Spatial decision support systems in urban area development in the Netherlands

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COLOPHON

SPATIAL DECISION SUPPORT SYSTEMS
IN URBAN AREA DEVELOPMENT IN THE NETHERLANDS

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PREFACE

2 weeks ago I have presented my P2 research proposal, my mentors have asked me to elaborate more on the interaction between the SDSS and the Dutch urban area development process and to improve the alignment between the research methods and research questions.

Therefore I have used previous two weeks to:

- Elaborate on the role of a SDSS in urban area development in the Netherlands;
- Further develop the problem statement;
- Align the research methods to the research questions and the research questions to the problem statement;
- Search for scientific reviews of the application of SDSS in urban area development in the Netherlands;
- Search for suitable case studies of the application of SDSS in urban area development in the Netherlands for my research;
- Contact the developers of those tools;
- Set up a theoretical framework for the evaluation of these models.

Accordingly I'll focus this presentation on the work I have done in the past two weeks to improve my research proposal (page 3 to 8). Which includes the following paragraphs:

2. Problem statement
3. Research motives
4. Research objectives & outcomes
5. Demarcation
6. Research questions
7. Research methodology
8. Research planning

Before I'll outline the adaptions of my research proposal, I'll briefly recap my findings from the literature study I have done so far and introduce you my findings of the application of SDSS in urban area development in the Netherlands.

As I have outlined in my previous report, GIS can be used to support the decision making process in urban area development. It is a computer-based system that provides the following four sets of capabilities to handle geo-referenced data (Huisman & de By, 2009):

1. Data capture and preparation
2. Data management, including storage and maintenance
3. Data manipulation and analysis
4. Data presentation

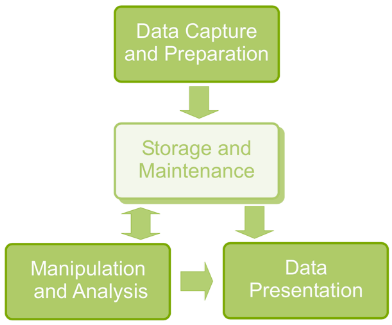

Figure 1 *Functional components of a GIS (Huisman & de By, 2009)*

GIS can contribute to:
(i) objective, accurate and quantifiable impact prediction and assessment;
(ii) evaluating the spatial and temporal variability of impacts,
(iii) predicting cumulative and large-scale effects; and, ultimately,
(iv) presenting all relevant information in geographic and visual form
(Antunes et al., 2001; González et al., 2011b; João, 1998; Vanderhaegen and Muro, 2005).

This contributes to providing information in a more efficient and comprehensive manner, improving understanding and raising awareness on the spatial implications of a planning intervention (Antunes et al., 2001; Carver, 2003; González, 2010; González et al., 2011b).

Spatial decision support systems (SDSS) are a category of information systems composed of a database, GIS software, models, and a so-called knowledge engine which allow users to deal specifically with locational problems. It is related to spatial information theory which focuses specifically on providing the background for the production of tools for the handling of spatial data.

According to the Spatial Decision Support Consortium (2008), a SDSS is “the computational or informational assistance for making better informed decisions about problems with a geographic or spatial component. This support assists with the development, evaluation and selection of proper policies, plans, scenarios, projects, interventions, or solution strategies”.

SDSS are commonly used to inform problem solving and assist decision-making processes by providing tools for combining quantitative data and qualitative knowledge/perceptions, and for processing this information in order to present, compare and rank planning alternatives and, ultimately, select the one that satisfies the established decision criteria (González et al., 2013).

Purposes of a SDSS are (González et al., 2013):
- Evaluating plans or policies (through impact assessment);
- Exploring alternatives or scenario’s;
- Testing and validating theories;
- Simulating urban processes in order to raise awareness and deal with these processes;
- Provision of more detailed scientific data to plan-making processes, enhancing the links between research and practice;
- Monitoring and evaluating indicator performance in a planning context, and;
- Improving stakeholder participation by using the model as a communication and negotiation tool.

Another term which relates closely to SDSSs are planning support systems (PSSs). PSSs aim to improve planning processes by structuring them better and/or making them more interactive, integrative and participatory, etc. Next to that PSS aim to improve the outcomes of these processes (e.g., strategies, plans and projects) by providing relevant knowledge and facilitating a design-analysis loop that improves the link between explicit knowledge and planning actions (te Brömmelstroet, 2013).

Table 1 *Differences between GIS, SDSS and PSS (Li & Jiao, 2013)*

	GIS	**SDSS**	**PSS**
Users	GIS Analysts	Domain Experts	Planners
Key Points	A set of tools Spatial data Spatial analysis GIS algorithms General flatform	Short-term decision Spatial and Non-spatial Data Spatial problem solving Decision support models Domain oriented platform	Long-term decision Spatial and Non- spatial Data Uncertainty and scenario planning Urban planning models Public participation platform

According to Li & Jiao (2013) SDSS are mainly used by domain experts, while PSS are mainly used by planners. However, other authors see PSS as a part of collaborative SDSS (Balram, 2006). This research will look at the overlap of SDSS and PSS as it will outline the application of SDSS to support the urban development process.

As shown in table 2 on page 18 a wide variety of SDSS are applied in practice and reviewed in literature, like SDSS:
- Regarding to simulation of multi-actor spatial planning (Ligtenberg et al., 2004);
- Regarding to strategic environmental assessment, like the BRIDGE tool (Carsjens & Ligtenberg, 2007; González et al., 2013);
- Regarding to urban infrastructures (Coutinho-Rodrigues, 2011);
- Regarding to land-use evaluations for site selection of parking in Tehran or of a park in Italy (Jelokhani-Niaraki & Malczewski, 2015; Zucca et al., 2008);
- Regarding to monitoring, evaluating and even simulating urban growth (Anthony Gar-on Yeh & Xia Li, 2007; Shen et al., 2009, Hana et al., 2009; Ying et al., 2009);
- Regarding to analysis of patterns of spatial occupancy (Marusic, 2001; 2012).

According to various researchers SDSS support the urban development process as it contributes to providing information in a more efficient and comprehensive manner, improves the understanding and raises awareness on the spatial implications of a planning intervention (Antunes et al., 2001; Carver, 2003; González, 2010; González et al., 2011b). A SDSS model provides insight into the processes within an urban area, and can be used as a communication and negotiation tool to support decision-making processes in urban area development. This allows a city to make better-grounded decisions regarding to urban area development and to solve problems through a more efficient and sustainable performance. A greater understanding in the operation of spatial decision support systems can help in the acceptance and improvement of these systems. It can support cities to meet their sustainability targets and to accommodate growth.

However, there have been also many critical reviews upon the application of SDSS.
Geertman and Stillwell (2009) state that despite a promising integration of technologies and a high number of pilot studies, the successful application of geo-technology by planning practitioners to support their activities is far from commonplace. Uran and Janssen (2003) identify the mismatch between the decision problem of end-users and the answers produced by the system as the main factor for this lack of success: technology-driven systems produce the correct answer to the wrong question at the wrong moment. Along the same lines, Geertman and Stillwell (2009) state "there exists a fundamental dichotomy between those systems that are demanded for use in practice by potential users and those systems supplied by systems developers according to their perception of what is required". Furthermore, most schemes take into account only a small proportion of urban processes. Therefore, many actions that are intended to improve a particular kind of urban performance can have even more damaging side effects (Saynajoki, 2012).
SDSS therefore often don't recognize dynamic and complex nature of decision-making processes. Additionally, local developers may find it difficult to select the tools that apply to the local conditions. Due to a lack of standardisation and transparency, different tools assessing the same may produce remarkably discordant results." (Saynajoki et al., 2011)
All researchers agree that the major challenge in this area is to better link decision-support tools to the ways in which stakeholders use those tools.

The reasons for this implementation gap are diverse. Their potential users see SDSS as:

- inadequate,
- far too generic,
- complex,
- too technology oriented (rather than problem oriented),
- not transparent enough,
- neither flexible nor user friendly,
- too narrowly focused on strict technical rationality, and
- incompatible with the unpredictable/flexible nature of most planning tasks and information needs

(see Batty, 2003; Bishop, 1998; Couclelis, 1989; Geertman & Stillwell, 2003a; Harris & Batty, 1993; Lee, 1973, 1994; Sieber, 2000; Uran & Janssen, 2003; Vonk, 2006; Brömmelstroet, 2013).

To be utilised in daily planning practices, a SDSS tool should be demand-driven in orientation (Reeve and Petch, 1999) and utilise participatory methods during the development process to better reflect stakeholders' needs for information in the design of the DSS tools (Schetke et al., 2012).

The reactions of these reviews are numerous. Some of these focus on improving PSS software by adding new functions to it, for example PSS that are more integrated (i.e. 'What If' developed by Klosterman (1999)), more interactive (i.e. 'Urban Strategy' developed by TNO (2011)) or more user-friendly (i.e. 'UrbanSim' developed by Waddell (2002, 2011)). Others follow a more hardware oriented path, such as 'Maptables', 'Sketchtables' and other visual gadgets (see Vonk & Ligtenberg, 2009). Then there is the process-oriented line that focuses on bridging the human gap between the potential end-users and the PSS developers with more participative, iterative PSS development structures (Te Brömmelstroet & Schrijnen, 2010), like the serious gaming tool of Tygron.

Especially these recent developments in SDSS are interesting to research to review if they have bridged the implementation gab between theory and their use in the practice of urban area development.

CONTENTS

1. INTRODUCTION

1.1. INTRODUCTION OF THE TOPIC

The graduation research will study the application of spatial decision support systems (SDSS) in urban area development. Due to limited and manipulated information, decisions regarding to urban area developing are not well grounded resulting in incompetent solutions that fail to meet the requirements of the project. Due to the high investment and long period of planning for redevelopment, it is hard to solve urban area failures. This causes a gab between the supply and demand of real estate, resulting in vacancy, value devaluation and user dissatisfaction. Furthermore, due to the complexity of urban redevelopment projects with many involved stakeholders, an impasse might occur, leading to slow decision making, stagnation, or even cancellation of the project.

Spatial decision support systems (SDSS) are a category of information systems composed of a database, GIS software, models, and a so-called knowledge engine which allow users to deal specifically with locational problems. SDSS contribute to providing information in a more efficient and comprehensive manner, improving understanding and raising awareness on the spatial implications of a planning intervention (Antunes et al., 2001; Carver, 2003; González, 2010; González et al., 2011b). A SDSS model provides insight into the processes within an urban area, allowing to make better grounded decisions and resulting in a more efficient and effective urban area development process.

However, currently there is a lack of knowledge in the constraints and benefits of spatial decision support systems in urban area development and how they can support the decision-making process in urban area development. Therefore I will explore the suitability of using a spatial decision support system in urban area development for the case of Buiksloterham in Amsterdam-Noord by executing a cross-case analysis of three SDSS applications: Tygron, Urban Strategy and the MapTable.

The main research question is: **"How can spatial decision support systems improve the decision-making process in urban area development in the Netherlands?"**

The sub questions are:

1. What are characteristics of the decision-making process in urban area development in the Netherlands?
2. What are SDSS and how do they work?
3. How are SDSS applied in urban area development?
4. What is the role of SDSS in urban area development projects in the Netherlands?
5. In which cases is the application of SDSS successful?
6. How can the development process in Buiksloterham be characterized?
7. How can SDSS improve the development process in Buiksloterham?

What I'm going to research is how spatial decision support systems can improve the decision-making process in urban are development in the Netherlands.
First I'll look at the features of SDSS and how they work, than I will look at the application of SDSS in urban area development. Subsequently I will look at the role of three applications in Dutch urban development projects. Consequently I will use the results of these case studies to review in which cases SDSS are successfully applied. At the same time I'll look at the characteristics of urban area development processes in the Netherlands, after which I'll look specifically at the characteristics of the development process in Buiksloterham.
Lastly, the results of the cross-case analysis will be applied in the case of Buiksloterham to determine if and how SDSS can improve the urban development process.

The aim of the research is to increase the understanding of the constraints and benefits of spatial decision support systems, to increase the understanding of the demand to support the decision-making process of stakeholders involved in urban area development in the Netherlands and to review in which cases SDSS are successfully applied. This will lead to recommendations considering the application of SDSS for the redevelopment project of Buiksloterham in Amsterdam Noord.
The current developments in Dutch practice in using spatial decision support systems will be especially valuable for data analysts, policy makers, and urban planners and developers.

1.2. PERSONAL RESEARCH MOTIVES

I like trying to make group processes more efficient and to integrate different perspectives into one solution that reflects the interests and meets the requirements of all the team players as much as possible: taking into account amongst others the economical, technological, environmental and societal perspectives. I am a rational, down-to-earth person. Therefore I like to find solutions for practical problems and I am goal-oriented. At the Master Real Estate & Housing attention is paid to different fields of research next to architecture. It deals with complex processes in a multi-disciplinary environment, taking the roles, objectives, and means of different actors into consideration. It aims to create solutions that contribute to the effective development and management of the spatial environment. One of these solutions could be a spatial decision support system. I am fascinated by the development and implementation of such a model as it covers innovative technologies and a new field of research. Additionally, it embodies a globally relevant topic that deals with different contexts and scales. A spatial decision support system can support the decision making process in urban area development and can thereby increase the efficiency of urban processes, contributing to the quality of life and a more sustainable living environment.

1.3. PERSONAL LEARNING OBJECTIVES

First of all, I am curious about the decision-making processes in urban area development. Who are the involved actors and what are their interests? Also I am interested in the way data is translated in relevant information. Furthermore, I want to research the role of spatial decision support systems in urban area development. What are the benefits and constraints of a spatial decision support system in practice? And how could you cope with those constraints?

Next to gaining knowledge, my personal learning objectives are also related to developing research skills: to be able to conduct a reliable and scientifically valid research, dealing with limitations such as time, budget and availability of information; To be able to work independently, motivating myself to get the most out of this graduation research and to critically asses my own work; To link literature to empirical findings and to draw lessons from that; To analyse the collected data and to justify my findings accurately.

My ultimate goal is to make an original contribution to this field of research, which is applicable and relevant in the practice of urban area development.

2. CONTEXT OF URBAN AREA DEVELOPMENT IN THE NETHERLANDS

Dutch cities are facing challenges, which has to do with urbanization, sustainability issues, rapid developments in ICTs and the economic crisis of 2008. As mentioned in the preface is the Netherlands one of the most urbanized countries of the world. Currently 87,1% of the Dutch population lives in cities, which will increase even further to 95% in 2030 (UN, 2014). This will increase the current scarcity of land in and around cities for urban development even further. Cities need to adapt to accommodate this growth by creating more facilities, greater infrastructure and to redevelop real estate using the available space efficiently. Therefore urban projects in the Netherlands are mainly brown-field or transformation projects within the urban fringe instead of green field developments, which affects many different actors.

Furthermore, while only covering 2% of the world's surface, cities are responsible for 75% of C02 emissions and world's energy consumption, suffer from air, ground and water pollution, urban heat island effect, and threats of flooding (Hollands, 2014; UNEP, 2014). Currently three primary sustainability issues are the depletion of fossil fuels, climate change and the scarcity of resources. The depletion of fossil fuels creates a need to become independent from fossil energy. However, The Netherlands is currently still dependent on finite energy resources by 96%. We are rapidly using our natural gas resources, causing the national natural gas fields to be emptied within 25 years, and import of fossil fuels from other regions has many considerations (Van den Dobbelsteen, 2015). If we continue to release greenhouse gasses at current rates, there will be an inevitable warming of 1.6°C to 2.6°C within the next two to three decades and a 2.6°C to 4.8°C by 2100 compared to 2013 baseline temperatures (Van Timmeren et al., 2014). A sustainable approach is needed to improve the quality of life by limiting green house gas emissions. Only this can solve the sustainability problems related to inter alia, air, ground and water pollution, the urban heat island effect, traffic congestions and threats of flooding. Also policies are stimulating public and private parties to improve the sustainability of cities. The EU 2020 target for instance strives to reduce greenhouse gas emissions with 20% comparing from 1990 levels;

raising the share of EU energy consumption produced from renewable resources to 20%; and an improvement of 20% in the EU's energy efficiency in 2020.

Additionally the urban area development and the building industry have experienced a great shift in working due to the economic crisis of 2008. Limited budgets and increased awareness of risk correlated with urban development projects induce profound cost-benefit analyses, including life cycle analyses, and demand driven developments with service level agreements. Quality of buildings and urban area's are now often measured with key performance indicators. Above that also the governmental system is changing. The Dutch government has currently a more facilitating role instead of being pro-active and risk bearing. This has lead to public-private partnerships and the rise of bottom-up initiatives (Van Timmeren et al., 2014).

Lastly, the rapid development of ICTs has led to globalization. People and companies are less tied to their physical location as they can connect to anybody, anywhere and anytime. This caused an increased competitiveness between cities and changes in society (Van Timmeren et al., 2014). Developments in ICT also influence GIS technologies, like GPS on smart phones.

Improved decision-making processes in urban area development can solve the above-mentioned challenges of cities through a more efficient and sustainable performance.

3. PROBLEM STATEMENT

Urban development processes are becoming increasingly complex. As Couclelis describes, “it involves actions taken by some to affect the use of land controlled by others, following decisions taken by third parties based on values not shared by all concerned, regarding issues no one fully comprehends, in an attempt to guide events and processes that very likely will not unfold in the time, place, and manner anticipated” (Couclelis, 2005, p. 1355).

According to various researchers SDSS support the urban development process as it contributes to providing information in a more efficient and comprehensive manner, improves the understanding and raises awareness on the spatial implications of a planning intervention (Antunes et al., 2001; Carver, 2003; González, 2010; González et al., 2011b). A SDSS model provides insight into the processes within an urban area, and can be used as a communication and negotiation tool to support decision-making processes in urban area development. This allows a city to make better-grounded decisions regarding to urban area development and to solve problems through a more efficient and sustainable performance. A greater understanding in the operation of spatial decision support systems can help in the acceptance and improvement of these systems. It can support cities to meet their sustainability targets and to accommodate growth.

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All researchers agree that the major challenge in this area is to better link decision-support tools to the ways in which stakeholders use those tools.

The reasons for this implementation gap are diverse. Their potential users see SDSS as:

- inadequate,
- far too generic,
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- too technology oriented (rather than problem oriented),
- not transparent enough,
- neither flexible nor user friendly,
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The reactions of these reviews are numerous. Some of these focus on improving PSS software by adding new functions to it, for example PSS that are more integrated (i.e. 'What If' developed by Klosterman (1999)), more interactive (i.e. 'Urban Strategy' developed by TNO (2011)) or more user-friendly (i.e. 'UrbanSim' developed by Waddell (2002, 2011)). Others follow a more hardware oriented path, such as 'Maptables', 'Sketchtables' and other visual gadgets (see Vonk & Ligtenberg, 2009). Then there is the process-oriented line that focuses on bridging the human gap between the potential end-users and the PSS developers with more participative, iterative PSS development structures (Te Brömmelstroet & Schrijnen, 2010), like the serious gaming tool of Tygron.

However, as these developments are occurred recently,there is insufficient knowledge about the constraints and benefits of these new spatial decision support systems (SDSS) in urban area development in the Netherlands and how they could improve the decision-making process. Furthermore, it is unclear if these applications have bridged the implementation gab between theory and their use in the practice of urban area development mentioned earlier in SDSS reviews.

4. RESEARCH MOTIVES

Next to my personal motives for this research are the following general motives applicable. As mentioned in the problem statement a spatial decision support system provides insight into the processes within an urban area. This allows a city to ground decisions regarding to urban area development and to solve problems through a more efficient and sustainable performance. A greater understanding in the operation of spatial decision support systems can help in the acceptance and improvement of these systems. It can support cities to meet their sustainability targets and to accommodate growth.
Due to recent developments in technology, this research topic is very topical. Therefore, it can be an original contribution to field of research relating to spatial decision support systems. Also it will research the application of SDSS from an urban development perspective.

5. RESEARCH OBJECTIVES & OUTCOMES

The aim of the research is to increase the understanding of the constraints and benefits of spatial decision support systems, to increase the understanding of their role in Dutch urban development processes and to provide insight into the different factors which influence the effectiveness of these applications in the decision-making process in urban area development in the Netherlands.
The redevelopment project of Buiksloterham will be used to apply my findings of the research into the specific Dutch context of urban area development, resulting in recommendations about the usage of SDSSs in this particular case.

Target group
The current developments in Dutch practice in using spatial decision support systems, will be especially valuable for data analysts, policy makers, and urban planners and developers.

6. DEMARCATION

Geo-information systems (GIS) and spatial decision support systems (SDSS) are broad concepts. Therefore this graduation research will focus on the usage of three SDSS applications in six Dutch urban development projects. As rapid developments in ICTs have influenced GIS and SDSS largely, the literature review especially handles recent research in GIS and SDSS. The research will be related to the current practice of urban area development by applying the findings Buiksloterham, a redevelopment project in Amsterdam Noord.

7. RESEARCH QUESTIONS

The following research questions will guide the research and provide a clear sense of what the research is about. The main research question is:

How can spatial decision support systems improve the decision-making process in urban area development in the Netherlands?

Sub-questions are:
1. What are characteristics of the decision-making process in urban area development in the Netherlands?
2. What are SDSS and how do they work?
    a. What kinds of functions are included in the SDSS?
    b. What are benefits of the SDSS?
    c. What are constraints of the SDSS?
3. How are SDSS applied in urban area development?
4. What is the role of SDSS in urban area development projects in the Netherlands?
    a. For what kind of urban area development process are SDSS applied?
    b. Why is a SDSS applied in this urban area development process?
    c. Why is chosen for this particular SDSS?
    d. At which moment in the process is the SDSS applied?
    e. By who are the SDSS used?
    f. What are the experiences of users?
        - In relation to its content (quality, completeness, speed, scale, level of detail of data), user-friendliness, flexibility of the system
    g. Has SDSS improved the urban area development process?
        - How has (not) SDSS improved the urban area development process?
5. In which cases is the application of SDSS successful?
6. How can the development process in Buiksloterham be characterized?
7. How can SDSS improve the development process in Buiksloterham?

8. RESEARCH METHODOLOGY

Research strategy
The research methodology is based on the research questions and guides the execution of a research method and the analysis of the subsequent data. There are different research approaches. Quantitative research emphasises the quantification in the collection and analysis of data, while qualitative research emphasizes words rather than quantification in the collection and analysis of data (Bryman, 2012). This research is mainly based on a qualitative approach.

Research design: A cross case-study research design

Research methods: Research methods used in this research are literature review, semi-structured and structured interviewing, and secondary data analysis.

The roadmap of this research will be as follows:

1. Determine the topic of research and research questions;
2. Set up the research proposal;
3. Start a literature review;
4. Write down the conclusions, set up a conceptual framework, and verify whether the problem statement, research objectives and research questions are still relevant;
5. Conduct the case studies: collect the relevant data, manage the data and analyse it;
6. Compare the case study results to each other and to the theoretical framework;
7. Analyse the urban development process in Buiksloterham;
8. Apply the findings of the cross case-study by giving recommendations for the usage of SDSS in Buiksloterham;
9. Evaluate the research process and research results;
10. Suggests topics for further research;
11. Write up the research process and its findings.

The main research question is:
How can spatial decision support systems improve the decision-making process in urban area development projects in the Netherlands?

The research sub-questions and methodology are:

1. What are characteristics of the decision-making process in urban area development in the Netherlands?

This research question will be answered through executing a literature review.

2. What are SDSS and how do they work?

This research question will be answered through executing a literature review. The table on page 20 and 21 gives an overview of the literature I will use for my thesis report.

3. How are SDSS applied in urban area development?

I will answer this question through a literature review. The table on page 19 gives a selection of literature related to case studies of spatial decision support systems. I have already read and summarized the relevant literature and it will take me approximately two weeks to process this in my thesis report.

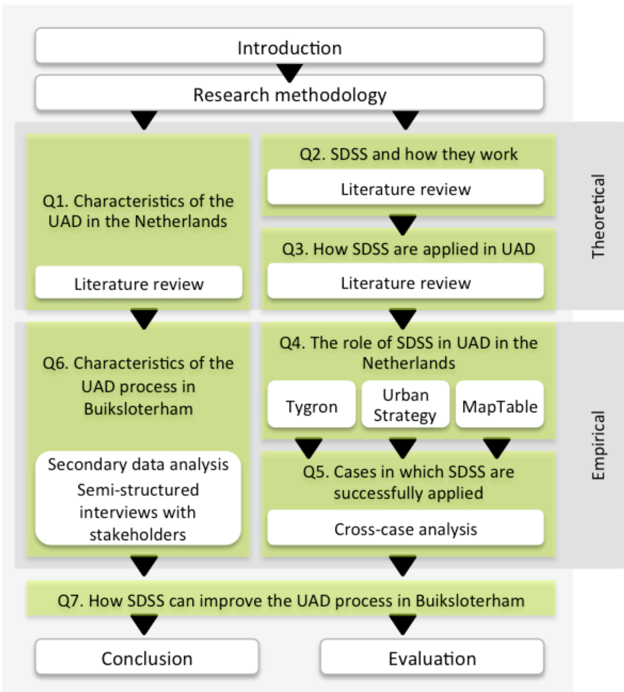

Figure 2 *Research design (own ill.)*

4. What is the role of SDSS in urban area development projects in the Netherlands?

I'll answer this sub-question through the execution of case studies of three SDSSs which are applied in six urban development projects: two projects per tool are reviewed.

Criteria for the selection of the SDSS were:

- It is a tool which is applied in a Dutch urban development project, on the scale of a neighbourhood;
- It is a tool which is applied in the past, by which I can research the role of the tool in the decision-making process.
- It is a comprehensive tool, taking into account economical, societal and environmental factors;
- The tool involves stakeholder participation;
- The working of the tool is clear, allowing to compare different tools with each other;
- The tool offers functions for storage, analysis, and display of GIS data and provides functions for establishing criteria and determining their importance for achieving the objectives. Urban designs and strategies can be evaluated on the basis of criteria and objectives. Alternatives can be compared and can be ranked according to their suitability;
- The tool is flexible and adaptable, by which it can be applied in different projects with different stakeholders, ambitions and demands.

On the basis of these criteria I selected to review Tygron, a serious gaming tool, MapTable (of Mapsup), a SDSS connected to a touch table, and Urban Strategy, a recently developed SDSS by TNO.

The research methods used for these case studies are secondary data analysis; semi-structured interviews with the developers; and structured interviews with the users.

5. In which cases is the application of SDSS successful?

This question will be answered by executing a cross-case analysis of the six application cases of the three SDSS tools and by comparing these findings to the findings from the literature review (sub-question 2).

6. How can the development process in Buiksloterham be characterized?

I will answer this question by analyzing the development process in Buiksloterham by executing secondary data analysis, supplemented with semi-structured interviews with the stakeholders.

7. How can SDSS improve the development process in Buiksloterham?

The redevelopment project of Buisksloterham will be used to apply my findings of the research into a specific Dutch context of urban area development.

The criteria for the selection of case study Buiksloterham were:

- The urban development project should be allocated in a medium to big Dutch city;
- The urban development project should be a retro-fit project (urban redevelopment);
- The urban redevelopment project should be in its initiative phase, whereby decision-making still plays a major role in the process.
- It should be a case that I can conduct in collaboration with a company;

Circular Buiksloterham is a bottom-up, organic, transformation project in Amsterdam Noord and part of the wider restructuring of the Northern IJ-Banks in Amsterdam. The redevelopment project is allocated in a big Dutch city: Amsterdam is the biggest city of the Netherlands having 825.000 inhabitants in its city centre and 1.300.000 in the urban agglomeration. Therefore the application of the research outcomes could not only be used for Buiksloterham, but also other projects in Amsterdam.

The industrial area of 100 ha will be translated into a mixed-use urban area with a timeline running from 2005 to 2030. This means that the project is in its initiative phase whereby decision-making still plays a major role in the process. The contaminated soil and the environmental impact of residual industry together with the high sustainable ambitions increases the complexity of the project, enlarging the need for decision support tools. Also the bottom-up approach of the redevelopment, through which many stakeholders are involved, increases the relevance for a SDSS. Furthermore it enables to research the many different perspectives and demands for information related to those different stakeholders.

I can execute this case study in collaboration with AMS, Amsterdam Institute for Advanced Metropolitan Solutions.

So what I'm going to research is how spatial decision support systems can improve the decision-making process in urban are development in the Netherlands.
Therefore I'll first look at the features of SDSS and how they work, than I will look at the application of SDSS in urban area development. Subsequently I will look at the role of three applications in Dutch urban development projects. Consequently I will use the results of these case studies to review in which cases SDSS are successfully applied.
At the same time I'll look at the characteristics of urban area development processes in the Netherlands, after which I'll look specifically at the characteristics of the development process in Buiksloterham.
Lastly, the results of the cross-case analysis will be applied in the case of Buiksloterham to determine if and how SDSS can improve the urban development process.

The evaluation framework for the review of SDSS in practice
For executing the case studies I need to set up an evaluation framework. As many reviews of urban development processes and SDSS have been executed previously I can use the evaluation frameworks mentioned in literature to execute the case study. Frameworks for reviewing SDSS in the Dutch urban are development process are i.a. designed by Marco te Brömmelstroet (2013), Stan Geertman (2006) and Guido Vonk (2005).

Marco te Brömmelstroet (2013) has based his evaluation framework on the multilevel group processes of Nijstad (2009) and the group model building performance studies of Rouwette, Vennix, and Van Mullekom (2002) and Vennix, Scheper, and Willems (1993). This has led to his multidimensional framework for PSS performance as shown in table 2.

Table 2 *Multidimensional framework for PSS performance (Te Brömmelstroet, 2013)*

Planning outcomes	Planning process
Novelty	Reaction
Original	Enthusiasm
Paradigm relatedness	Satisfaction
Workability	Credibility
Implementability	Insight
Acceptability	Insight in problem
Relevance	Insight in assumptions
Applicability	Commitment
Effectiveness	Behavior
Specificity	Communication
Completeness	Development of shared language
Implicational explicitness	Consensus
Clarity	Consensus on problem
	Consensus on goals
	Consensus on strategies
	Cohesion
	Efficiency gains

Geertman (2006) has evaluated worldwide practices of PSS on the basis of seven factors as illustrated in figure .
(1) specific characteristics of information, knowledge, and instruments;
(2) characteristics of planning and policy process;
(3) dominant planning style;
(4) political context;
(5) user characteristics;
(6) content of planning issue; and
(7) dominant policy model.

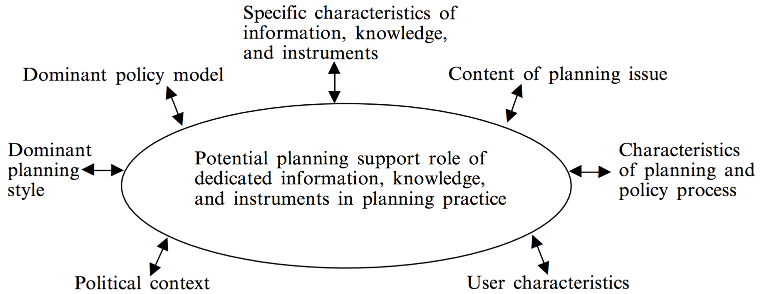

Figure 3 *Factors influencing the potential planning support role (Geertman, 2006)*

Guido Vonk (2005) has divided his analysis in an instrument approach, transfer approach and user approach. The instrument approach reviews the SDSS in terms of fit between planning task, PSS technology and the user using the SWOT framework. The classification of planning tasks is done according to the work of Geertman and Stillwel (2003).

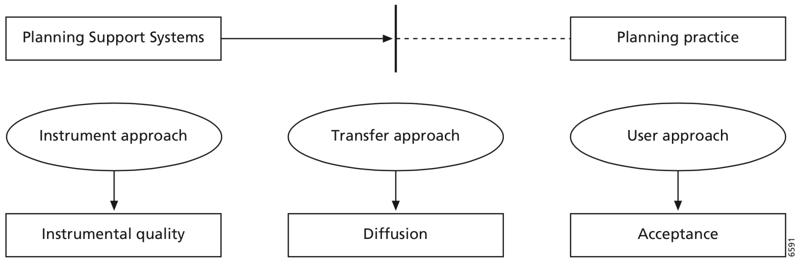

Figure 4 *Theoretical framework for reviewing PSS applications (Vonk, 2005)*

The transfer approach looks at formal and informal deviant diffusion processes (Rogers, 1995; 2003). The user approach incorporates the technology acceptance model (Davis, 1989; Rogers, 2003) and uses the framework for innovation adoption after Framback and Schillewaert (2002).

The evaluation framework of the urban development process

Urban development processes can be categorized according to the framework of PBL and urhahn urban design (2012) which distinguishes integral urban area development versus organic urban area development as illustrated in figure 5. These are two extreme types of urban development processes.

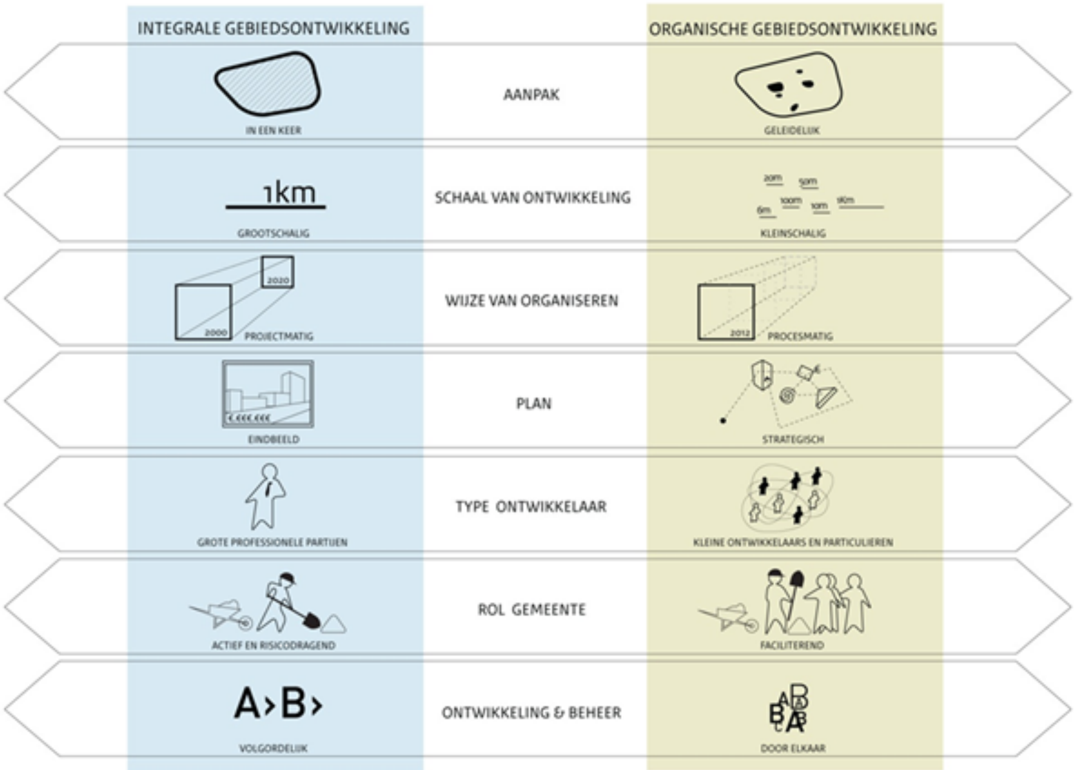

Figure 5 *Characteristics of urban area development (PBL and urhahn urban design, 2012)*

Furthermore the project can be characterized by its functional program, owner of the real estate, type of development (e.g. renewal, transformation, intervention, modification, or greenfield development), its status (initiative, preparation, realisation, and maintenance phase), the level of participation, sources of funding and the duration and start year of the development process.

The level of participation can be subdivided according to i.a. the ladder of participation designed by Arnstein (1969), IAPP (2000), and OECD (2001). For this research the IAPP spectrum of public participation seems the most suitable. This categorisation is also used in other reviews of SDSS (See: Geertman & Stillwell, 2009; Nyerges et al., 2006). Nyerges (et al., 2006) has connected these levels of participation to participation activities and public impact as shown in table 3.

These evaluation frameworks from a good starting point to review the application of SDSS in Dutch urban development projects, but need to be further adjusted and aligned to this research proposal.

Table 3 *Participation spectrum levels, activities and impacts (Nyerges et al., 2006)*

Participation level	Participation activities	Public impact on overall process
Inform	Listen	Public is informed
Consult	Listen, respond	Public is informed and provides feedback
Involve	Listen, respond, negotiate, recommend	Public concerns are incorporated
Collaborate	Listen, respond, negotiate, recommend, analyze	Public helps form concerns and solutions
Empower	Listen, respond, negotiate, recommend, analyze, decide	Public helps decide concerns and solutions

A detailed planning of the research is as follows:

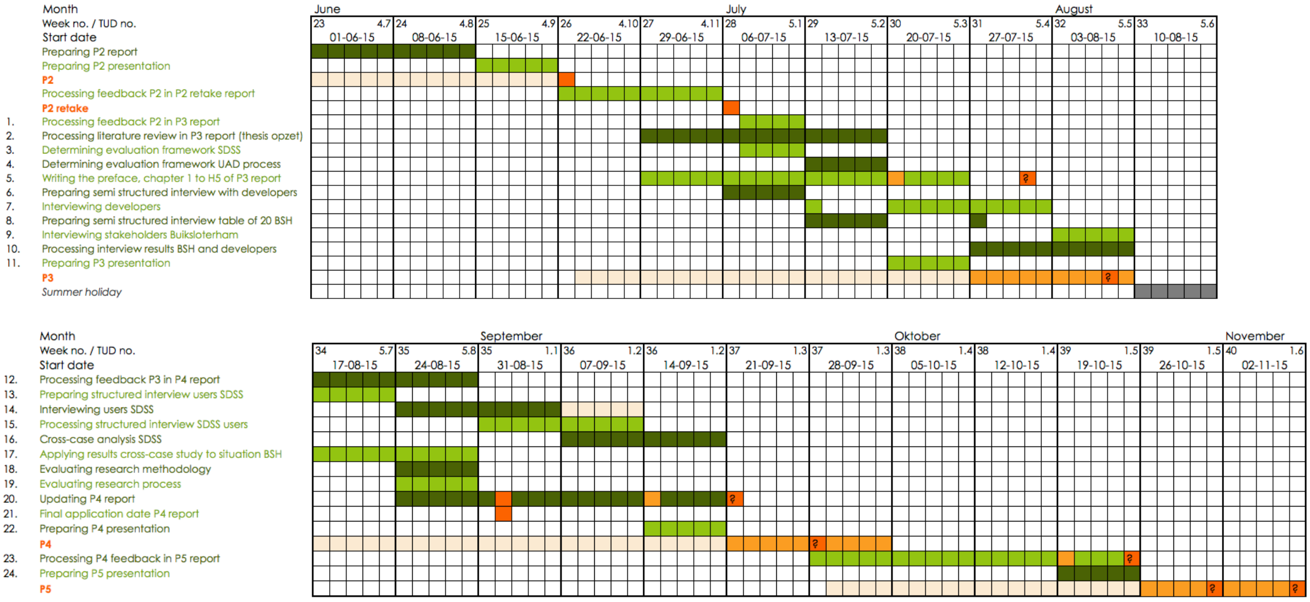

Figure 6 *Detailed research planning (own ill.)*

9. RESEARCH ORGANISATION

This graduation research is conducted as part of the Master Management in the Built Environment (formerly Real Estate & Housing) at the faculty Architecture and the Built Environment at the TU Delft, The Netherlands. This research is related to the Urban Adaptation Strategies research project of the Urban Development Management graduation laboratory, under guidance of dr. ir. Tom Daamen. My second mentor is dr. ir. Ruud Binnekamp. He has researched preference-based design in relation to multi-criteria decision making methods and decision-making processes in real estate management.

The topic of this research covers research areas of spatial decision support system (SDSS), planning support systems (PSS), and urban area development.

The usage of SDSS will influence urban area development by giving insight into the urban processes and thereby supporting the decision-making process relating to urban area development. This research will study SDSS as a tool to analyse urban areas, evaluate development plans and validate urban area strategies.

I will accomplish this research at AMS: Amsterdam Institute for Advanced Metropolitan Solutions.

The time schedule for this research is as follows:

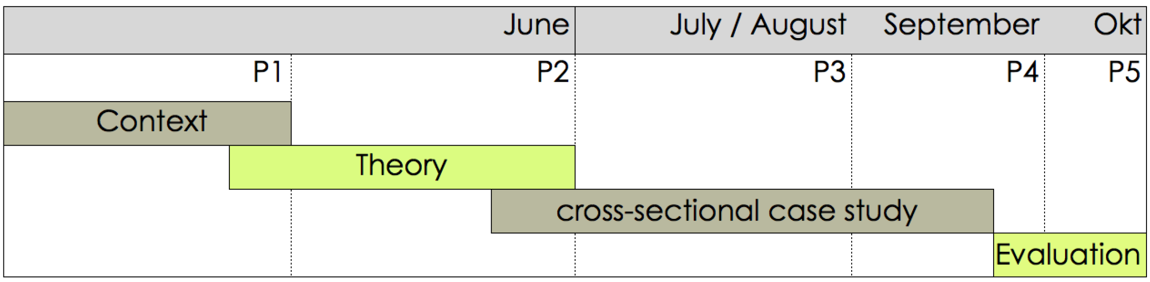

Figure 7 *Time schedule of this research proposal (own ill.)*

10. LITERATURE REVIEW

Spatial tools such as Geographic Information Systems (GIS) can support impact assessment and planning processes by integrating and simultaneously analysing multiple datasets (i.e. socio-economic and environmental, as well as urban metabolism aspects), thus providing spatial evidence about environmental conditions (González, 2010; González et al., 2011b).
Moreover, they can be combined with external modelling tools to predict likely future socio-economic and/or environmental conditions, based on the characteristics of given planning alternatives (e.g. Bryan, 2003; Chen et al., 2009; Munier et al., 2004; Stevens et al., 2007; Vienneau et al., 2009).
GIS can contribute to:

(i) objective, accurate and quantifiable impact prediction and assessment;
(ii) evaluating the spatial and temporal variability of impacts,
(iii) predicting cumulative and large-scale effects; and, ultimately,
(iv) presenting all relevant information in geographic and visual form (Antunes et al., 2001; González et al., 2011b; João, 1998; Vanderhaegen and Muro, 2005).

This contributes to providing information in a more efficient and comprehensive manner, improving understanding and raising awareness on the spatial implications of a planning intervention (Antunes et al., 2001; Carver, 2003; González, 2010; González et al., 2011b).

Spatial decision support systems (SDSS) are a category of information systems composed of a database, GIS software, models, and a so-called knowledge engine which allow users to deal specifically with locational problems. It is related to spatial information theory which focuses specifically on providing the background for the production of tools for the handling of spatial data.

In light of the above, the FP7 project BRIDGE (SustainaBle uRban planning Decision support accountinG for Urban mEtabolism) has developed a GIS-based Decision Support System (DSS) that systematically integrates urban metabolism components into impact assessment processes (Chrysoulakis et al., 2010). The DSS is based on impact assessment principles, assessing proposed planning interventions against previously defined sustainability objectives and associated environmental and socio-economic indicators. In particular, the DSS examines how a planned urban structure may affect the exchange and transformation of energy, water, carbon and pollutants within a city. It adopts a bottom-up approach to urban metabolism, based on quantitative estimates of urban metabolism components at local to regional scales, and thus examines the 3D exchange and transformation of energy and matter between a city and its environment (Chrysoulakis et al., 2009). Correspondingly, it examines how such energy and material flows affect socio-economic activities and how socio-economic activities affect such flows. The environmental and socio-economic quantification of the potential effects of proposed interventions in the DSS facilitates a systematic and spatially specific identification of the most sustainable proposal and, arguably, better informs decision-making. The methodology combines impact assessment with decision-making principles, enabling integration of end-users' (e.g. planners, stakeholders and decision-makers) perceptions on the importance of assessment criteria. Engaging end-users in the assessment process contributes to fulfilling statutory public consultation requirements in planning and environmental assessment, as well as contributing to a better understanding of the decision problem and, ultimately, to transparency and support in decision-making (González et al., 2013; Fitzpatrick, 2006; Risse et al., 2003; Runhaar and Driessen, 2007).

This project is in line with the circular economy ambitions of the case study Buiksloterham in Amsterdam Noord. However, a wide variety of spatial decision support systems are mentioned in literature. Before analysing the suitability of a spatial decision support system for Buiksloterham, I will give you a brief overview of the context of urban area development in the Netherlands.

Figure 8 *SDSS in relation to urban area development (own ill.)*

This will be followed by an outline of current GIS technologies and applications with its constraints and benefits. Subsequently SDSS technologies and models will be reviewed. The literature study will end with zooming in on spatial decision support systems using multi-criteria evaluation methods.

10.1. URBAN AREA DEVELOPMENT

The context of urban area development is inter alia formed by political, institutional, and social-economic aspects. As mentioned in the problem statement the Netherlands is a highly dense country with 87,1% of its population living in cities. This will increase even further to 95% in 2030 (United Nations, 2014), which will increase the current scarcity of land in and around cities for urban development even further. Cities need to adapt to accommodate this growth by creating more facilities, greater infrastructure and to redevelop real estate using the available space efficiently. Therefore urban projects are mainly brown-field or transformation projects within the urban fringe instead of green field developments.
Additionally the urban area development and the building industry have experienced a great shift in working due to the economic crisis of 2008. Limited budgets and increased awareness of risk correlated with urban development projects induce profound cost-benefit analyses.
A shift in governmental frameworks has given rise to public-private partnerships, bottom-up initiatives and distributed governance.
Also the rise of information and communication technologies (ICTs) has influenced the urban area development sector. People and companies are less tied to their physical location as they can connect to anybody, anywhere and anytime due to these technologies and coincided globalization. This caused an increased competitiveness between cities. (Van Timmeren et al., 2014).

Fundamental characteristics of urban development projects are its long-term, high investment, cyclic process and multi-disciplinary nature. The many different actors, with their own interests, mean, background and objectives increase the complexity of the urban development process even further. The cyclic process of urban development projects can be divided into four phases: initiative, design, realisation and maintenance.

The perspective of Peder Hjorth and Ali Bagheri (2006) relating to perceiving sustainable development as an unending process defined neither by fixed goals nor by specific means of achieving them, could also be related to urban area development in general. The way we look at the process and project of urban area development today, will differ to the way we will look to it in a few years, just as we perceive urban area development different comparing to years ago. A fixed decision support system would therefore make no sense. It needs to be flexible in order to be able to adapt the model to different ways of perceiving urban area development.

10.2. GEOGRAPHIC DATA AND GEO-INFORMATION SYSTEMS

After an introduction and the history of geo-information systems, examples of the application of geo-information systems in practice will be given. This will be followed by a background in different characteristics and types of data. Subsequently, the processing of data will be discussed. This paragraph is mainly based on the explanatory books of Mathias Lemmens (2011) and Otto Huisman and Rolf de By (2009). Per stage of the process of handling data the related terms, technologies and errors will be discussed. Afterwards considerations relating to processing data with regards to the quality data will be discussed. Prior to the spatial data infrastructure (SDI), the different available GIS software packages will be discussed. The spatial data infrastructure forms the context of geo-information systems by paying attention to the base collection of technologies, policies and institutional arrangements that facilitate the availability of and access to spatial data.

Geo-information systems have their back ground in geomatics. “Geomatics is the science and study of spatially related information focusing on the collection, interpretation/analysis and presentation of the natural, built, social and economic environments.” (RICS, 2015) This includes geodesy, surveying, mapping, positioning, navigation, cartography, remote sensing, photogrammetry, GIS and global positioning system.

A GIS platform enables integration of datasets in relation to its spatial context. It can be used for storage, analysis and visualization of data.

History of geo-information systems

Maps were the first form of geo-information. During the 16th century there was a rise of cartographers for mapping the newly discovered territories. After measuring the distance between Dunkerkque and Barcelona by using the repetition circle, the exact length of a meter was determined between 1792 and 1799. The East India Company established the institution of the Survey of India in 1767 for creating accurate maps for road construction and visual telegraphy and later on for the purpose of railways and electric telegraph. In 1815 the first-order geodetic reference frame of the Netherlands was realised by triangulation. "Triangulation is based on measuring the angles of a series of connected triangles. When the distance between two points is known the distances from these points to the third point in the triangle can be calculated." (Lemmens, 2011, p. 5) This method was used for producing accurate large-scale maps from the end of the 18th century up to the 1990s (Lemmens, 2011). From the 1950s the development of electronic distance measurement instruments made it easier to measure distances using full and partial waves of electromagnetic energy. During the 1970s space technologies were combined with electronic distance measurement technology leading to positioning and navigation by means of orbiting satellites. Global navigation satellite systems, the development of sensors, and evolvements in information and communication technologies have become essential for GIS applications we use today (Lemmens, 2011).

Application of geo-information systems in practice

This paragraph will review the application of GIS in urban development projects, like the examples mentioned by Lemmens (2011). GIS is also often part of spatial decision support systems, however, these examples will be mentioned separately in the paragraph 9.3.

Characteristics of data

Data are representations that can be operated upon by a computer (Lemmens, 2011)
According to Geert-Jan Houben (2015) big data is data that is too big to handle with conventional means. Technology to handle big data asks for a fundamentally new computing science and its descriptions of the world bring a new complexity. Technology and systems to make sense of data is therefore needed, like database management systems and GIS software. A great challenge in the usage of big data is the way in which an information request can be decompose into the required data and vice versa the way data can be translated in relevant information.
The majority of data is geo-data or spatial data: data that contains positional values such as x-,y-coordinates. About 80% of all public sector information has a geo-component (lemmens, 2011, p. 11).
Metadata is data about data: data that has been interpreted by a human being.

Data can be used for static and dynamic models, using statistical data or temporal data.
A distinction can also be made between qualitative and quantitative data, between primary (base) data and secondary data (indirect captured data derived from other sources or purchased data), between raster data and vector data and between open data and private data.

Next to these general terms, data can be specified according to its characteristics like:

- measurement unit;
- measurement scale: nominal, ordinal, interval or ratio scale;
- scale of data;
- the geographical area it covers;
- resolution (level of detail) of data;
- speed: time-span;
- quality;
- And data source

Processing of data

Processing of data occurs in different phases: data capture is followed by data preparation, data storage and maintenance, data query and analysis, and data representation. This paragraph will outline these different phases with its related technologies and possible errors.

Data capture

Geo-information technologies can be divided in direct spatial data capture (primary data) and indirect spatial data capture (secondary data). Technologies related to primary data capture are:

- Ground-based field surveys;
- Remote sensing;
- Sensor networks;
- Internet of things;
- GPS global positioning system;
- Mobile GIS;
- Terrestrial laser scanning;
- Photogrammetry, and;
- Airborne Lidar.

Technologies related to secondary data capture are:

- Data derived from existing paper maps through scanning;
- Data digitized from a satellite image, and;
- Processed data purchased from data capture firms.

Errors in capturing data are inter alia related to errors in the absolute positioning of data. This can be subdivided in errors related to the space segment, the medium the receivers' environment, and the relative geometry of satellites and receiver.

Data preparation

This section will discuss data preparation activities, like:

- Data checks & repairs;
- Combining data from multiple sources;
- Image classification;
- Point data transformation, and;
- Data organization.

Furthermore it will discuss possible errors in data preparation.

Data storage and maintenance

This section will discuss the database management system and errors in data storage and maintenance.

Data query and analysis

The purpose of GIS data models can be descriptive, prescriptive, or predictive. Four fundamental types of data models are the rule-based model, stochastic model, deterministic model, and the agent-based model. Data analysis can be executed on single layers or multiple layers. Examples of single layer functions are classification functions, retrieval functions, generalization functions and measurement functions. Multiple layer functions can be subdivided in overlay functions, neighbourhood functions, and connectivity functions. Intersection, union, difference, and complement operations are types of overlay functions. Search, proximity computation, interpolation functions, topographic functions are examples of neighbourhood functions. Connectivity functions can be subdivided in contiguity operations, network analytic operations (like optimal path finding) and visibility operations. This section will end with possible errors in data analysis.

Data representation

This paragraph will discuss representation technologies and errors in representing data.

Quality of data

Quality of data can be related to:

- Accuracy and precision
- Positional accuracy
- Temporal accuracy
- Attribute accuracy
- Lineage
- Completeness
- Logical consistency
- Source data errors and processing errors
- Gross errors and classification errors

GIS software

Different examples of GIS software packages are ILWIS, Intergraph's geomedia, ESRI's ArchGIS and MapInfo. Furthermore there are numerous types of open source software and web-based GIS tools. This section will also discuss participatory GIS:

Participatory GIS (Carver, 2003; Jankowski, 2009), which focuses on improving human participation within group spatial decision-making and has evolved along two paths: Public Participation GIS (PPGIS) and Group Spatial Decision Support Systems (GSDSS). PPGIS focuses on improving public access to geospatial data and maps, providing possibilities for participatory learning and analysis by the general public, community groups and marginalized groups in planning and decision-making for their communities (Craig, Harris, & Weiner, 2002). The shift to collaboration created the need for GSDSS, which support the identification of trade-offs, conflict and compromise between stakeholder groups (Boroushaki & Malczewski, 2010)." in (Arciniegas & Janssen, 2012)

Spatial data infrastructure (SDI)

SDI is defined as relevant base collection of technologies, policies and institutional arrangements that facilitate the availability of and access to spatial data". In this paragraph I will outline the responsibilities of processing and disseminating data, like copyright and pricing, security of data, ownership, maintenance, preserving quality and data standards.

10.3. SPATIAL DECISION SUPPORT SYSTEM

After a short introduction in the operation and objectives of a SDSS, this paragraph will pay attention to the aspects of the SDSS, like data input, stakeholder involvement, indicators, reliability of the model and the different types of spatial decision support tools.

Introduction of SDSS

Integrating multi-criteria analysis (MCA) and GIS has contributed to the development of spatial tools for the analysis of decision alternatives. This integration provides methods to evaluate, compare, rank, map and present the performance of decision alternatives on the basis of several criteria and/or objectives (Malczewski, 2006).

Spatial decision support systems (SDSS) are a category of information systems composed of a database, GIS software, models, and a so-called knowledge engine which allow users to deal specifically with locational problems. It is related to spatial information theory which focuses specifically on providing the background for the production of tools for the handling of spatial data.

DSS are commonly used to inform problem solving and assist decision-making processes by providing tools for combining quantitative data and qualitative knowledge/perceptions, and for processing this information in order to present, compare and rank planning alternatives and, ultimately, select the one that satisfies the established decision criteria (González et al., 2013).

MCA and GIS are promising tools for the translation of output of integrated models into integrated knowledge for policy makers. They may help to reduce the gap between the worlds of science and policy making. These tools can be combined in spatial decision support tools for collaborative decision-making (Arciniegas et al., 2013).

Purposes of a SDSS are (González et al., 2013):

- Evaluating plans or policies (through impact assessment);
- Exploring alternatives or scenario's;
- Testing and validating theories;
- Simulating urban processes in order to raise awareness and deal with these processes;
- Provision of more detailed scientific data to plan-making processes, enhancing the links between research and practice;
- Monitoring and evaluating indicator performance in a planning context, and;
- Improving stakeholder participation by using the model as a communication and negotiation tool.

<u>Review of a spatial decision support systems</u>
Spatial decision support systems can be based on overlay mapping, artificial intelligence and multi-criteria evaluation. Overlay mapping makes usage of weighted linear combinations (WLC) and Boolean operations. Artificial intelligence makes usage of evolutionary algorithms, genetic algorithms, multi-agent systems, cellular automata, system dynamics and fuzzy systems. A combination of those methods can be applied as well. The methods related to multi-criteria evaluation will be discussed in section 6.4.
Next to dealing with errors in the input data and the model (like discussed in section 6.2), critics on spatial decision support systems are also related to its completeness, level of detail, timeframe, the geographic area the model covers, subjectivity, flexibility and user-friendliness.

According to Saynajoki (2012, p. 8) "municipalities and construction companies require regional evaluation tools that:

(1) are based on credible, comprehensible and transparent calculations or criteria,
(2) produce simple, clear and illustrative results,
(3) are effortlessly available and easy to introduce,
(4) can be applied to multiple levels of urban planning,
(5) are based on scientific research, and
(6) respond to the specific needs of local urban planning."

<u>Design process of a SDSS</u>
The design process of spatial decision support systems can be subdivided in the following steps:

1. Establishing plan of approach for the project area
    - What is the purpose of the model? (What do we want to get to know?)
    - What are requirements of the model?
        - In relation to its content (input data and the type of model), its completeness, level of detail, timeframe, the geographic area the model covers, subjectivity and user-friendliness.
        - What kind of data is already available?
        - Is it required and feasible to capture extra data? What kinds of data need to be captured?
    - What kind of data do we want to process?
    - What are the limitations / constraints of the input data?
2. Capturing relevant data
3. Processing data
4. Combining different data sources into a GIS system
    - What are the limitations / constraints of processing data?
5. Setting up indicators or parameters
6. Setting up model requirements: level of detail, scale, time-span, geographical area, completeness
7. Setting up relations between different data streams
    - Validating relations by literature,
        - Validating relations by case-based reasoning
    - Translating relations into algorithms
    - What are the model assumptions?
    - What are the model constraints?
8. Mapping the initial state conditions
9. Running the model

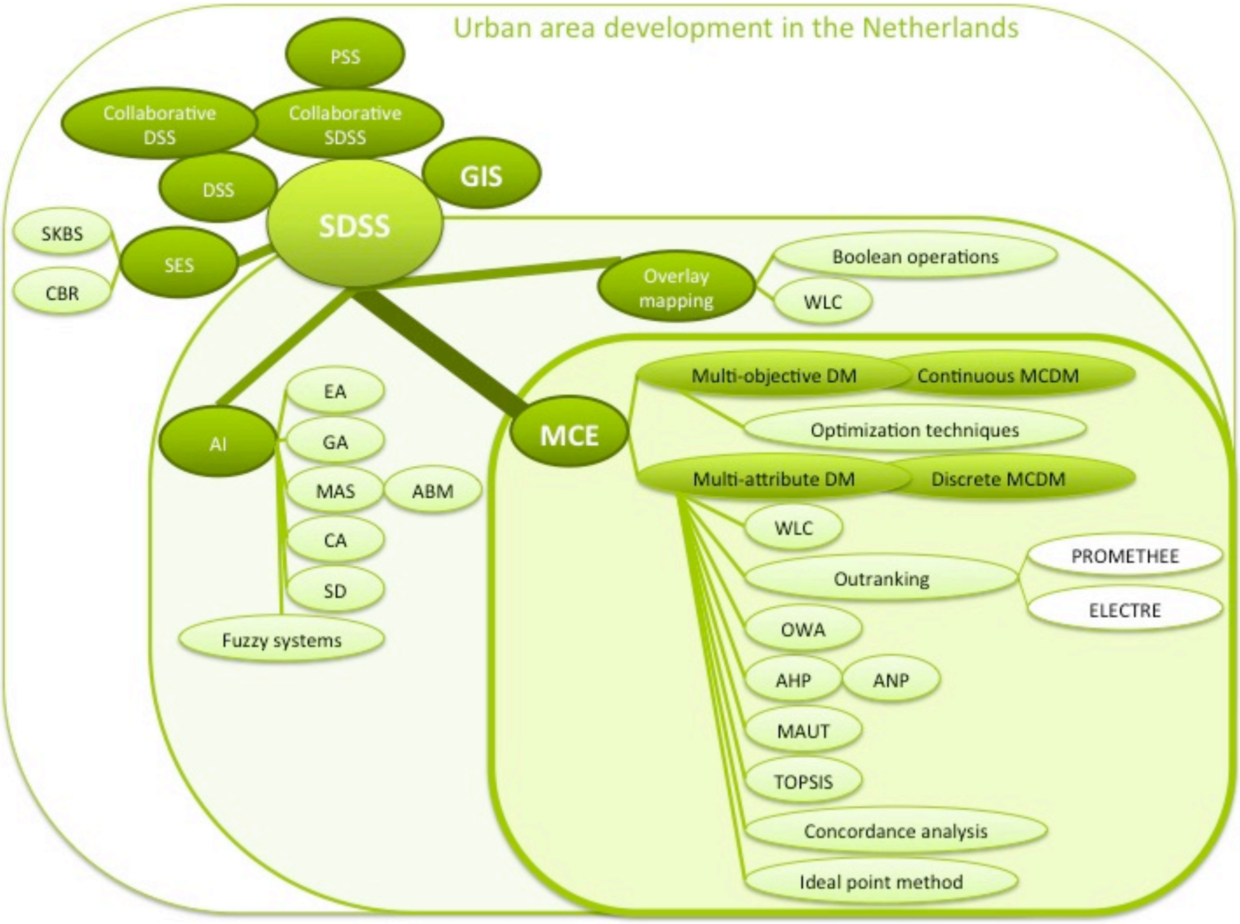

Figure 9 *Mindmap (own ill.)*

10.4. MULTI-CRITERIA DECISION-MAKING

Multi-criteria assessments constitute both a framework for structuring decision problems which encompass multiple decision criteria and alternatives, and a set of methods to generate/elicit and aggregate preferences regarding previously established objectives and performance of evaluated alternatives. Multi-criteria assessment techniques are widely used in impact assessment (e.g. Antunes et al., 2001; Cavallaro and Ciraolo, 2005; Geneletti, 2008; González et al., 2011b; Ravetz, 2000). They help planners and decision-makers learn about the decision problem and explore the alternatives available as well as the decision outcome by helping elicit value judgments about trade-offs between conflicting objectives and, ultimately, facilitating the selection of best alternatives. In (González et al., 2013)

Important aspects of these models are the indicators (criteria) or integrity constraints. These indicators determine the working of the model and state conditions according to the model entities behave.
These indicators are also without a simulation model effective to determine the performance of different ideas, policies or an urban area in general. Recently the European Union and ISO came up with standards for measuring urban performance in order to improve the transparency in the way indicators are measured. Furthermore it aims to align different assessment methods with each other by using the same indicators, by which urban performance of different areas can be compared.

There are different kinds of MCDM techniques, determining the way indicators are ordered and weighted. Well-known techniques are the analytical hierarchical process (AHP), the ordered weighted average (OWA) and the weighted linear combination (WLC) also known as simple additive weighting (SAW). PROMETHEE and ELECTRE are examples of outranking methods.

10.5. COMPARISON OF DIFFERENT SDSS-MCE TOOLS

There are a wide variety of applications of SDSS and MCDM in practice mentioned in literature, like topics:

- Regarding to simulation of multi-actor spatial planning (Ligtenberg et al., 2004);
- Regarding to strategic environmental assessment, like the BRIDGE tool (Carsjens & Ligtenberg, 2007; González et al., 2013);
- Regarding to urban infrastructures (Coutinho-Rodrigues, 2011);
- Regarding to land-use evaluations for site selection of parking in Tehran or of a park in Italy (Jelokhani-Niaraki & Malczewski, 2015; Zucca et al., 2008);
- Regarding to monitoring, evaluating and even simulating urban growth (Anthony Gar-on Yeh & Xia Li, 2007; Shen et al., 2009, Hana et al., 2009; Ying et al., 2009);
- Regarding to analysis of patterns of spatial occupancy (Marusic, 2001; 2012).

A brief overview of different relevant applications will be outlined.
An overview of different models mentioned in literature is shown in table 2 on the next page.

In the thesis report different MCDM models will be compared to each other whereby its constraints and benefits will be reviewed.

Table 4 *Inventarisation SDSS (own ill.)*

Name model	City / region	Country	Type of model	Primary function	Relevance for UAD	The role of the model in the DM process	Suitable for comparison	Source: Author	Year	Title	Publication
BRIDGE	Athens, Gliwice, Helsinki, Firenze and London	Multiple	MCDM: AHP	SEA	focus on environment and allignment with EU legislation			Ainhoa González, Alison Donnelly, Mike Jones, Nektarios Chrysoulakis, Myriam Lopes	2013	A decision-support system for sustainable urban metabolism in Europe	Environmental Impact Assessment Review 38 (2013) 109–119
FML	Iskandar Development Region (IDR)	Malaysia	AI: SD	CO2 emmissions	Non-holistic approach			Wee-Kean Fong, Hiroshi Matsumoto,Yu-Fat Lun	2009	Application of System Dynamics model as decision making tool in urban planning process toward stabilizing carbon dioxide emissions from cities	Building and Environment 44 (2009) 1528-1537
-	Polog Region	Macedonia	MCDM: OWA, AHP and fuzzy	Site selection: landfill (stortplaats)	Non-holistic approach			Pece V. Gorsevski, Katerina R. Donevska, Cvetko D. Mitrovski, Joseph P. Frizado	2012	Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection: A case study using ordered	Waste Management 32 (2012) 287–296
MAEAC	Georgia Basin	Canada	MCDM: SAW, TOPSIS, ELECTRE	Climate change impact assessment	Focus on climate change			X.S. Qin, G.H. Huang, A. Chakma, X.H. Nie, Q.G. Lin	2008	A MCDM-based expert system for climatechange impact assessment and adaptation planning: A case study for the Georgia Basin, Canada	Expert Systems with Applications 34 (2008) 2164–2179
MCPUIS	Coimbra	Portugal	MCDM: SAW, TOPSIS, ELECTRE	Planning of urban infrastructure systems	Non-holistic approach			Jo Coutinho-Rodrigues, Ana Simo, Carlos Henggeler Antunes	2011	A GIS-based multicriteria spatial decision support system for planning urban infrastructures	Decision Support Systems 51 (2011) 720-726
-	Shanghai	China	AI: SD and CA	Simulating urban growth	Non-holistic approach			Ji Han, Yoshitsugu Hayashi, Xin Cao, Hidefumi Imura	2009	Application of an integrated system dynamics and cellular automata model for urban growth assessment: A case study of Shanghai, China	Landscape and Urban Planning 91 (2009) 133–141
(MCA-DSS)	Essen	Germany	MCDM: WLC	Sustainable land use evaluation	Focus on sustainable performance			Sophie Schetke, Dagmar Haase, Theo Kötter	2012	Towards sustainable settlement growth: A new multi-criteria assessment for implementing environmental targets into strategic urban planning	Environmental Impact Assessment Review 32 (2012) 195-210
-	Hong Kong	Hong Kong (China)	AI: SD	Sustainable land use evaluation	Non-holistic approach			Qiping Shen, Qing Chen, Bo-sin Tang, Stanley Yeung, Yucun Hu, Gordon Cheung	2009	A system dynamics model for the sustainable land use planning and development	Habitat International 33 (2009) 15-25
IPDSS	-	Cyprus	MCDM and AI	Land consolidation (ruil verkaveling)	Non-holistic approach			Demetris Demetrioua, John Stillwella, Linda See	2012	Land consolidation in Cyprus: Why is an Integrated Planning and Decision Support System required	Land Use Policy 29 (2012) 131-142
(MC-SDSS)	Tehran	Iran	MCDM: OWA	Site selection: parking area	Non-holistic approach			Mohammadreza Jelokhani-Niaraki, Jacek Malczewski	2015	A group multicriteria spatial decision support system for parking site selection problem: a case study	Land Use Policy 42 (2015) 492-508
(FMCDM)	Harlingen	south Texas, USA	MCDM: AHP and fuzzy	Site selection: landfill (stortplaats)	Non-holistic approach			Ni-Bin Chang, G. Parvathinathan, Jeff B. Breeden	2008	Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region	Journal of Environmental Management 87 (2008) 139-153
Various								Gustavo Arciniegas, Ron Janssen, Piet Rietveld	2013	Effectiveness of collaborative map-based decision support tools: Results of an experiment	Environmental Modelling & Software 39 (2013) 159-175
								Gustavo Arciniegas, Ron Janssen	2012	Spatial decision support for collaborative land use planning workshops	Landscape and Urban Planning 107 (2012) 332-342
	Bodegraven polder	the Netherlands	MCDM: WLC	Land use evaluation				Arciniegas, G.A., Janssen, R., Omtzigt, N.	2011	Map-based multicriteria analysis to support interactive land use allocation.	International Journal of Geographical Information Science 25 (12), 1931-1947.
								Arciniegas, G.A. and Janssen, R.	2009	Using a touch table to support participatory land use planning	In: B. Anderssen et al., eds. 18th IMACS world congress – MODSIM09 International Congress on
-	Viena	Austria	AI: ABM	simulate new residential patterns				Veronika Gaube, Alexander Remesch	2013	Impact of urban planning on household's residential decisions: An agent-based simulation model for Vienna	Environmental Modelling & Software 45 (2013) 92-103
Vensim PLE	Dalian	China	AI: SD	Urban transportation system	Non-holistic approach			WANG Jifeng, LU Huapu, PENG Hu	2008	System Dynamics Model of Urban Transportation System and Its Application	Journal Of Transportation - Systems Engineering And Information Technology, 2008, 8(3), 8389.
(CA-MAS) in NetLogo	Salt Lake City	Utah, USA	AI: CA, MAS	Urban gentrification	Non-holistic approach			Paul M. Torrens, Atsushi Nara	2007	Modeling gentrification dynamics: A hybrid approach	Computers, Environment and Urban Systems 31 (2007) 337–361
in D-Sight software	Kampala city	Uganda	MCDM: PROMETHEE II	Water loss management	Non-holistic approach			Harrison E. Mutikanga, Saroj K. Sharma, Kalanithy Vairavamoorthy	2011	Multi-criteria Decision Analysis: A Strategic Planning Tool for Water Loss Management	Water Resources Management, November 2011, Volume 25, Issue 14, pp 3947-3969
SAORES	Yangou catchment of the Loess Plateau	China	MCDM: MOSO	Ecosystem services / management	Non-holistic approach			Haitang Hu, Bojie Fu, Yihe Lü, Zhenmin Zheng	2015	SAORES: a spatially explicit assessment and optimization tool for regional ecosystem services	Landscape Ecol (2015) 30:547–560
-	core region of Changsha, Zhuzhou, Xiangttan city cluster	China	AI: MAS, GA	Land use allocation	Non-holistic approach			Zhang, H. H., Zeng, Y. and Bian, L.	2010	Simulating multi-objective spatial optimization allocation of land use based on the integration of multi-agent system and genetic algorithm	Int. J. Environ. Res., 4(4):765-776, Autumn 2010
WePWEP	Norfolk	England, UK	MCDM	Site selection: of wind farm sites	Non-holistic approach			Ana Simão, Paul J. Densham, Mordechai (Muki) Haklay	2009	Web-based GIS for collaborative planning and public participation	Journal of Environmental Management 90 (2009) 2027–2040
MAS in REPAST software	Land van Maas en Waal (hyothetical case)	the Netherlands	AI: MAS	spatial planning: zoning	Non-holistic approach			Arend Ligtenberg, Monica Wachowicz, Arnold K. Bregt, Adrie Beulens, Dirk L. Kettenis	2004	A design and application of a multi-agent system for simulation of multi-actor spatial planning	Journal of Environmental Management 72 (2004) 43–55
STEPP	Nijmegen	the Netherlands	MCDM	spatial planning: zoning	Non-holistic approach			Gerrit J. Carsjens, Arend Ligtenberg	2007	A GIS-based support tool for sustainable spatial planning in metropolitan areas	Landscape and Urban Planning 80 (2007) 72-83
SWARM (in Arc/Info GIS)	Nijmegen	the Netherlands	AI: MAS, CA	Land suitability analysis:conflict management	Non-holistic approach			Jacek Malczewski	2004	GIS-based land-use suitability analysis: a critical overview	Progress in Planning 62 (2004) 3-65
					Non-holistic approach			Arend Ligtenberg, Arnold K. Bregt, Ron van Lammeren	2001	Multi-actor-based land use modelling: spatial planning using agents	Landscape and Urban Planning 56 (2001) 21-33
-	Dongguan, Pearl River Delta	China	MCDM	Land use evaluation	Non-holistic approach			Anthony Gar-on Yeh & Xia Li	2007	An integrated remote sensing and GIS approach in the monitoring and evaluation of rapid urban growth for sustainable development in the Pearl River Delta, China	International Planning Studies, 2:2, 193-210,
ILWIS (SMCE module)	Bergamo Province	Italy	MCDM: AHP	site selection: park	incorporation hypothetical view sta			Antonella Zucca, Ali M. Sharifi, Andrea G. Fabbri	2008	Application of spatial multi-criteria analysis to site selection for a local park: A case study in the Bergamo Province, Italy	Journal of Environmental Management 88 (2008) 752-769
BUDEM	Beijing	China	AI: CA	Urban development	Non-holistic approach			Long Ying, Mao Qizhi, Dang Anrong	2009	Beijing Urban Development Model: Urban Growth Analysis and Simulation	Tsinghua Science And Technology. pp 782-794 Volume 14, Number 6, December 2009
UrbanSim	Eugene-Springfield, Oregon	USA	AI: ABM: Bayesian	Urban development				Hana Sevcikovaa, Adrian E. Rafteryb, Paul A. Waddel	2007	Assessing uncertainty in urban simulations using Bayesian melding	Transportation Research Part B 41 (2007) 652-669
								Paul Waddell	2002	UrbanSim: Modeling Urban Development for Land Use, Transportation, and Environmental Planning	Journal of the American Planning Association, 2002, 68:3, 297-314,

Table 6 *Literature review (own ill.)*

Author	Yr.	Title	Publication
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Arend Ligtenberg, Monica Wachowicz, Arnold K. Bregt, Adrie Beulens, Dirk L. Kettenis	2004	A design and application of a multi-agent system for simulation of multi-actor spatial planning	Journal of Environmental Management 72 (2004) 43–55
Gerrit J. Carsjens, Arend Ligtenberg	2007	A GIS-based support tool for sustainable spatial planning in metropolitan areas	Landscape and Urban Planning 80 (2007) 72-83
Barbara Golicnik Marusic	2001	Analysis of patterns of spatial occupancy in urban open space using behaviour maps and GIS	URBAN DESIGN International (2011) 16, 36-50.
Ursula C. Benz, Peter Hofmann, Gregor Willhauck, Iris Lingenfelder, Markus Heynen	2004	Multi-resolution, object-oriented fuzzy analysis of remote sensing data for GIS-ready information	ISPRS Journal of Photogrammetry & Remote Sensing 58 (2004) 239-258
Antonella Zucca, Ali M. Sharifi, Andrea G. Fabbri	2008	Application of spatial multi-criteria analysis to site selection for a local park: A case study in the Bergamo Province, Italy	Journal of Environmental Management 88 (2008) 752-769
Hana Sevcikovaa, Adrian E. Rafteryb, Paul A. Waddel	2007	Assessing uncertainty in urban simulations using Bayesian melding	Transportation Research Part B 41 (2007) 652-669
Barbara Golicnik Marusic and Damjan Marusic	2012	Behavioural maps and GIS in place evaluation and design	in Application of Geographic Information Systems
Long Ying, Mao Qizhi, Dang Anrong	2009	Beijing Urban Development Model: Urban Growth Analysis and Simulation	Tsinghua Science And Technology. pp 782-794 Volume 14, Number 6, December 2009
Jeremy W. Crampton, Mark Graham, Ate Poorthuis, Taylor Shelton, Monica Stephens, Matthew W. Wilson & Matthew Zook	2013	Beyond the geotag: Situating big data and leveraging the potential of the geoweb	Cartography and Geographic Information Science (2013) Vol. 40, No. 2, 130-139,
Van Oort, N.	2014	Big data supports light rail in Utrecht	International Railway Journal and Rapid Transit Review 54 (4)
Sooyong Park, Vijayan Sugumaran	2005	Designing multi-agent systems: a framework and application	Expert Systems with Applications 28 (2005) 259-271
Anthony Gar-On Yeh, Xia Li	2006	Errors and uncertainties in urban cellular automata	Computers, Environment and Urban Systems 30 (2006) 10-28
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Jacek Malczewski	2004	GIS-based land-use suitability analysis_a critical overview	Progress in Planning 62 (2004) 3-65
D. Stevens, S. Dragicevic, K. Rothley	2007	iCity: A GIS en CA modelling tool for urban planning and decision making	Environmental Modelling & Software 22 (2007) 761-773
Martin Clarke and Einar Holm	1987	Microsimulation Methods in Spatial Analysis and Planning	Geografiska Annaler. Series B, Human Geography, Vol. 69, No. 2 (1987), pp. 145-164
Nils Ferrand	1995	Modelling and Supporting Multi-Actor Spatial Planning Using Multi-Agents Systems	Unpublished?
Anthony Gar-On Yeh & Xia Li	2000	Modelling sustainable urban development by the integration of constrained cellular automata and GIS	International Journal of Geographical Information Science, 14:2, 131-152,
Arend Ligtenberg, Arnold K. Bregt, Ron van Lammeren	2001	Multi-actor-based land use modelling: spatial planning using agents	Landscape and Urban Planning 56 (2001) 21-33
Tom P. Evans, Hugh Kelley	2004	Multi-scale analysis of a household level agent-based model of landcover change	Journal of Environmental Management 72 (2004) 57-72
Wonseok Oh and Alain Pinsonneault	2007	On the Assessment of the Strategic Value of Information Technologies	MIS Quarterly, Vol. 31, No. 2 (Jun., 2007), pp. 239-265
Michael Beck	2003	Real-time visualisation of big 3D city models	International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXIV-5/W10
Michael K. McCall	2003	Seeking good governance in participatory-GIS: a review of processes and governance dimensions in applying GIS to participatory spatial planning	Habitat International 27 (2003) 549-573
Yichun Xie, Daniel G. Brown	2007	Simulation in spatial analysis and modeling	Computers, Environment and Urban Systems 31 (2007) 229-231
Psyllidis, Achilleas	2013	SmartScapes: big data and urban Informatics for performative cities	Atlantis, 24 (2), 2013.
Anthony Gar-On Yeh & Xia Li	1998	Sustainable land development model for rapid growth areas using GIS	International Journal of Geographical Information Science, 1998, 12:2, 169-189,
Paul Waddell	2002	UrbanSim: Modeling Urban Development for Land Use, Transportation, and Environmental Planning	Journal of the American Planning Association, 2002, 68:3, 297-314,
Tine van Langelaar and Stefan van der Spek	2010	Visualizing pedestrian flows using GPS-tracking to improve inner-city quality	Unpublished?
Helen Couclelis	2005	Where has the future gone: Rethinking the role of integrated land-use models in spatial planning	Environment and Planning A 2005, volume 37, pages 1353-1371
Ainhoa González, Alison Donnelly, Mike Jones, Nektarios Chrysoulakis, Myriam Lopes	2013	A decision-support system for sustainable urban metabolism in Europe	Environmental Impact Assessment Review 38 (2013) 109–119
Jo‹o Coutinho-Rodrigues, Ana Sim‹o, Carlos Henggeler Antunes	2011	A GIS-based multicriteria spatial decision support system for planning urban infrastructures	Decision Support Systems 51 (2011) 720-726
Mohammadreza Jelokhani-Niaraki, Jacek Malczewski	2015	A group multicriteria spatial decision support system for parking site selection problem	Land Use Policy 42 (2015) 492-508
A. Laaribi, J. J. Chevallier and J. M. Martel	1996	A spatial decision aid: a multicriterion evaluation approach	Comput., Environ. And Urban Systems, Vol. 20, No. 6, pp. 351-366, 1996
Qiping Shen, Qing Chen, Bo-sin Tang, Stanley Yeung, Yucun Hu, Gordon Cheung	2009	A system dynamics model for the sustainable land use planning and development	Habitat International 33 (2009) 15-25
Eeva Saynajoki	2012	An analysis of the factors that impact and define environmental sustainability in Nordic societies, in the context of urban structures and land use	Unpublished?
Ji Hana, Yoshitsugu Hayashi, Xin Cao, Hidefumi Imura	2009	Application of an integrated system dynamics and cellular automata model for urban growth assessment_A case study of Shanghai, China	Landscape and Urban Planning 91 (2009) 133–141

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	Wee-Kean Fong, Hiroshi Matsumoto,Yu-Fat Lun	2009	Application of System Dynamics model as decision making tool in urban planning process toward stabilizing carbon dioxide emissions from cities	Building and Environment 44 (2009) 1528-1537
	Batty	2011	Building a science of cities	Book summary
	Batty	2008	Cities as Complex Systems: Scaling, Interactions, Networks, Dynamics and Urban Morphologies	In The Encyclopedia of Complexity & System Science, Springer, Berlin, DE, forthcoming 2008. Date paper: February 25, 2008.
	Ni-Bin Chang, G. Parvathinathan, Jeff B. Breeden	2008	Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region	Journal of Environmental Management 87 (2008) 139-153
	Chen Zhong, Stefan Müller Arisona, Xianfeng Huang, Michael Batty & Gerhard Schmitt	2014	Detecting the dynamics of urban structure through spatial network analysis	International Journal of Geographical Information Science, 2014
	Gustavo Arciniegas, Ron Janssen, Piet Rietveld	2013	Effectiveness of collaborative map-based decision support tools: Results of an experiment	Environmental Modelling & Software 39 (2013) 159-175
	Juan Porta, Jorge Parapar, Ramón Doallo, Francisco F. Rivera, Inés Santé, Rafael Crecente	2013	High performance genetic algorithm for land use planning	Computers, Environment and Urban Systems 37 (2013) 45–58
	Veronika Gaube, Alexander Remesch	2013	Impact of urban planning on household's residential decisions: An agent-based simulation model for Vienna	Environmental Modelling & Software 45 (2013) 92-103
	Eeva Saynajoki, Jukka Heinonen, Jari Rantsi And Seppo Junnila	2011?	Improving Eco-Efficiency Of The Built Environment - Tools For Local Action	JOINT CIB W070, W092 & TG72 INTERNATIONAL CONFERENCE: DELIVERING VALUE TO THE COMMUNITY
	Pece V. Gorsevski, Katerina R. Donevska, Cvetko D. Mitrovski, Joseph P. Frizado	2012	Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection: A case study using ordered weighted average	Waste Management 32 (2012) 287–296
	Demetris Demetrioua, John Stillwella, Linda See	2012	Land consolidation in Cyprus: Why is an Integrated Planning and Decision Support System required	Land Use Policy 29 (2012) 131-142
	Paul-Marie Boulanger, Thierry Bréchet	2005	Models for policy-making in sustainable development: The state of the art and perspectives for research	Ecological Economics 55 (2005) 337-350
	Ivy B. Huang, Jeffrey Keisler, Igor Linkov	2011	Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends	Science of the Total Environment 409 (2011) 3578-3594
	Peder Hjorth, Ali Bagheri	2006	Navigating towards sustainable development: A system dynamics approach	Futures 38 (2006) 74–92
	Gustavo Arciniegas, Ron Janssen	2012	Spatial decision support for collaborative land use planning workshops	Landscape and Urban Planning 107 (2012) 332-342
	WANG Jifeng, LU Huapu, PENG Hu	2008	System Dynamics Model of Urban Transportation System and Its Application	Journal Of Transportation_Systems Engineering And Information Technology, 2008, 8(3), 8389.
	Sophie Schetke, Dagmar Haase, Theo Kötter	2012	Towards sustainable settlement growth: A new multi-criteria assessment for implementing environmental targets into strategic urban planning	Environmental Impact Assessment Review 32 (2012) 195-210
	Batty	2009	Urban Modeling	in N. Thrift and R. Kitchin (Editors) International Encyclopedia of Human Geography, Elsevier, Oxford, UK, pp. 51-58.

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	Gelezen
	Gelezen, maar niet heel wetenschappelijk / ongepubliceerd werk

Books

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	Otto Huisman & Rolf A. de By	2009	Principles of Geographic Information Systems	The International Institute for Geo-Information Science and Earth Observation (ITC)

Thesis

	Iris van de Kerk	2015	Data use versus privacy protection in public safety in smart cities	Msc GIMA
	Barend Dronkers	2015	Energy mapping: an exploration of instruments that further the urban energy transition	Msc in Sustainable Energy Technology at TU Delft

11. PROVISIONAL TABLE OF CONTENTS OF THE FINAL REPORT

12. ABBREVIATIONS

ABM	agent-based models
AHP	analytical hierarchical process
ANP	analytic network process
AI	artificial/computational intelligence
CA	cellular automata
CBR	case-based reasoning (systems)
DBMS	data base management system
DM	decision-making
DSS	decision-support system
DEM	digital elevation model
DLL	dynamic library links
DTM	digital terrain model
EA	evolutionary algorithms
EIA	environmental impact assessment
ELECTRE	ELimination and Choice Expressing Reality
GA	genetic algorithms
GIS	geo-information system
LIS	land information system
MAS	multi-agent systems
MAUT	Multi-Attribute Utility Theory
MCE	multi-criteria evaluation
MCDA	multi-criteria decision analysis
MCDM	multi-criteria decision-making
OWA	ordered weighted average
P-GIS	participatory GIS
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
PSP	participatory spatial planning
PSS	planning support system
RM	remote sensing
RMSE	root mean square error
SAW	simple additive weighting
SD	system dynamics
SDSS	spatial decision support system
SEA	strategic environmental assessment
SES	spatial experts systems
SKBS	spatial knowledge based system
SQL	structured query language
TOPSIS	Technique for Order Preference by Similarity
WLC	weighted linear combination

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