at hand.
Concept-Zoning Plan	Next, the municipality is required to publish a concept plan (Rijksoverheid, 2023). However, before this can be done, research into a lot of subjects like soil, archaeology and ecology must be completed first. Once this has been finalized, the municipality swill start working on the concept.
Concept-Zoning Plan Views	After the concept plan has been published, everyone (residents, companies, organizations) is allowed to submit their suggestions on the new plan. This can be done via multiple ways, like online submissions, or

	information meetings. Based on the received views, the municipality can consider changing plans accordingly but is not required to do so.
Design-Zoning Plan	After processing the views, a design (destination) plan is published. This plan is formally presented for inspection for six weeks, in which stakeholders have the option to formally submit views against the plan in its current state. After six weeks, submissions close, and the municipality is required to consider all the views before finalizing the design plan.
Finalizing the Plan	After deciding on implementing views in the final plan or not, the official plan is published. Stakeholders have the option to appeal the decision in the highest court in the Netherlands (Raad van State).
Implementation of the Zoning Plan	If no court cases arise, the finalized plan is legally implemented.

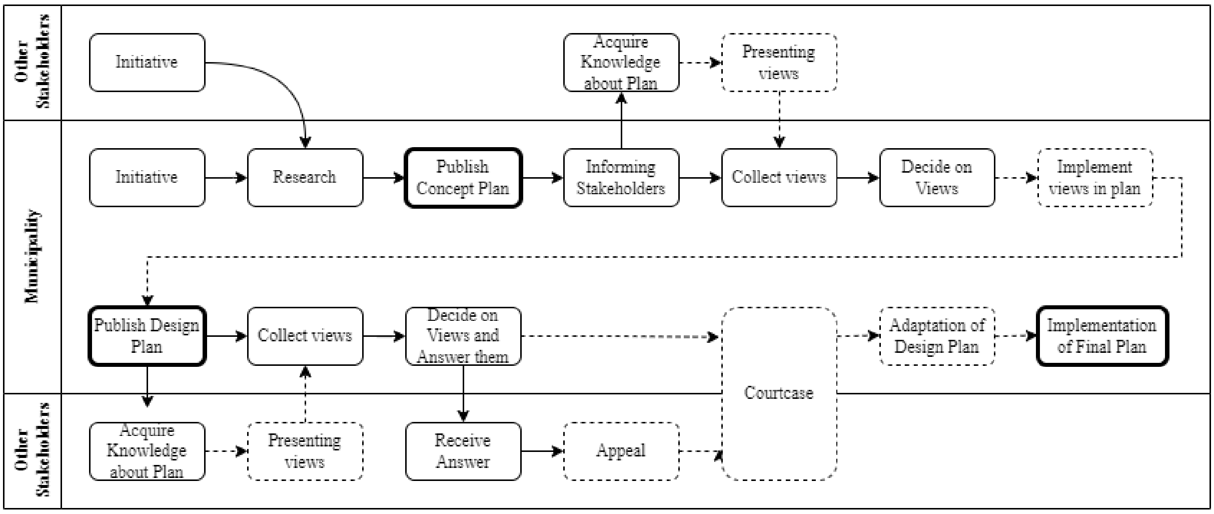

Figure 3. Process of implementing a new zoning plan according to Kenniscentrum InfoMil (2023a).

The steps elaborated in Figure 3 ensure a couple of core principles of the plan. The plan itself provides a transparent, legal basis for development that can provide opportunities for, or limit certain types of development. Additionally, preliminary research and the possibility of other stakeholders' input forces the zoning plan to be thoroughly substantiated. This last point also improves democracy and involvement from the community.

Although it is the municipality's task to publish a plan, they are not required to carry out the work themselves. This has led to a situation where plans are often delegated to other parties. According to Dolstra & Couwenbergh (2020), up to 70% of municipalities delegate the development of plans (partially), and zoning plans are often completely delivered by developers. The following reasons for outsourcing were found.

- Capacity problems due to excessive workload
- The complexity of composing plans.
- The lack of content-related involvement
- The lack of software knowledge

2.3 Stakeholders and Interests

Allocation of housing is one of the key features of a zoning plan. In the literature, a large diversity of criteria to measure the suitability of location for a particular function can be distinguished. However, the choice of criteria to measure suitability by is inconsistent and not always justified (Saleh & Setyowati, 2020) Also, instead of basing the criteria on research, it sometimes happens that authors pick criteria based on their own experience or reasoning (e.g. Albacete, Pasanen, & Kolehmainen, 2012). It can also be seen that several methods are used to classify the criteria for the evaluation of a site's suitability for housing development. Although criteria are often subdivided per topic like public amenity criteria, economic factors, and population factors (Saleh & Setyowati, 2020), there is no consensus on how to divide and pick criteria. This stems from differences in research aim, availability of data, local circumstances, and researchers' insight and personal preference. Patterns of recurring criteria can be distinguished. The first of these is that there is often some form of accessibility to amenities included (Albacete et al., 2012; Liu, Zhang, Zhang, & Borthwick, 2014; Wei & Ding, 2015; Saleh & Setyowati, 2020; Karna, Shrestha, & Koirala, 2023). However, specific amenities differ, and sometimes the accessibility to amenities is simplified as the distance to a downtown area. The importance of access to amenities is nevertheless rarely disputed. Aside from amenities, constraining site characteristics and health safety factors are also often included. These are for instance the existence of roads (Albacete et al., 2012), slopes (Liu et al., 2014), or existing buildings on the plot (Wei & Ding, 2015). Safety factors include air quality (Albacete et al., 2012; Saleh & Setyowati, 2020; Binta Samad & Mahbub Morshed, 2016; Garad et al., 2020) and danger of flooding (Binta Samad & Mahbub Morshed, 2016). In the development process, multiple stakeholders are involved. However, what is the definition of a stakeholder, and who are these? In the following parts, the term stakeholder is elaborated first, after which the different stakeholders that are relevant to housing development are identified.

2.3.1 Definition

According to Mitchell, Agle, & Wood (1997), stakeholders can be persons, neighbourhoods, institutions, groups, organizations, society, or the environment. However, the exact definition is often not agreed upon in literature and must be described in general terms to avoid inconsistencies. According to Sousa (2012), the term stakeholder stems from management theory, and a common definition of stakeholder refers to any group or individual who can affect or be affected by an organization's objectives, policies, and subsequent actions. McGrath & Whitty (2017), use a simplified definition, where a stakeholder is an entity with a stake in the subject activity. This latter definition is applied to this research's subject. The general definition of stakeholders in this research will thus be: "entities with a stake in the development of housing".

2.3.2 General Stakeholder in Housing Development

Multiple researchers have sought to define all stakeholders that are associated with housing development. One of the most complete lists is described by Sousa, (2012) At least seven groups of stakeholders, with multiple subdivisions are identified as visualised in Table 5. Not all stakeholders will be relevant in every project, but it can be expected that in general several stakeholders are present in any housing development project. Although the specific stakeholders can differ, each of these can be expected to have their interests. Sousa, (2012) also mentions that these can clash and that this stems from the fundamental tension persisting in determining whose criteria should be considered. It is a matter of the degree to which stakeholder's interests can thus be accounted for when they conflict with the interests of other ones. Tensions are usually caused by actors who do not feel heard.

Table 5. Universal housing development stakeholders as described by Sousa, (2012).

Quasi-government organization or agency
- District health boards
- Housing authorities or corporations
- Local government
- Post-secondary education institutions

Private sector
- Building and construction businesses Labour and public-sector unions
- Mortgage lenders
- Private landlords Property developers

Government departments or ministries
- Corrections
- Economic development
- Environment
- Finances
- Health
- Housing
- Labour
- Social development
- Statistics
- Transportation

Community-based organisations
- Churches
- Community associations
- Housing resource groups
- Interest groups
- Voluntary and charitable organisations

Housing providers
- Local housing authorities
- Non-profit or cooperative corporations
- Voluntary and charitable organisations

Research-oriented institutions
- Centres for housing research
- Individual departments or faculties
- University housing services

Users and the general public
- Applicants for social assistance
- Current tenants or members
- Potential tenants or members

The stakeholder groups visualized in Table 5 are universal, but specific stakeholders differ per project. Furthermore, it can be expected that there are differences between countries as well. Since this research is scoped towards the situation in the Netherlands, only Dutch equivalents of the Stakeholder groups are relevant. Two types of stakeholders can be distinguished: one that includes stakeholders that are directly involved in the development process like the developer, and one that includes stakeholders that are indirectly involved in the development process because they do not play an active role per se but have a stake in the future development because it could affect them.

2.3.3 Stakeholder Overview

The stakeholders in Paragraph 2.3.2 are not all relevant to the housing development process itself. Three main stakeholder groups can be distinguished: government, developers, and society. The synergy between these stakeholder is visualised in Figure 4.

Government
Since the municipality is the sole body in charge of composing the zoning plan and thus the allocation of housing sites (see Paragraph 2.2.1), they are the most obvious first stakeholder. It is entrusted with the responsibility for realising new housing by the national government. The zoning plan discussed in Paragraph 2.2 is partially responsible for this, together with other societal goals. Additionally, the zoning plan must be in line with provincial and national goals elaborated in the structure visions. Provision of adequate housing is guaranteed by social developers: housing association.

Developers
Aside from the municipality, developers can also play an active role in the identification of housing sites. On the one hand, they can submit a request for a change of the zoning plan, and on the other hand, it often happens that the zoning plan is delegated to them by the municipality (Paragraph 2.2.2). The final decision to change a zoning plan rests with the municipality, but when a developer has a good case against the existing situation and the new development is in line with municipal goals, it can be expected that the municipality is willing to make changes. There are two types of developers: social and private developers. Social developers, housing corporations, and associations used to be government-run instances to provide adequate housing, they used to do a lot of development, but construction is currently at a historic low (partially) due to the lack of access to affordable locations (Autoriteit Woningcorporaties, 2022). In 1992, all housing corporations were privatized, but special rules still apply to them. They are not allowed to make a profit and are thus forced to reinvest any profits into their portfolio. This rule does not apply to private housing developers. These developers primarily built for the free market with the primary aim being business interests. It must however be said that municipalities often make it mandatory to include some percentage of social housing in new development to ensure adequate housing.

Society
Aside from stakeholders that play a direct role, there are also indirect stakeholders. Municipalities represent the interests of higher bodies of government, and local civilians, and developers represent the interests of civilians by developing housing, by sometimes identifying housing sites themselves. When they do not comply with laws or the wishes of these indirect stakeholders, there might be consequences. A zoning plan might be rejected in court, or housing might not be sold. It is therefore that direct stakeholders do not only account for their interests but also for those of indirect stakeholders whom they represent.

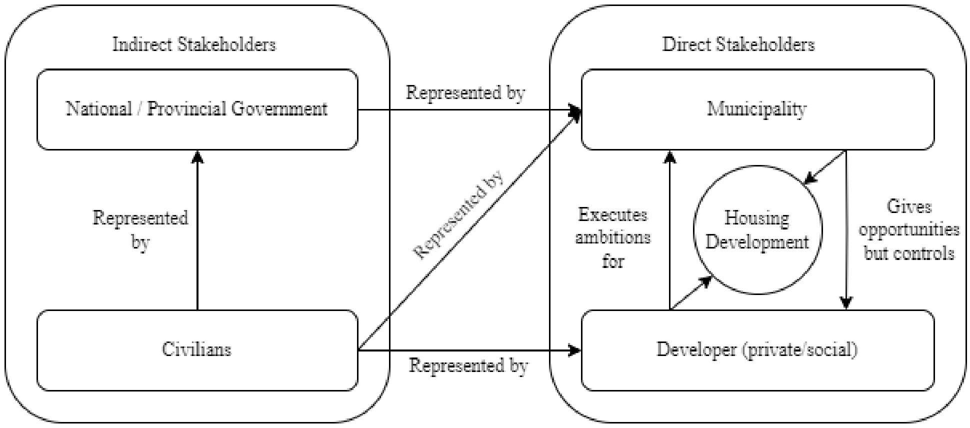

Figure 4. Stakeholder synergy.

2.3.4 Interests

It can be expected that all stakeholders have their interests. These might be in line with each other, or clash. Three main stakeholder groups can be distinguished: government (municipal or higher), developers (private or social), and society.

Government Interests

The Dutch government knows three main scales: national, provincial, and municipal (Rijksoverheid, 2023d). The municipality is entrusted with the responsibility for realising new housing by the national government. The zoning plan discussed in Paragraph 2.2 is partially responsible for this, together with other societal goals. Additionally, the zoning plan must be in line with provincial and national goals elaborated in the structure visions.

The most recent vision of the national structure vision was published in 2012 and is applicable until 2028 (Kenniscentrum InfoMil, 2023c). Until this deadline, the document is focussed on three main goals:

1. Increasing the national competitiveness by strengthening the spatial-economic structure
2. Improving and ensuring accessibility
3. Ensuring a safe environment in which natural and cultural-historic aspects come first

The first point is primarily focused towards maintaining international companies within the Netherlands and attracting additional companies, entrepreneurs, and internationals. This is not just about high-quality space for working, transport and living, but also about ensuring a sufficient supply of education, culture, accessible greenery, and recreational opportunities. For the second point, the government seeks to work together with the decentralized authorities on a robust and coherent mobility system, by strengthening different modalities and their connection to each other. The government focuses not only on more infrastructure or capacity increases but also on influencing demand for sustainable mobility. The third point, a healthy and safe living environment is achieved by focusing on environmental quality, water safety, and protecting natural and cultural heritage (Ministry of Infrastructure and Environment, 2012).

The two main spatial tasks delegated to the municipal government are providing housing for the population of the municipality and protecting societal interests in spatial development via a zoning plan (often in a framework of sustainability), which must in turn be in line with provincial or national interests, as depicted in the structure visions, which are aimed at sustainable development. The branch of government enforcing the government's spatial interests is the municipality. The main interests of the municipality in housing development are thus also fulfilling their two primary tasks, which manifest themselves in enforcing the zoning plan, and other spatial laws that have been set by higher branches of government. Additionally, there are also guidelines set by the government and the Association of Dutch Municipalities (Dutch: Vereniging van Nederlandse Gemeenten (VNG)), that are aimed at protecting societal interest, like health, safety, and the protection of heritage. Municipalities also consider these aspects when designing a zoning plan (Kenniscentrum InfoMil, 2023a). Table 6 gives an overview of interests that were found.

Table 6. Municipal interests in housing development.

Stakeholder	***Interests***
Municipality	*Enforcing spatial laws* • *No construction in protected areas* • *No construction within certain guideline distances* • *Ensuring a housing stock concurrent with demand* • *Ensuring public facilities* • *Complying with structure vision*

Developer Interests

Although not always the case, development is often delegated to developers. For social developers, the primary interest is supplying adequate housing stock (Rijksoverheid, 2015). They can do this by acquiring real estate on the market, or by constructing it themselves. In both cases, it is of importance that this is done in a responsible manner without too many financial risks. Multiple cases are known where this went wrong, like the acquisition of the SS Rotterdam by Woonbron, and the construction of a student housing campus by housing corporation Servatius (Omtzigt, 2022). A prime interest of social developers is thus avoiding risks while fulfilling business interests. Additionally, social developers often have several topics of interests that are specifically mentioned to be important (Table 7)

Table 7. Topics of interest according to the ten largest social housing corporations.

Social Developer	**Important Topics**							
	Affordability	**Sustainability**	**Quality Neighbourhoods**	**Quality Housing**	**Inclusivity**	**Ivolvement / Transparancy**	**Safety**	**Financial Control**
Ymere	x	x		x			x	
De Alliantie	x	x	x	x	x			
Vestia Groep	x	x	x					
Portaal	x	x			x			
AWV Eigen Haard	x	x		x		x		
Rochdale	x	x	x	x				
Lieven de Key	x				x			x
Woonbron	x	x	x	x	x			
Mitros	x	x	x					
Woonstad Rotterdam	x	x	x	x	x	x		
Total	10	9	8	6	5	2	1	1

Affordability is the topic most often mentioned as important, Followed by Sustainability, and Quality neighbourhoods, and Quality Housing.

Private developers are allowed to take as much risk as they wish but are expectedly not inclined to do this to an excessive extent either. This is even specifically mentioned by some of the largest Developers of the country in their mission/vision, like Heijmans, and Van Wanrooij. When looking at the mission/vision or strategy of ten of the largest companies according to Velox Knowledge Platform (2018), several recurring topics can be identified that are universally perceived as important as shown in Table 8, according to their website.

Table 8. Important topics according to the ten largest developers in the Netherlands.

Private Developer	Interests						
	Sustainability	**Affordability**	**Inclusivity**	**Quality**	**Safety**	**Avoiding Risk / Maintaining Stability**	**Accessibility**
BPD	x	x					
Heijmans	x		x	x	x	x	
Van Wanrooij	x					x	
AM	x	x					
Dura Vermeer	x				x		
VanWonen	x	x	x				x
Van Wijnen	x						
De Bunte Vastgoed	x			x			
Vorm	x	x	x				
Amvest	x						
Total	10	4	4	3	2	2	1

Sustainability is universally perceived as important. Affordability and Inclusivity are often perceived as very important factors. Although not all factors are explicitly mentioned by these developers, it can be expected that some topics like safety and quality are also universally appreciated.

Societal Interests

Spatial Interests regarding safety, well-being and protection of heritage are guarded by the government through the zoning plan, which is based on laws and guidelines, and internal knowledge of the municipality (See Paragraph 2.3.3). Aside from that, future users might have interests regarding the location of their house. Schirmer et al. (2014), found multiple location factors like the density of the surrounding area, presence of water, accessibility to transport, and access to amenities.

Interests Summary

Interests concerning the location of new housing differ per stakeholder group, although some might overlap. This becomes evident when comparing the interests that were identified. The primary objectives of the government, represented by the municipality is the enforcement of laws that protect general health, safety, and heritage. Aside from primary goals, both primary stakeholders also have secondary interests that are often aimed at societal goals like sustainability, affordability, and quality neighbourhoods. By combining recurring interests from primary stakeholders, Table 9. Interests of primary stakeholders. is created.

Table 9. Interests of primary stakeholders.

#	Interest	As stated by
1	Protecting health, safety, and heritage.	Municipality
2	Providing adequate housing	Municipality, Social Develop, Commercial Developer
3	Providing affordable housing	Municipality, Social Develop, Commercial Developer
4	Providing public facilities	Municipality
5	Quality Neighbourhoods	Social Develop, Commercial Developer
6	Inclusivity	Social Developer
7	Involvement	Private Developer
8	Fulfilling business interests	Private Developer
9	Avoiding risk	Private Developer
10	Safety	Private Developer
11	Sustainable development / Sustainability in general	Municipality, Social Develop, Commercial Developer

It can be expected that some of these interests overlap in their spatial dimension. The next subchapter therefore elaborates on which specific spatial characteristics are relevant to these interests and includes the resulting list.

2.3.5 Spatial Characteristics associated with Stakeholder Interests

The interests that were found are not specifically represented as important during the screening for new housing sites, but rather as important during the whole development process. Since the activities of stakeholders also include other types of work like the actual development of housing after screening, it must be established which of the interests have a spatial dimension, before these can be translated into spatial criteria. In some instances, this is not a straightforward job since the interests are sometimes represented in abstract terms without substantiation. Therefore, the interests are approached from a literature perspective to connect these interests to spatial characteristics that are associated with them. As will become clear, there is a lot of overlap between the spatial characteristics.

Interest 1: Protecting health, safety, and heritage
Interests that are perceived to be most important by the government are protected by law. This primarily concerns factors like health, safety, and protection of certain areas against development. There are certain guidelines concerning the placement of housing that are rarely deviated from. Surrounding influences on a plot for the measure of suitability are largely included in the guidelines of the Dutch Association of Municipalities (Dutch: Vereniging van Nederlandse Gemeenten (VNG)). They presented the newest version of the Company and Environmental Zoning Guide (Handreiking bedrijven en milieuzonering) in 2019. This is an important work that is often used for spatial decision-making, and it is often quoted on VNG's

website. The report indicates for companies and company branches which environmental subjects can play a part, and which average distances would be fitting for their enterprises.

The advantage of the report is that it uses an integral approach. For each type of company type specifically, a recommended distance for the protection against aerosols, smell, noise and external safety is introduced. The largest of these counts as the overall recommended distance. The functions included in this report are meant for everything from transport functions like airports or industrial, to agricultural types. Currently, the report possesses a semi-legal status, that can only be omitted by motivated and constructive cases in court. What should be considered is that the distances are guidelines, which might need adaptation under special circumstances (Ministry of Infrastructure and Water Management, 2023). Furthermore, distances differ per type of residential area. The distinction is made between a 'quiet neighbourhood', and a 'mixed area'. For mixed areas, the distance norm is reduced by one step, except for functions of category 1 which cannot be reduced further. However, the definition of what entails a quiet or otherwise mixed area is not defined in detail and is to be interpreted by the municipality using the guideline distances (Table 10).

Table 10. Guideline distances between enterprises and housing (VNG, 2019)

Function	**Subcategory**	**Recommended distance (source: VNG)**
Enterprises	Category 1	Quiet Area: 10 m; Mixed Area: 0 m
	Category 2	Quiet Area: 30 m; Urban Area: 10m
	Category 3.1	Quiet Area: 50 m; Urban Area: 30m
	Category 3.2	Quiet Area: 100 m; Urban Area: 50 m
	Category 4.1	Quiet Area: 200 m; Urban Area: 100m
	Category 4.2	Quiet Area: 300 m; Urban Area: 200 m
	Category 5.1	Quiet Area: 500 m; Urban Area: 300m
	Category 5.2	Quiet Area: 700 m; Urban Area: 500m
	Category 5.3	Quiet Area: 1000 m; Urban Area: 700 m
	Category 6	Quiet Area: 1500 m; Urban Area: 1000 m

One function type that is not included in the VNG report is the distances between housing and utility infrastructure such as powerlines. Currently, the legal minimum distance between housing and powerlines is 6 meters, but over the last two decades, health concerns have come up regarding the Electromagnetic Radiation (EMR) that is produced by these lines, produced by statistical research into the relation between EMR and child Leukemia (Ahlbom et al., 2000; Kheifets et al., 2010) Although it is not clear how this relations works (Kelfkens, 2007), the Ministry of Housing, Spatial Management and Environment (VROM), has introduced a precautionary policy in 2005, where power lines are put underground or rerouted when possible, existing housing under power lines is being bought up by the state, and no more new housing, and other functions where children are present like schools are supposed to be constructed near power lines. The Dutch Institute for Health and Environment (Dutch: Rijksinstituut voor Volksgezondheid en Milieu (RIVM)) has produced guideline numbers that should be used for planning new housing near power lines as illustrated in Table 11, although the exact distance must be calculated for each location specifically. The rules are less strict for gas and water infrastructure: 30 meters for gas pipes, and no indicative distances for water pipes.

Table 11. Indicative distances between housing and power lines according to RIVM (2023)

<table>
<tr><th>Function</th><th>Subcategory</th><th>Theme</th><th>Legal Minimal distance of housing to function</th><th>Recommended distance of housing to function (RIVM, 2018)</th></tr>
<tr><td rowspan="6">Power Lines and Cables</td><td>50 kV</td><td>EMR</td><td>No indication</td><td>40 m</td></tr>
<tr><td>110 kV</td><td>EMR</td><td>3 m</td><td>50 m</td></tr>
<tr><td>150 kV</td><td>EMR</td><td>4 m</td><td>80 m</td></tr>
<tr><td>220 kV</td><td>EMR</td><td>5 m</td><td>45-215 m</td></tr>
<tr><td>380 kV</td><td>EMR</td><td>6m</td><td>45-215 m</td></tr>
<tr><td>combination</td><td>EMR</td><td>No indication</td><td>200 m</td></tr>
<tr><td colspan="3">Gas pipes</td><td>30 meters</td><td>30 meters</td></tr>
<tr><td colspan="3">Water pipes</td><td>0 meters</td><td>0 meters</td></tr>
</table>

Additionally, to the guidelines by VNG, and the recommended distances to utilities by RIVM, The Dutch Municipal Health Service (Gemeentelijke Gezondheidsdienst (GGD)), recommends several guideline distances between housing and infrastructure as elaborated in Table 12.

Table 12. Recommended distances between housing and roads according to GGD. (2023).

<table>
<tr><th>Road Type</th><th>Recommended Distance</th></tr>
<tr><td>Motorway</td><td>150 meters</td></tr>
<tr><td rowspan="2">Busy road</td><td>Urban area: 25 meters</td></tr>
<tr><td>Rural area: 50 meters</td></tr>
<tr><td>Rail (not specified whether train/metro/tram)</td><td>30 meters</td></tr>
</table>

Aside from guidelines, some criteria are fully legally substantiated. These are the laws on the protection of heritage and drinking water areas. When concerning heritage, this can be either human-made or natural. The National Service for Monuments (Dutch: Rijksdienst voor cultureel erfgoed) makes the distinction between three types of built heritage: National monuments (Dutch: Rijksmonumenten), provincial monuments (Dutch: Provinciale monumenten), and municipal monuments (Dutch: Gemeentemonumenten). These are historic buildings, archaeological sites, or man-made green structures like parks, and are protected due to their cultural-historic value. Aside from man-made structures, there are also natural protected areas These are protected by law as well. All protected natural areas can be placed in either of the following two categories from Table 13. In both types of areas, it is not allowed to build new housing.

Table 13.Types of protected natural areas in the Netherlands ((Rijksoverheid, 2023b).

Type	**Elaboration**
Nature Network Netherlands (Dutch: Natuurnetwerk Nederland (NNN))	A network of areas in the Netherlands where nature has priority. The network helps prevent plants and animals in isolated areas from becoming extinct and nature reserves from losing their value. Larger nature reserves are beneficial for biodiversity and the quality of the living environment. If nature reserves are also connected, animals and plants can survive more easily. (Atlas leefomgeving, 2023)
Natura 2000 areas	Natural areas that are part of a network of protected natural networks in the European Union, where certain species of animal and their natural habitats are protected to preserve biodiversity.

Lastly, local soil conditions can prevent development as well. As is mentioned about protected monuments, archaeological conditions, or suspected conditions can prevent development. Each municipality has divided its area into archaeological zones, which indicate the depth of soil that may be affected during construction without research (Figure 5).

Two other types of soil conditions may affect whether a plot is suitable for housing: The possibility of pollution, and a drinking water area. Some municipalities have polluted soil, especially in the larger cities. This is often due to the historical location of industry, as is the case with Amsterdam (Figure 6). This limits the amount of soil that may be dug up, which increases the costs of construction due to additional measures that have to be taken when this is the case.

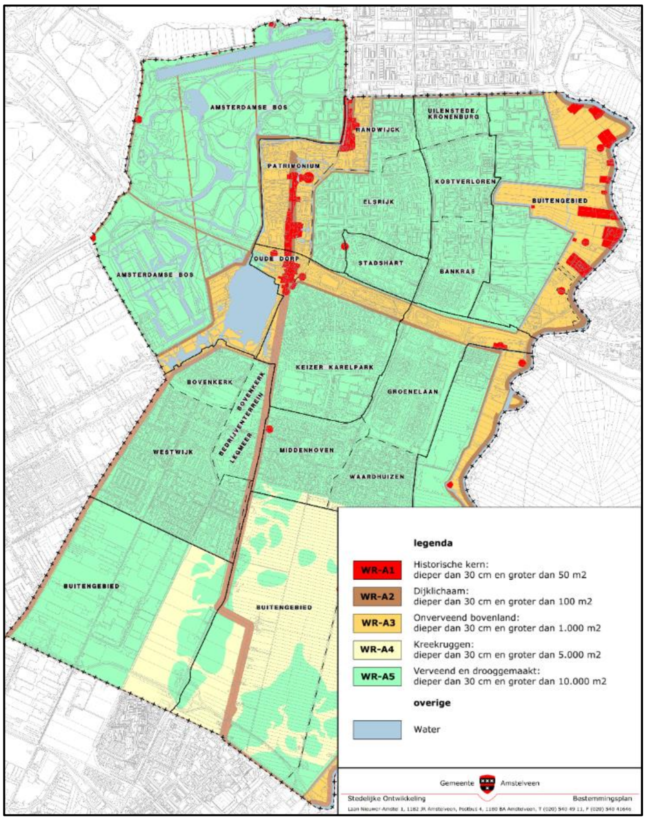

Figure 5. Example of an archaeological zoning map (Municipality of Amstelveen, 2018).

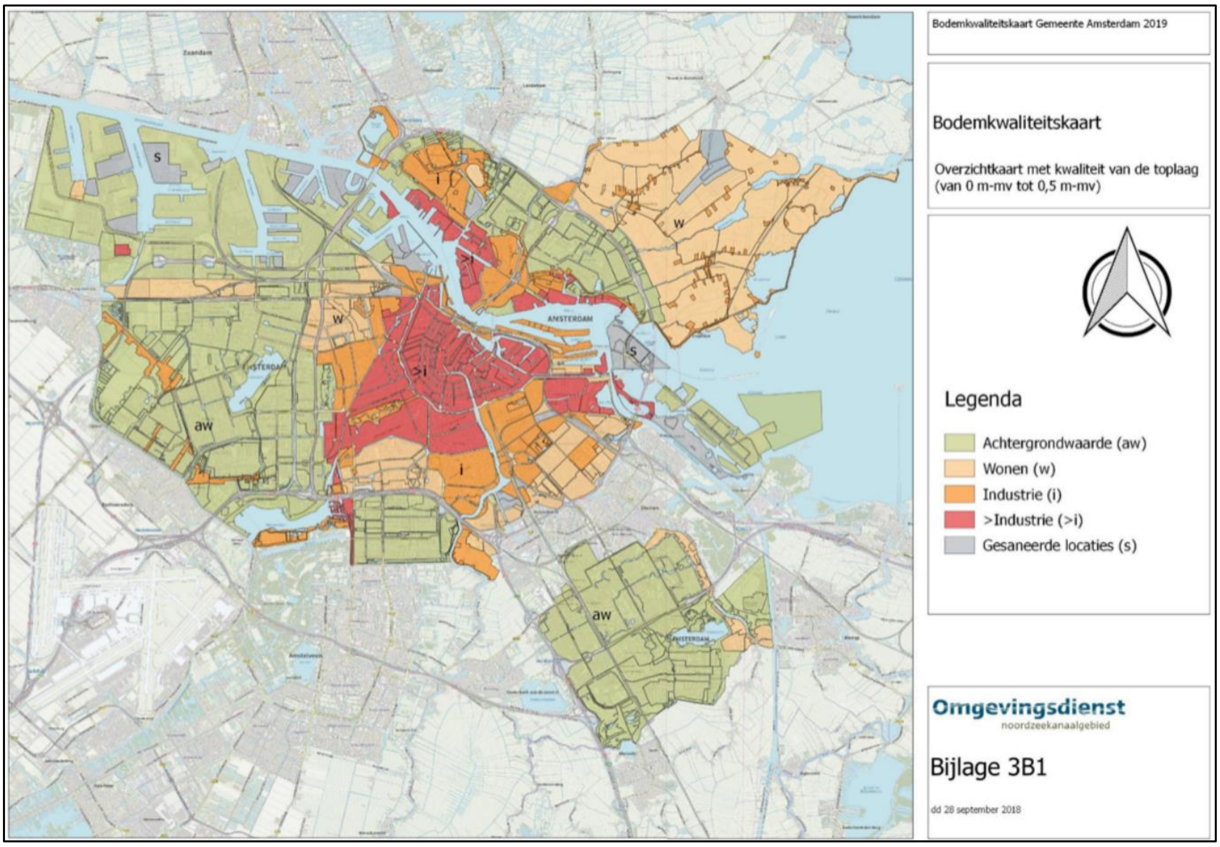

Figure 6. Map visualizing soil conditions in Amsterdam (Municipality of Amsterdam, 2022).

The final soil condition that may obstruct development is the presence of a drinking water protection area. In the Netherlands, provinces are responsible for protecting drinking water sources (Atlas Research, 2022). Although the rules slightly differ per province, a twofold distinction can generally be made between drinking water areas which can be seen in Table 14.

Table 14. Drinking water protection areas classification (Atlas Research, 2022)

Type of water winning area	**Elaboration**	**Limitations**
Water winning site	Site where water is retrieved	No construction allowed
Drinking water protection site	Area surrounding a water winning site	No limitation for housing development, only for more pollution-prone functions like industry,

Interest 2 and 3: Providing adequate and affordable housing

Affordability and availability are two often mentioned points by stakeholders to be important. However, the spatial aspects mentioned in the sustainability list primarily concern aspects in existing neighbourhoods, and do not go much into detail about new sites and the possibility that the new site represents for implementation of housing. When ‘adequate’ is perceived as a quantitative measure, the spatial domain logically becomes the size of the site where development can take place. This size is not only relevant 2 dimensionally, by floor area size, but also 3-dimensionally since building height plays a part in this. Consequently, the volume where construction can take place is connected to this interest. Spatial characteristics are thus the plot size and possible height restrictions on this site.

The housing market is a typical supply market since there is a large stock and the net addition annually is quite small (Dam & Eskinasi, 2013). Because production of new housing is quite slow, and reaction to demand changes only takes place with a big delay due to development time, the market is also responsive to factors in the living space market, and financial market, but also to stock being for sale. Prices are almost entirely dependent on existing stock (Dam & Eskinasi, 2013). New housing prices react to this via residual ground prices, which are mostly used as the price of ground for new development. The housing price is thus indirectly dependent on three submarkets: the housing market, the financial investment market, and the construction market. However, the price can directly be linked to the residual ground price, since this is calculated by subtracting realization costs from the market value of a plot (de Leve & Kramer, 2020).

Interest 4: Providing public facilities
This point is relevant for residential development because it concerns the accessibility to facilities or amenities. This point can logically be classified as inherently spatial. The network of public facilities represents a fundamental feature within urban settlements, that dramatically influences both the liveliness of the built tissue, as well as the general level of life quality for the members of the local community (Badescu etal., 2016). The spatial characteristic connected to these interests is thus the range of facilities that are present at or around the site that is being analysed.

Interest 5: Quality Neighbourhoods
A unanimous definition of what is perceived as a qualitative neighbourhood is not provided by the stakeholder interests. However, the network of public facilities represents a fundamental feature within urban spaces, that dramatically influences both the liveliness of the built tissue, as well as the general level of life quality for the members of the local community. (Badescu et al., 2016). The spatial characteristic connected to these interests is thus the range of facilities that are present at or around the site that is being analysed and the consequential attractiveness. (Rahman et al., (2012) also perceive the accessibility of these amenities as important, and add several infrastructure aspects, together with environmental qualities:

- Infrastructure
- Walkability
- Noise nuisance
- Air quality
- Pollution levels

At first sight, this variable concerns the building quality. However, Nainggolan includes ‘a good area for employment’ as being part of this point as well. Therefore, the accessibility to employment must be included as a spatial characteristic. What can be seen in the literature is that qualitative neighbourhood design is often associated with sustainable neighbourhood design. For additional spatial characteristics, see Interest 11.

Interest 6 and 7: Inclusivity and Involvement
(Kerr, 2021) did research into inclusivity and involvement in urban planning and made an overview of aspects that were relevant for doing so. Another literature review by Liang et al. (2021) builds upon this research and adds a couple of features. Their results conclud that inclusiveness is comprised of spatial, social, environmental, economic, and political dimensions in which the characteristics of participation, equity, accessibility, and sustainability are sometimes interwoven. For the spatial dimension, they identified the following list of factors to be most often mentioned as important:

- Access to utilities
- Fair land rights and tenure
- Access to transportation
- Employment
- Financial Services
- Cultural Services

Excluding groups from society by the lack of access to these amenities can have multiple negative effects. Transport energy expenditure is an area in which exclusionary planning practices have a detrimental effect in terms of urban development. Residential planning in urban areas in an era of high population increases has struggled to keep pace, and such planning where it exists is often predicated on the use of private transportation for residents of urban areas far away from economic centres of cities (Kerr, 2021).

Interest 8 & 9: Fulfilling business interests and avoiding risk
For commercial developers, it can be expected that fulfilling business interests is the main objective, since without doing so, a company is not viable. The same can be said for the social developer as well, although these are required by law to reinvest their profits in their portfolio as is described in Paragraph 2.3.4. As was mentioned in the paragraph ‘Providing affordable housing’, the price of housing is dependent on multiple submarkets. One of the main interests of developers is risk, expectedly because these can cause unexpected delays, which in their turn can result in additional costs reducing the profit margin. According to Factors, Newell, & Steglick (2020), location risk factors are associated with heritage, contamination, and ecology. According to the law on archaeology from 1988, archaeological findings must always be reported, and it is possible that additional research must be conducted before work can commence. The same goes for unexpected contamination in the soil. Aside from soil characteristics, the site surface might also have limiting factors. These could be protected monuments are natural areas, as elaborated in Interest 1. Additionally, unexpected, protected ecology might be found on the surface.

Interest 10: Safety
According to Rastyapina & Korosteleva (2016), urban safety ensures the safe life of the population on the basis of a combination of factors. Their article contains a theoretical analysis of the classification of factors forming urban safety of an inhabited area and they divide all factors forming the local urban safety into five groups: natural, architectural, social, environmental, technogenic, infrastructural and urban.

In the Netherlands, the most important natural aspect that should be considered is that of water (PBL Netherlands Environmental Assessment Agency, 2013), and these problems stem from climate change. The results of these are that the sea level rises, and that drainage problems arise from large river discharges. The direct spatial effects of these problems are in the first case the risk of flooding of low-lying sites, and salinification of the soil. For housing the former effect is the most dangerous one, since saline soil primarily poses a problem to non-residential development (Informatiepunt Leefomgeving, 2023). Therefore, the first spatial aspect is that of avoiding flood-prone sites.

Interest 11: Sustainable development / Sustainability in general
The most often mentioned interest is that of sustainability (the only interest mentioned by all stakeholders). However, the interpretation of what sustainability constitutes seems to be inconsistent, since it often happens that interests that are often considered as a part of sustainability are mentioned separately. Many authors agree that it would be more logical to use a multivariate yardstick that would offer a `sustainability profile' for the dwelling (Priemus, 2005). (Nainggolan et al., 2020), did a literature study on which characteristics were most often mentioned as important for sustainable neighbourhoods, and found the ten most important characteristics as summarized in Table 15.

Table 15. The 10 aspects of sustainable neighbourhoods according to Nainggolan (2020).

#	**General Sustainability Aspects**	**Elaboration**
1	Physical building	Materials, construction, building shape, physical building, climate change adaptation consequences without incurring damage, green area, and building durability, etc.
2	Energy	The energy use of the building, building emission, the using of technology for new energy resources, maintenance etc.
3	Waste, water and wastewater (WWW)	managing solid waste, reusing wastewater, using the potential of rain water, etc.
4	Site & Surroundings	Land use, location, green infrastructure, facilities, shops, health services, children's areas, leisure facilities, green open public spaces, school, etc.
5	Human behaviour	Not polluting the environment, ecological behaviour, pro- environmental behaviour.
6	Quality of housing	House meets the needs, self-support financial system, building management and policy, circular economy, a good area for employment opportunities, etc.
7	Culture and values	It is important that these apply in housing.
8	Communication and transportation	The availability of internet networking, pedestrians, bikeways, public transportation services, green transportation, properly integrated, etc.
9	Safety and comfort living	Healthy place to stay, healthy community, sustainable communities, low crime, safety, acoustic comfort, light quality comfort, noise level, etc.
10	Housing price and availability	Affordability and availability are important for housing.

Many of the sustainability aspects have already been elaborated in other interests. ‘Site and surroundings’, and ‘quality of housing’, can be linked to Interest 5: ‘Quality Neighbourhood’. Furthermore, ‘communication and transportation’, factors have already been mentioned in multiple other interests, safety has been elaborated under Interest 10, and ‘housing price and availability’ has already been elaborated in Interest 2. This leaves, ‘physical building’, ‘energy’, ‘WWW’, ‘human behaviour’, and ‘culture and values’. The first two of these concern building characteristics and thus do not apply to a specific site. Since this research is about site characteristics, these points are perceived to not be related to spatial characteristics, although it does relate to the interest 7 ‘Quality Neighbourhoods’, since buildings are part of neighbourhood quality (Rastyapina & Korosteleva, 2016). ‘WWW’, however, is relevant. The only spatial constraint that exists for housing construction in the context of water management in the Netherlands is the illegality of constructing within drinking water protection areas. Additionally, many water surfaces are essential for shipping, wildlife, or drainage (Ministry of Infrastructure and the Environment & Ministry of Economic Affairs, 2015). The human behaviour described by (Nainggolan et al., 2020) is primarily focussed on environmentally conscious behaviour. This is not a spatial matter and does not yield spatial variables Lastly, as is discussed in Paragraph 2.1 and Paragraph 2.2, the Netherlands has known an extensive planning system for over a century. This system is aimed at guarding societal interests, including culture and values like sustainability, protection of natural and cultural areas, qualitative design with access to amenities, and mixed neighbourhoods (Lodder, Rotmans, & Braungart, 2014).

2.5 Spatial Analysis Methods

The large number of criteria that contribute to whether a plot is potentially suitable, on to which magnitude, makes it a complex task to determine this. A plot might be very suitable according to one criterion but be completely excluded from analysis by another one.

2.5.1 Multi-Criteria Decision Analysis (MCDA)

When researchers are dealing with a large number of criteria in similar analyses, the most commonly used method to determine the overall outcome is the multi-criteria decision analysis (MCDA). Alternative names for MCDA found in the literature are Multi-Criteria Analysis (MCA), multi-criteria decision-making (MCDM), multi-objective decision analysis (MODA), multiple-attribute decision-making (MADM) or multi-dimensional decision-making (MDDM). These methods can be defined as 'collection of formal approaches which seek to take explicit account of key factors in helping individuals or groups explore decisions that matter’ (Belton & Stewart, 2002). Multiple-criteria decision analyses helps decision makers in analysing potential actions or alternatives based on multiple incommensurable factors or criteria, using decision rules to aggregate those criteria to rate or rank the alternatives (Greene et al., 2011) They have been applied in many fields, e.g., environment, geography, soil science, land-use planning, and community planning (Saleh & Setyowati, 2020). Examples of land-use planning are the work of Thomson & Hardin (2000)and Liu et al. (2014).

Basic Elements

Although more than 100 approaches were already identified in the 1980s, all approaches include a fixed set of elements (Dean, 2022), as elaborated in Table 16.

Table 16. Basic elements of an MCDA according to Dean (2022).

Element	**Elaboration**
Option	An alternative course of action proposed to address a perceived problem and achieve an overarching result.
Objective	An intended and specific aim against which any proposed option is being assessed. Objectives are usually clustered around different overarching appraisal and evaluation dimensions. Sometimes, objectives are instead grouped according to their geographical scope and temporal dimension.
Criterion	A specific measurable indicator of the performance of an option in relation to an objective that allows measuring the extent to which an option meets that objective. In principle, however, any objective may imply several different criteria. Another possible criterion for assessing growth maximization is, for example, the actual individual consumption per capita. It is possible to distinguish between quantitative indicators, measuring the performance of an option in a numerical fashion, and qualitative indicators, containing a (qualitative) description of the performance of the option. Qualitative criteria are generally more subjective than quantitative criteria as the former indicators tend to be largely based on the personal feelings, perceptions and attitude of the people involved in the MCA exercise.
Performance Score	A number, belonging to a given, that identifies the performance of an option against a specific objective/criterion. High-performing options are ascribed high scores, whilst low-performing options score lower on the scale. Critical objectives and criteria may also be assigned some constraints in the form of specific threshold values, which place some restrictions concerning the worst acceptable performance of an option against those criteria.
Criterion Weight	A coefficient which is commonly intended to represent the level of importance of an objective and corresponding criterion relatively to the other objectives and criteria under consideration. However, the actual meaning of weights can change substantially according to the different MCA method employed.

Approaches

Despite the inclusion of all the basic elements in Table 16, there are also several distinctions to be made between various approaches. Dean makes distinctions between different approaches, as visualized in Figure 7.

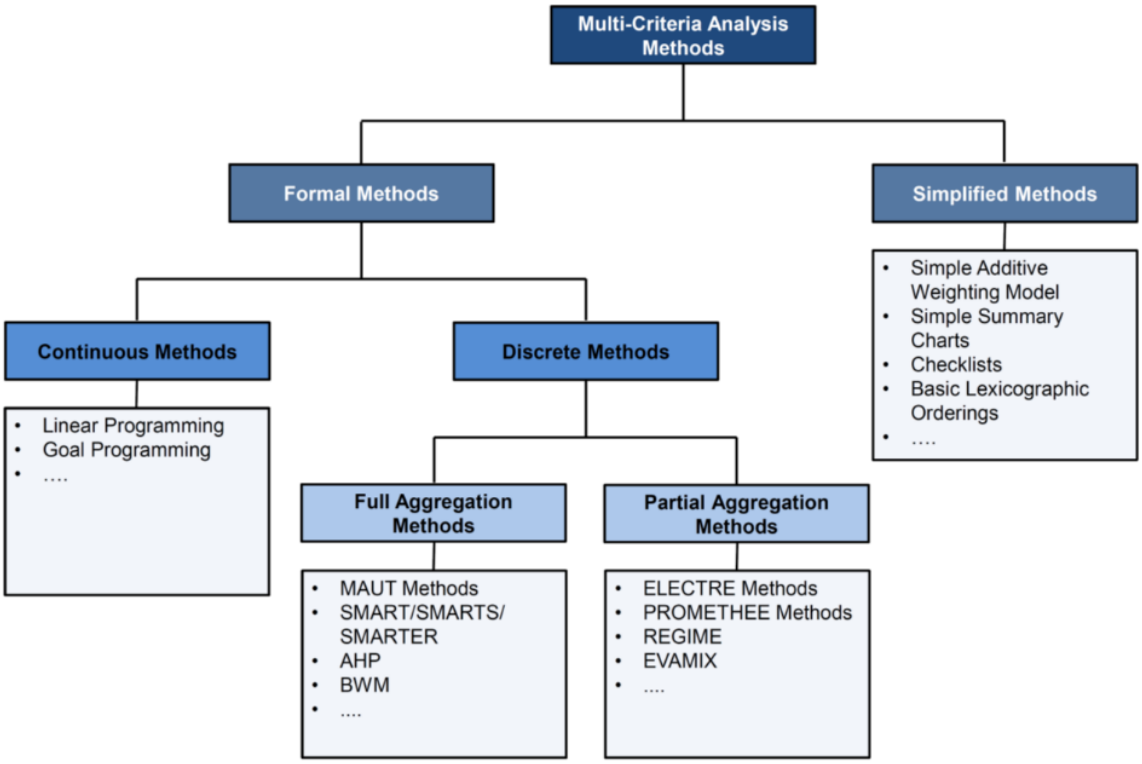

Figure 7. Different distinctions between MCA approaches (Visualised by Dean, 2022).

Dean (2022) makes three distinctions in the classification of MCDA methods. He elaborates them as elaborated in Table 17.

Table 17. Distinctions in MCDA methods according to Dean (2022).

Distinction	Elaboration
1: Formal vs. Simplified	The first distinction that makes is between formal and simplified methods. He states the following: Formal methods are the most elaborate and time-consuming form of MCDA's, but that due to time and capacity constraints, simplified methods are sometimes chosen instead. These can be quite flexible and are easy to understand. However, it must be noted that, if used improperly (with no consideration of the basic rules), elementary methods are likely to lead to many inconsistencies and errors. Formal methods are thus more likely to yield reliable results.
2: Continuous vs Discrete	Formal methods consist of two sub-methods: continuous and discrete ones. Problems that deal with an extremely large number of possible options continuous methods are most commonly applied. In contrast, discrete methods are more suitable for real-world planning and policy problems, where the alternatives to assess are relatively limited and well-defined.
Full vs. Partial Aggregation	The last distinction is made between full or partial aggregation methods. Full aggregation discrete methods aim at synthetising the performances of an option against all the different criteria into a single, global score.

These methods include, amongst others, the Multi-Attribute Utility Theory (MAUT) methods, whose aim is to determine an overall utility of an option under study with reference to a given number of decision criteria, which here are termed ‘attributes’. The multi-attribute utility function can assume different forms according to the nature of the problem at hand and the types of criteria considered in the analysis. In the simplest case, it presents a linear form so that the overall utility of an option can be calculated as a weighted sum of the utility functions for each individual criterion. In other words, given an option a and a set of N appraisal criteria, the overall utility U of a, measured against the N criteria, is calculated using the following equation:

$$u_x = \sum_{j=1}^{n} w_j * u_j = w_1 * u_1 + w_2 * u_2 + \cdots + w_n * u_n \qquad (1)$$

$$w_x = \sum_{j=1}^{N} w_j = 1 \text{ and } 0 \leq w_j \leq 1$$

A typical multi-criteria problem is represented by a situation where there is no optimal solution: option a1 may be better than option a2 according to one criterion but, at the same time, it may be worse than a2 according to another criterion, so that eventually, there is no best option. Thus, full aggregation methods assume that the decision-makers involved in the decision-making process have a complete preference system, which enables them to produce a complete rank order of the options at hand. Partial aggregation methods reject this view, and instead seek to ‘rank’ options from best to worst by comparing them one by one and describing the relative dominance of one option over another.

Aside from MAUT, there is also the Analytic Hierarchical Process (AHP) method, developed by Saaty (1980). This method is strongly related to the MAUT method. Essentially, this method equates to a MAUT method, with a specific approach to determining weights, namely a pairwise comparison.

Weights

By including weights to attributes in a MCDA, it becomes possible to describe relative importance. When all attributes are deemed to be equally important, they would all receive a weight of 1/*N*, with *N* being the number of attributes. However, it is expected that users find some criteria more important than others, and therefore equal weights are rarely applied in real-life problems. Determining the right distributions is hard to identify objectively, and is, therefore, a controversial subject (Dean, 2022). Multiple methods, as summarized in Table 18, have been proposed to determine them.

Table 18. MCA weighting approaches as found by Dean (2022).

Proposed weight determination approach	Source
Deriving weights (directly or indirectly) from past decisions on problems similar to the decision-making situation under study.	Nijkamp and colleagues (1990)
Using weights to differentiate and strike a balance between short-terms and long-term objectives.	Van Pelt (1993)
Using weights to reflect ethical principles like an 'ecological stability' position, leading to higher weights for criteria related to environmental dimension. Different weighting schemes should thus be used to examine their consequences on the final option ranking.	Munda (2004 and 2008)
Testing different sets of weights as part of an interactive process between the analysts and decision-makers.	Australian Resource Assessment Commission (RAC, 1992)
Deriving weights from policy documents and government guidelines.	Dimitriou and colleagues (2010) and Brown and colleagues (2001)
Roleplaying the position of different stakeholders to ensure that the chosen weighting scheme reflects the interests of all the different parties and groups involved or affected by the given decision-making situation.	Dodgson and colleagues (2009)
Deriving weights directly from problem stakeholders as part of a participatory MCA exercise.	Several authors including Stirling and Mayer (2001), Proctor and Drechsler (2006) Macharis and Bernardini (2015)

Dean (2022) also states: *"If weights are chosen by the analysts or the decision-makers, they unavoidably turn out to be largely arbitrary. They will thus tend to vary according to the will of the person (people) in charge of the process."* The last of the approaches in Table 18 is therefore expected to be the most reliable since the weights are based on research. However, small discrepancies may be expected.

A pairwise comparison is unique to the Analytic Hierarchy Process (AHP). In assessing weights, the decision maker is asked a series of questions, each of which asks how important one criterion is relative to another for the decision being addressed (Pearman & Phillips, 2014). For a set of predetermined criteria, the decision-maker is required to repeatedly pick the most important criterion from different pairs. These decisions are gathered and the importance of one criterion over another is indicated on a 9-point scale. Using a complex algorithm, relative weights are then calculated on a scale between 0 and 1, where the sum of all weights always equals 1. To make sure that the decision-maker makes consequent choices, a consistency ratio is always included in a pairwise comparison. This ratio indicates the level of consistency in assigning levels of importance to one criterion over others and may not exceed a certain threshold value.

2.5.2 Geographic Information Systems (GIS)

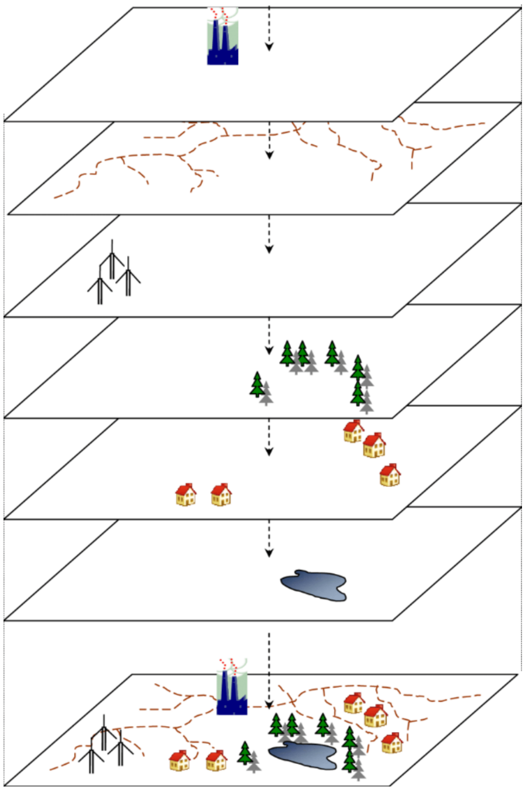

Figure 8. Visualisation of different data layers that can be created about a geographical location, from (Tegou et al., 2007)

For the last thirty years, a combination of MCDA with GIS has been used to analyse spatial problems (Greene et al., 2011). ESRI, (2023), defines GIS as 'A spatial system that creates, manages, analyses, and maps all types of data'. The most basic intention underlying spatialised applications of MCDA is to augment the traditional question of 'what' with the additional question of 'where' (Malczewski, 1999). GIS allow researchers to do so in a structured and integrated manner. A GIS always consists of the following elements: Software, Hardware, Data, and Personnel (Ali, 2020). Sometimes, hardware is added to this list as well (Hussain, 2016). The main principle of data organization in GIS is that of a spatial data layer (Huisman & de By, 2009), as visualised in Figure 8. A spatial data layer is either a continuous or a discrete field, or a collection of objects of the same kind. Data layers can be overlaid with each other, so as to study combination of geographic phenomena and the relations between these. This is consequently often called a 'map overlay analysis' (MOA). Data manipulation and analysis can be achieved using a multitude of GIS functions (differencing per system), that can be classified in multiple ways. Huisman & de By (2009), classify the multitude of GIS functions according to Table 19.

Table 19. General classification of GIS functions according to Huisman & de By (2009).

GIS Functions	**Elaboration**	**Function Examples**
Classification, Retrieval, Measurement	Are of these functions all performed on a single layer and are based on the associated attribute data.	Assignment of features to a class on the basis of attribute data. Selective search of attribute data. Joining different classes of objects based on comment characteristics. Calculation of distances/ areas, etc.
Overlay Functions	These belong to the most frequently used functions. They allow the combination of two or more data layers, comparing them position by position, and treating overlapping and non-overlapping areas in a distinct way. Many GISs allow for an	<u>Intersecting layers</u>: Finding areas that overlap. Difference of layers: Find parts of layers that do not overlap. <u>Union of layers</u>: Merging multiple layers into one. <u>Dissolving layers</u>: Moulding overlapping features into one.

	overlap through an algebraic language, expressing an overlay function as a formula in which the data layers are attributes.	
Neighbourhood Functions	Whereas overlays combine features on the same location, neighbourhood functions evaluate the characteristics of an area surround a features location.	<u>Search functions</u>: Finding areas within a certain distance. <u>Buffering</u>: Determining as spatial envelope around features. <u>Interpolation</u>: Predict unknown values based on nearby known values.
Connectivity Functions	These functions work on the basis of networks, which represent spatial linkages between features	<u>Contiguity functions</u>: Evaluate the characteristic of a set of connected spatial units. <u>Visibility functions</u>: Compute points visible from a certain location.

Development of GIS started after an initial pioneering period from the late 1950's onwards (Waters, 2018), and has steadily progressed since. The period from 1975 to 1990 saw the commercialization of GIS (Ali, 2020; Waters, 2018). Since this era, GIS has been coupled with MCDA methods regularly for spatial problems, as is evident from numerous examples in this research. After 1990, GIS progressed with specific applications in different fields, initially as archive systems, analysis systems, presentation systems, and finally as the decision-making systems (Xhafa & Kosovrasti, 2015). This was partially caused by the presence of multiple favouring ingredients like cheaper, faster and more powerful computers, multiple software options and data availability, and the launch of new satellites and integration of remote sensing technology (Ali, 2020).

Since 2010, a new era can be distinguished: that of open-source data (Ali, 2020). Following a decade of rapid development, the contemporary domain of open-source software and data presents numerous opportunities to conduct a large number of urban analytical processes from modelling to visualisation, and is increasingly seen as a robust alternative to proprietary software (Boeing, 2017; Lindberg et al., 2018; Morley & Gulliver, 2018; Rossetto et al., 2018; Smith, 2016; Yang, Heppenstall, Turner, & Comber, 2019, as cited in Yap et al., 2022). QGIS is the most popular free GIS tool in the world. Rosas-Chavoya et al. (2022) conducted a bibliometric analysis of documents published in Scopus from 2005 to 2020 of 931 manuscripts and found that the annual rate of publications increased 40.3%. Aside from that, they conclude that there is a growing acceptance of QGIS by the scientific community. According to Rosas-Chavoya et al. (2020), this has been largely influenced by the extensibility of the software, and the dissemination of scientific studies on development of plugins and applications in various areas of knowledge.

Aside from practical opportunities, open-source GIS also provides multiple societal opportunities, namely, to promote the democratization of geographical information, the transparency of governments and institutions, as well as social, economic, and environmental opportunities (Mobasheri et al., 2020). However, what should be noted is the following. According to Yap et al. (2022), there is still much room for development. A significant chasm continues to exist between theoretical discourse and the range of functions offered by tools. Notably, the representation of tools for urban planning tasks is largely skewed towards the site analysis phase. However, they maintain their position on the potential of the open-source ecosystem to meet the professional needs of modern-day urban planners, which is also shared by Mobasheri et al. (2020). Multiple studies, like that of Sandhya (2020), conclude that this is indeed the case after applying open-source GIS in real-world problems. Open-source GIS provides multiple opportunities, namely, to promote the democratization of geographical information, the transparency of governments and institutions, as well as social, economic and environmental opportunities (Mobasheri et al., 2020)

2.5.3 GIS Strengths

Perhaps MCDA's greatest strength is its ability to simultaneously consider both quantitative and qualitative criteria, as long as the latter can be represented using an ordinal or continuous scale (Greene et al., 2011). Many approaches of implementing a GIS-MCDA are possible, based on a large number of factors, and selection of an appropriate method or combination of methods depends on the context (Greene et al., 2011). To create visualised suitability maps for users and decision makers, the integration of MCDA and GIS has been widely promoted for solving spatial problems in urban assessment and planning (Phua & Minowa, 2005). These spatial problems stem from multiple fields of urban development (Saleh & Setyowati, 2020). Examples are low-income housing siting (Thomson & Hardin, 2000), finding the optimal retail location (Trubint, Ostojić, & Bojović, 2006) or identifying flood-prone areas (Sultana Nasrin Baby et al., 2021).

2.6 Conclusion

Studying the literature has provided useful insights into the background of the research problem. It was found that the cause of the Dutch housing shortage is a multi-dimension challenge partially caused by economic choices from the past, and on the other hand exacerbated by a chronic scarcity of available space. The question that is central to this challenge is where to do this. Three stakeholders were identified in the screening process for new housing sites, and the determination of level of suitability of these locations. These were: government, the developer, and society indirectly, answering the first sub-research question.

Whether a plot is deemed suitable for development is based on the stakeholder's interests concerning development, or from other stakeholder groups that they represent. Some of the most important societal interests are ensured by laws and guidelines enforced by municipalities, like natural or cultural heritage, or the protection of drinking water. However, these are not all the interests that stakeholders have in the spatial context. Characteristics that influence the price of housing on a site, or the feasibility of development are also important. Until know, it has not been thoroughly researched what the complete set of interests is of all stakeholders involved in the spatial identification of housing development sites. Therefore, an analysis on stakeholder interests was conducted. For Government, policy documents, structure visions, and laws were analysed to come up with the interests that the municipality seeks to protect. For developers, literature on the development process, and company-stated missions, visions, and public documents were reviewed to come up with a set of additional developer interest. Societal interests were assumed to be included in government interests, and thus not further elaborated.

All interests could be aggregated into a single list of general interest that answered the second research question:

- Sustainable development / Sustainability in general
- Protecting health, safety, and heritage.
- Providing adequate housing
- Providing affordable housing
- Providing public facilities
- Quality Neighbourhoods
- Inclusivity
- Involvement
- Fulfilling business interests
- Avoiding risk
- Safety

Since these interests are quite generic, additional research was conducted into the spatial characteristics of sites that are associated with these interests. As it turned out, there was a lot of overlap. This was partially since a lot of these interests overlap in definition depending on the source. Almost all interest can to some degree be linked to sustainability. By identifying the spatial characteristics that are associated with these interests, it should become possible to define useable criteria for new housing sites, which answers the third research question. By doing so, it becomes possible to conduct a MCDA in the spatial context to determine the locations of potential housing sites, and to determine their level of suitability. It was found that such an application of MCDA is a very useful tool to solve spatial challenges, since MCDAs help decision makers in analysing potential actions or alternatives based on multiple factors or criteria, using decision rules to aggregate those criteria to rate or rank the alternatives., thus answering the fourth sub-research question. A MCDA always consists of several factors. These are the option, objective, criterion, performance score and criterion weights. Many methods are available and are applied depending on the kind of research. One of the most often used methods is the MAUT method, which sums the weighted scores for several attributes to come up with a general utility.

In case of spatial challenges, it is very useful to couple MCDA with GIS. GIS is a spatial system that creates, manages, analyses, and maps all types of data. The main principle of GIS is that of spatial data layers that are being overlaid to analyse and augment these. There is large magnitude of software available, but they often have similar tool aimed at augmenting and analysing data, which provides a promising perspective for answering the fifth sub-research question. An interesting development of the last ten years within the GIS community is the development of open-source options as opposed to commercial ones. Some authors are of the opinion that these open sources have the potential to accommodate the needs of modern-day planners, despite limits of open-source development software. However, this has not been proven in a real-world scenario. It is therefore interesting to test whether a suitability analysis for housing sites can be conducted, based on real life stakeholder interests, in the context of a country experiencing great challenges in finding suitable locations.

It has yet to be tested to see whether it is indeed possible to answer the fifth, sixth and seventh research question, namely whether it is indeed possible to combine a MCDA and GIS in practice, using the criteria that were found, what kind of data should be used, and what kind of results would be produced. It is not yet possible to decide whether such a tool would yield realistic results, and whether it is usable. Furthermore, it is not yet clear whether this can be done with open-source software and data, or whether only commercial alternatives would suffice.

3. Methodology

With the findings from the literature review, it has become possible to design a methodology for answering the main research question, namely the implementation of the findings about the development process, stakeholders, and their interests, and how these should be compared to eachother to come up suitable housing sites and to compare these to each other. From the literature, it has already become clear that a MCDA is very suitable option for making decision based on many criteria. For spatial problems, it appears to be very useful to incorporate GIS in this analysis, because it allows the user to incorporate spatial data. Therefore, the analysis will take the form of a MCDA conducted in GIS. This Chapter will first elaborate on the specific parts of the MCDA analysis, before describing the general method of implementation into GIS. As will be elaborated into more detail in Paragraph 3.2, the MCDA is only executed once unsuitable land has been excluded from the analysis using map overlay functions. Thus, a 2-step approach applies here. Together with a preliminary phase where the Project Area is selected by a user, this is the process that takes, which is also visualised in Figure 9.

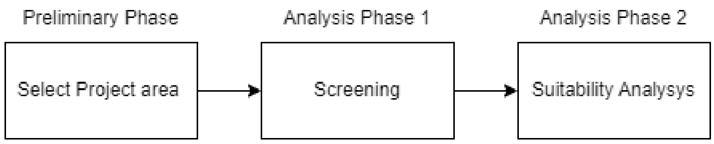

Figure 9. Basic analysis components.

3.1 Screening

This part of the analysis equates to the first part, namely the screening process for potential housing sites, and precedes the MCDA.

3.1.1 Exclusion Criteria

Three categories of exclusion criteria are defined: legality, semi-legality, and practicality. The first two categories are directly derived from laws and guidelines concerning spatial development. Within protected areas, it is illegal to build, and within the minimum distance of guidelines, only very specific circumstances allow construction to take place, but these are omitted in this research. Table 20 gives an overview of all exclusion criteria.

Table 20. Exclusion criteria.

Category	Exclusion Criterion	Elaboration
Legality	Protected Natural Areas	The Netherland knows a lot of heritage areas that enjoy some kind of protection. A distinction was made by natural, and cultural heritage. The two kinds of protected natural area described in Paragraph 2.4.1, NNN and Natura2000 both are very strict about new construction, which is often only allowed under a plethora of conditions, or not at all.

		Consequently, these areas were expected to not be suitable for large-scale housing realization, and therefore excluded.
Legality	Protected Man-Made Structures	The other category, cultural heritage, consists of human-made areas. These include monuments and protected city or village areas. Although it is often possible to redevelop these sites into new residential areas, it is expected that the possibilities are very specific per case, and dependent on criteria that may not seem obvious. These are therefore excluded as well. Another legal obstacle is present for the construction of housing in drinking water areas (see Paragraph 2.4.1). These aeras are excluded for legal reasons as well.
Legality	Protected Drinking Water Areas	It is illegal to build within drinking water protection areas in order to protect drinking water quality.
Semi-Legality	VNG distances	VNG distances discussed in Paragraph 2.3.4 are included because they are only deviated from in very rare cases. They enjoy semi-legal status and are therefore hard to omit. Areas that do not comply with these guidelines are unlikely to be approved for development and including them therefore makes no sense.
Semi-Legality	Utility distances	Another category is the minimum distance from utility (gas, water, electricity) infrastructure. These are currently not integrated in VNG distance guidelines because not much proof exists of their harmfulness. However, in the case of power cables and lines, strong suspicion does, and the government has already initiated a policy to prevent further construction near them. Therefore, the recommended distances by RIVM are incorporated as additional exclusion criteria. For gas lines, the minimum distance is less strict: only five meters, and since water lines are often small and only running underneath road infrastructure, no minimum distance is required.
Practicality	Road and Water Infrastructure	In practice, large infrastructure and bodies of water are rarely built upon There is not official law exempting them from housing development, but it would require additional changes in the zoning plan, and in some cases replacing infrastructure to build at these locations. Although it does sometimes happen that roads are demolished to make way for housing, it was expected that this relied on a very large

		number of criteria like accessibility, whether the surrounding area was also redeveloped, urban planning choices etc. This was deemed too complex to deal with in this in specific research, and therefore infrastructure is excluded altogether from the analysis. For the same kind of reasons, water was also included from the analysis: Whether it is allowed to build on water is dependent on many criteria that are not clear and must often be identified per individual case, which is not within the capacity of this research. Flood-prone areas were also included, because although these are dry most of the time, they tend to flood and are therefore unsuited for housing construction.
Practicality	Plot Size	A minimum plot size is implemented to avoid areas that are too small to realistically be considered for development.

3.1.2 Creating Inclusion Area

First, a Project Area layer is created, indicating the area that is going to be screened for potential housing sites. In practice this area is a large polygon covering the area that is to be analysed. Then, spatial data is loaded about exclusion criteria, limited to the area covered by the Project Area layer. This results in multiple layers indicating areas that are not suitable to build within, which equates to the exclusion criteria. These exclusion criteria layers are unionized (added together), and dissolved (into one large vector field), creatin the 'Exclusion Area'. Next, this layer is overlaid with the project area layer, and the exclusion areas is subtracted from the project area layer using a 'difference' function. The new layer can be perceived as a negative of the exclusion layer, indicating sites that are suitable for housing development. This layer will from now on be referred to as the 'Inclusion Area'. In most cases, this layer will consist of a collection of polygons representing possible development sites, within the area that was originally indicated to be the project area.

3.2 Suitability Analysis

In the second part, the sites that were found to be suitable in the first step are analysed for their level of suitability. This will be done by implementing a MCDA in a GIS environment. First, all the relevant part of the MCDA will be elaborated before more detail is given about the implementation method. A MCDA always consists of an option, objective, criteria, and weights (Dean, 2022). Additionally, this research makes use of a MAUT method, meaning that the whole MCDA can be summarized into a single multi-attribute utility function as described in Paragraph 2.5, which can be found at the end of this sub-Chapter. First, all elements of the MCDA are discussed.

3.2.1 Options and Objective

In the framework of this research, sites from the inclusion layer described in Paragraph 3.1 represent the options that are to be analysed. Here, the objective is to determine the level of suitability for each of these sites (polygons), based on how the site scores on stakeholder criteria. This is done by rasterizing the Inclusion Area sites into 1-meter by 1-meter squares and calculating suitability scores with a MAUT function for each of these. The attributes in this MAUT function equate to the stakeholder criteria.

3.2.2 Criteria

Stakeholder criteria were selected in line with the spatial characteristics associated with stakeholder interests identified Paragraph 2.3.4. Unlike the exclusion criteria, these criteria did not represent hard conditions that must be met before a site can be considered for potential housing development, but rather preferences, that must be met as much as possible, but are not crucial per se. The criteria that were identified are summarized in Table 21.

Table 21. Stakeholder criteria.

Stakeholder Criterion	**Elaboration**
Accessibility	End users' accessibility to amenities was mentioned by multiple stakeholders separately as an interest, and additionally is part of sustainable development. The choice was made to represent this criterion by two sub-criteria, using a layered approach as described by (Dean, 2022), namely accessibility to the nearest public transport stop, and to the nearest highway access. This approach was chosen because it was thought to represent both public, and private transport. By including a weight for each of these, the relative importance of one over the other could be adjusted during analysis. Although found to be often considered part of accessibility to transport, for instance by (Rahman et al., 2012), it was found in other research that when considered in its fullest sense, walkability is a very broad definition is and must be derived from a lot of factors as elaborated in (Liao et al., 2020).
Amenities	Due to the large number of potential amenities, and difference of importance of amenities among different target groups, accessibility to amenities was simplified to a plots distance to different scales of the metropolitan urban centres. A combined weighted sum is taken of the distance to the metropolitan centre (representing highly specialized amenities), municipal centre (specialized amenities), and neighbourhood centre (daily amenities). This method was based on similar approaches in the literature, like that of (Liu et al., 2014). End users' accessibility to amenities is represented by sub-criteria as well: A distinction is made between three layers of the amenity supply: that one a metropolitan scale, a municipal scale, and a local scale. People This subdivided approach, with sub-criteria for

	amenities, was chosen because cities are often structured according to a certain hierarchy (Batty, 2006) with one main centre, and multiple smaller local centres. People visit local centres for daily shopping, while they are more likely to visit larger centres for rarer shopping trips, for instance to buy clothes. The metropolitan centre is here defined as the largest of the neighbouring municipalities, the municipal centre as the centre the Project Area is within, and the local centre as the nearest supermarket, since it was assumed that people would go here for daily shopping, and that additional daily shopping amenities would be near supermarkets.
Urban Density	Dense cities have numerous benefits over less dense cities. Municipalities often strive for increased density because it can increase efficiency of public amenities. The opposite, sprawl is often frowned upon (see Paragraph 2.1.1). Preferably, brownfield land is used to construct new housing, because it is vacant, most likely not of natural importance, and by constructing housing here, the neighbourhood quality will most likely increase, since vacant parcels decrease the quality of life for residents, negatively impact property values, and significantly weaken the city's tax base (Archer et al., 2021). Furthermore, no, or very little demolition needs to take place on a brownfield plot. Which reduces development costs (something developers prefer). However, this is not always possible. Plots are often still occupied by buildings before development. In that case demolition needs to take place. Construction could also take place on land that has not been developed before, called greenfield land. However, these plots often have natural value, and additionally, because these plots are often located at the fringes of built-up area, developing them means additional urban sprawl, something that is undesirable according to municipal goals.
Plot size	An often-mentioned interest of stakeholders is that of supplying adequate housing. The current shortage of housing asks for a large number of houses to be built. Larger plots are consequentially more desirable because more options are available.
Avoiding soil risk	Some terrain can be tricky for developers. Soil can cause problems for multiple reasons: pollution, archaeology, or unfavourable conditions for foundations. Soil that has been indicated to potentially contain one of these aspects is considered potentially risky for development.
Avoiding opposition	Developers or municipalities must often deal with some sort of objection on their development from other parties. When objections are raised, this can cause a lot of delay during development (see Chapter 2). Therefore, it is beneficial to circumvent these objections. Objections often have to do with building characteristics like its perceived fitment within the

neighbourhood, expected traffic congestion, etc. However, these have more to do with building characteristics than spatial characteristics. Only the latter was relevant in this research, and therefore spatial characteristics had to be identified. Monkkonen & Manville (2019) name two important things: On the one hand that people are more likely to oppose in their own vicinity, and that objection is more likely where housing is expensive.

3.2.3 Standardization

Scores are one of the elements of any MCDA. However, before scores can be calculated in a MAUT function, it must be determined how they are measured, and how the scores are standardized. As was mentioned, the scores are calculated for each 1x1 meter square, from now on referred to as a 'cell' of the Inclusion Area sites. Scoring is done on two scales based on the stakeholder criterion. Most are scored on a continuous scale, however, there are also some criteria that are scored on an ordinal scale.

Continuous criteria

There are two types of continuous stakeholder criteria, namely those that where the score is preferably maximized, and those were the opposite is true. This consequently results in two types of formulas to calculate scores. There is only one criterion that is to be maximized: plot size. The unit of measurement here is the area of the site in m^2. The bigger the plot, the better, because more housing can be constructed (when other factors are not considered). This results in the following formula to calculate the score:

$$u_{plot\ size,x} = \frac{a_x - a_{min}}{a_{max} - a_{min}} \tag{2}$$

Where:

$u_{plot\ size,x}$ = Suitability score of cell x for attribute plot size.
a_x = Area of cell x.
a_{min} = Area of smallest plot.
a_{max} = Area of biggest plot.

For criteria that are to be minimized, another formula is used:

$$u_{plot\ size,x} = 1 - \frac{a_x - a_{min}}{a_{max} - a_{min}} \tag{3}$$

Where:

$u_{plot\ size,x}$ = Suitability score of cell x for attribute plot size.
A_x = measured value of cell x.
A_{min} = smallest measured value among cells.
A_{max} = largest measured value among cells.

In some cases, attributes are comprised of a weighted sum of sub-scores. This means that the following equation applies:

$$u_x = w_{partial,1} * u_{partial,1} + w_{partial,2} * u_{partial,2} + \dots \qquad (4)$$

Where:
u_x = overall suitability score for criterion x.
$w_{partial}$ = weight of sub-criterion.
$u_{partial}$ = suitability score or sub-criterion.

It is important to note that $u_{partial}$ is calculated using Equation 2 or 3.

Ordinal criteria
Aside from criteria that area measured continuously, there are two criteria that are measured on an ordinal scale. These are the 'Densification potential' and 'Risk level of soil'. For these, scores are assigned to different scenarios on a 0 to 1 scale.

For urban density, five scores are distinguished: [1, 0.75, 0.50, 0.25, 0]. These are assigned as elaborated in Table 22.

Ordinal Scale Urban Density

Table 22. Score allocation for level of urban density.

Current category of development	Ranking	Scoring
Open Urban area	Highest score	$u_{Urbandensity,z}$ = 1
Open Green Area	Intermediate scores	$u_{Urbandensity,z}$ = 0.75
Forest area		$u_{Urbandensity,z}$ = 0.5
Built-up area		$u_{Urbandensity,z}$ = 0.25
Water area	Lowest	$u_{Urbandensity,z}$ = 0

For the variable 'Risk level of soil', knowledge of soil conditions is ordered on an ordinal scale. This criterion is also layered, and consists of a sub-criterion about potential pollution, and a criterion about potential archaeological finds. The sub-scores are calculated on an ordinal scale as summarised in Table 23 and Table 24.

Table 23. Score assigning for sub-criterion soil pollution.

Soil pollution knowledge	Ranking	Scoring
Soil is known to be clean	Highest score	$u_{pollution}$ = 1
Soil potentially has pollution	Intermediate score	$u_{pollution}$ = 0.5
Soil it known to be polluted	Lowest score	$u_{pollution}$ = 0

Table 24. Score assigning for sub-criterion soil archaeology.

Soil archaeology knowledge	**Ranking**	**Scoring**
Soil is known to be clean	Highest score	$u_{archaeology}$ = 1
Soil potentially has archaeology	Intermediate score	$u_{archaeology}$ = 0.5
Soil it known to contain archaeology	Lowest score	$u_{archaeology}$ = 0

The overall utility score for the criterion ‘Risk level of soil’, is calculated using the same weighted additive function that is used for the continuous criteria.

3.2.4 Weighting

Weights are an essential part of any MCDA and can have a significant effect on the outcome. Weights are based on the preferences of users and cannot be measured from spatial data. Therefore, the user has to determine them himself. (Dean, 2022) names several methods as summarized in Table 18. Many options are available to determine weights. Saaty’s Pairwise Comparison method in the Analytical Hierarchy Process (AHP) (1980) was selected because it reduces the multi-criteria decision-making problem into smaller contained analyses. In these multi-attribute functions, the weights are determined by comparing pairs and rating the importance of one over the other. Once the tool is used, it is necessary to implement weights in the MCDA suitability analysis to achieve reliable results.

During the testing phase of the tool, after the completion of development, semi-arbitrary weights must be used to complete testing, because determining standard weights is not within the scope of this research. However, a pairwise comparison can be ‘simulated’, using the identified stakeholder interests. Here, the method recommended by Pearman et al. (2009) can be applied, where the analyst undertaking the analysis role plays the positions of the different problem stakeholders to ensure that the chosen weighting scheme reflects the interests of all the different parties and groups involved or affected by the given decision-making situation. By doing so, importance can be ascribed according to the most-mentioned stakeholder interests, meaning that criteria stemming from the most often-mentioned interests receive the highest importance.

3.2.5 Complete MAUT function

By elaborating all parts of the MCDA, it becomes possible to establish the complete MAUT function that will be used to determine the level of suitability for cells in the raster layer. By summing up all the attribute functions, the following summary function is created:

$$\begin{aligned} u_x = \; & w_{plot\ size} * u_{plot\ size,x} + w_{Transport} * u_{Transport,x} + w_{Amenities} \\ & * u_{Amenities,x} + w_{Opposition} * u_{Opposition,x} \\ & + w_{Densificationpotential} * u_{Densificationpotential,x} + w_{Soil} * u_{soil,x} \end{aligned} \tag{5}$$

Where:

u_x =suitability of cell x for housing development
$w_{plot\ size}$ =weight for attribute plot size
$u_{plot\ size,x}$ =suitability of cell x for attribute plot size
$w_{Transport}$ =weight for attribute access to transport
$u_{Transport,x}$ =suitability of cell x for attribute access to transport
$w_{Amenities}$ =weight for attribute access to amenities
$u_{Amenities,x}$ =suitability of cell x for attribute access to amenities
$w_{Opposition}$ =weight for attribute opposition risk
$u_{Opposition,x}$ =suitability of cell x for attribute opposition risk
$w_{Densification}$ =weight for attribute densification potential
$u_{Densification,x}$ =suitability of cell x for attribute densification potential
w_{Soil} =weight for attribute soil risk
$u_{Soil,x}$ =suitability of cell x for attribute soil risk

Furthermore, all attribute scores except for $u_{plot\ size,x}$, and $u_{Densificationpotential,x}$ are calculated using sub-criteria:

$$u_{Transport,x} = w_{PT} * u_{PT} + w_{Highway} * u_{Highway} \tag{6}$$

Where:
$w_{Highway}$ =weight for sub-attribute distance to Highway
$u_{Highway,x}$ =suitability of cell x for sub-attribute distance to Highway
w_{PT} =weight for sub-attribute distance to PT
$u_{PT,x}$ =suitability of cell x for sub-attribute distance to PT

$$u_{Amenities,x} = w_{Metropolitan} * u_{Metropolitan} + w_{Municipal} * u_{Municipal} + w_{Supermarket} * u_{Supermarket} \tag{7}$$

Where:
$w_{Metropolitan}$ =weight for sub-attribute distance to metropolitan centre
$u_{Metropolitan,x}$ =suitability of cell x for sub-attribute distance to metropolitan centre
$w_{Municipal}$ =weight for sub-attribute distance to municipal centre
$u_{Municipal,x}$ =suitability of cell x for sub-attribute distance to municipal centre
$w_{Supermarket}$ =weight for sub-attribute distance to supermarket
$u_{Supermarket,x}$ =score of cell x for sub-attribute distance to supermarket

$$u_{Opposition,x} = w_{Populationdensity} * u_{Populationdensity} + w_{Housingvalue} * u_{Housingvalue} \tag{8}$$

Where:
$w_{Populationdensity}$ =weight for sub-attribute population density
$u_{Populationdensity}$ =suitability of cell x for sub-attribute population density
$w_{Housingvalue}$ =weight for sub-attribute housing value
$u_{Housingvalue}$ =suitability of cell x for sub-attribute housing value

$$w_{Soilpollution} * u_{Soilpollution} + w_{Soilarchaeology} * u_{Soilarchaeology} \quad (9)$$

Where:

$w_{Soilpollution}$	=weight for sub-attribute soil pollution
$u_{Soilpollution}$	=suitability of cell x for sub-attribute soil pollution
$w_{Soilarchaeology}$	=weight for sub-attribute soil archaeology
$u_{Soilarchaeology}$	=suitability of cell x for sub-attribute soil archaeology

The outcome of each equation is calculated for every cell within the raster layer. This results in a score between 0 and 1.

3.3 Conclusion

In this Chapter, the methodology for answering the research question is elaborated. First, it is established that a MCDA is used in combination with GIS to execute the analysis The analysis in GIS will take place according to a 2-step process. First, the Project Area is screened for potential housing sites. This is done using a vector overlay analysis that overlays layers with spatial data about exclusion criteria, to come up with a final Exclusion Aera layer. This area is subtracted from the Project Area, creating the inclusion layer. This layer represents the area, in the form of numerous sites, for which a suitability analysis is going to be conducted. This is done by rasterizing the Inclusion Area and conducting a MCDA using a MAUT function for each of the resulting cells, which are 1 by 1 meter. The MAUT function sums the weighted scores of individual attributes (sometimes resulting from a partial MAUT function for partial attributes), to come up with a final score for each individual cell. All cell scores are between 0 and 1 and indicate the relative level of suitability compared to other cells.

4. Software and Data

In the literature, it was found that coupling MCDA with GIS is a very suitable approach to solving spatial questions that rest on several spatial factors. In Chapter 3, the underlying MCDA mechanism that could serve as the basis for the implementation in a GIS tool was elaborated, which makes it possible to design a general framework for the implementation of this MCDA mechanism in a GIS environment. This stage consisted of the following steps. First, a schematic model is elaborated that schematically indicates all the operations that must be executed in a GIS environment to achieve the correct output. Once this has been achieved, the software in which to elaborate the schematic model is selected. This is done by the desires of stakeholders and the state of the art. After selecting software, the same is done for data. Finally, the schematic model, together with the data is incorporated into QGIS, and automated to come up with a usable package.

4.1 Schematic Model

The schematic model serves as a blueprint or roadmap for the implementation of the 2-step approach into any GIS environment. The general operations that are necessary are elaborated, and schematic Figures are included to visualise the general GIS process that must take place to achieve the desired output. As will be seen, the distinction between the two steps of the analysis can become quite fuzzy, because some intermediate layers are used both for the first and second stages. Additionally, all raster layers that are used in the second stage are created from vector layers, which also decreases the distinction that can be made. The schematic model is in essence a more detailed version of Figure 9, which represents the basic components of the analysis. Circles represent user or model actions, and squares layers in the GIS Environment. The schematic model is visualised in Figure 10

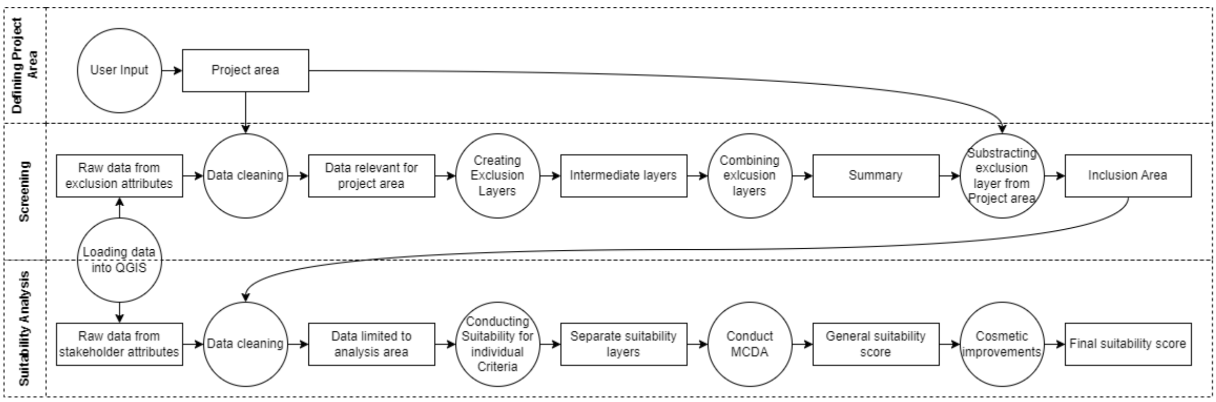

Figure 10. Schematic model.

4.1.1 Preliminary Phase: Defining Project Area

Although this phase is defined as a model phase, it is not automated, but rather consists of the user defining the area that is to be analysed. This is done by creating a vector layer with a polygon, or polygons of the area of interest which from now on will be referred to as the ‘Project Area’.

4.1.2 Analysis Phase 1: Screening

Phase 1 is much more comprehensive than the preliminary one because it consists of a large magnitude of GIS operations that need to be fulfilled. The goal of this phase is to screen the Project Area for possible sites for housing development, by excluding areas that are not deemed suitable based on the exclusion criteria defined in Paragraph 3.2.2. In its most basic form, the screening phase takes place as visualised in Figure 10. As was already partially explained in Chapter 3, the main goal of Phase 2 is to define the ‘Inclusion Area’. This is done using vector data, namely polygons, and overlaying these with each other. The polygons represent sites where it is unsuitable to build, and by adding all these polygons together, a summary exclusion layer is created.

4.1.3 Analysis Phase 2: Stakeholder Criteria Analysis

In the final phase of the analysis, the remaining sites are scored in an automated MCDA analysis. To do so, all the relevant data must be loaded into the model just as in the screening phase. These layers are rasterized, and a partial suitability analysis is conducted for each of the separate criteria. These raster layers are then combined into a single raster layer that represents these raster layers in a heatmap that follows from the weighted MCA sum of the stakeholder criteria.

4.2 Software

4.2.1 GIS

For the past ten years, the domain of GIS stood in the light of the development of open-source options. Although still in development, multiple authors believe that open-source options are not inferior to commercial ones (see Paragraph 2.5). By developing the tool in an open environment, it becomes more accessible to different stakeholder groups, which could help in its promotion and inclusion in the screening, and suitability analysis process for new housing sites. There is also another benefit. According to OECD (2023), the Dutch government scores badly on integrity and transparency. Transparency is one of the key benefits of open-source development, and therefore it also provides an opportunity in this sense. Due to these benefits, it was decided to implement the tool in an open-source environment. This will not only have benefits, but if successful also substantiate whether open source indeed is a viable alternative to commercial solutions, which contributes to the literature. Due to QGIS’ popularity, accessibility, and extendibility described in Paragraph 2.5, it was selected as the software of choice for implementing the screening and suitability analysis in.

4.2.2 Weighting

For determining weights, additional software can be used. The goal is to determine weights based on stakeholder interests as described in Paragraph 2.5.1. for this purpose, a free Pairwise Comparison tool was used that works according to the method developed by Saaty (1980). This tool allows the user to conduct the AHP for up to 13 different criteria, which is more than enough for this analysis. The users compare 2 criteria at a time, where a choice must be made between either of both, together with a scale to indicate the measure of importance of the chosen criterion over the other, as described in Paragraph 2.4.1. The following rating scale as represented in Table 25 was applied.

Table 25. AHP scoring according to Saaty (1980).

Intensity	**Definition**	**Explanation**
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one element over another
5	Strong importance	Experience and judgment strongly favour one element over another
7	Very strong importance	One element is favoured very strongly over another, its dominance is demonstrated in practice.
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation

2,4,6,8 can be used to express intermediate values

4.3 Data Sources

The main principle of GIS is that of spatial data layers that are being overlaid to analyse and augment these (see Paragraph 2.5). Thus, data is one of the most important elements of any analysis, which cannot take place without it: For each attribute, one, or multiple data sources are necessary to provide the ingredients for the spatial analysis associated with them. In line with the opportunities and benefits of open-source options, it is also decided to base the spatial analyses entirely on open-source data.

4.3.1 Open Street Map

QGIS development is closely linked to Open Street Map (OSM), a community-driven, open source map service, that makes use of local knowledge, aerial imagery, GPS devices, and low-tech field maps to verify that OSM is accurate and up to date (OpenStreetMap, 2023). The data from OSM allows the user to include a base layer as visualised in Figure 11, that serves as a reference layer on which additional layers can be projected.

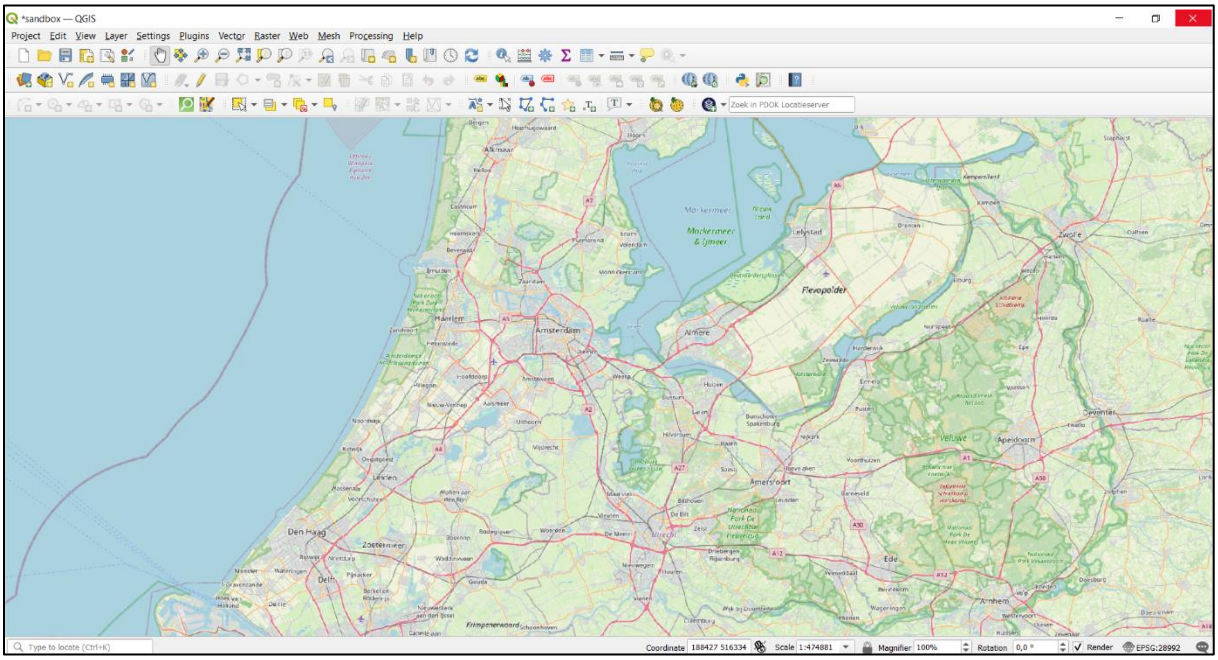

Figure 11. OSM base layer in QGIS.

OSM represents physical features on the ground using tags attached to its basic data structures (its nodes, ways, and relations). Each tag describes a geographic attribute of the feature being shown by that specific node, way or relation (openstreetmap.org, 2023). The system allows the map to include an unlimited number of attributes describing each feature. Nevertheless, the community has agreed on certain key and value combinations for the most commonly used tags, which act as informal standards. OpenStreetMap provides a page that has the up-to-date informal standards elaborated. A key most often describes a certain map feature category like ‘shop’, the value of the key describes the kind of shop, e.g., ‘alcohol’. A feature always had one key and one value. Map features can be points, lines, or polygons. For many of the spatial criteria identified for this research, OSM data is comprehensive enough to carry out analyses. To make the best use of OSM data, two plugins were installed:

- QuickOSM: Allows the user to download map features based on keys, attributes, or data types (version 2.2.2)
- OSM Map Services: Allows the user to download layers that represent geographical borders (version 2.2.2)

4.3.2 INSPIRE

Although OSM data is very comprehensive, it proved that additional data was needed. However, this is not always the case, and additional data sources had to be identified and incorporated. Two different ways of data retrieval are possible in QGIS: downloading data manually from external sources and uploading them into QGIS, or directly via Plugins. When necessary, the latter option was preferred over the former for ease of use. The first additional source that was used to collect data was the INSPIRE geoportal, which is the central European access point to the data provided by EU Member States and several EFTA countries under the

INSPIRE Directive. This geoportal allows the monitoring the availability of INSPIRE data sets, discovering suitable data sets based on their descriptions (metadata), and accessing the selected data sets through their view or download services (INSPIRE Geoportal, 2023). INSPIRE datasets for the Netherlands can be accessed by the use of a plugin called 'INSPIRE Nederland plugin voor QGIS' (version 2.8). This free plugin allows the user to access 35 spatial databases in the Netherlands. These include among others: datasets from the Central Bureau of Statistics (CBS), the Dutch Royal Meteorological Institute (KNMI), the University of Wageningen, and PDOK, an organization that spreads reliable open-source government data.

4.3.3 PDOK

This last organization that can be accessed via the INSPIRE plugin also has its own plugin: 'PDOK services Plugin' (version 4.1.5). PDOK is a platform that gives access to geo datasets of the Dutch government. This is actual and reliable data for both the public and private domain (Publieke Dienstverlening Op de Kaart, 2023). There is a lot of overlap between the datasets of INSPIRE and PDOK, but there are some exceptions.

4.3.4 Criterion Data

The plugins discussed in Paragraph 4.3.2 and Paragraph 4.3.3 ensure easy access to data sources online. Table 25 elaborates on which datasets were used for which stakeholder.

Table 26. Data sources

Attribute		Data set	Source
Exclusion	No development on infrastructure	Custom OSM query	Open Street Map via QuickOSM Plugin
	No development on water	Custom OSM query	Open Street Map via QuickOSM Plugin
	No development on natural heritage sites	Beschermde gebieden - CDDA (INSPIRE geharmoniseerd) WFS	Nationaal Geogregister accessed via INSPIRE plugin
	No development on cultural heritage sites	Beschermde Gebieden - Cultuurhistorie (INSPIRE geharmoniseerd) WFS (Only national monuments, no data found for provincial and municipal monuments)	Nationaal Geogregister accessed via INSPIRE plugin
	No development on drink water protection sites	Kwaliteit van drinkwater in Nederland (2012) (WFS) - Grondwaterbeschermingszones	Nationaal Geogregister accessed via INSPIRE plugin
	No development within VNG guideline distances	Custom OSM query via QuickOSM Plugin	Open Street Map via QuickOSM Plugin
	No development within recommended	Custom OSM query via QuickOSM Plugin	Open Street Map via QuickOSM Plugin

	power line distances		
Stakeholder	Accessibility 1: Distance to PT	Custom OSM query via QuickOSM Plugin	Open Street Map via QuickOSM Plugin
	Accessibility 2: Distance to Highway	Custom OSM query via QuickOSM Plugin	Open Street Map via QuickOSM Plugin
	Amenities 1: Distance to metropolitan centre	Custom OSM query via QuickOSM Plugin + QGIS analysis	Open Street Map via QuickOSM Plugin
	Amenities 2: Distance to municipal centre	Custom OSM query via QuickOSM Plugin + QGIS analysis	Open Street Map via QuickOSM Plugin
	Amenities 2: Distance to supermarket	Custom OSM query via QuickOSM Plugin	Open Street Map via QuickOSM Plugin
	Densification	Multiple Custom OSM queries via QuickOSM Plugin + QGIS analysis	Open Street Map via QuickOSM Plugin
	Plot size	QGIS analysis	-
	Soil Risk 1: pollution	*No suitable source found *	-
	Soil Risk 2: archaeology	*No suitable source found *	-
	Opposition 1: density	Wijk- en Buurtkaart 2022 versie 1	Nationaal Geogregister accessed via PDOK plugin
	Opposition 2: housing price	Wijk- en Buurtkaart 2022 versie 1	Nationaal Geogregister accessed via PDOK plugin

Suitable data is identified for all attributes except non-national monuments, and soil. Here, smaller sets of municipal data are found, but these were scattered and not available for every municipality. For all the other attributes, data is found. However, this data was not suitable from the start. All data used for the model is on the national scale since the aim of the model is to be able to be universally applicable to any case area in the Netherlands. Otherwise, different models would have to be developed for specific locations. Data files on a national are almost universally big, often comprising multiple Gigabytes of information. However, QGIS has an integrated function that limits the maximum number of rows in an attribute table to 50,000. This proves to be too little for the data files at hand, meaning that the loading of data into the project cuts off before completion, leaving incomplete files to work with. This problem can be omitted by downloading the data externally and manually clipping it to the relevant parts using software like Excel or Python, as will be done with some files for this study, but this severely undermines the goal of practicality and user-friendliness that was aimed for in developing the tool. Aside from this, some files that can be loaded via plugins are not ready for use and need additional processing before the analysis can start.

4.4 Data Loading and Processing

Raw data from the sources identified in Paragraph 4.2 is not immediately suitable for analysis but need additional processing to be used. The processing that needs to be conducted is dependent on the type of data that is loaded, and the type of criterion that it is used for.

4.4.1 Preliminary Phase: Defining Project Area

This phase consists of the user defining the Project Area in QGIS. The user does this by creating a vector layer with a polygon of the area of interest. After creating the layer, the user can create a polygon in the layer that indicates the area of interest, which from now on will be referred to as the 'Project Area'.

4.4.2 Phase 1: Screening

In this phase, exclusion layers are created from spatial data layers, added together to create an exclusion layer, as visualised in Figure 12

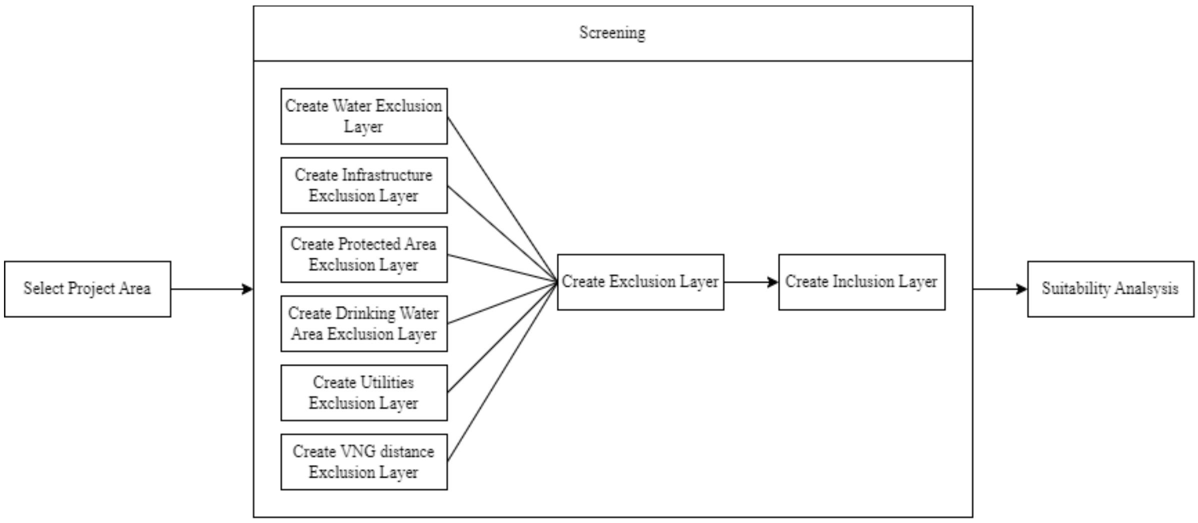

Figure 12. Screening phase.

For creating the exclusion layers, all layers must be in polygon format and are reprojected to have the same projection as the project CRS. This will be the focus of processing before adding the layers together.

Creating Water Exclusion Layer

Defining the Water Exclusion Layer is done as visualized in Figure 13. First, an OSM query is executed that retrieves the correct data from OSM. This was easy; All water surfaces in OSM are defined using the query parameters above. This is one of the informal standards discussed in Paragraph 3.2.2. Although seemingly illogical, since man-made water features are also defined as ‘natural’, ‘water’ in OSM, this is useful for the model since only a single query is necessary to identify all water surfaces. The output from the query is a single layer consisting of all the water polygons. Then, as will be done with all other polygon layers, the layer is dissolved, meaning that overlapping polygons are merged into one. This will speed up later operations. The final dissolved layer represents the Water Exclusion Layer.

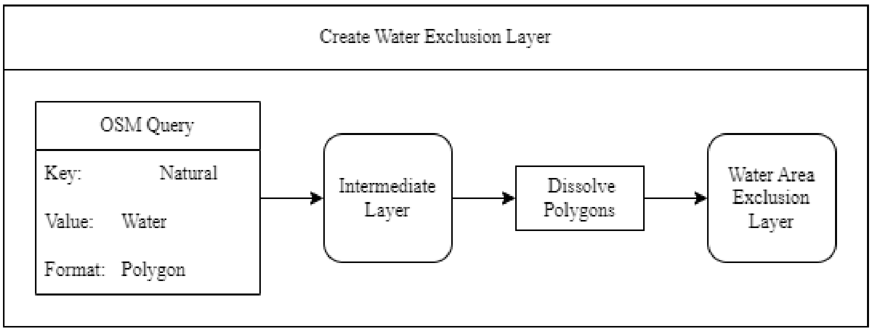

Figure 13. Water exclusion layer operations schematic.

Creating Infrastructure Exclusion Layer

For infrastructure surfaces, the relevant data can be retrieved from OSM as well. However, this data retrieval process was more complex than that of water surfaces as visualised in Figure 14. Infrastructure has a very broad definition; it includes water, land, and air infrastructure. Water infrastructure is already covered by the water surface query, but land infrastructure needs to be identified separately. All road infrastructure is classified under Value = ‘Highway’, under QGIS community guidelines, including footpaths, forest tracks, highways, regular streets and a very large collection of other keys. Aside from the problem that this large diversity posts, OSM represent streets using lines instead of polygons. Since a polygon layer is necessary for the overlay analysis, this means that additional operations are necessary after loading the data. However, first, it needs to be decided what values and keys are to be used in the OSM query. OSM makes main distinctions between roads as summarized in Table 27. To make the roads a polygon, a buffer is applied consisting of the minimum distance according to policy guidelines, plus a surplus buffer for the width of the road.

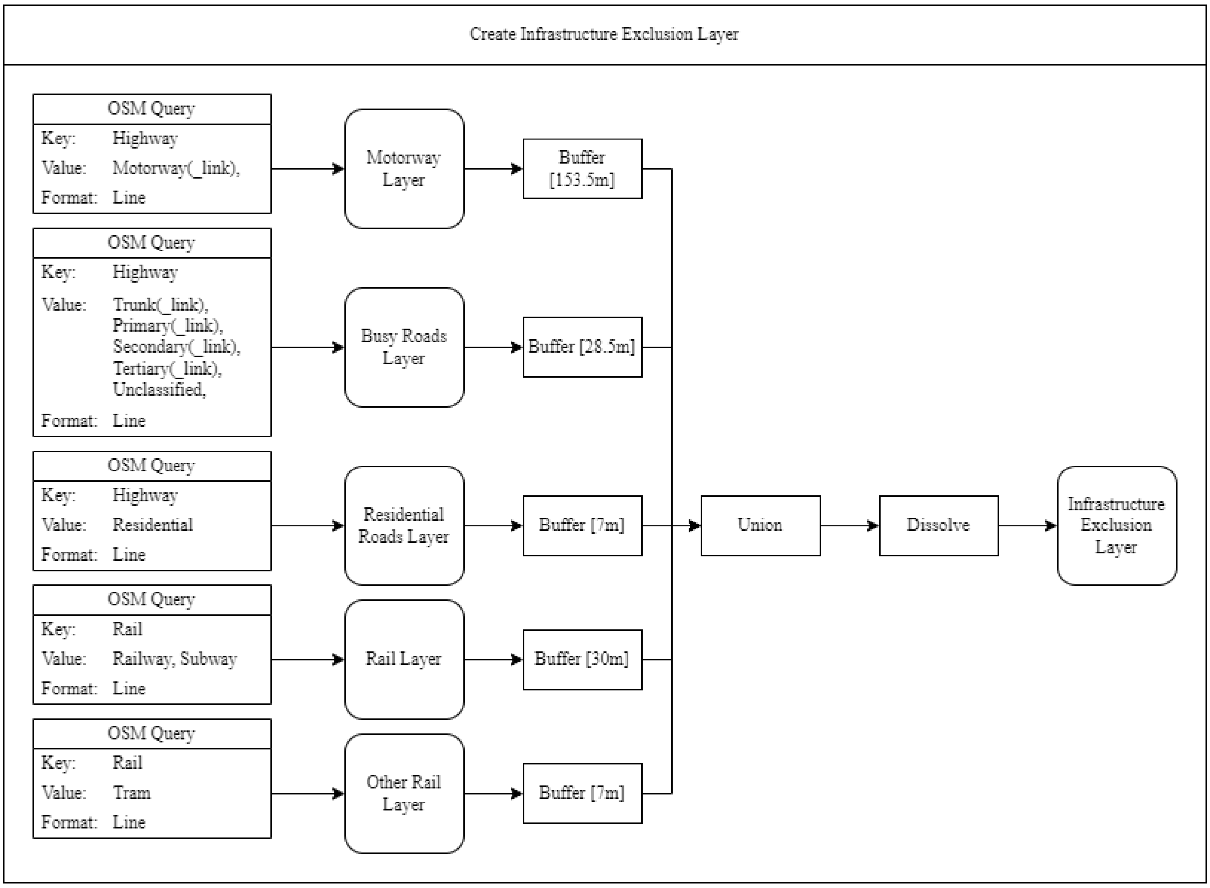

Figure 14.. Infrastructure exclusion layer operations schematic.

Table 27. Road types according to OSM (2023).

Key	**Value**	**Description**	**Minimum distance + buffer**
Highway	Motorway; Motorway_link	A restricted access major divided highway, normally with 2 or more running lanes plus emergency hard shoulder. Equivalent to the Freeway, Autobahn, etc..	153.5
Highway	Trunk; trunk_link	The most important roads in a country's system that aren't motorways. (Need not necessarily be a divided highway.)	28.5
Highway	Primary; Primary_link	The next most important roads in a country's system. (Often link larger towns.)	28.5
Highway	Secondary; Secondary_Link	The next most important roads in a country's system. (Often link towns.)	28.5
Highway	Tertiary; Tertiary_Link	The next most important roads in a country's system. (Often link smaller towns and villages)	28.5

Highway	Unclassified	The least important through roads in a country's system – i.e., minor roads of a lower classification than tertiary, but which serve a purpose other than access to properties.	3.5
Highway	Residential	Roads which serve as an access to housing, without the function of connecting settlements. Often lined with housing.	3.5
Highway	Living_street	For living streets, which are residential streets where pedestrians have legal priority over cars, speeds are kept very low and this results in narrow roads.	3.5

The minimum distance from these roads is based on the GGD distances discussed in paragraph 2.4.2. In Table 27, only residential roads are considered to not be ‘busy’ streets. The distances are also extended to link roads, which are diverting arms of the roads like on or off ramps. As can be seen in Table 26, the distance does not correspond to the distances noted in paragraph 2.4.2 exactly but is 3.5 meters bigger. This extra distance accounts for the width of the roads. According to the handbook ‘Quality and Public Spaces’ (Gemeente Leiden, 2013), the minimum width of a road that must allow freight traffic is 7 meters. Therefore, 3.5 meters is added to the buffer distance on either side of the road that is to be implemented to compensate for this discrepancy.

Aside from the list of road types listed in Table 27, OSM distinguishes many other keys for ‘Highway’ Value infrastructure. These are too comprehensive to handle individually, and therefore a method needs to be developed to determine how to handle these other types. In OSM, sidewalks are sometimes (not consistently) defined as an individual line alongside roads, while they are part of the general street layout. Therefore, the minimum distance of 7 meters is used for all other types as well, since no other comprehensive options were at hand. It could be expected that this approach will cause problems later in the analysis, with undefined areas between road surfaces and buildings for instance, but this problem is solved using operations that will be elaborated further on in Paragraph 4.4.2.

Aside from the keys falling under the Value ‘Highway’, there is also another infrastructure type that had to be incorporated, namely ‘Railway’. Luckily, selecting the right keys is easier. The keys visualised in Table 28 are selected from rail.

Table 28. Rail types used for infrastructure analysis.

Value	**Key**	**Description (openstreetmap.org)**	**Buffer distance**
Railway	rail	Full sized passenger or freight train tracks in the standard gauge for the country or state.	30.7 meters
Railway	subway	A city passenger rail service running mostly grade separated. Often a significant portion of the line or its system/network is underground.	30.7 meters

Railway	tram	One or two carriage rail vehicle tracks, usually sharing motor road, sometimes called "street running".	3.5 meters

The buffer distance is based on the minimum allowed distance by law, plus an extra 0.7 meters for compensation of track width (~1.4 metres). For trams, no indication can be found. However, by measuring the distance of some streets containing tram tracks in the Netherlands, it was found that some streets containing trams weren't more than 10 meters wide, meaning a buffer distance of roughly 5 meters on either side. Nevertheless, the buffer distance of trams is set at the same width as streets.

After loading all the data into the model, lines are buffered according to the corresponding buffer distances and added together using the 'Union' operation. Additionally, all polygons in the layer are dissolved, meaning that overlapping polygons are unified into one. This resulting layer is the exclusion layer for infrastructure.

Creating Protected Areas Exclusion Layer

Since some areas are protected, they are illegal to build in, or know strict rules concerning construction that hamper development. Therefore, these areas are excluded using the model from Figure 15. The main distinction is made between natural, and cultural or historical areas. The data for the first of these is not present in OSM and therefore needs to be loaded from an external database. This is done using the INSPIRE plugin to access the National Geo Register. Using this tool, natural areas, and protected cultural areas can be loaded into QGIS. For protected natural areas, a dataset is used that consists of Natura2000 areas, national parks, and Nature Network Netherlands areas. The data is already in polygon format and only needs to be clipped to the project area. See Figure 15 for visualisation.

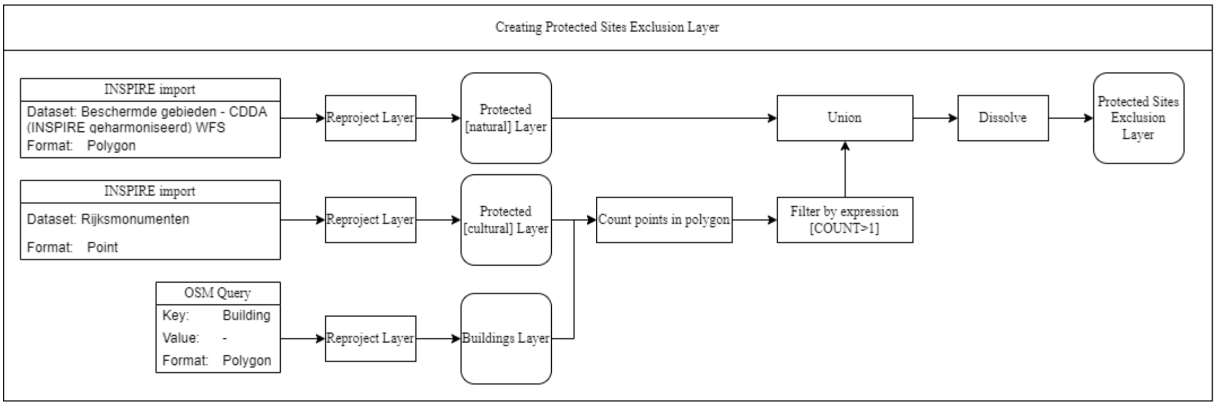

Figure 15. Protected sites exclusion layer operations schematic.

For protected cultural areas, a more comprehensive method is necessary. Two kinds of cultural/historical sites are distinguished: national and municipal monuments. Sadly, national monuments is the only type for which nation-wide data is accessible easily; the availability of municipal monuments differs per municipality and must be downloaded externally. The data on monuments is in point format and must thus be converted into usable polygons. To do this, an OSM query is used to retrieve all buildings within the Project Area. The monument point layer, and building polygon layer are overlaid, and a new layer is created containing only the building polygons that have a monument point within them, creating a building polygon layer with only monuments. This layer is added together with the INSPIRE natural areas map to create the protected areas exclusion layer.

Creating Drinking Water Area Exclusion Layer

The data for drinking water areas can be loaded using the INSPIRE plugin as well. However, the data is not fit for use yet. Since the areas in this dataset only include the buffer area around water retrieval sites and not the water retrieval sites themselves, almost all polygons form a halo with a hole in the middle. This hole is filled in using an extra operation, after which the hole disappears. The whole process is visualised in Figure 16.

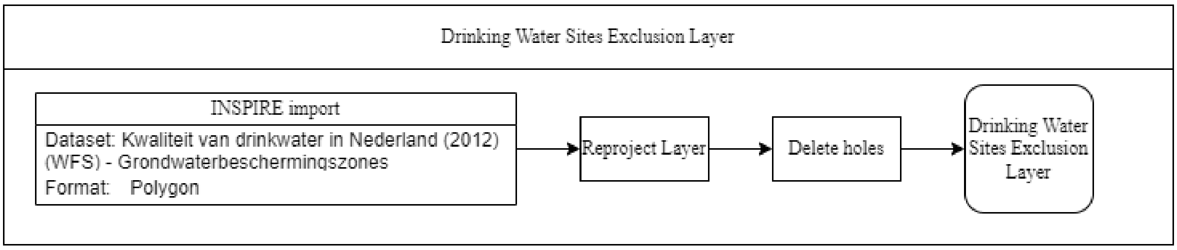

Figure 16. Drinking water exclusion layer operations schematic.

Creating Utilities Exclusion Layer

Utilities consist of three main categories: electricity, gas and water. Only for the first two of these, the infrastructure needs to be considered because water mains almost always run under streets and can relatively easily be relayed or omitted. Two types of power electricity infrastructure are identified: above ground and under ground. For both, no official laws exist, except that construction directly under or above is illegal. However, as was discussed in Paragraph 2.4 the GGD recommends certain distances for the lines, depending on the voltage running through them, as summarised in Table 29. Luckily, power lines, both above and under ground are retrievable from OSM, and the voltage running through them is included in the form of metadata. The layer is consequently split and buffered according to voltage resulting in numerous power line exclusion layers. Finally, these are unified into a single exclusion layer, as visualised in Figure 17.

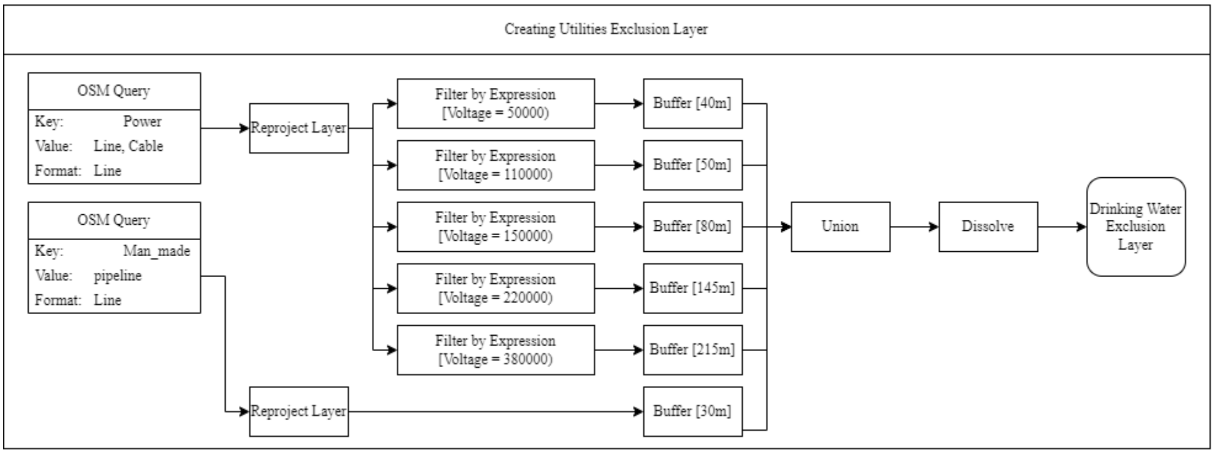

Figure 17. Utilities exclusion layer operations schematic.

Table 29. Buffer distances for power lines and cables.

Key	Value	Description (openstreetmap.org)	Buffer distance [GGD recommendation]				
			50kv	110vk	150kv	220kv	380kv
Power	Line	An insulated cable carrying electrical power, such as transmission or distribution cables located underground and undersea cables	40m	50m	80m	145m	215m
Power	Cable	An insulated cable carrying electrical power, such as transmission or distribution cables located underground and undersea cables.					

For pipelines containing gas, the minimum distance is 30 meters. As with power cables and lines, these can be retrieved from OSM in line format via roughly the same operations.

Creating VNG Distances Exclusion Layer

The last of the exclusion criteria layers is that containing VNG distances. This is by far the most challenging criterion to include in the model for the following reason: The VNG list goes into a very high degree of detail when recommending minimum distances, and consequently distinguishes more than 500 categories of functions, which are classified into six separate ‘environment categories’, that indicate the level of nuisance associated with a function in chronological order: each of these recommending a minimum advised distance based on nuisance which is based on a combination of noise, smell, and safety. Ideally, data would be available that depicts the locations of all functions per category nationwide. However, no such data is available. Another option is to look at the zoning plans of the municipality since these often include the maximum allowed environmental category per plot. Data for this was found;

Gronddatabank has an online web viewer depicting this exact information as visualised in Figure 18.

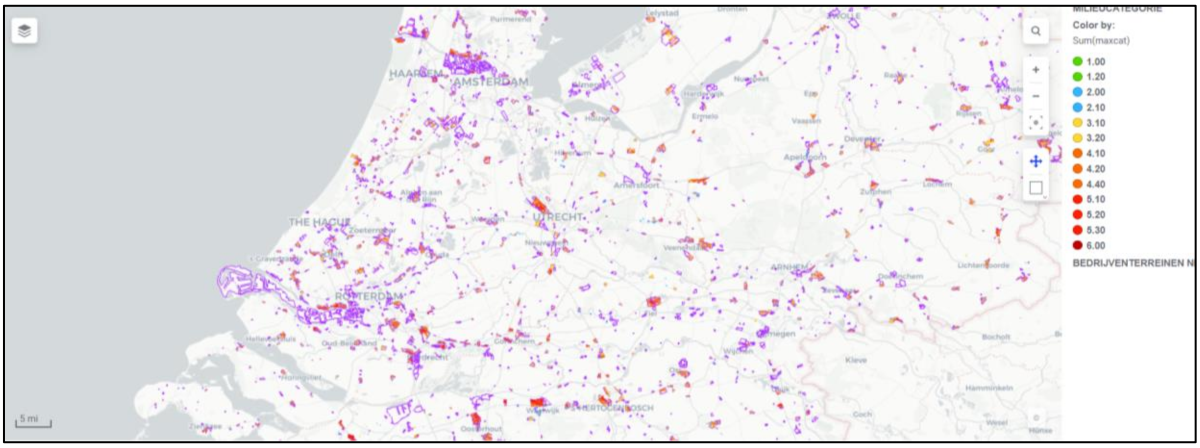

Figure 18. Gronddatabank environmental categories webviewer.

This web viewer contains the most complete dataset, where all environmental categories are grouped, but sadly this data is not retrievable, and not complete. When looking at Figure 19, it can be seen that information is missing for large parts of industrial areas. This incompleteness of data is partly caused by the fact that zoning is a decentralized task in the Netherlands and that there is not a standardized format to publish environmental zoning of areas in. When looking at zoning plans that are available online, a multitude of formats can be seen, from maps to policy documents.

Figure 19. Data incompleteness.

The lack of complete, freely available data necessitates a simplified approach based on data that is available. As can be seen in Figure 20 and Figure 21, most functions are assigned to the middle categories, with only a relatively small number assigned to low, and especially high categories. Category 1 and 2 can generally be associated with functions that can be found within a city. Their guideline distances, 10 and 30 meters respectively, are sometimes even omitted. For instance, Gymnasiums, which have an indicative distance of 10 meters, are sometimes incorporated into apartment complexes. It furthermore often happens that bakeries occupy the ground floor of a building, with residences directly above them. Therefore, it was decided to exclude these functions from the analysis completely. Apparently, there already exist a lot of exceptions to these indicative distances, and the distances are negligible on a city-wide level.

Category	Minimum distance	Number
1	10	41
2	30	86
3.1	50	80
3.2	100	93
4.1	200	60
4.2	300	74
5.1	500	42
5.2	700	22
5.3	1000	14
6	1500	11

.

Figure 20. Number of functions per category.

Nummer	Categorie	Subcategorie	OMSCHRIJVING	AFSTAND	CATEGORIE		Value
2	GROOTHANDEL EN HANDELSBEMIDDELING	Grth in metaalertsen:	- opslag opp. >= 2.000 m2	700	5.2		
5	DIENSTVERLENING T.B.V. HET VERVOER	zeeschepen:	- steenkool, opslagopp. >= 2.000 m2	700	5.2	building/landuse	Industrial
4	DIENSTVERLENING T.B.V. HET VERVOER	binnenvaart:	- ersten, mineralen, e.d., opslagopp. >= 2.000 m²	700	5.2	building/landuse	Industrial
9	DIENSTVERLENING T.B.V. HET VERVOER	binnenvaart:	- olie, LPG, e.d.	700	5.2	building/landuse	Industrial
C2	MILIEUDIENSTVERLENING	Composteerbedrijven:	- niet-belucht v.c. 5.000 tot 20.000 ton/jr	700	5.2	building/landuse	Industrial
D	CULTUUR, SPORT EN RECREATIE	uur/week in gebruik	Autocircuits, motorcrossterreinen e.d., < 8 uur/week in gebruik	700	5.2	sport	raceway,speedway, motorcross
2	VERVAARDIGING VAN VOEDINGSMIDDELEN EN DRANKEN	Suikerfabrieken:	- v.c. >= 2.500 t/j	1000	5.3	building/landuse	Industrial
A2	VERVAARDIGING VAN CHEMISCHE PRODUKTEN	Organ. chemische grondstoffenfabrieken:	- vallend onder "post-Seveso-richtlijn"	1000	5.3	building/landuse	Industrial
1	VERVAARDIGING VAN CHEMISCHE PRODUKTEN	Landbouwchemicaliënfabrieken:	- fabricage	1000	5.3	building/landuse	Industrial
	VERVAARDIGING VAN CHEMISCHE PRODUKTEN	Kruit-, vuurwerk-, en springstoffenfabrieken	Kruit-, vuurwerk-, en springstoffenfabrieken	1000	5.3	building/landuse	Industrial
2	VERVAARDIGING VAN GLAS, AARDEWERK, CEMENT-, KALK- EN	Cementfabrieken:	- p.c. >= 100.000 t/j	1000	5.3	building/landuse	Industrial
2	VERVAARDIGING VAN METALEN	IJzeren- en stalenbuizenfabrieken:	- p.o. >= 2.000 m2	1000	5.3	building/landuse	Industrial
B2	VERVAARDIGING VAN METALEN	Non-ferro-metaalwalserijen, -trekkerijen e.d.:	- p.o. >= 2.000 m2	1000	5.3	building/landuse	Industrial
2	VERVAARDIGING VAN TRANSPORTMIDDELEN (EXCL. AUTO'S,	Vliegtuigbouw en -reparatiebedrijven:	- met proefdraaien motoren	1000	5.3	building/landuse	Industrial
A1	WINNING EN DITRIBUTIE VAN WATER	Waterwinning-/ bereiding- bedrijven:	- met chloorgas	1000	5.3		
4	GROOTHANDEL EN HANDELSBEMIDDELING	Grth in vuurwerk en munitie:	ton	1000	5.3		
3	DIENSTVERLENING T.B.V. HET VERVOER	zeeschepen:	- ertsen, mineralen e.d., opslagopp. >= 2.000 m2	1000	5.3		
6	DIENSTVERLENING T.B.V. HET VERVOER	zeeschepen:	- olie, LPG, e.d.	1000	5.3		
10	CULTUUR, SPORT EN RECREATIE	Schietinrichtingen:	- buitenbanen met voorzieningen: pistoolbanen	1000	5.3	sport	shooting
C	CULTUUR, SPORT EN RECREATIE	uur/week in gebruik	Skelter- en kartbanen, open lucht, >=8 uur/week in gebruik	1000	5.3	sport	Karting
	AARDOLIE-/STEENKOOLVERWERK. IND.; BEWERKING SPLIJT-	Splijt- en kweekstoffenbewerkingsbedrijven	Splijt- en kweekstoffenbewerkingsbedrijven	1500	6	building/landuse	Industrial
2	VERVAARDIGING VAN METALEN	Ruwijzer- en staalfabrieken:	- p.c. >= 1.000 t/j	1500	6	building/landuse	Industrial
	VERVAARDIGING VAN OVER. ELEKTR. MACHINES, APPARATEN EN	Koolelektrodenfabrieken	Koolelektrodenfabrieken	1500	6	power	Power plant
A4	PRODUKTIE EN DISTRIB. VAN STROOM, AARDGAS, STOOM EN	vermogen >= 50 MWe)	- kerncentrales met koeltorens	1500	6	power	Power plant
A	DIENSTVERLENING T.B.V. HET VERVOER	Luchthavens	Luchthavens	1500	6	aeroway	
A3	MILIEUDIENSTVERLENING	Afvalverwerkingsbedrijven:	- verwerking radio-actief afval	1500	6	amenity	waste_transfer_station, landfill
4	CULTUUR, SPORT EN RECREATIE	Schietinrichtingen:	- vrije buitenbanen: schietbomen	1500	6	sport	shooting
5	CULTUUR, SPORT EN RECREATIE	Schietinrichtingen:	- vrije buitenbanen: geweerbanen	1500	6	sport	shooting
6	CULTUUR, SPORT EN RECREATIE	Schietinrichtingen:	- vrije buitenbanen: pistoolbanen	1500	6	sport	shooting
9	CULTUUR, SPORT EN RECREATIE	Schietinrichtingen:	- buitenbanen met voorzieningen: geweerbanen	1500	6	sport	shooting
E	CULTUUR, SPORT EN RECREATIE	uur/week in gebruik	Autocircuits, motorcrossterreinen e.d., >=8 uur/week in gebruik	1500	6	sport	raceway,speedway, motorcross
0							

Figure 21. Cropped view of VNG list.

Category 3 primarily consists of agriculture and light manufacturing. Like categories 1 and 2, it was decided to exclude these functions from the analysis as well, since their nuisance level was considered to be relatively low, and agricultural land is one of the most potential sites for new housing development.

Categories 4, 5 and 6 and their subcategories are the hardest to convert to useful numbers, mainly due to the almost exponentially increasing indicative distance. (100 à 200 à 500 à 700 à 1000 à 1500). There is also another problem since the OSM map does not distinguish between different intensities of industry or all separate industrial functions. However, in some exceptions, the OSM map does do so, like for power plants. The sum of functions of categories 5.3 and 6 is 25, of which many functions like airports, power plants, and racetracks can be individually distinguished in OSM, unlike the functions in lower intensities of industry. Therefore, the following approach is chosen: For categories 6 and 5.3, the functions will be manually mapped into separate layers of industry, for which the distance is 1500, and 1000 meters respectively. Then, for all other functions, the next highest maximum industrial distance, the one indicated for category 5.2 of 700 meters, is applied. The original and new list can be seen in Table 30 and Tale 31.

Table 30. Original VNG classification.

Original	
Categories	**Distance**
1	10
2	30
3.1	50
3.2	100
4.1	200
4.2	300
5.1	500
5.2	700
5.3	1000
6	1500

Table 31. Transformed classification used in this research.

Used	
Categories	**Distance**
Agriculture	50
Industry	700
Sugar Factories	1000
Org. raw material production	1000
Agriculture Chemicals	1000
Firework Factories	1000
Cement Factories	1000
Aerospace Factories	1000
Water Winning	1000
Munition Factories	1000
Shipping Transfer	1000
Iron Factories	1500
Shooting Ranges	1500
Racing Circuits	1500
Power Plants	1500
Airports	1500

The result is a simplified, but usable Table. It is possible that during mapping, distances are not the same as with the VNG guidelines, but it is better to apply a rudimentary form as opposed to none at all. Table 32 gives an overview of the OSM queries that were used to retrieve data.

Table 32. OSM queries used for VNG layer.

Category		**Distance**	**OSM query**	
			Key	**Value**
Industry		700	Landuse	Industrial
Heavy Industry	Sugar factories	1000	Custom map	
Heavy Industry	Organic raw material production	1000	Custom map	
Heavy Industry	Agriculture chemicals	1000	Custom map	
Heavy Industry	Firework factories	1000	Custom map	
Heavy Industry	Cement factories	1000	Custom map	
Heavy Industry	Aerospace factories	1000	Custom map	
Heavy Industry	Water winning	1000	Already exclusion variable	
Heavy Industry	Munition factory	1000	Does not exist in the Netherlands	
Heavy Industry	Shipping transfer	1000	Man_made	crane
Super heavy industry	Iron factories	1500	Custom map	
Super heavy industry	Shooting ranges	1500	Military	range
			Sport	shooting
Super heavy industry	Racing circuits	1500	Highway	Raceway
			Sport	Motocross, Motor, Speedway
Super heavy industry	Power plants	1500	Power	Plant
Super heavy industry	Airports	1500	Aeroways	Aerodrome

It is not possible to retrieve all functions from OSM features. However, most of these are so few in functions that they only pose an obstruction to housing development in exceptions. The final operations schematic is visualised in Figure 22.

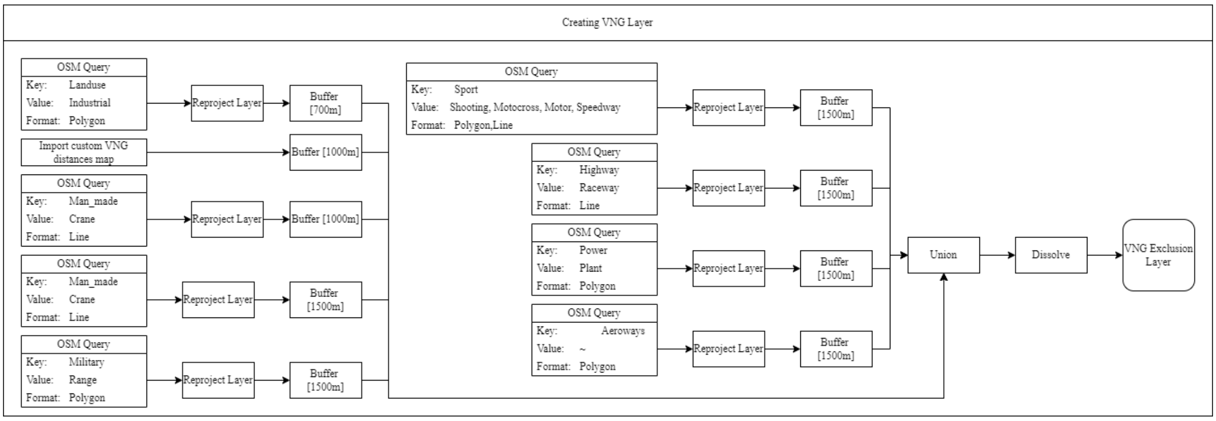

Figure 22. VNG exclusion layer operations schematic.

Remove Small Areas and Create Inclusion Layer

Once all data has been loaded into the model, it is possible to combine all the data into a single layer. All exclusion layers are combined into a single layer using the union function and dissolved. One last operation is conducted in line with the last Exclusion Criterion, namely the removal of sites that are too small. Too small is perceived from two perspectives; on the one hand, plots may not be too narrow, because this is impractical for construction. Parts of plots that are too narrow are excluded as follows: First, a negative buffer is put on the summary exclusion layer, shrinking it to a certain fraction of its former size. Then, the same buffer is applied again, but in positive. Sites that were narrower than the negative buffer do not reoccur.

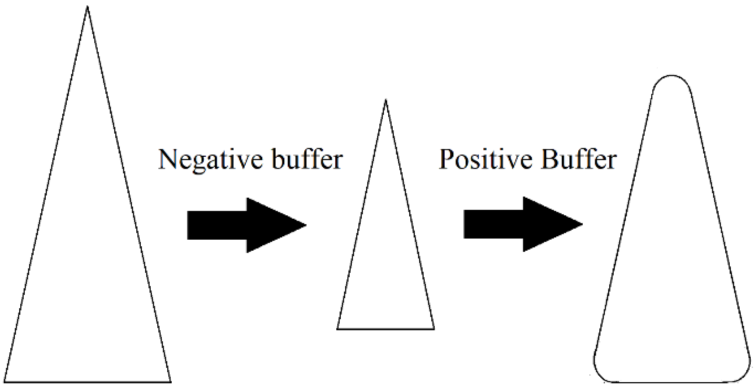

Figure 23. Removing narrow parts of sites.

Once parts that are too narrow have been deleted, it is assessed whether the sites are big enough for the implementation of housing in terms of floor area size. This is done by calculating the areas of all individual polygons and deleting the ones that do not meet a certain threshold value. Once this has been done, the resulting layer is subtracted from the exclusion layer, creating the final inclusion layer. The deletion of arrows that are too small and too narrow, and the creation of the inclusion layer are schematically visualised in Figure 23.

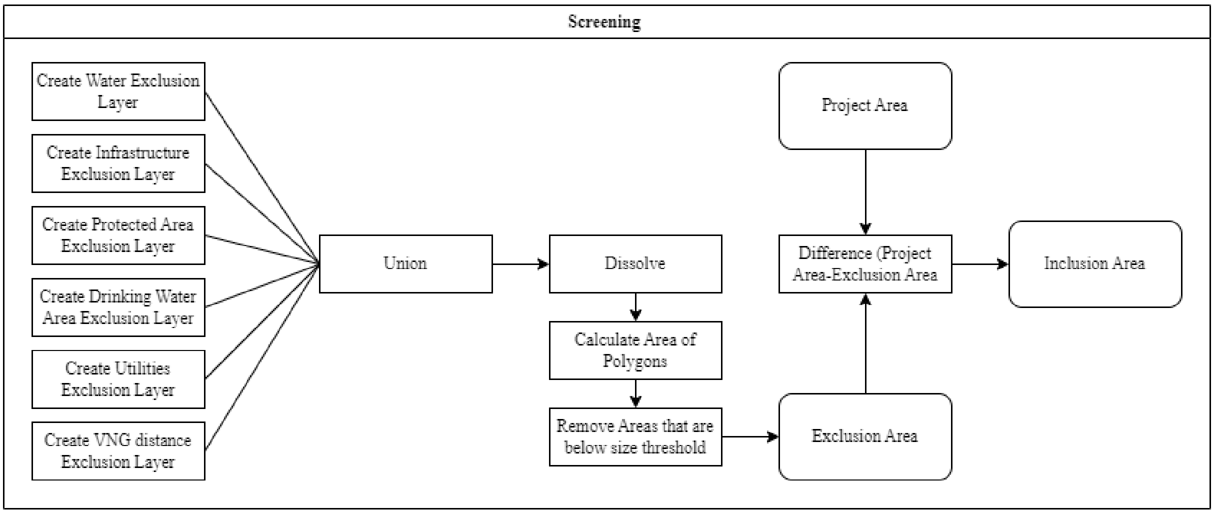

Figure 24. General exclusion layer operations schematic.

4.4.3 Phase 2: Suitability Analysis

In the final phase of the analysis, a MCDA is conducted on the Inclusion Area to determine the level of suitability. To do so, all the relevant data must be loaded into the model just as in Phase 1. First, all data must be converted into raster layers. These raster layers are then combined into a single raster layer that represents these raster layers in a heatmap that follows from the weighted MCA sum of the stakeholder criteria, as visualised in Figure 25.

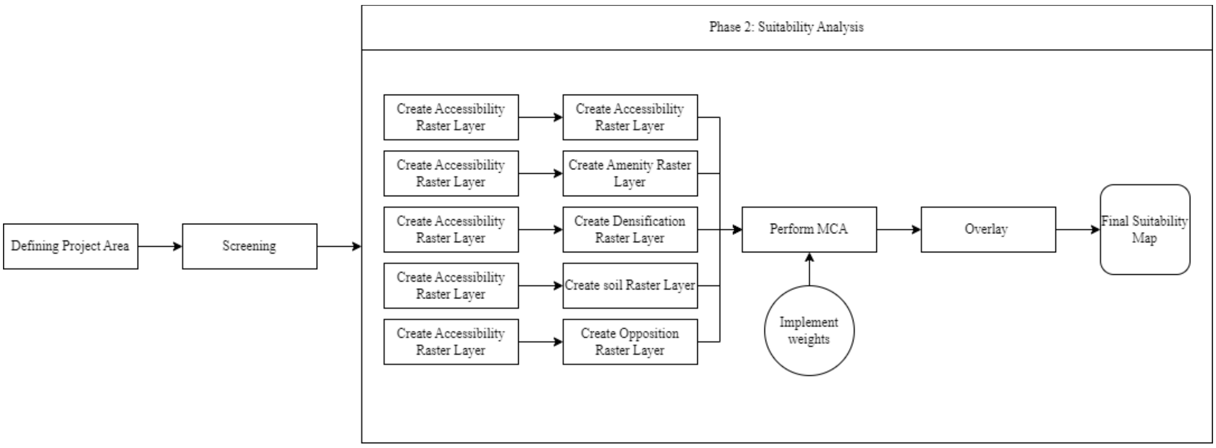

Figure 25. Phase 3 operations schematic.

One important note must be made about the loading of data. Since a lot of suitability layers are based on proximity to certain spatial features, data must be loaded not only from within the Project Area but also from beyond its borders. It could well be that relevant amenities exist just beyond the Project Area borders, and it is unlikely that stakeholders consider municipal borders when finding the nearest PT stop, supermarket, etc. Therefore, a special algorithm was incorporated for the extent to which features should be loaded. It was decided to include all features, that were within the distance to which features are measured at any point at the extremities of the Project Area and is just as big 'inside' the Project Area outside as 'outside'

The layer is created as follows: First, the centroid of the Project Area is set, indicating the geographical mean. Then, the distance from the border of the Project Area to this point is measured at regular intervals of 1 meter, creating a chain of measuring points along the border of the Project Area. Finally, a buffer is placed on each of these points, with a length of 2 times the measured distance from the border to the centroid, representing a sort of diameter. What this means is that the diameter of the Project Area, on any given point, is extrapolated outwards, creating a much larger polygon that should in theory include all relevant data. The process is visualised spatially in Figure 27, and schematically in Figure 28. It is not incorporated in Figure 26, because it happens outside of the creation of raster layers.

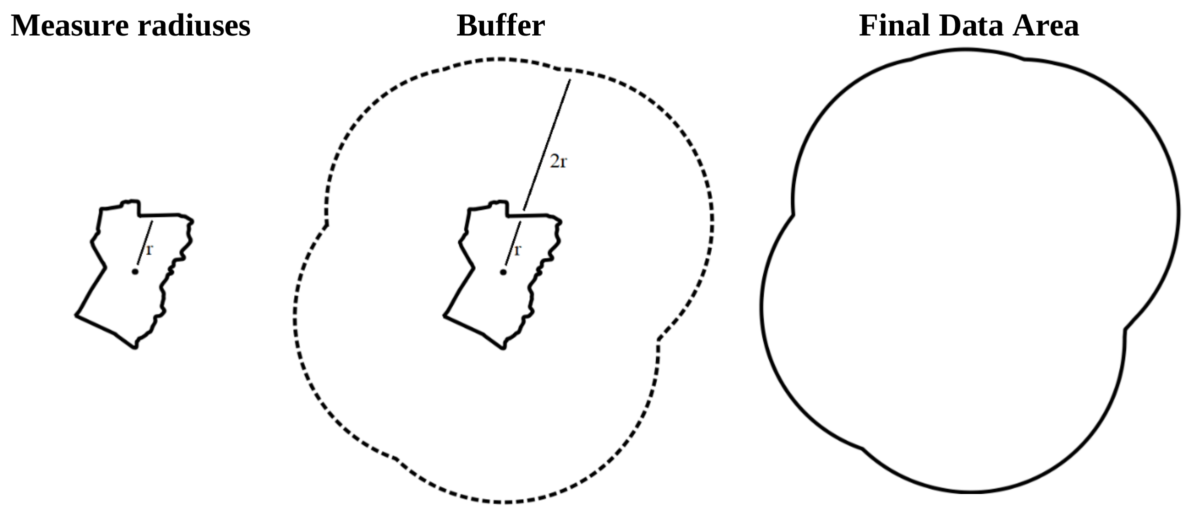

Figure 26. Data Area creation (spatially).

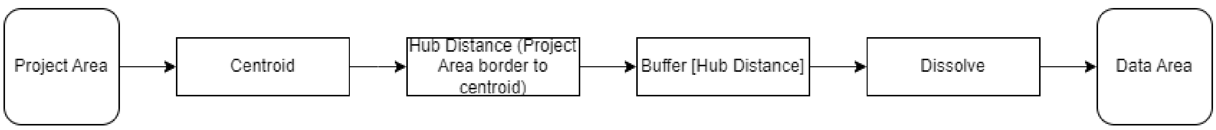

Figure 27. Data Area creation (schematically).

After creating the Data Area layer, all raster layers are created, and their data is loaded within the extent of the Data Area.

Create Accessibility Raster Layer

Creating the raster layer for accessibility requires a lot of operations. First, the relevant data is loaded from OSM within the Data Area. This consists of all highway accesses, and all PT stops. These data layers are both reprojected and rasterized, after which a proximity analysis is conducted that produces a raster heatmap. The scores, which correspond to distances in metes, are then standardized to a 0 to 1 scale with the rescale function. The grids are then aligned, and the MCA is conducted using the raster calculator command, together with user input about weights. This produces the final accessibility score map, as visualised in Figure 28.

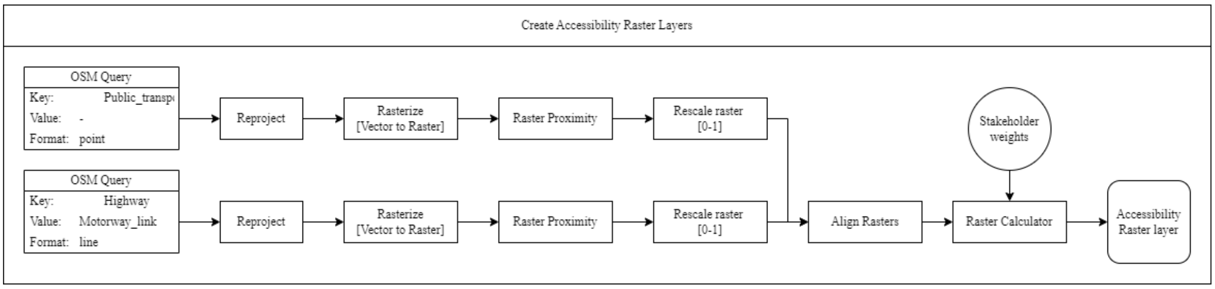

Figure 28. Create accessibility raster layer operations schematic.

Create Amenities Raster Layer

For amenities, roughly the same operations are followed as with Accessibility as can be seen in Figure 29. Three different levels are distinguished: metropolitan centre, municipal centre, and supermarkets, as elaborated in Paragraph 3.2.2.

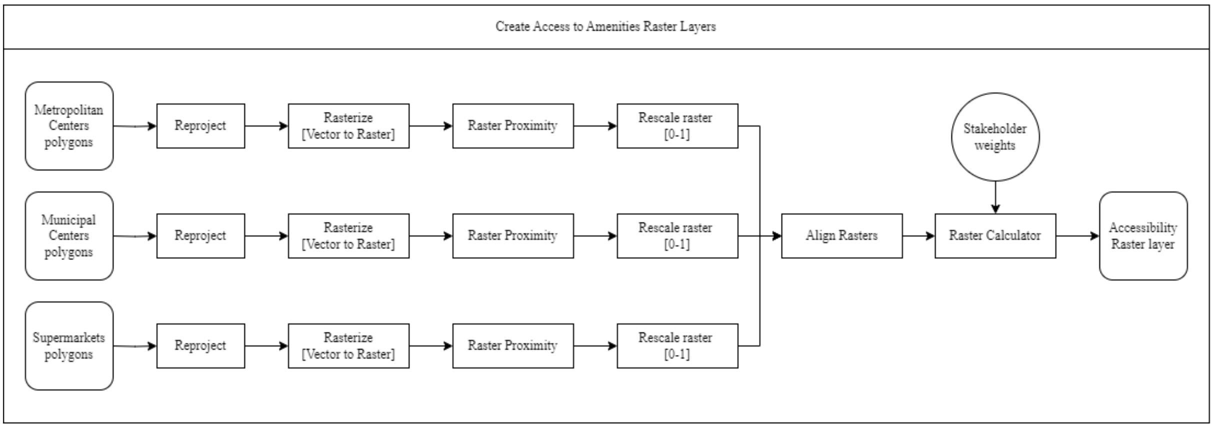

Figure 29. Create amenity raster layer operations schematic.

Create Densification Raster Layer

As can be seen in Figure 30, for densification, the data is loaded from three separate OSM queries. Luckily, all the features can be loaded directly. They are then combined into a single layer with a different value in the same attribute table column for their status. According to this value, a heatmap raster layer is created.

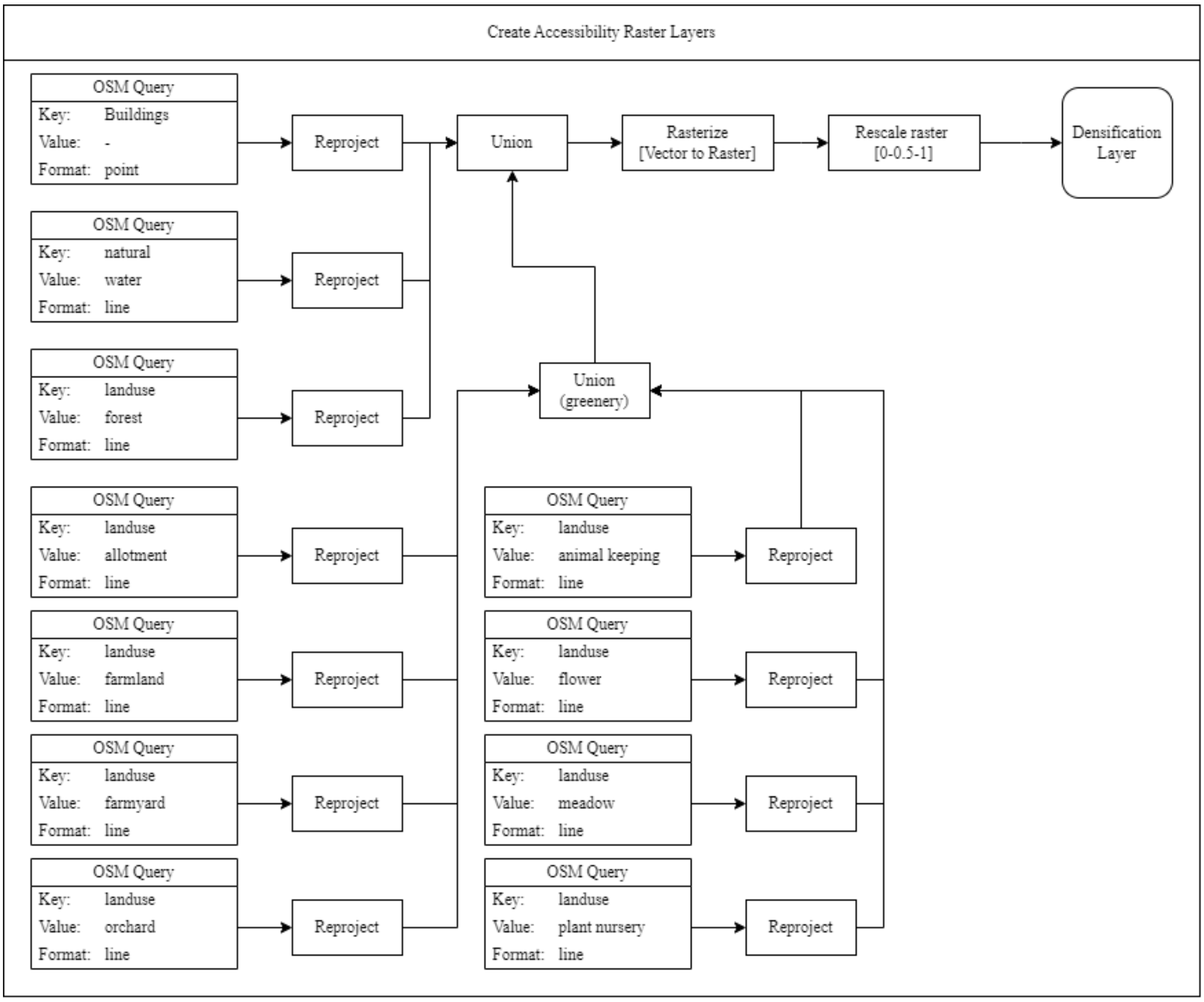

Figure 30. Create densification raster layer operations schematic.

Create Soil conditions Raster Layer
For soil conditions, no useable data was found. Although there are local options available, no national dataset was found, and thus this criterion is not included in the suitability analysis.

Create Opposition Risk Raster Layer
Opposition risk consists of two criteria: population density and average housing price. These can both be retrieved from the same dataset, namely ‘CBS Wijken en Buurten. After reprojecting this layer to the right CRS, two separate raster layers are made using different columns in the attribute table corresponding to the criteria. These are standardized to a scale of 0 to 1, after which their rasters are aligned, and an intermediate MCA is conducted with user weight input. This creates the final layer, seen in Figure 31

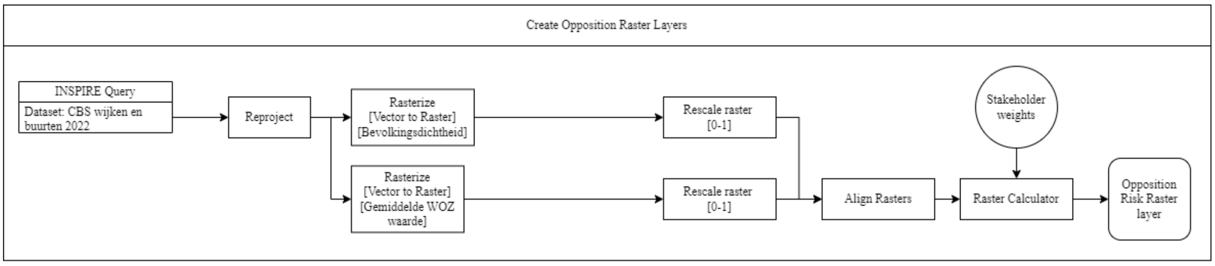

Figure 31. Create opposition risk raster layer operations schematic.

Conduct MCDA on partial raster layers

Once all sub-raster layers have been created, the main MCA can be conducted as visualised in Figure 32. This is done using the raster calculator function, and again with the input of the criteria values and user weights. This creates a final suitability heat map expressing for all considered sites the level of suitability for housing development.

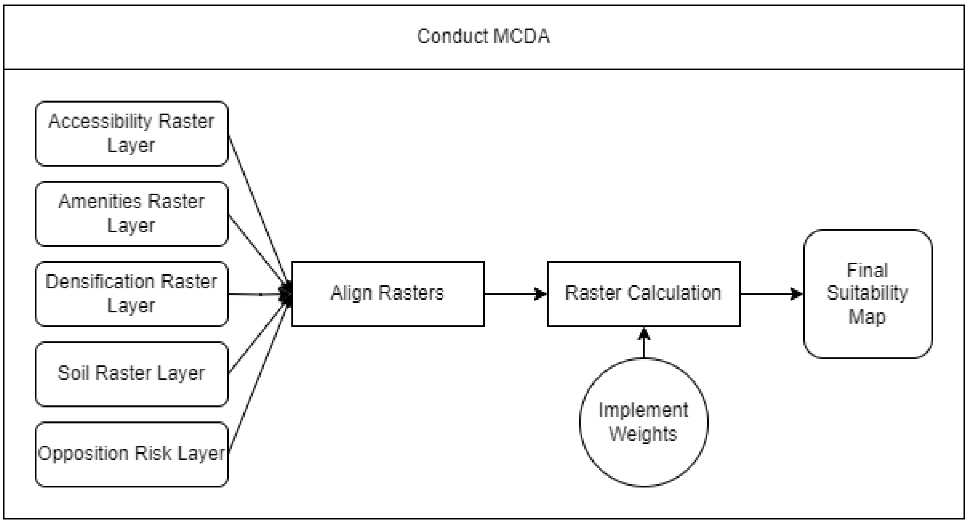

Figure 32. Conduct general MCA operations schematic.

4.5 Visualisation

There were two options available for the visualization of the suitability, namely clipping the suitability layer with the exclusion layer, or by simply overlaying the mask layer over the suitability layer. The latter of these options was chosen because the former is in raster format, and raster pixels cannot be partially clipped, producing borders that are very coarse. The latter option only visually clips the suitability layer, allowing for partial clipping of raster cells.

Suitability is represented by a heat map. It was decided to not use the standard QGIS grayscale, but instead a single band pseudo-colour scale, since the use of colours creates more visual depth (Atlı, 2010), and thus makes it easier for a user of the tool to distinguish between different magnitudes of suitability.

4.6 Automation

The methods for executing the screening process and suitability analysis elaborated in Paragraph 4.5 are very comprehensive. The consequence of this is that executing these operations by hand is very laborious and takes up a lot of time. Therefore, it was decided to automate all QGIS commands into a usable and easy-to-use package. This would allow users to execute the MCA automatically, without the need for them to execute the model by hand. QGIS has two main options for automation: Python Code, and a visual modeler. It has a Python coding window that can be used to insert, write, and execute operations by code. Automation here could be achieved by writing the code completely and saving it in a text file that can be pasted into QGIS once people want to execute the model. The alternative to the latter option was to record the model in the visual modeller; QGIS has the option to visually save models. Here, the automation would take place by saving the model and loading it into QGIS to execute the analysis. To choose the best option, the two options were globally compared as visualised in Table 33. A 5-point scale was used, with 5 being the maximum, and 1 being the minimum possible score.

Table 33. Comparing Python coding vs. visual modelling as tool format.

	Python Code		**Visual Modeler**	
Category	**Score**	**elaboration**	**Score**	**elaboration**
User-friendliness	4	Easy to use by pasting the code into coding box and executing model	4	Easy to use for users as well. The model can be loaded into the program and executed by only a small number of clicks.
Overview	1	Bad compared to model alternative	5	Overview much better to comprehend by the user of path lines that run from model to model.
Adaptability	1	When user wants to alter code, this must probably be done in other software	3	Much easier to adapt than Python code but remains complicated.
Function	5	Python code allows for the most precise input by far.	3	Visual modeler allows for most functions. Some functions need to be run as separate models because intermediate loading is necessary.
Final score	*11*		*15*	

From the comparison, it was concluded that the best format of the tool would be a visual model, with the deciding factors being an overview of operations and adaptability. The importance of these factors might be perceived as questionable, but the benefit of being able to add additional attributes, if the users decide as such, to score a site's suitability on, allows for more user freedom when desired, which makes the tool more adaptive to potentially deviating situations where more attributes are relevant than were identified. Coding indeed allows for the most comprehensive functionality of the software, but it was expected that the visual modeller would allow for enough functionality. All operations that were part of the MCDA were saved in a QGIS visual model visualised in Figure 33.

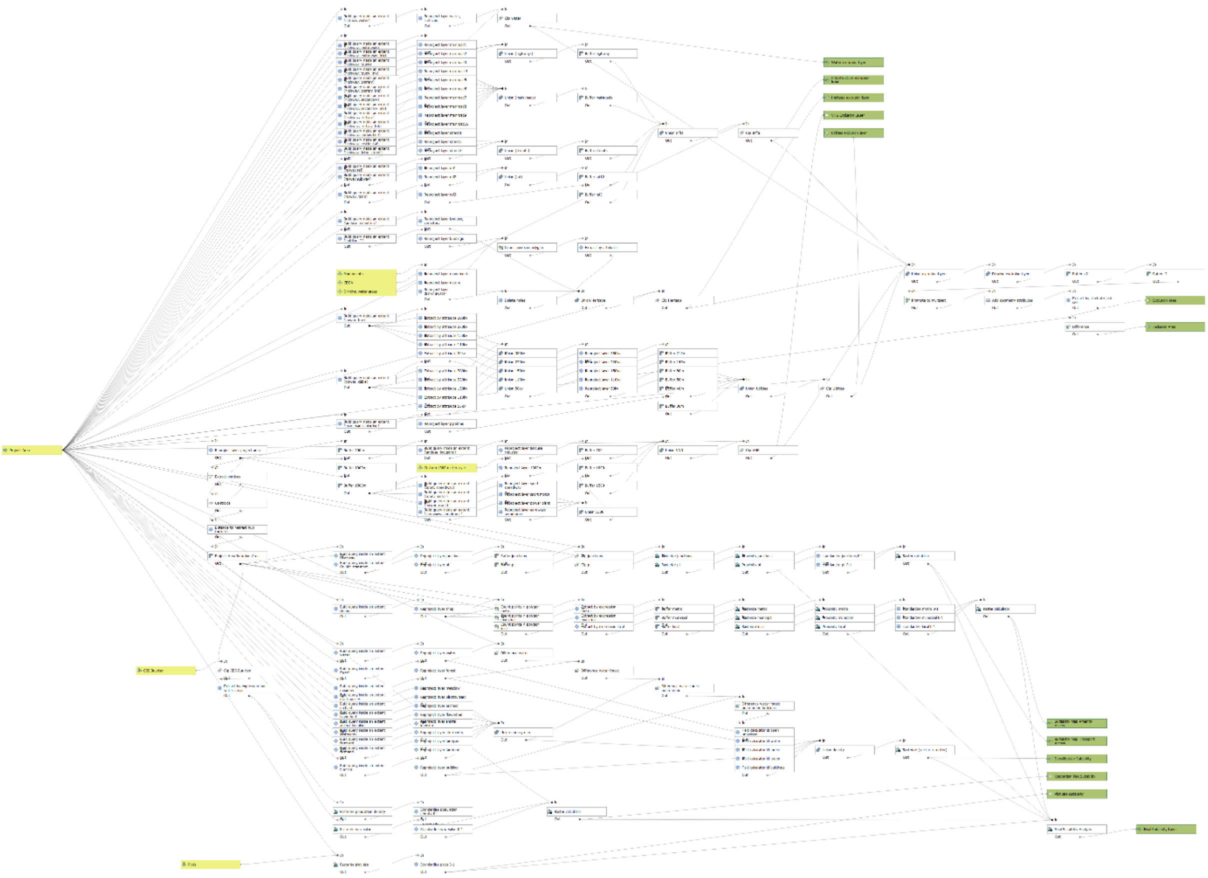

Figure 33. QGIS visual model.

This provided a clear overview of the whole model. Additionally, the model can be saved, and when loaded into QGIS and executed, it conducts the screening process and suitability analysis automatically. However, users must define their own weights following their preferences. Additionally, the following notion must be made: Although the visual modeller is very useful in theory, some problems exist with its implementation. First of all, operations from the INSPIRE and PDOK plugins cannot be automated in the versions of QGIS and plugins that were used for this research. OSM data loading is integrated into the visual modeller options, but it appears that in the current version of QGIS, the functionalities responsible for loading OSM data into projects via the visual modeller, are not functional. They do not return output once run. When executed manually, they do return a result with the same parameters, indicating faulty software. This possibly has to do with version incompatibility. The result of these two problems is that no data loading can be automated in the current version of QGIS, significantly undermining practicality and time-effectiveness since the manual execution of these tasks is very time-consuming, and potentially confusing for new users of the software. Were these problems to be solved, the result would be an open-source and user-friendly tool that is free.

Nevertheless, almost all other functions are working, and therefore the visual model is still used for automation.

4.7 Conclusion

This Chapter has elaborated on the Software and Data that is used to implement the methodology in a GIS environment. First, a schematic model is developed that describes the basic underlying process that takes place in GIS for the execution of the analysis. This is a 2-step process of first screening the Project Area using a MOA using vector data polygons and then conducting a suitability analysis using an automated MCDA analysis on raster layers. Next, it is explained why QGIS has been selected as the environment to execute the analysis in, followed by which data sources are used for each specific criterion. The next section elaborates on how this data is loaded and processed to become usable for the analysis. This section first elaborates on the screening process, after which the details of the suitability analysis are explained. Finally, the Chapter concludes with a section about the automation in QGIS, which is done to make the tool more usable and accessible for users.

5. Results

In this Chapter, a demonstration is conducted using the developed tool to visualise its functionalities. It is investigated whether the designed tool works and what kind of results it yields. First, a case area is chosen. Then, the automated model is loaded into QGIS, and run..

5.1 Selecting Project Area

According to Atlas Research (2023), the municipality with the greatest pressure on housing in the Netherlands is that of Amstelveen, which although independently governed, practically is a satellite city of the greater Amsterdam Metropolitan Area, as can be seen in Figure 34.

Figure 34. Project area (Esri World Imagery, 2020).

First, a small analysis of the case Project Area is conducted to achieve a better understanding of the morphology of the area. This will help in assessing the functionalities of the tool. Figure 35 shows the physical characteristics of the area. The area is characterized by an elongated urban area that grows south. On either side, a green area can be distinguished that's primarily characterized by forest in the west, and open green in the east. Through the area, a large highway runs from west to east and vice-versa, straight through the most densely developed area. Although not visualized on the map, the density of buildings decreases from North to South. This has to do with the fact that the more densely developed areas are more towards the city of Amsterdam, which is to the North of the project area. The eastern border of the area is the river

Amstel, and the eastern border is along the ring canal that surrounds the Haarlemmermeer polder. Here, the country's largest airport, Schiphol is located, almost directly bordering the area. It is expected that the airport will severely decrease the suitability of housing development on the western side of the Project Area.

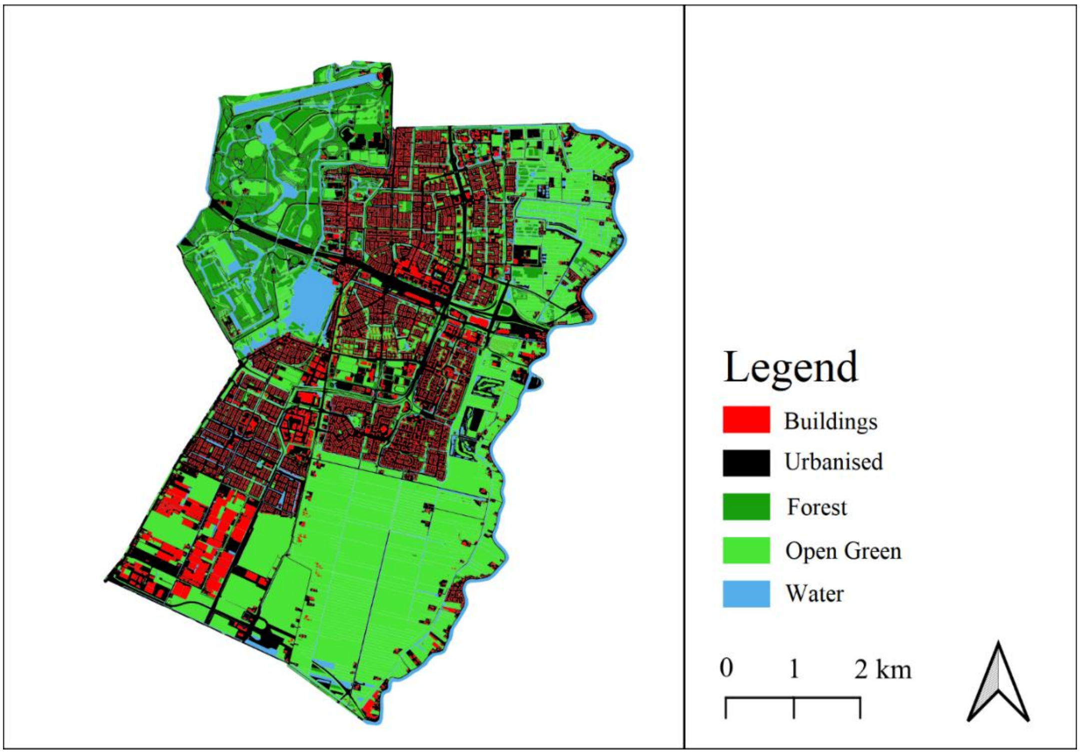

Figure 35. Project area physical characteristics.

5.2 Demonstration

Although the model can be run all at once, separate parts of it are executed in different steps, equating to the phased approach of the analysis, to be able to review the output for each phase. All intermediate layers are visualised, and their contents are assessed.

5.2.1 Screening

To create the main exclusion layer in QGIS, exclusion layers are first individually plotted. Once all of these have been created, they are overlaid. This creates the overall exclusion layer. The outputs for the exclusion layers are visualized in Figure 36. For two criteria, namely drinking water protection areas, and utilities areas, the QGIS output is empty because both layers have no output: there are no drinking water protection sites and constraining utilities (i.e. power lines/ cables or gas pipes) in the Project Area. When exclusion layers are combined the map from Figure 37 is produced. By excluding the Exclusion Area from the Project Area, the Inclusion Layers are produced. This concludes the screening analysis. The grey areas that remain in Figure 37 equal the Inclusion Area, which will be analysed by the MCDA described in Chapter 3 for the level of suitability.

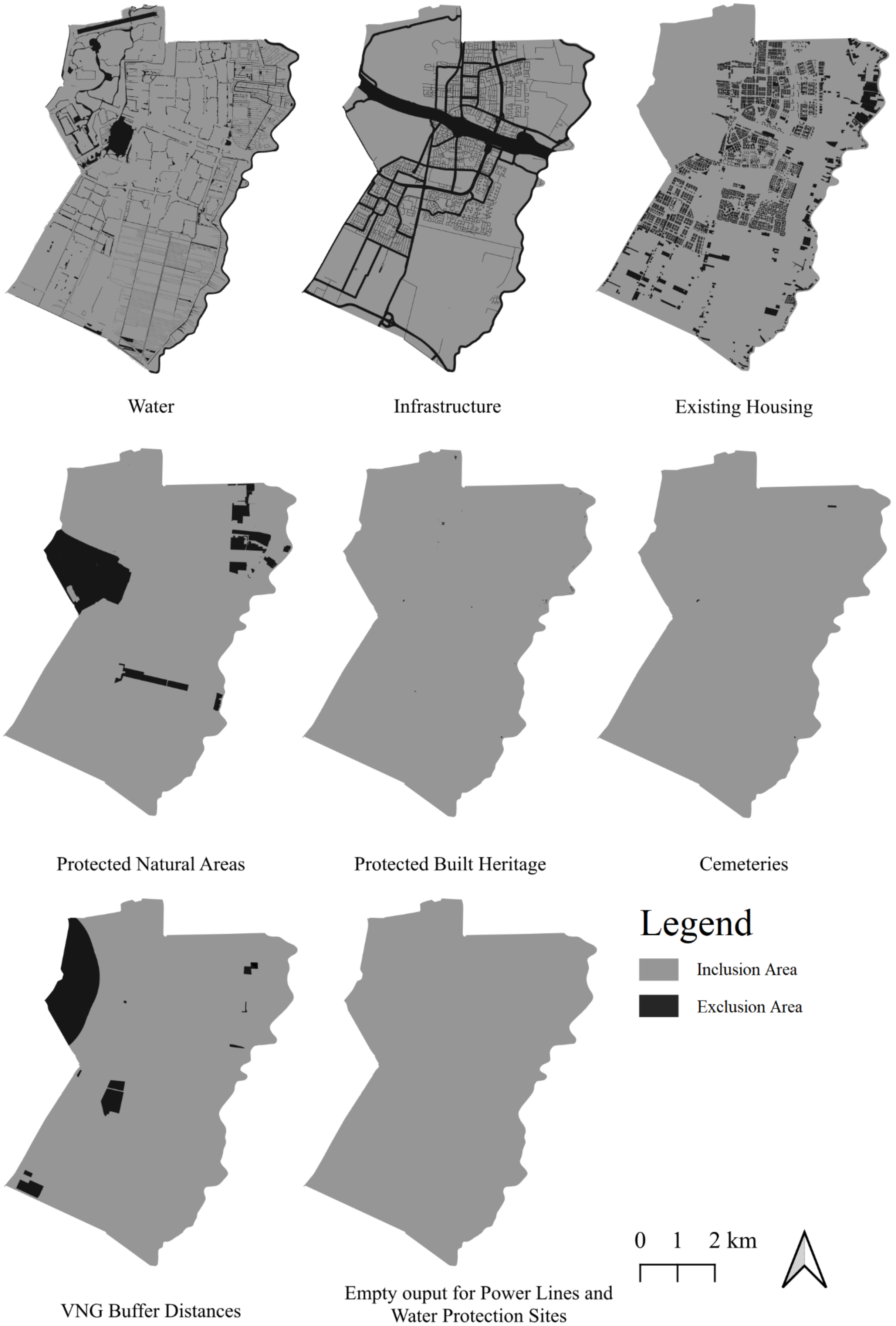

Figure 36. Exclusion layers.

Figure 37. Final exclusion layer.

5.2.2 Individual Suitability Layers

After the screening phase, the suitability analysis is executed. Suitability is visualised using a heat map, that indicates the suitability on a scale from 0 to 1 according to individual stakeholder interests. The individual layers are eventually added together using a weighted additive model, with weights determined by stakeholders. Some suitability layers are the product of a sub-analysis and are also weighted. The user of the model will be able to adapt these weights as well, but for the visualization in this report, these are equalized, meaning that sub-weights are all equal.

- Accessibility to Transport: The first stakeholder criterion is the accessibility to transport. The suitability for this criterion is formed from two sub-criteria: accessibility to public transport, and the accessibility to the nearest highway.
- Accessibility to Amenities: The second criterion is the accessibility to amenities. This suitability index is created from three sub-criteria: vicinity to metropolitan centre, vicinity to local centre, and vicinity to neighbourhood centre.
- Densification & Plot Size: These criteria do not consist of sub-criteria and are directly formed.
- Opposition Risk: This criterion is formed from two sub-criteria, population density, and housing price.

As can be seen in Figure 38, the suitability in terms of individual criteria is quite different for each case. For some cases, locations within the urban area are deemed more suitable, while for other criteria, rural areas are preferred. These individual layers are visualised in more detail in Appendix II. The final suitability is the weighted sum of the criteria according to the weighted additive model.

Figure 38. Suitability according to different stakeholder criteria.

5.2.3 Final Level of Suitability

The final level of suitability results from the suitability layers visualised in Paragraph 5.2.2 in combination with weights. However, as was mentioned in Paragraph 3.2.4, determining standard weights was not within the scope of this research. Therefore, the model analysis is run using the method described in the same section, where a pairwise comparison is conducted and filled in for each stakeholder, based on how often certain interests were found to be mentioned as important in Paragraph 2.3. This produces semi-arbitrary results, that can give an indication of what differences might be expected in suitability scores for sites according to different stakeholders but must be taken with a grain of salt because they are not based on expert interviews. Five semi-arbitrary scenarios are tested for the tool:

- Case 1 - Equal weights, meaning that all criteria are deemed equally important.
- Case 2 - Municipality weights, from the perspective of the municipality
- Case 3 - Developer weights, from the perspective of a developer.
- Case 4 - End user weights, from the perspective of future inhabitants.
- Case 5 - General Stakeholder Weights, the average of all weights

The first scenario was chosen because it gives a good impression of how individual criteria affect the overall outcome. Weights are equal, and all criteria thus have equal importance. This gives a good base scenario for reviewing the results. The second, third and fourth scenarios are meant to simulate the suitability according to several stakeholder perspectives, and the last scenario visualises what happens when the average weights of stakeholders are applied.

Case 1 – Equal Weights
For the first case, weights are equalized, and thus no pairwise comparison was necessary. Since there are 5 usable criteria, the weight of each criteria equals 1/5th: 0.2. The subsequent formula used is thus:

$$u_x = 0.2 * u_{access\ to\ amenities}(a) + 0.2 * u_{access\ to\ transport}(a) + 0.2 * u_{densification}(a) + 0.2 * u_{plot\ size}(a) + 0.2 * u_{avoiding\ opposition}(a)$$

This resulting map is visualised in Figure 39. As can be seen, there is a large difference in suitability among sites. This results from the different scores of individual criteria. As can be seen in Figure 39, the sites with a high suitability are primarily in the Northwest and Southeast. This is the case because these sites have a high suitability score according to multiple criteria. Since criteria are not weighted, this automatically means a good suitability score.

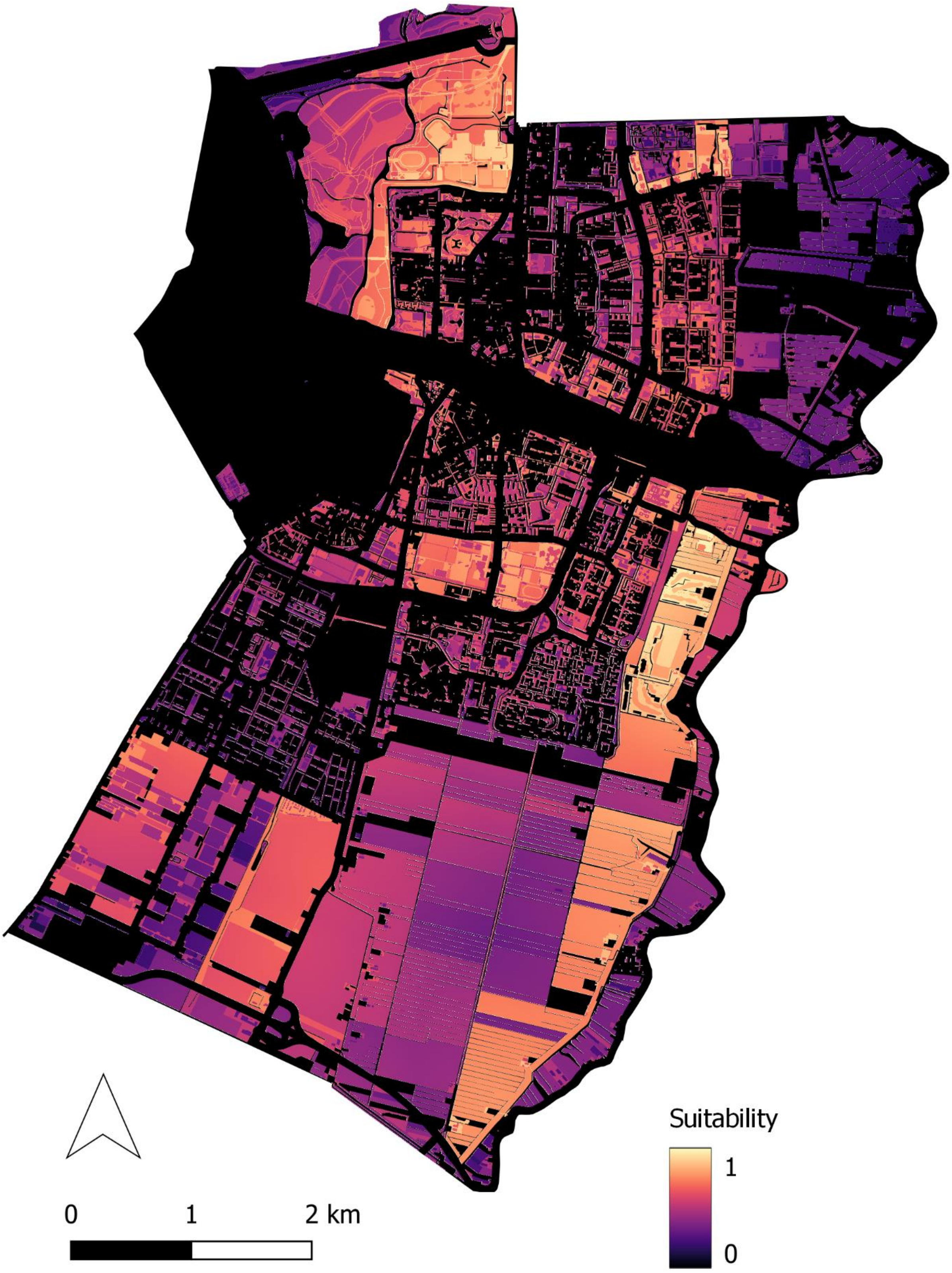

Figure 39. Suitability output for equal weights.

Case 2, 3, 4 – Simulated Stakeholder Weights

In the three following cases, a visualisation is made of semi-hypothetical preferences of different stakeholder groups. The two main stakeholders are selected, namely the municipality and developers. Aside from that, a third indirect stakeholder is included, namely a future inhabitant. As was mentioned in the introduction of this Chapter, a pairwise comparison was simulated, not by conducting interviews, but by assigning the highest importance to criteria that were based on the most often-mentioned interests of stakeholders in Paragraph 2.3. For each stakeholder, the consistency ratio is set at a maximum of 10% This results in the choices summarized in Table 34.

Table 34. Pairwise comparison input.

Criteria		Stakeholder					
		Municipality		**Developer**		**Future Inhabitant**	
A	B	Most important	By magnitude	Most important	By magnitude	Most important	By magnitude
Access to Transport	Access to Amenities	B	5	A	1	A	1
	Densification Potential	A	1	A	3	A	5
	Plot Size	A	3	B	7	A	7
	Opposition Risk	A	9	A	7	A	7
Access to Amenities	Densification Potential	A	3	B	3	A	7
	Plot Size	A	7	B	5	A	7
	Avoiding Opposition	A	7	B	7	A	7
Densification Potential	Plot Size	A	7	B	5	B	7
	Avoiding Opposition	A	7	B	7	A	3
Plot Size	Avoiding Opposition	B	1	B	3	A	1

The municipality places high emphasis on municipal goals like densification, accessibility to amenities, and mobility. These are more important than things like the prevention of opposition, which is more of a developer criterion. The developer additionally places high emphasis on avoiding risks and increasing revenue. Developers do however also place importance on interests like sustainability and quality. In the third case, the perspective of an end user, namely a future inhabitant is taken. The end user primarily focuses on accessibility to transport and amenities and is not, or very little concerned with the preferences of the municipality and developer, although the municipality does somewhat represent the interests of inhabitants. The model automatically calculates weights based on how the pairwise comparison was filled in, and these are summarized in Table 35.

Table 35. Weights calculated by pairwise comparison.

Criterion	**Calculated Weights**		
	Municipality	**Developer**	**Future Inhabitant**
Access to Transport	0.188	0.073	0.374
Access to Amenities	0.507	0.075	0.394
Densification Potential	0.219	0.042	0.071
Plot Size	0.046	0.296	0.111
Avoiding Opposition	0.039	0.514	0.052

Resulting from these weights, the scenario-specific MCDA functions can be summarized:

Municipality:

$$u_{x,municipality} = 0.188 * u_{access\ to\ transport}(a) + 0.507 * u_{access\ to\ amenities}(a) + 0.219 * u_{densification}(a) + 0.046 * u_{plot\ size}(a) + 0.039 * u_{avoiding\ opposition}(a)$$

Developer:

$$u_{x,developer} = 0.073 * u_{access\ to\ transport}(a) + 0.075 * u_{access\ to\ amenities}(a) + 0.042 * u_{densification}(a) + 0.296 * u_{plot\ size}(a) + 0.514 * u_{avoiding\ opposition}(a)$$

Future Inhabitant:

$$u_{x,futureinhab} = 0.374 * u_{access\ to\ transport}(a) + 0.393 * u_{access\ to\ amenities}(a) + 0.071 * u_{densification}(a) + 0.111 * u_{plot\ size}(a) + 0.052 * u_{avoiding\ opposition}(a)$$

By conducting the suitability analyses with these different weight distributions, three separate suitability maps are created. The suitability map according to municipal interests is visualised in Figure 40, the one based on developer interest in Figure 41, and the map resulting from Future Inhabitant interests in Figure 42. It can be seen that the output differs per case. Since the municipality has put a great emphasis on amenities, sites that score well on the amenity criterion dominate the output. Suitable sites are primarily in the centre and North of the municipality, where the distance to the municipal centre, and metropolitan centre is the smallest. Only transport, and densification potential have some additional influence on the output. Access to transport also causes some small increases in the suitability along roads outside of the built-up area, and larger plots can be seen to be a bit higher in suitability as well.

For the hypothetical developer, the map output differs strongly. This is the result of a completely different emphasis on criteria. The hypothetical developer places a high emphasis on large plots and avoiding opposition. Due to the high housing prices in the Northeast, this area scores badly. Additionally, sites in the South score relatively well, due to the larger plots that are available here. Apart from some large sites, the centre of Amstelveen scores badly.

The hypothetical end-user map shows a result that shows similarities with that of the municipality. This is caused by comparatively similar weights. However, the end-user places almost equal importance on access to transport, and access to amenities. The result of this is that sites far from the municipality’s centre, but near roads, score slightly better than in the municipality case.

Figure 40. Suitability according to hypothetical municipal preferences.

Figure 41. Suitability according to hypothetical developer preferences.

Figure 42. Suitability according to hypothetical end user preferences.

Case 5 – Combining Weights

Finally, one last scenario is simulated, where the average importance of all three simulated stakeholder weights is calculated, by calculating average scores. This is to simulate a scenario where the interests of all stakeholders are considered equally. In the real world, such a scenario would expectedly be the best solution. The average weights are summarized in Table 36.

Table 36. Average weights.

Criterion	Weight
Access to Transport	0.187
Access to Amenities	0.506
Densification Potential	0.221
Plot Size	0.047
Avoiding Opposition	0.039

The subsequent formula used is thus:

$$u_x = 0.187 * u_{access\ to\ transport}(a) + 0.506 * u_{access\ to\ amenities}(a) + 0.221 * u_{densification}(a) + 0.047 * u_{plot\ size}(a) + 0.039 * u_{avoiding\ opposition}(a)$$

This resulting map is visualised in Figure 43. The resulting map shows a lot of similarities to the output of the hypothetical municipality, and that of the hypothetical end-user. Because these maps showed similarities, to begin with, and all hypothetical stakeholders have the same weight, the output is naturally skewed towards maps that show similarities. The overall conclusion regarding suitability is that the city centre of Amstelveen is the most suitable for development.

Figure 43. Suitability according to average weights.

5.3 Evaluation of the System

The implementation process of the schematic model into an automated QGIS model and the resulting output of the model allows to make certain conclusions about the process. These are summarised per topic in this Paragraph.

5.3.1 MCDA Model Implementation

Implementing the schematic model into QGIS has indeed proven to be possible. First, the user creates the Project Area in the form of a layer consisting of a polygon that encompasses the area(s) to be analysed Then, a screening process is conducted by the use of a MOA. This results in the Exclusion Area a map layer consisting of polygons representing sites which are unsuitable. This layer is subtracted from the Project Area, creating the Inclusion Area, which consists of multiple polygons indicating potential housing development sites.

Then, a MCDA is conducted to determine the suitability of the Inclusion Area plots. Data is loaded about spatial characteristics relevant to stakeholder criteria, and these layers are rasterized. Then, the raster calculator function is used to sum the criteria according to a MAUT function. The user can change the weights in this function to account for personal preferences. The resulting layer indicates a general suitability for each site in the Inclusion Area
It has indeed proven possible to develop a model for the screening process of new housing sites, and suitability analysis of resulting options, using only open-source software and data. The model was designed according to the schematic model presented in Paragraph 3.3. Designing the GIS model proved quite easy, as well as its implementation in QGIS. QGIS itself has proven to be a very capable, and user-friendly tool. The toolbox allows for a wide range of operations that make it possible to conduct all kinds of analyses. There were no cases of tools that were missing, and most operations worked as intended.

5.3.2 Output Quality and Face-Validity

The quality of the output in terms of understandability is quite good. All sites are scored on a scale between 0 and 1, and the different levels of suitability are visualised using a colour scale that makes it easy to distinguish between different levels of suitability. Furthermore, the 1x1 grid output is quite precise, and thus also allows for exact suitability levels of the smaller sites. Because a grid is used where all cells are scored separately, it also becomes possible to determine different suitability levels within sites. It can be seen which side of the site has the biggest suitability, which is useful for larger plots.

When implementing different weights, the model responds by producing different outputs. These are in line with expectations based on different weight inputs which are based on the different interests that were found for stakeholders in Paragraph 2.3.4. Because interests, although overlapping in some regards, differ, they also differ per hypothetical stakeholder scenario. The face validity of these outputs seems to be good, but this cannot be confirmed, because no experts were involved in research.

5.1.3 Run Time

One of the biggest challenges with running large models in QGIS is the runtime. Because the number of operations is very large, the model must run a very long time before producing a result. Despite that the general operations on the layers are quite straightforward, a lot of intermediate reprojecting, clipping, dissolving, and aligning operations must be executed before the data is suitable for analysis. Additionally, the grid size that was selected to conduct the suitability analysis was set at a 1 by 1-meter scale, which is necessary when the user wants to accurately determine the suitability of smaller plots. Reducing the plot size to for instance a 10*10m grid helps with speeding up the model, but by far the most time-consuming operations are those of intermediate formatting. These can unfortunately not be omitted. For the case study, this was done due to the lack of alternatives, but this is not a viable solution because it is extremely time-consuming. One other problem, with the functionality of the visual modeller operations was encountered: For the creation of the Data Area layer, a buffer is laid on the project area's border, based on a column value in the corresponding row in the linked attribute table. In the manual operation, there is the option to select a column from the attribute table to base the buffer length on, but in the visual modeller, the list of columns to choose from always returns an empty field and is thus unusable.

6. Conclusion

This Chapter provides a general conclusion on the research by recapitulating the research question, reflecting on the process that is executed to answer it, and reviewing whether this process was indeed able to answer it. Additionally, it will conclude with limitations and recommendations for further research that can built upon the findings of this research.

There is currently a large housing shortage in the Netherlands, which is partially caused by a lack of suitable sites for development. Based on the challenges associated with finding new housing sites, and the lack of a general and accessible approach for municipalities to tackle these challenges, this research aims to provide a general framework for the screening process of new housing sites and the measurement of suitability for newly identified potential locations, by the development of a decision-support tool. Consequently, the main research question is as follows:

"How can a decision support tool that can be used by different stakeholders, to assess suitability for new housing development land be designed?

In Chapter 2, a literature review is conducted about the development process in the Netherlands, and how this relates to the problem. Research is conducted into the screening for new land, and which stakeholders are relevant in this process. After analysing the development and screening process, a list of the primary stakeholders in this process is compiled. It is found that there are two main stakeholders, namely municipalities and developers. On top of that, there are secondary stakeholders whose interests are represented by these two primary ones. For each of these, interests are identified based on stated topics of importance in policy papers, missions, and visions. For the primary stakeholders, interests are rated on importance. For the municipalities, this is done by analysing structure visions, and the stated goals of the largest municipalities in the country. For developers, the mission, vision, and policy documents of the 10 largest social, and 10 largest commercial developers are analysed, and it is counted how often individual interests were mentioned to come up with a list of the most important ones. For societal interests, literature is analysed. Several topics were named repeatedly. The most often mentioned topic of interest was sustainability. Often, topics that are deemed part of sustainable development are mentioned separately, like access to transport, access to amenities, and dense urban environments. For these interests, spatial characteristics are identified that were associated that could influence whether an interest could be fulfilled or not, and from these spatial characteristics, spatial criteria are derived. Some of these criteria are based on sub-criteria. For instance, access to transport is based both on the distance to PT stops, and the distance to highways.

Aside from clarifying the housing problem, and the development process, decision support tools that are relevant to the problem and development process are reviewed. By comparing multiple studies, it is found that MCDA methods provide a very suitable approach to tackling these multi-criteria challenges. In the spatial domain, these MCDA approaches are often coupled with GIS, which are spatial systems that create, manage, analyse, and map all types of spatial data. This combination is used extensively in the literature for tackling spatial problems. Utility scores for areas are calculated using a MAUT function. This MAUT function is a weighted sum of scores for different spatial criteria, like distance to PT. This calculation is repeated for each area under analysis, and the final utility scores can be compared to come up with the best option.

One of the most relevant developments in the field of GIS is the use of open-source data. Open-source options have already been used in numerous studies and are perceived by many scientists to become a viable alternative to commercial options. Aside from benefits such as cost-effectiveness, open-source alternatives also provide transparency, which is useful for the Dutch government since they score badly on transparency. Due to the multi-criteria, and spatial nature of the problem at hand, it is decided to develop the tool in an open, combined MCDA-GIS environment.

Development of the tool was done in several stages. First, the general method of analysis is described. There are two analysis phases and one preliminary phase. The preliminary phase is about setting up the software and selecting the Project Area. The two analysis phases are based on different types of criteria that were identified. The first of these are the exclusion criteria, which classify an area as unsuitable when one or more criteria are not met. This includes criteria like: sites must not be within a protected natural area. The analysis phase based on these criteria is called the screening phase, where all non-potential sites are excluded from the analysis. This is done using a MOA. Polygons representing non-suitable areas are overlaid and added together producing the Exclusion Area, This Exclusion Area is subtracted from the Project Area, creating the Inclusion Area, which contains all potential housing sites. The second analysis phase is done based on stakeholder criteria, which originate from stakeholder interests. The remaining sites are divided into 1x1 cells by rasterizing the Inclusion Area polygons from analysis phase 1. For each of these cells, a MCDA is conducted using a MAUT function, that produces an overall suitability score for each cell, based on the weighted sum of suitability sub-scores per criteria. The suitability overall suitability is visualised using a heatmap. All the analysis phases are mapped in a schematic model, that visually summarises the analysis steps that should be applied in software to come up with the wanted results.

Following its completion, the schematic model is applied in a specific GIS software package. QGIS is chosen as the software to implement the analysis in since it is freely available, gets updates regularly, has a big supporting community and, additionally, is known to be user-friendly. For data, several sources were used. The first of these is OSM, whose data can be loaded into QGIS by default. Additionally, two plugins are installed via which data can be retrieved from online databases. These are the INSPIRE, and PDOK plugins. For each criterion, the relevant data was identified. Suitable spatial data is available for almost all criteria, except for soil conditions, and VNG distances. However, for VNG distances, an alternative method is developed to still be able to partially assess this criterion. For all other criteria, data was found, but much of this data is not instantly usable and needs additional processing. The operations that are necessary to do so are defined and visualised schematically.

After identifying the schematic model, software, data, and QGIS operations for data processing, the process is automated in QGIS using the visual modeller. The visual modeller was chosen over the Python alternative based on a comparison of pros and cons. However, although yielding more potential theoretically, the visual modeller has some drawbacks that prevent the full automation process. This primarily has to do with data loading, which does not work for integrated options, and cannot be done for plugin sources because their operations are not integrated in the visual modeler. Nevertheless, the schematic model is automated in QGIS to the highest degree possible. By conducting some non-functioning operations by hand, it still becomes possible to run the model.

After automation, a demonstration is conducted. Five hypothetical stakeholder scenarios are simulated in QGIS, by implementing different weights in the raster MCDA. The weights for the first case are all set equally, to come up with a base scenario to compare the others to. For scenarios 2, 3 and 4, stakeholder weights are 'simulated' by the author, by conducting a Pairwise Comparison. In this pairwise comparison, importance is assigned to individual criteria based on how often interests were found to be mentioned in the literature. This produced three separate sets of weights for each stakeholder scenario, and the output of the model responded to these by producing three distinct outputs. In the last scenario, the average weights of the stakeholder weights are used, creating an average suitability score based on all hypothetical stakeholder inputs. The quality and face validity of the model output seem to be okay. Furthermore, it seems that the output of the model is quite different for separate stakeholder groups. Because the Pairwise Comparison was filled in according to stated interests, they are suspected to be at least partially indicative of what real-life stakeholder input would yield. However, this is not confirmed, because real-life stakeholders were involved with this research.

There are some limitations associated with how this research was conducted. First of all, the development process, relevant stakeholders, and their interests are fully based on literature findings. This method sometimes makes it hard to find out the exact details of these subjects and excludes expert opinions that might not be obvious from the outset. Furthermore, because society is a very broad term, the interests of this stakeholder group are assumed to be mostly represented by the two main stakeholders, while it could well be that there are numerous additional interests of sub-groups. Furthermore, no correlation analysis between criteria is developed, although this is recommended in the literature for MCDAs. It might thus be the case that suitability is skewed towards certain spatial aspects. Another point that must be made is that it is not possible to include all spatial criteria in the analysis, due to the lack of suitable or complete data. Some criteria are simplified, like monuments and VNG distances, and soil characteristics are omitted completely. VNG distances especially, are quite important to the spatial suitability of a plot since they are exclusion criteria. By not being able to assess this criterion in detail it might be the case that some areas are deemed potentially suitable by the model, while they aren't in real life at all. There is also a point to be made about the quality of data. For both INSPIRE and PDOK, the data is said the be quite complete, up to date, and reliable, but no such statement can be made about the data from OSM. All the data of OSM is produced by volunteers, and the validity of this data cannot be checked. It might well be that some of this data is incomplete, or out of date.

These limitations and assumptions lead to multiple recommendations for further research. A more extensive literature review, combined with expert interviews could be conducted to gain more in-depth knowledge about relevant stakeholders in the development process and their interests, if not to confirm the interests that are found from the literature review only. Societal interests especially, with all subgroups, could be expanded significantly. Future research could also be conducted on the correlation between different interests. As for data, additional research can be conducted into the possibilities of creating datasets from multiple local sources, to come up with additional sources for criteria that this cannot be done at the moment. Ideally, more reliable sources than OSM are found as well, because the validity of data from this source is not confirmed. It is also interesting to re-test the visual model in QGIS in other versions, to see whether it is completely functional once plugin operations have been integrated into the visual modeler, and once software bugs have been fixed. Another suggestion is that the demonstration of results is superseded by a case study, based on real stakeholder weights, instead of hypothetical ones. This could give a much more reliable assessment of results and could definitively give an idea about the output quality of the tool.

All in all, the main research question can be answered as follows: It has indeed proven possible to design a decision support tool for the screening of new housing sites, by identifying stakeholder interests and translating these into usable spatial criteria. For the screening process, a map overlay analysis can be applied, and for the suitability analysis using a combination of MCDA-GIS. The face validity of the model output seems to be sufficient but cannot be proven because weights were not based on expert input. On top of that, there is room for improvement and further development on multiple elements of the tool, consisting of criteria, data, and validity.

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Appendices

Appendix I – History of Spatial Management in the Netherlands

Table 37. History of spatial policies in the Netherlands (Bruinsma & Koomen, 2018).

Name	Year	Main points for housing
De Ontwikkeling van het Westen des Lands	1958	• Demolition of dated 19th century housing and lowering the population density • Constructing new housing on fringe locations
Nota inzake de Ruimtelijke Ordening in Nederland	1960	• Realization of large uniform, prefab neighbourhoods that could be built quickly. • First signs of suburbanization with the goal to create a network hierarchy, with viable suburbs that are able to support themselves.
Tweede Nota over de Ruimtelijke Ordening in Nederland	1966	• Conclusion that bigger cities are no longer able to provide enough housing; urbanization is primarily taking place in fringe locations. This endangered the green heart of the west of the country. • Growth in rural areas was frowned upon, but so was development within urban centres. Therefore, large numbers of flats were built at designated areas to satisfy the strong demand for housing that existed during this age. • However, an increase in wealth meant that there was a bigger demand for ground-bound housing with gardens. • To satisfy this additional demand, the government implemented a policy of 'bundled de-concentration'. Here, suburbanization took place only at designated urban cores near larger cities.
Derde Nota over de Ruimtelijke Ordening	1973-1977	• Growth cores become mandatory and receive financial support in the 1970's. • Already in the 1980's however, the volume of new housing that is to be built at these growth core locations is drastically reduced due to an economic crisis, and the now obvious problem that suburbanization caused impoverishment in the inner cities. • Development of the compact city concept. • Redevelopment of impoverished areas • Redevelopment of inner-city industrial areas.

Vierde Nota over de Ruimtelijke Ordening	1988-1997	• Post-war housing shortage came had improved. • New problem: the reduction of household size, and consequential additional demand for housing. • Older policies had caused impoverished areas. Quantitative housing shortage had turned into a qualitative housing shortage. • It had become clear that older policies had caused a reduction in spatial and environmental quality. • Large national construction plan. Preferably within existing urban centres or directly next to them. • Large emphasis on accessibility. • Large increase in amenities.
Vijfde Nota over de Ruimtelijke Ordening	2002	• Primarily aimed at indicating main policy lines. • No suburbanization anymore, only densification in existing urban areas. • Responsibility at municipal level.
Nota Ruimte	2004	• Additional need for housing, preferably within urban centres but allowed on fringes when necessary. • Small developments are allowed in the green heart.
Structuurvisie Infrastructuur en Ruimte	2012	• It was concluded that strong population growth was over and that the demand for housing would fall in the following years. • Focus on compact cities. • Ladder of sustainable development is introduced, that describes how it must always first be assessed whether certain development is necessary within cities, and in case yes, this can be achieved by redeveloping existing buildings. • New development should always have optimal multimodal characteristics. • Further delegation of governmental responsibility to municipalities.
Nationale Omgevingsvisie	2020	• Reintroduction of the ministry of housing. • 14 large core location for housing development. • Densification as much as possible.

Appendix II – Full Scale Suitability Layers

Access to PT

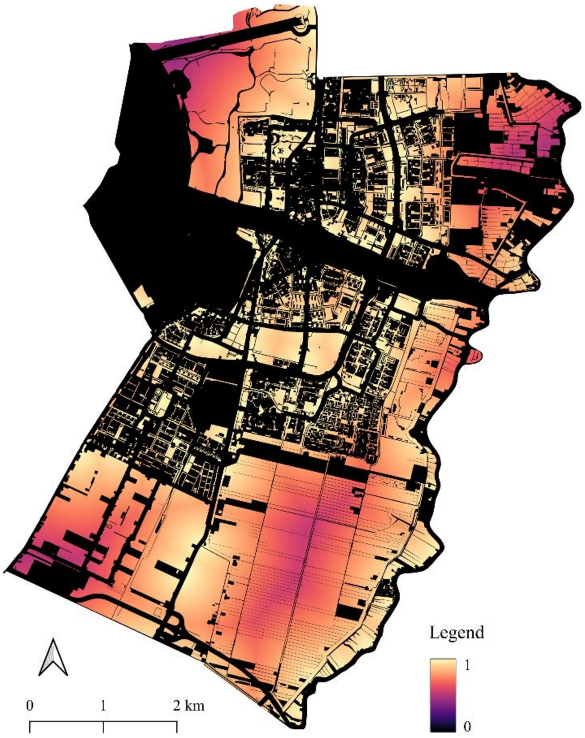

Figure 44. Access to PT.

As can be seen in this map, high suitabilities primarily exist in built up areas and around large roads. This is due to the fact that PT stops primarily exist along traffic arteries. Open areas are consequentially not very accessible.

Access to Highway

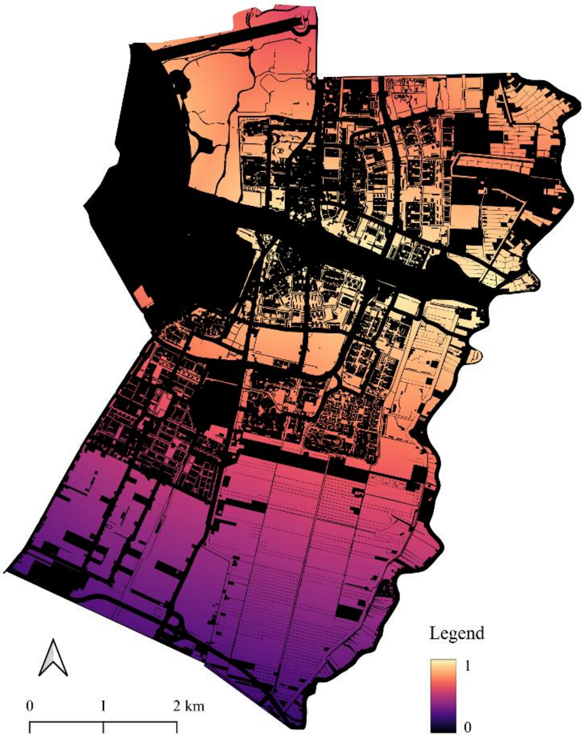

Figure 45. Access to highway.

The municipality of Amstelveen is dissected by a large motorway that runs through it from east to west right through the municipality's centre. This has the consequence that suitability is thus highest for this criterion along this corridor. Aras to the south score relatively badly because the motorway is further away.

Access Transport in General

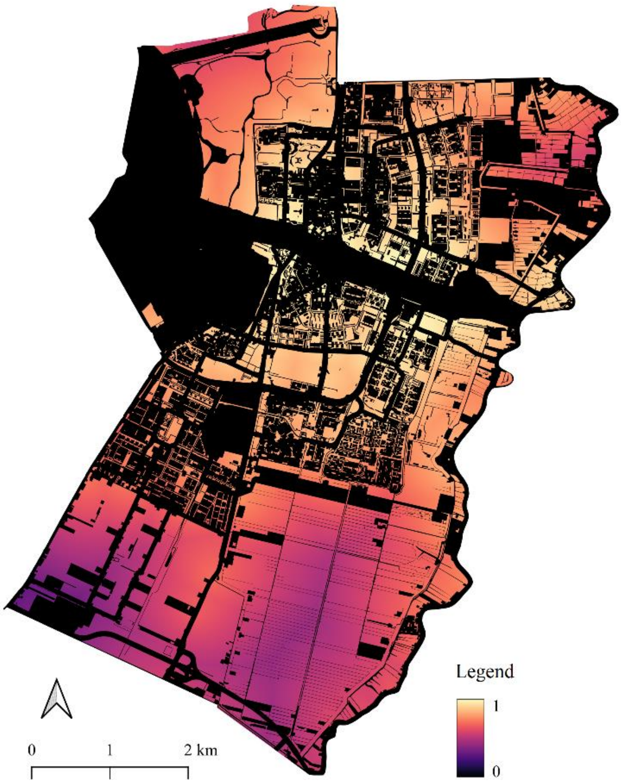

Figure 46. Access to transport in general.

The general transport accessibility is best in the centre of the municipality. This is due to the higher concentration of PT stops and, the presence of a highway only in the centre. Consequentially, when stakeholders implement a high importance to accessibility in the analysis, sites in the centre will score better.

Densification Potential

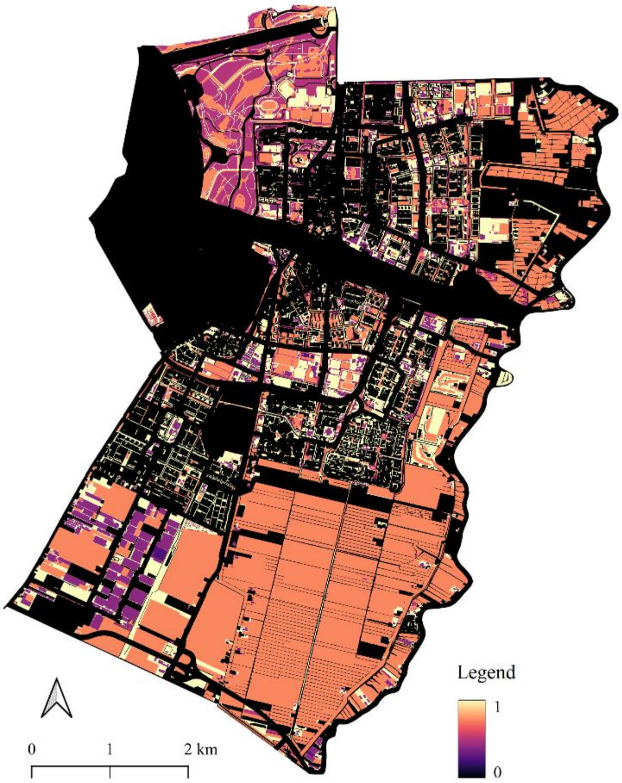

Figure 47. Densification potential.

Densification potential is highest in the centre of the municipality as well. This is the case, since there is a lot of vacant areas within the built-up area that is not open green or forest. These are preferred over the development in greenfield land because reduction of green areas is perceived as bad. As can be seen, there are a lot of options for densification, but these are primarily cluttered in the centre of the municipality.

Access to Supermarket

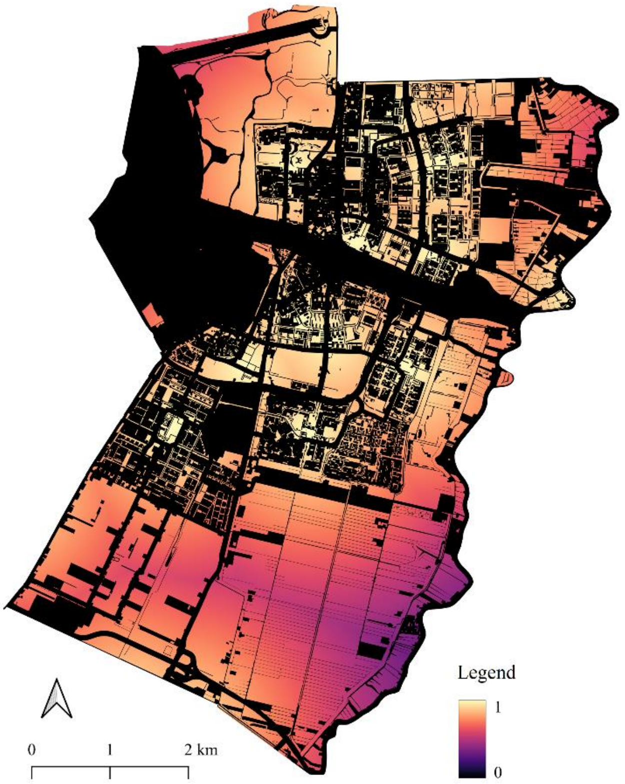

Figure 48. Access to supermarket.

Access to supermarkets is spread relatively evenly in the municipality, due to the relatively even spread of municipalities. Again, the South of the municipality scores badly, because there are few supermarkets in the non-built-up areas.

Access to Municipal Centre

Figure 49. Access to municipal centre.

Logically, the centre of the municipality scores the best for this criterion. Here are the most shops in the area, and sites further from the centre score worse than those near it.

Access to Metropolitan Centre

Figure 50. Access to metropolitan centre.

The access to the metropolitan centre is best in the North of the municipality, due to its vicinity to the city of Amsterdam. Not coincidentally, this also equates to the built-up area of the municipality, which is often considered a suburb of Amsterdam, although it is officially its own municipality.

Access to Amenities in General

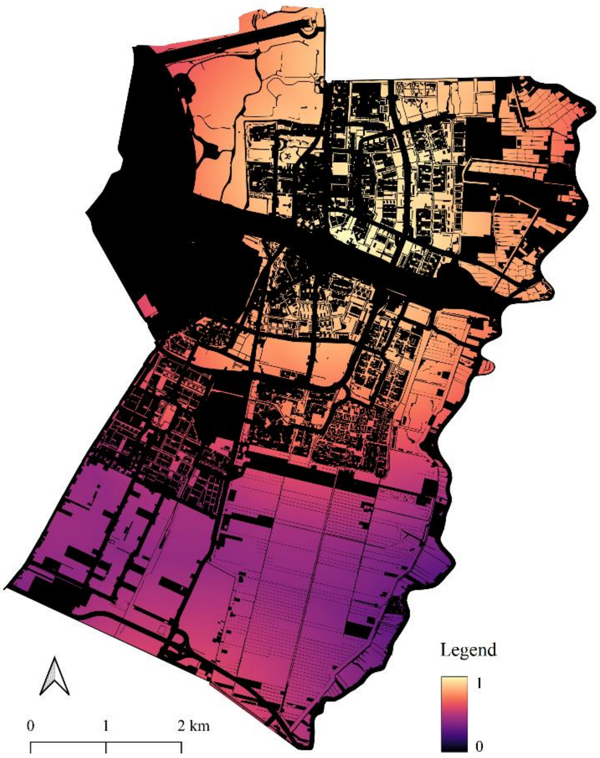

Figure 51. Access to amenities in general.

The general accessibility to amenities is best in the centre and North of the municipality. The South scores relatively badly. This result makes sense because the northern half is more built up. When stakeholders implement a high weight for amenities, the North will consequentially be more likely to score high on overall suitability.

Plot Size

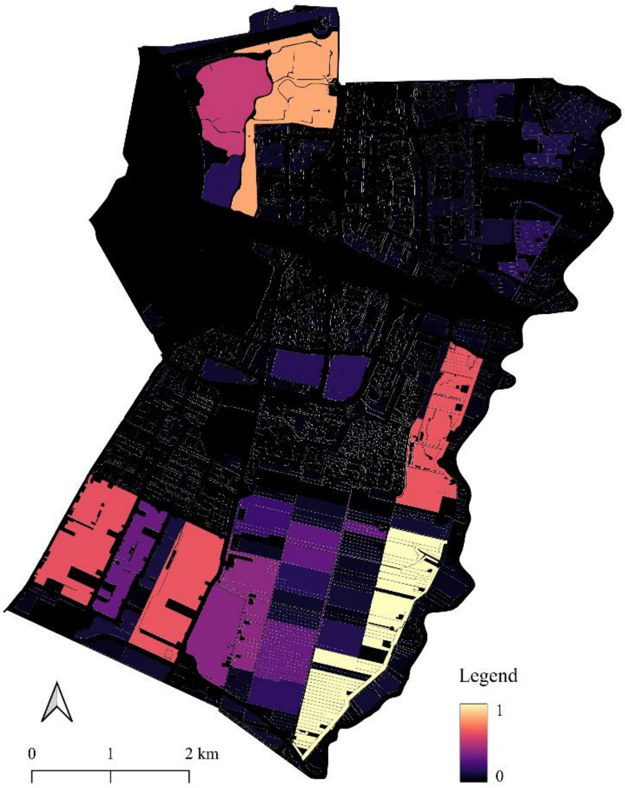

Figure 52. Plot size.

The output for plot size is polarised. Here, unlike for most other criteria, the south scores better, due to the existence of large open areas. It is easier to implement large-scale housing here because there simply is more room. The largest open area is to the Southeast. This is open farmland that has barely any buildings on it.

Population Density

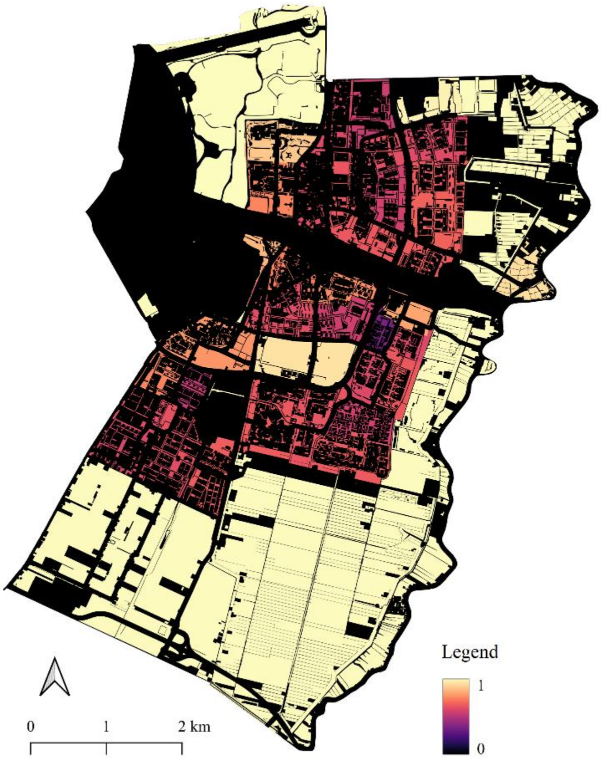

Figure 53. Population density.

Population density is logically high in the built-up area, and low in the open areas. Since it was found that areas with a higher density are more likely to yield resistance from their inhabitants, the suitability score is higher for open farmland.

Housing Value

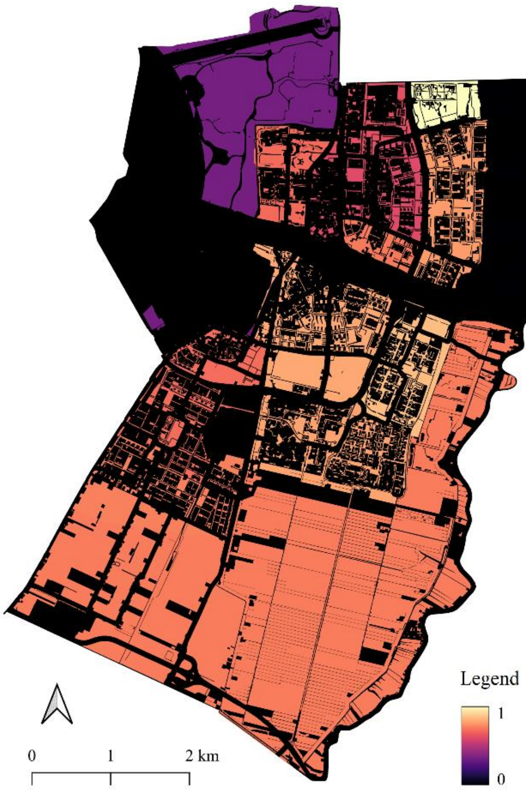

Figure 54. Housing value.

High housing prices equate to a lower suitability, because there is more chance of resistance of the population. This is primarily the case in the Northwest, and Northeast. Here, housing prices are higher. The Northeast is especially unsuitable.

Opposition Risk

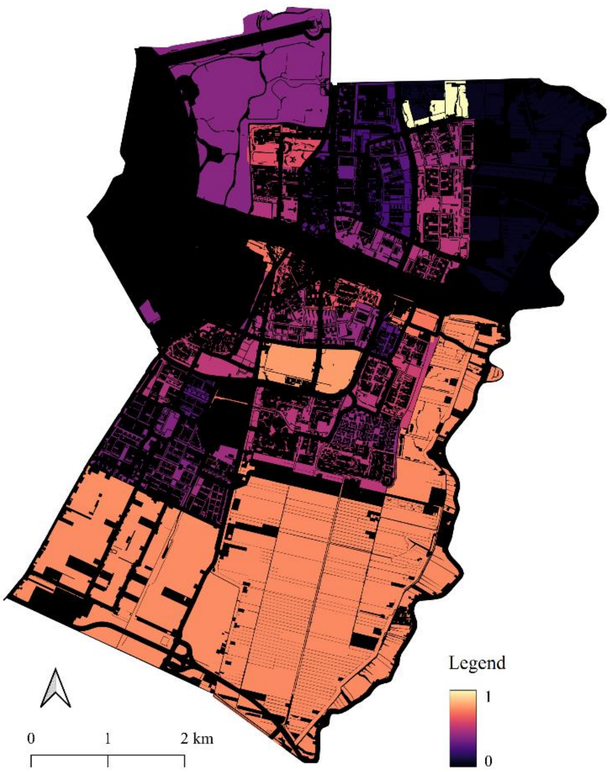

Figure 55. Opposition risk.

Following from the two previous criteria, the suitability according to opposition risk is the highest in the South of the area, because less people live here, and housing prices are lower. Ther is a small exception in the North. However, generally, stakeholders that want to avoid opposition should focus on development in the South according to this criterion.