Evaluation of methods for calculating the green roof potential on already existing buildings in urban areas.

Malin Rauhala

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Environmental and Energy Systems Studies
Department of Technology and Society
Faculty of Engineering at Lund University

LUNDS UNIVERSITET
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By Malin Rauhala

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Telefax: 046-222 86 44

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Sammandrag

Denna studie utvärderar och jämför fyra grönatakmetoder med syftet att beräkna hur många gröna tak som potentiellt kan byggas på redan befintliga byggnader i en stad. Metoderna är skapade för städerna Braunschweig, Thessaloniki, Lissabon och Lund. Alla metoder använder huvudsakligen Geografiska informationssystem och fjärranalys som verktyg. För att besvara forskningsfrågorna har en litteraturstudie och en intervjustudie genomförts. Vidare observerar denna studie de kriterier som valts ut i metoderna och undersöker möjligheten att skapa en liknande metod för Malmö i Sverige. Relevanta intressenter i Malmö, med kunskap om grönatakteknologi och stadsplanering, ger sina åsikter om huruvida en sådan metod är intressant eller inte. Framtiden för gröna tak i Malmö, och vad som motverkar en snabbare expansion, diskuteras också.

Taklutning och tillgänglig takareal används som kriterier i alla de fyra metoderna. Andra kriterier som visade sig vara användbara är väderförhållanden såsom tillgängligt solljus samt vattentätt takskikt och bärförmåga. Det senare är mycket viktigt att inkorporera i metoden eftersom det starkt påverkar resultatet.

De fyra metoderna i litteraturstudien följer en mycket liknande struktur. Skillnader beror på de initiala syftena, vilka ytterligare verktyg som användes, tillgängliga inmatningsdata och vilka scenarier som valts. Endast en av grönatakmetoderna inkluderar en fältstudie. Forskarna till en av de andra metoderna påpekar dock att fältstudier och mätningar in situ bör adderas för att förbättra noggrannheten. Vidare bör en känslighets -och osäkerhetsanalys utföras. Det kan också vara användbart med en drönare för att samla ihop bilder på byggnader både från långt och kort avstånd.

De personer som intervjuats i denna studie tror att antalet gröna tak så småningom kommer att öka i Malmö. Svaren visar också att det bör finnas tillräckligt med inmatningsdata för att skapa en gröntakmetod för Malmö, och respondenterna verkar positiva till det. En av de svåraste uppgifterna skulle dock vara att hitta bärigheten på alla tak. Dessutom finns det inga aktuella politiska krav eller subventioner i Sverige, i jämfört med Tyskland, som kräver eller främjar fler gröna tak. Beroende på utvecklingen av denna fråga kan det bli mer intressant att använda en grönatakmetod i framtiden istället. Man kan dock också argumentera motsatsen. Om en grönatakmetod skapades och användes i Malmö idag, skulle det kunna bli ett argument för att införa lagar eller subventioner för att öka antalet.

Andra saker som kan hindra en snabbare expansion av gröna tak i Malmö är bygglov, ekonomi och en allmän brist på kunskap. Tillgänglig information om grönatakteknikér måste distribueras kontinuerligt så att fler förstår konceptet bättre.

Det skulle vara intressant att göra ytterligare undersökningar, och jämföra Tysklands lagar och subventioner med Sveriges, när det kommer till gröna tak. Det skulle dessutom vara användbart att samla in och sammanställa information om fysiska egenskaper hos alla tak i Malmö. Tak kan betraktas som tomma utrymmen användbara inte bara för växtlighet utan också för solcellssystem eller vattenhållningssystem. Dessutom skulle det vara intressant att följa upp ifall de grönatakmetoder som analyserats i denna studie har implementerats och varit användbara i de valda studieområdena.

Nyckelord

Green roof, urban planning, environmental engineering, GIS, remote sensing, potential, green roof technology, gröna tak, stadsplanering,

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LUND UNIVERSITY
Department of Technology and Society
Environmental and Energy Systems Studies
Box 118
SE - 221 00 Lund, Sweden
Telephone: int+46 46-222 00 00
Telefax: int+46 46-222 86 44

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Malin Rauhala

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Abstract

This study evaluates and compares four green roof methods with the purpose to calculate how many green roofs that potentially can be built on already existing buildings in a city. The methods are created for the cities Braunschweig, Thessaloniki, Lisbon and Lund. All of the methods mainly use Geospatial Information Systems and remote sensing analysis as tools. In order to answer the research questions, a literature study and an interview study have been conducted. Furthermore, this study observes the criteria that have been chosen in the methods and examines the possibility to create a similar method for Malmö in Sweden. Relevant stakeholders in Malmö, with knowledge on green roof technology and urban planning, give their opinion. The future for green roofs in Malmö, and what hinders a faster expansion, is also discussed.

Roof slope and available roof area are used as criteria in all of the four methods. Other criteria found useful are weather conditions like sunlight availability as well as waterproofing membrane layer and load-bearing capacity. The latter is very important to incorporate in the method since it highly affects the result.

The methods evaluated follow a very similar structure. Differences depend on the initial aims, which additional tools that were used as well as available input data and which scenarios were chosen. Only one of the green roof methods include a field study. However, it is concluded by the researchers of one of the other methods that field studies and in-situ measurements should be added in order to improve accuracy. Furthermore, a sensitivity -and uncertainty analysis should be performed. It might also be convenient to use a drone in order to collect both remote images and detailed images of buildings.

The people interviewed in this study believe the number of green roofs will eventually increase in Malmö. The answers also demonstrate that there should be enough input data to create a green roof method for Malmö and the respondents appear positive towards it. However, one of the most difficult parts would be to find the load-bearing capacities of all roofs. Moreover, up to date there exist no political requirements or subsidies in Sweden, compared to Germany, that requires or promote more green roofs to be built. Therefore, depending on the development of this matter, a green roof method may be of more interest in the future. However, one can also argue the opposite. If a green roof method was created and used in Malmö now, it could become an argument to implement supporting laws or subsidies to increase the number.

Other things that may hinder a faster expansion of green roofs in Malmö are building permits, finances and a general lack of knowledge. Available information on green roof technology needs to be distributed continuously so that more people understand the concept better.

It would be interesting to do further investigations and compare the laws and subsidies of Germany with the ones in Sweden when it comes to green roofs. It would furthermore be useful to collect and compile information about physical properties of all roofs in Malmö. Roofs can be considered as empty space for not only vegetation, but also for solar cell systems or water retention systems. Moreover, it would be interesting to follow-up if the green roof methods analysed in this study have been implemented and been useful in the chosen study areas.

Keywords

Green roof, urban planning, environmental engineering, GIS, remote sensing, potential, green roof technology, gröna tak, stadsplanering,

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Acronyms

Green roof potential = In this study it means how many green roofs that potentially can be built on already existing buildings in a city or study area.
Green roof method = In this study it means a method with the purpose to calculate how many green roofs that potentially can be built on already existing buildings in a city or study area.
SGRI = Scandinavian green roof institute situated in Augustenborg in Malmö.
GEOBIA = Geographic-Object based image analysis. Used for analysing high-spatial resolution remote sensing imagery (Chen et al. 2018).
Orthoimage = A geometrically corrected aerial or satellite image. Once it has been orthorectified, it can be called an orthophoto (Dempsey 2003).
DSM = A digital surface model symbolises the earth's shell and includes all objects on it such as trees and buildings. Not to be confused with a digital terrain model DTM or a digital elevation model DEM (gisresources 2016).
Building's footprint = Explained by The Free Dictionary by Farlex (nd) as "the area on a project site that is used by the building structure and is defined by the perimeter of the building plan".
WorldView-2 image (WV-2) = An image provided by the DigitalGlobe's WorldView-2 satellite sensor and operates at an altitude of 770 km (Satellite imaging corporation nd).
Ångström-Prescott formula = An equation that defines the relationship between solar energy available at ground level and sunshine duration (Paulescu et al. 2016).
BIM = Building information modelling. Used for 3D design to model structure and timeline of a project (engineering.com 2016).
Green and blue/bluegreen = An expression which refers to vegetation and aquatic areas. Often used when talking about sustainable infrastructure.
Retrofit a roof = It means, in this study, converting a conventional roof into a green roof.
Butterfly roof, monopitched roof… = Names of roofs with different shape and slope.

Translations

Roofing felt = Takpapp
Statistics Sweden = Statistiska centralbyrån
Planning and Building Act = Plan och bygglagen (PBL)
Swedish National Board of Housing, Building and Planning = Boverket
Developer = Byggherre
Swedish environmental protection agency = Naturvårdsverket
Swedish Meteorological and Hydrological Institute = Sveriges meteorologiska och hydrologiska institut (SMHI)
Swedish University of Agricultural Sciences = Sveriges lantbruksuniversitet (SLU)
City planning Office of Malmö City = Malmö stads stadsbyggnadskontor
Environmental Administration of Malmö City = Malmö stads miljöförvaltning
Executive director = Förvaltningschef
Environmental building strategist = Miljöbyggstrateg
Detailed development plan = Detaljplan
Technical property requirements = Tekniska särkrav
Turf roof = Torvtak
Green Area Ratio or Biotope Area factor = Grönytefaktor

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1. Introduction

Green roofs are not a new phenomenon, although the way of creating them has been upgraded to a modern version for urban areas (Lawrence technological university 2019).

Traditional green roofs have historically been used in the Nordic countries as protection from natural elements, cooling in the summer and warming in the winter. Turf roofs, with grass growing on top, were commonly used but gradually replaced by cement tiles between the 17th to 19th century since they were considered to be more waterproof. The transition took a long time because of the brick prices at the time but was favoured in Nordic urban areas due to increased safety against fire outbreaks (Dunnet & Kingsbury 2004).

The concept of "modern green roofs" can be defined as *"…isolated, novel, anthropogenic patches consisting of membranes, engineered substrate (the growing medium), and assemblages of plants places atop buildings and other structures"* (Sutton 2015, p 2).

In a fast-changing world, modern green roof technology may be one of the necessary solutions for greener and more sustainable cities. Green roofs can be built on top of already existing and suitable roofs or be part of the building process of new houses from the start. Other than direct benefits such as storm water retention, decrease of urban heat islands or a potential improvement of biodiversity, green roofs can also be combined with leisure areas for employees, solar energy systems or rooftop gardens to improve mental health (Grönatakhandboken 2017).

When starting to investigate green roofs for this paper, it was realised that no specific method has been used in order to plan for more green roofs in the city of Malmö in Sweden. This led to an idea for the aim and research questions. Furthermore, after some reading about green roofs in connection to geographical information systems (GIS) and remote sensing analysis, the investigation continued with more focus on these tools.

Photo 1: *View from Emporia rooftop garden in Hyllie, Malmö (photo taken by the author in 2019).*

1.1. Aim & research questions

The aim of this study is to critically evaluate four green roof methods that have been used to model how many green roofs that potentially can be built on already existing buildings in a city. The methods analysed are mainly created with GIS and remote sensing analysis. A similar method could possibly be created for Malmö in Sweden and the possibility and interest for this will be evaluated too. There will also be a part looking into the future for green roofs in Malmö.

In order to answer the aim, some specific research questions have been formulated:

1. What criteria can be used, and should be used, in order to model the green roof potential of a city?

2. What is the structure of the four green roof methods? What similarities and differences can be seen and what improvements can be made?

3. Would it be possible to create a green roof method for Malmö and is there an interest for such tool among relevant stakeholders? What does the future look like for green roofs in Malmö? What hinders a faster expansion?

1.2. Scope

Only modern green roofs in urban areas will be considered and not green roofs that can be built in rural areas and villages. Even though the same building method may be used for the different locations, the focus will be on cities and sustainable urban planning.

The four papers, described in the literature study in chapter three, are all from countries in Europe produced between 2005 and 2017. One of them is from Lund which is located about two kilometres from Malmö. Three of the papers are written by researchers and the fourth is written by a former student of Lund university on master's level. These papers were chosen because they all include information about methods on how to calculate the green roof potential using GIS and remote sensing analysis. Furthermore, the papers do not take into consideration empty spaces in a studied area where new buildings with green roofs can be built. Only already existing rooftops are considered, and whether or not it is suitable to build green roofs on them depending on different criteria.

The interview study includes respondents from, or with a connection to, Malmö and the answers were collected in July and August 2019. Questions and answers were sent via email.

This paper will not include green roof potential calculations for Malmö and a method will not be created. However, this paper may be seen as a pilot study.

1.3. Method & material

Both a literature study and an interview study were conducted in order to answer the research questions and aim of this paper. Additional material was collected through participation in a 4 day long *Green roof summer course* at the Scandinavian green roof institute (SGRI) running between 25 of June until 28 of June 2019. This course is organised for the 7th time by the employees of the institute and they work there to spread knowledge about green roofs, and everything related. On the website of SGRI it can be read that "Green Roof Institute is 100% owned by the northern green roof association in Europe, Scandinavian Green Infrastructure Association (SGIA)."

Most of the sources used in the literature study were taken from the LUBSearch engine with access via the student portal of Lund Faculty of Engineering. Other sources were physical and online books as well as green roof associations and various authorities.

The selection during the literature study has been connected to keywords like "green roof potential", "green roof GIS" and "remote sensing potential green area" and "green roof study Sweden". The keywords were chosen because of the aim to look at methods using GIS and remote sensing, and this is also why the four papers were chosen from the total search result. When reading the resources of one paper, another relevant paper could be found on the same topic.

The persons to be interviewed were found by visiting the website of SGRI as well as the City of Malmö, through recommendations and by searching for companies that are active in the green roof branch of industry. Email was then used to reach out with questions to the relevant people with knowledge on green roofs, urban planning and/or spatial analysis. The answers to the questions are presented in the literature study in chapter four. The questions asked can be found in appendix.

2. Background

In this chapter some background facts will be presented in order to fully understand the succeeding text. Malmö will be presented since there is a focus on this city in the interview study. The concept of green roofs will be described more deeply as well as connecting theories. Additionally, a part of the background touches Germany and the laws and subsidies that have been implemented there, followed by a description of GIS and remote sensing.

2.1. Malmö city

It is expected that the part of the world's population, that live in urban areas, will reach 70 % by the year 2050. Although this fact results in more pressure to create sustainable cities, there are also possibilities when it comes to innovation and economy (UN 2019).

Malmö, situated in the southwestern part of Sweden, has on average 1.3 hours of sunshine per day in January and 8.7 hours of sunshine per day in May (World Weather & Climate Information 2019). Temperatures range between 0°C and 17°C throughout the year. Average yearly precipitation varies between 500 mm and 1000 mm (Swedish Meteorological and Hydrological Institute (SMHI) 2019).

Malmö has a strong population growth and there has been a shortage of housing since 2009 (Malmö stad 2019a). Comparing 2018 with 2028, the population of Malmö is estimated to grow by 13 %; an increase from around 339 000 to 383 000 inhabitants (Malmö stad 2019b).

The architectural style of Malmö ranges from medieval to postmodernism, with many functionalistic houses brought up between the First and Second World wars. The original functionalistic houses with flat roofs were however developed into a more traditional version with a bit more colour and decoration as well as yellow brick walls and saddleback roofs with red tiles (Malmö stad 2001). During the 1950s, the first concrete houses were built. The area Rosengård is an example of this new building technique with prefabricated concrete and building cranes (ibid.). Going into the 1960s, flat roofs, butterfly roofs and mono-pitched roofs with roofing felt became increasingly used (Malmö stad 2004).

2.2. Sustainable goals in Malmö

The current environmental program for Malmö started in 2009 and will end in 2020. The environmental program is analysed every year with a tool called *Miljöbarometern* as well as written environmental statement. *Miljöbarometern* is a tool that provides information, for anyone interested, about the status of the goals measured with key figures (Malmöstad 2019c).

In June 2019, the status of the environmental goals of Malmö was that only two of the 19 goals may be reached in 2020 and that four goals will not be reached at all. The rest of them can partly be reached. The non-achievable goals are for example relating to the green and the blue qualities to be developed, a good living environment for everyone in Malmö and that the nature of Malmö shall be protected (Malmö stad 2019d).

It is further stated that vegetated and aquatic areas are to be increased in Malmö with a complementation of green roofs and walls, and visual water storages. Nevertheless, in 2015 the area of green space per inhabitant was calculated to 106 m^2 which was a decrease from 2000 by around 30 %. However, this also reflects the city's population growth and some differences in calculation method between the years (ibid.). Area of green space is defined and calculated by the government agency Statistics Sweden. It includes all vegetated areas within the defined urban border such as common parks, grasslands, gardens, green areas between apartments or industries, green areas between roads and more (Statistiska centralbyrån nd).

A small increase of hard-made surfaces can be seen between the years 2000 and 2010, for example surfaces like roofs, parking lots, pavements, roads etc. According to Statistics Sweden, this does not improve the situation since more penetrable surfaces are instead needed to avoid floods (Malmö stad 2019d).

2.3. Green roofs

Urban green roofs can be described as an extended system of the existing conventional roof of the building underneath, which encompasses plants, a lightweight substrate, filter cloth, drainage system, root repellent system and water proofing (Greenroof.org nd).

The following statements are possible advantages with building green roofs. The strain on the stormwater system of a city can be lowered due to reduction and detention of rain runoff performed by plants and substrate. Evapotranspiration and reflection of plants softens urban heat islands and provide a cooling effect. Biodiversity can be improved if a mix of plants is added to the roofs which also can act as green corridors to connect insects and pollinators with other green areas in the city. Noise and air pollution can be reduced. The use of air conditioning can be reduced in warm climates which also lowers energy consumption. Mental health can be improved, as it is proven that green spaces have a positive effect on human well-being and depending on the design possibilities the green roof can act as a recreation area. There are also great possibilities to combine green roofs with solar cell panels or build in extra water retention capacity (Grönatakhandboken 2017).

According to Jonathan Malmberg [1], head of project and development at the SGRI in Malmö, certain confusion exists concerning the terminology of extensive, semi intensive and intensive green roof types. During the *Green roof summer course* in June 2019 he explains that these terms should be used when explaining the amount of maintenance needed during and after the construction of a green roof. The terms can not only be connected to the thickness of the green roof.

In the manual from SGRI, intensive roof plantation refers to a vegetation cover that demands continuous maintenance in order to keep the original function. This depends on the choice of design, layout and plants. Extensive roof plantation refers to a vegetation cover that can manage to keep its initial function on its own, as long as it is checked upon once or twice a year. A semi intensive vegetation cover is consequently something in between intensive and extensive (Grönatakhandboken 2017).

[1] Jonathan Malmberg. Lecture during the Green Roof course at the Scandinavian Green Roof Institute in Augustenborg in Malmö the 25th of June 2019.

The vegetation choice mirrors the substrate or growth media thickness. Sedum and mosses are able to grow in a minimum depth of 30 mm of substrate depth while a big tree would require 2m of substrate. This in turn affect weight and cost (ibid.).

If the right plant species and habitat conditions are chosen on a green roof, it is possible to attract pollinators and other animals such as hummingbirds and nectar feeding bats[2]. The plants should be drought tolerant, support local wildlife and have a long flowering season. Heterogeneous green roofs can be created with stones and wood in order to provide different microclimates and shading. The amount of nutrients, stress and disturbance should be considered carefully since this is the key to avoid invasive species. Different kinds of substrate can be created with a mix of for example green waste compost, crushed stones, pumice, foam glass and biochar depending on plant types and desired weight [2].

The so-called sedum roof is a popular type of vegetated roof to build since the succulent sedum plants do not require much maintenance, are drought and wind tolerant and only need to be planted in a thin layer of soil which lowers cost and weight (Sempergreen nd). However, according to Ksiazek-Mikenas et al., a designer should not specify solely sedum roofs in an area, and instead focus on adding early-flowering annuals and late-flowering perennials, in order to favour biodiversity (2018).

Urban areas tend to have a higher ambient temperature than the neighbouring countryside and this temperature difference is called the Urban heat island effect. Cities have a higher amount of dense and darkly exposed building material, with a low albedo, that absorbs sunlight and reradiates it during the night-time. A surplus of urban heat can lead to an extra demand for air conditioning or fans as well as a risk of amplified air pollution (Livingroofs nd). The evapotranspiration of plants and substrate, which is an important part of the water cycle, provide a cooling effect in the nearby area since energy is required to change liquid water into gas form (Grant 2012).

Vegetated surfaces also have the potential to decrease pollutants and gases such as particulate matter, nitrogen oxides, sulphur dioxide, carbon monoxide and ground level ozone. This is done through dry deposition as well as carbon sequestration and storage (U.S. Environmental Protection Agency 2008).

Previously quoted Johan Malmberg [3], head of project and development at the SGRI in Malmö, highlights some important factors when it comes to building a green roof. It is vital that there is good communication between all stakeholders as leakage from a green roof is more difficult to locate afterwards than on a conventional roof. Furthermore, excess water from the plant bed, as from the entire roof, needs to be drained off. Additionally, the roof must be safe for people to stay on which means both fire regulations and anchoring systems need to be considered carefully.

[2] Jonathan Malmberg. Lecture during the Green Roof course at the Scandinavian Green Roof Institute in Augustenborg in Malmö the 25th of June 2019

[3] Jonathan Malmberg. Lecture during the Green Roof course at the Scandinavian Green Roof Institute in Augustenborg in Malmö the 25th of June 2019

Photo 2: *Sedum plants from Opmanna plantskola in Skåne, Sweden (photo taken by the author in the summer of 2019).*

In a study made in Malaysia, where green roof technology is still at the infancy stage, a questionnaire survey was sent to architects in order to identify factors that hinder green roof expansion. It resulted in nine obstacles where two of them were the most profound, e.g. limited local expertise (which can lead to mistakes during the construction phase and lack of proper maintenance) and higher cost of material supply (due to the lack of green roof suppliers in the country) (Zulhabri et al. 2012).

When it comes to Sweden, each constructed roof needs to be built accordingly to the Planning and Building Act (PBL), the Plan and Building Regulation (PBF) as well as the Building and Construction rules (BBR and EKS) distributed by the Swedish National Board of Housing, Building and Planning (Boverket 2018a). In 2015 an extra restriction was introduced to the PBL which stated that each municipality does not have the opportunity to set its own requirements on technical properties. The purpose of the restriction is to unify technical property requirements and prevent an increase of cost. However, this does not apply if the municipality is the developer and property owner (ibid). Nevertheless, some argue that this decreases the opportunity for municipalities to require better environmentally friendly solutions than in accordance with the requirements of the state regulations (Klimatkommunerna 2018).

2.4. Green roof strategies in Germany

Germany has been a country ahead of others when it comes to developing new green roof technology, and the new knowledge spread to other countries from the 60s and forward (Dunnet & Kingsbury 2004). According to the *European Federation Green Roofs and Walls* (EFB) the number of green roofs in Germany were estimated to around 86 million m^2 in 2014 with an estimated increase of 8 million m^2 each year (EFB 2015).

A paper on green roof policies in Germany, published 2004, states that there are four distinctive policy categories which have already been in place for a decade (Ngan 2004). These are direct financial incentives, indirect financial incentives, ecological compensation measures and development regulations (ibid.).

Ecological compensation means values are provided in one region due to losses of values in another region. This is done by restoration, new establishments or management of protected nature areas (Centrum för miljö -och klimatforskning 2018).

Each state in Germany has to have a landscape plan were environmental harm should be compensated with the establishment of green infrastructure (Buehler et al. 2011). For example, in the city of Hamburg decided that a minimum of 70% of all suitable rooftops should be covered with vegetation. This initiative is subsidised from the government from 2015 (Hamburg.com nd).

2.5. Tools

The four papers, in the upcoming literature study in chapter 3, use mainly GIS and remote sensing to create their green roof methods.

2.5.1. GIS

Geographic information systems (GIS) is a tool to analyse input data in relation to different locations on the surface of Earth. These locations can be expressed as for example latitude, longitude, address or ZIP code. By relating seemingly unrelated data to each other, it can become easier for people to see relationships and patterns and thereby make better decisions (Evers 2017).

Data that can be put into GIS is:
* Cartographic - such as location already in a map form.
* Digital -such as computer data collected by satellites.
* Remote sensing -such as images or other data collected by satellites, balloons or drones.
* Table -or spreadsheet forms -such as population demographics about for example recent purchases (ibid.).

Geospatial analysis and GIS packages are under a rapid change and are improving constantly. GIS can be used to find answers for challenges like choosing the best routes, where to place a facility and the optimum flow. It provides another perspective of the world and helps to examine events, patterns and processes both two and three dimensional in time and space (Smith et al. 2018).

What are the challenges when it comes to GIS? Firstly, without adequate data that fits the tool, no good analyses can be performed. Key datasets are often provided by a third party rather than being produced during the research. Data from one location is not independent of another location, and this should be taken in consideration as well as when the data was collected and where. Accuracy, quality, consistency, completeness and origin of the metadata should be discussed, and may be improved with other data sets like corporate (crime incident

records, automatically tracked events, medical details…) or field research (remote-sensed data, soil samples, market research…). Nevertheless, no data set is perfect.
More advanced GIS tools are available to tackle the issue of missing data or lack of continuity (ibid.).

Secondly, GIS is difficult for an average individual to use without proper training and this calls for experts to perform analyses. Moreover, when executing an analysis, generalization habitually occurs due to the complex data structures and large inputs of data. The process of collecting, storing and analysing data is in general very time consuming and it is not cheap to acquire the software (Grind GIS 2018).

2.5.2. Remote sensing

The definition of remote sensing is that it includes the ways of gaining information about earth and its surface without any physical contact with it. To do this, one has to measure the reflected and emitted energy at a distance from the area to be monitored. The word *remote* refers to the long distance up in the atmosphere, where cameras collect the images of the Earth. The word *sensing* refers to the researchers that thereafter use these images to identify patterns. The special cameras can be put on airplanes, space shuttles and satellites to for example see the growth of a city over time (The United states geological survey nd).

Example of applications for remote sensing are infrastructure planning, land cover classification, surface temperature monitoring and much more (Grind GIS 2017).

Images nowadays can be delivered down to a very high accuracy resolution, but future generation systems are estimated to enhance resolution and quality even more (Henning 2013).

3. Literature study

Three research papers were found using *LUBSearch* (Lund University Libraries) with key words like “green roof potential”, “green roof GIS” and “remote sensing potential green area”. Furthermore, when searching for “green roof study Sweden” on Google, a master’s thesis paper published in LUP Student Papers of Lund University was found. The keywords were chosen because of the aim to look at methods using GIS and remote sensing, and this is also why the four papers were chosen from the total search result.

The common factor of these four papers is the way that the authors have constructed a method to calculate how many green roofs that potentially can be built on already existing buildings in the chosen study area. All of the papers include mainly GIS and remote sensing analysis as tools and the input data is similar. However, criteria were chosen differently depending on the aim of the publications and what input data that were possible to find.

The four papers chosen will be presented in the following sections starting with the newest published in 2017 and ending with the oldest published in 2005. The study areas lie in Braunschweig in Germany, Thessaloniki in Greece, Lisbon in Portugal and Lund in Sweden.

3.1. Summary of research paper: Braunschweig

A GIS-based mapping methodology of urban green roof ecosystem services applied to a central European city is a paper published in the journal *Urban forestry & urban greening* in 2017. The authors are three researchers based in Germany. The aim of the study is to estimate the spatial variation of green roof urban ecosystem services across an urban area in Braunschweig. In the introduction it is explained that there are four categories of ecosystem services, e.g. provisioning (food), regulation (climate), supporting (habitat) and cultural (recreation) that are increasingly used in scientific studies. The researchers argue the potential benefit from green roofs are higher in certain areas of a city where the risk of air pollution or heat stress is greater. The researchers suggest the method may be used for urban planners to define priority areas for promotion or subvention (Grunwald et al. 2017).

The study area chosen is located in Braunschweig, a city in northern Germany. The study area is described with some background facts considering population, city area and building plan area.

The tool used is GIS (ArcMap version 10, Software ArcGIS, ESRI) and the available geodata comes from the Environmental Agency of the City Administration of Braunschweig:

- A digital elevation model from 2003: Airborne laser scanning with a 2 m resolution and a height accuracy of 0.15 m including buildings and vegetation as point vector data.
- A land use polygon vector map from 2010.
- A building ground plan as vector data from 2010.
- A traffic count map as line vector data from 2012: The annual average daily traffic intensity (AAT) of the urban road network as a predication for 2015.
- A climate function map as polygon vector data from 2012.

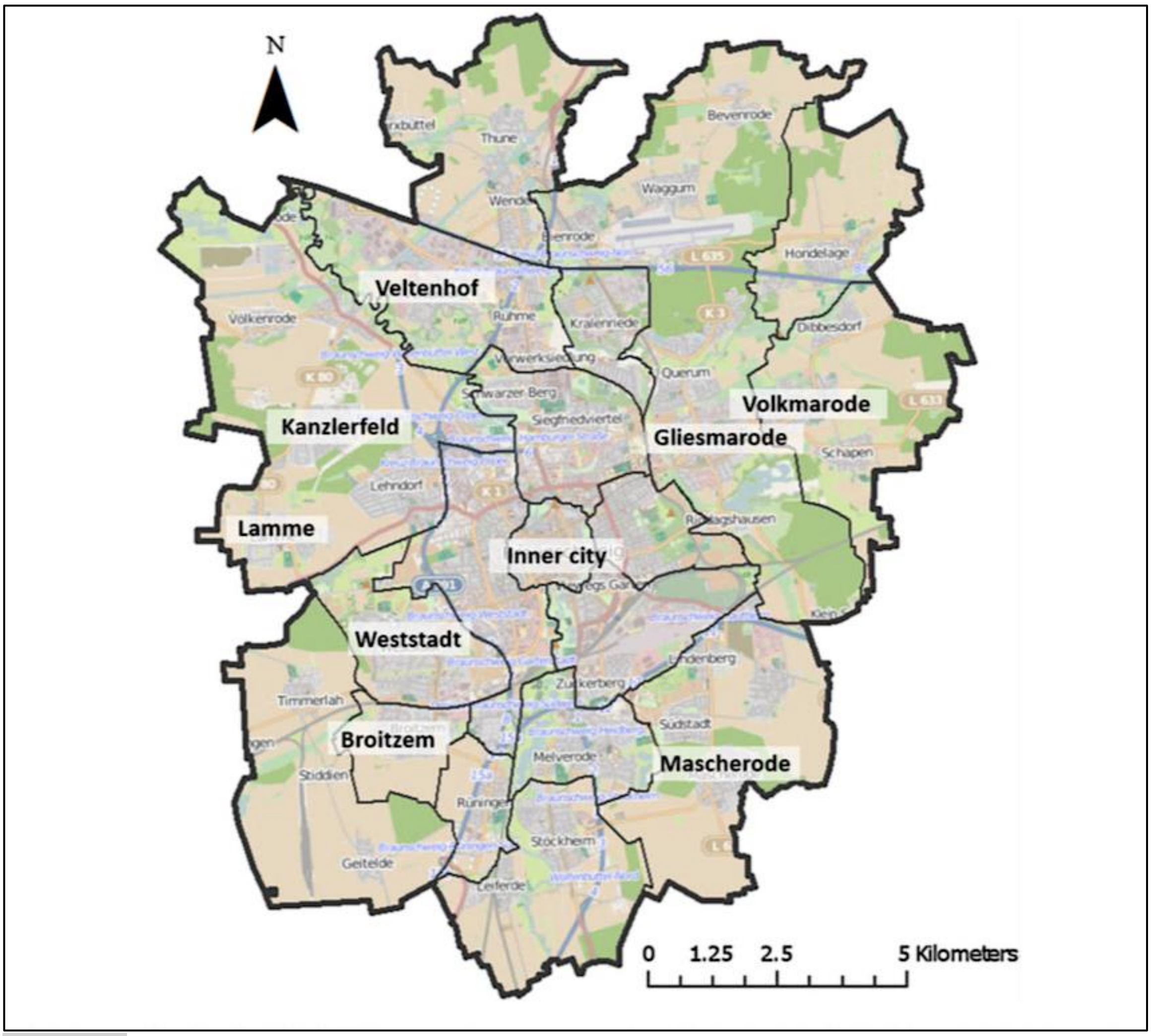

Figure 1: *The map represents Braunschweig with city districts (black lines). Map source: Stadt Braunschweig -Open GeoData, 2016, Lizenz: dl-de/by-2-0, modified. (Grunwald et al. 2017).*

Roof slope is modelled using ArcEsri's 3D analyst tool and the slopes are allocated to categories A (<1°), B (1° to <5°) and C (≥5°). However, only buildings in categories A and B are allowed in order to avoid tiled roofs. Thereby all buildings in category C are set to "not appropriate".

Roof obstructions like chimneys, antennas, staircases and elevator shafts, make a roof less suitable for green roofing, Buildings that have ≥ 75 % of their roof area in slope categories A or B are set to "appropriate". Buildings that have <75 % of their roof area in categories A or B are set to "limited appropriate".

The new housing areas in the city, that developed during the 7-year difference of publication of the elevation model and the building ground plan (see the geodata listed above), are allocated to "not appropriate" to prevent misclassification.

In summary, no tiled roofs are included in the model and a roof slope between 0° and 5° is chosen. Additionally, a minimum roof area of 10 m^2 is selected. The tiled roofs are not included since "specific constructional measures would be required".

Green roofs are ranked high benefit (1 point), moderate benefit (2 points) or low benefit (3 points) within the four urban ecosystem services categories, e.g. thermal urban climate (regulative), air quality (regulative), stormwater retention (regulative) and biodiversity (supporting).

The term “priority green roofs” includes only the appropriate roofs with the highest benefit in the ranking system, e.g. with the lowest ranking number. These priority roofs will give the highest effect in terms of ecosystem services.

A quantity of 14128 rooftops, or 5.7 km^2, is found appropriate or limited appropriate for greening which corresponds to 14 % of all buildings in Braunschweig. A number of 8595 of these rooftops, or 2.6 km^2, is considered appropriate for greening which corresponds to 8.6 % of all buildings in Braunschweig. Out of the 8595 rooftops, 0.9 % are ranked as “high benefit”, 3.5 % “moderate benefit” and 4.2 % as “low benefit”.

However, it is seen that a large part of the area of all appropriate and limited appropriate roofs are still partly limited by roof obstructions. This lowers the previous calculated area to 3 km^2, or 1.5 m^2 for the appropriate category and 1.5 m^2 for the limited appropriate category.

It appears like the inner-city of Braunschweig has a higher potential for greening than the surrounding suburbs, due do more densely built areas.

The researchers point out that load-bearing capacity properties of roofs could not be considered due to lack of data. Furthermore, roof obstructions should be better analysed and extracted from the beginning (Grunwald et. al. 2017).

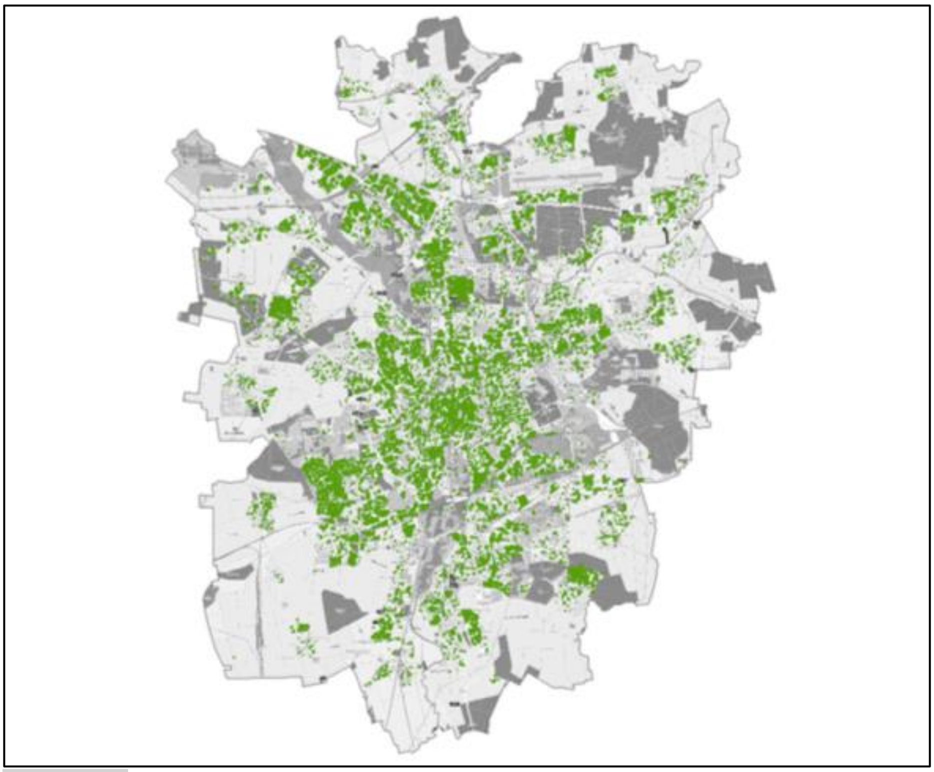

Figure 2: *The green polygons represent the appropriate and limited appropriate roofs for greening (14138 buildings with a total rooftop area of 5.7 km^2) (Grunwald et a. 2017).*

3.2. Summary of research paper: Thessaloniki

Towards a green sustainable strategy for Mediterranean cities: Assessing the benefits of large-scale green roof implementation in Thessaloniki, Northern Greece, using environmental modelling, GIS and very high spatial resolution remote sensing data is a paper published in Renewable & Sustainable Energy reviews in 2016. The authors are five researchers based in Greece. The aim of the study is to assess the green roof potential and its possible benefits in Thessaloniki. The rapid urbanisation of the Mediterranean area after the 1950's, has led to complex environmental problems. In the introduction, one can read about the way of softening the negative impacts of impermeable surfaces by converting them into multifunctional land cover that consider both human needs and ecological standards. An example is the unused roof space (Karteris et al. 2016).

The chosen study area is the second largest city of Greece named Thessaloniki. The study area is described with some background facts considering the high population density, type of buildings, the lack of green urban spaces and the historic centre destruction due to a fire outbreak in 1917.

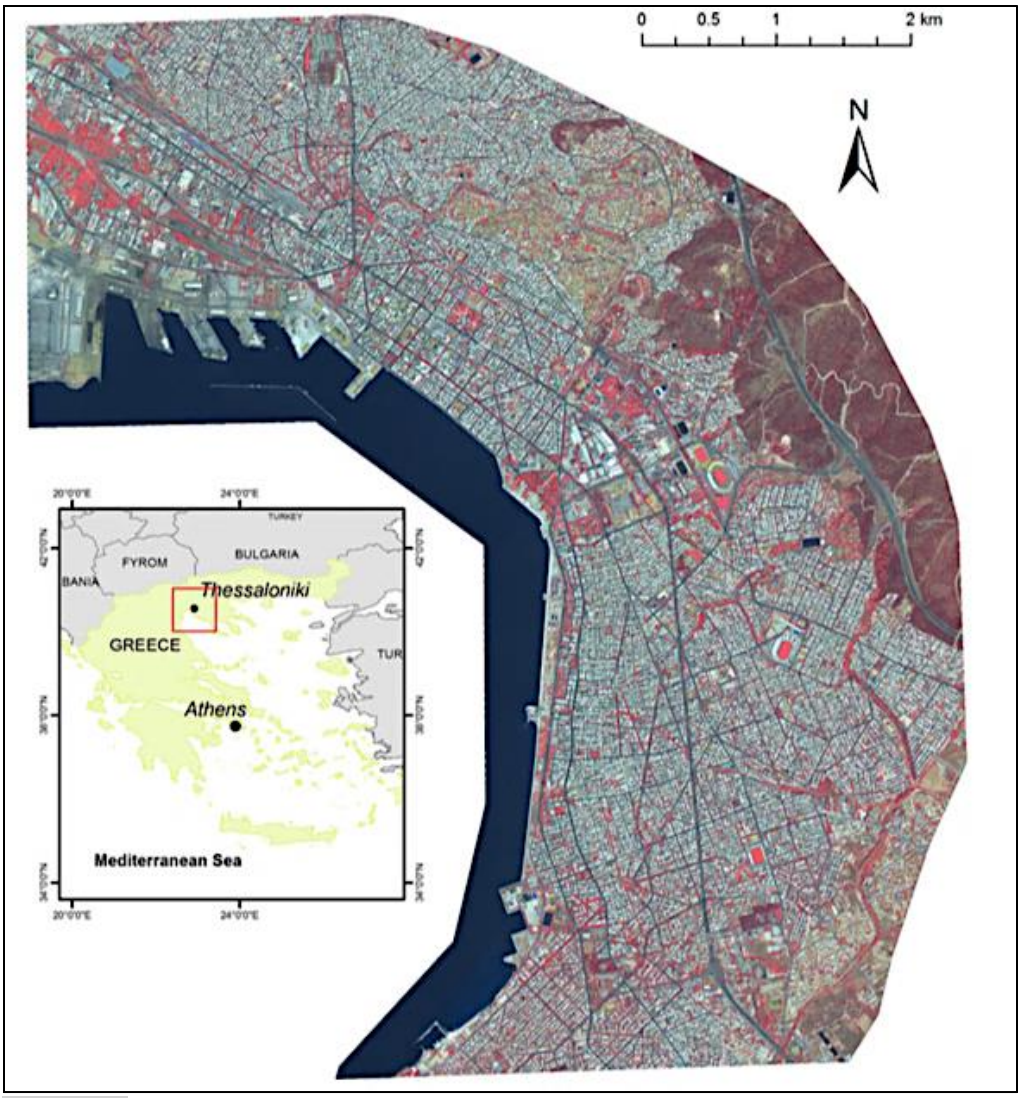

Figure 3: *The study area in Thessaloniki (Karteris et al. 2016).*

Tools used are GIS and GEOBIA image analysis. Input data is obtained from the technical authority of the municipality and the Hellenic Statistical authority:

- Orthoimages collected in 2007 using Leica ADS40 Airborne digital sensor (push broom camera). The photos were pre-processed.
- A digital surface model (DSM)s with 80cm spatial resolution using expert defined fuzzy rules. Pre-processed.
- Vector layers containing spatial data regarding building's footprints.
- Additional information about land uses, building elevation, construction systems and dates as well as socioeconomic -and population data.

Due to the risk of earthquakes in the area, a primary criterion is the maximum allowable load-bearing capacity. Because of a national antiseismic regulation implemented in 1980, studied buildings in the city are divided into "before 1980" and "after 1980".

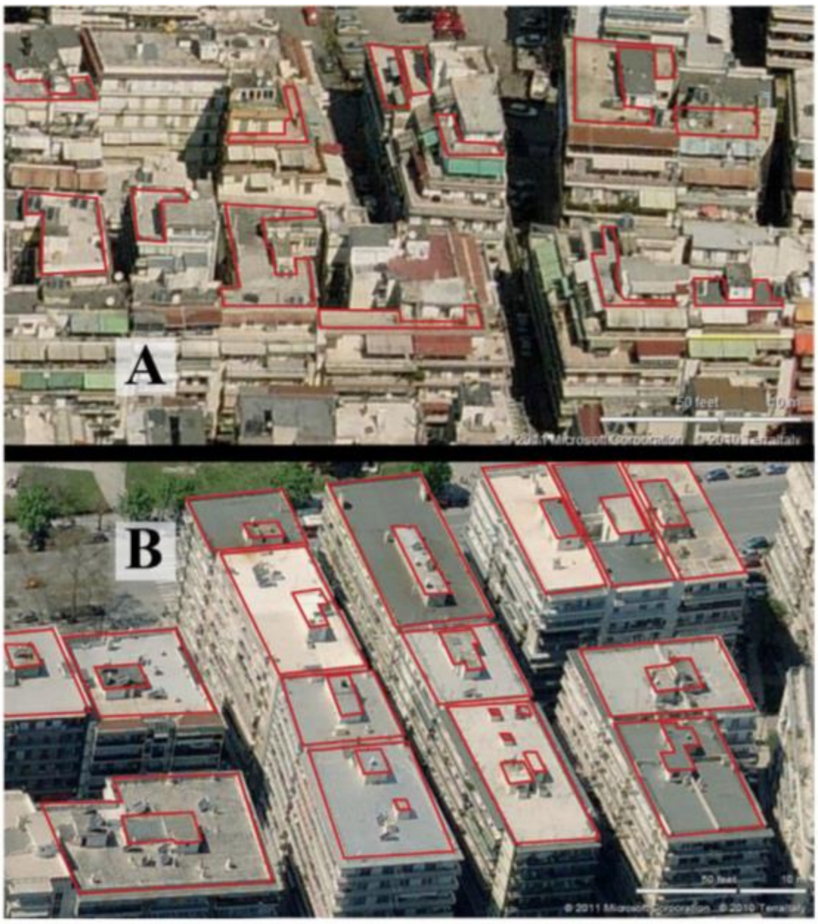

Figure 4: *A typical view of extracting roof artefacts with a GIS tool. The unavailable (occupied) areas of roof features are subtracted from the gross roof areas. Example A -the regulated perimeter safety zones and the penthouse terraces. Example B -the stairwells and elevator shafts (Karteris et al. 2016).*

The three main scenarios are:

- Semi-intensive roofs for buildings and residential houses constructed after 1980
- Semi-intensive roofs for bigger public buildings
- Extensive roofs for buildings and residential houses constructed before 1980

Furthermore, only flat rooftops are considered, which means sloped roofs are extracted with help from the remote sensed data. As expected, most of the buildings in Thessaloniki have flat roofs.

Staircases, elevator shafts, perimeter parapets, penthouse terraces and similar are extracted from the total available roof area. However, air conditioning units and solar thermal systems are neglected since these were seen as movable objects. This is done with a Geographic-Object based image analysis (GEOBIA) approach.

Image segmentation in the program eCognition Trimble (version 8.7) is used in order to identify tiled roofs that are to be extracted from the total available roof area.

One of the table outputs (see figure 5) show the mean percentage available roof area for the implementation of green roofs per building block and city district. The best areas for green roof implementation are the newly built districts with a mean percentage available roof area of 69% to 81%. The city centre and the old town districts are both less suitable because of penthouse terraces and sloped roofs. There the mean percentual range is between 36% and 56%. Furthermore, the green roof potential can reach 2,29 km^2 which represents 16,70% of the gross built areas of the city.

Mean percentage available roof area for the implementation of green roofs per building block and city district.

Mean roof exploitation per building block [%]	Building block percentage [%]				
	1st City District (City Centre)	2nd City District (Ksyrokrini)	3rd City District (Ano Poli)	4th City District (Toumpa)	5th City District (Faliro, Charilaou, Ntepo)
1–36	5.46	0.50	41.01	0.50	0.63
36–56	41.30	8.00	39.57	3.81	13.15
56–69	34.47	21.00	11.51	13.60	34.12
69–81	13.65	45.50	5.04	41.29	42.10
81–100	5.12	25.00	2.88	40.80	10.02

Figure 5: *Results from the Thessaloniki research paper (Karteris et al. 2016).*

The possibility to build semi-intensive roofs is most suitable in district Toumpa and district Faliro, Charilaou and Ntepo where most of the buildings are dated from 1980 and forward. Moreover, since the roof availability is the highest in district 4, and since the lack of green public spaces are limited, the amount of green area can be raised 7 times with the implementation of green roofs in this district.

The researchers stress the need for legalisation frameworks as well as economic inducements -and funding programmes for improvements to happen.

The researchers further suggest an investigation regarding biodiversity, social impact, recreation, in situ measurements and field experiments to make the method more accurate (Karteris et al. 2016).

3.3. Summary of research paper: Lisbon

Quantifying the City's green area potential gain using remote sensing data is a paper published in Sustainability in 2016. The authors are three researchers based in Portugal. The aim of the paper is to create and investigate a method that can function as a mapping tool for decision -and policy makers during urban planning, to target suitable buildings for green roof establishment. The introduction of the paper includes information about the lack of vegetation in cities and that green roof technology can be one of the necessary solutions. Examples are given of governments of various cities like Berlin and Munich in Germany, Philadelphia in USA and Singapore. These are cities that use financial initiatives, reduced taxes, ecological compensation or land-use plan integration to promote more green roofs. Additionally, some municipalities decide that all new buildings with roofs of a certain area or slope must be vegetated, e.g. Copenhagen in Denmark and Linz in Austria (Santos et al. 2016).

The study area chosen is the capital of Portugal, Lisbon. The study area is described with some background facts considering population, climate, average sunshine hours per day, what type of buildings that exist and current vegetation density, e.g. square meter vegetation per inhabitant. According to the municipality of Lisbon, only 12 green roofs exist in 2013 with an area of 52,085 m_2.

Tools and input data are chosen and collected in order to estimate the potential vegetation cover at rooftop level. The chosen tool is ArcGIS 10 (ESRI) software (Redlands, CA, USA) and the raw data that is used for the 3D analysis is listed below:

* Building's footprints: Retrieved from a 1:2000 Lisbon Municipal map from 1998 but updated in 2006.
* A DSM of the city: Altimetric set (to decide elevation) consist of 3D information obtained from a Light Detection and Ranging-LIDAR flight that covered Lisbon in 2006. A surface image was produced, based on the 2nd return with 1 m resolution, which represents the DSM of the city.
* A WorldView-2 image (WV-2) from 29 June 2010 covering the city of Lisbon: An off-Nadir angle of 7,1° available in Ortho Ready format. The image was pre-processed (image pan sharpening and image orthorectification in order to reduce geometric distortions introduced by the terrain).

The chosen criteria are roof area, roof slope and shadowing effects. Shadowing effects are chosen in order to select the right types of plants. Area and slope are modelled using the DSM and the location from the building's footprints. Other criteria like roof load bearing capacity, waterproofing membrane type and drainage conditions are mentioned but not to be tested in this research paper.

The WV-2 image and building's footprints are used to classify the roof's covering material. The ones with red tiles are not used because of the initially high investment in tile removing to be able to build a green roof. An extension to ArcGIS 10 (ESRI), called Feature Analyst 5 (FA), is selected as classifier.

The available daily sunlight is obtained with ArcGIS 10 (ESRI)'s solar radiation analysis tool and the Angström-Prescott formula. As input, the local annual average beam and diffuse irradiation are needed, and the output becomes a map with the incident global solar radiation at each pixel.

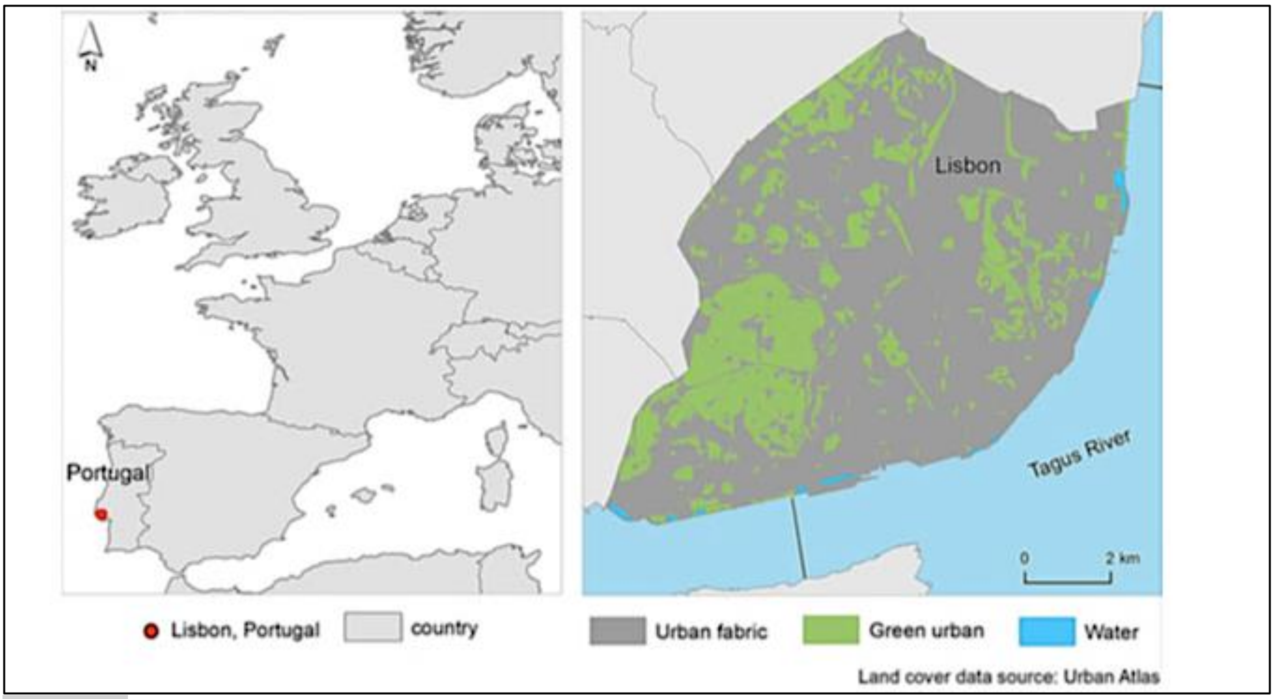

Figure 6: *The study area in Lisbon (Santos et al. 2016).*

Two slope scenarios and three sunlight scenarios are tested and combined:

- Flat rooftops less or equal to 11°.
- Pitched rooftops more than 11° and less or equal to 20°.
- Sunny roofs = 3 to 4 h per day as a requirement for plant growth.
- Shaded roofs = for plants that can tolerate less than 3 h of sunlight per day.
- Sunny to shaded roofs = for plants that can tolerate ranges between maximum sunlight to minimum sunlight

Additionally, only rooftops with an area of a 100 m^2 or more are considered and a neglection of artefacts like roof overhangs, chimneys, dormers and antennas are made. Neglection makes it possible to avoid an increased data cost and volume which would lead to the need for more complex processing tools.

Figure 7: *A picture of red-tiled roof classification done with a GIS tool (Santos et al. 2016).*

The output data consists of a map with all roofs without tiles, digital data for area and slope as well as a map with the incident global solar radiation at each pixel. This makes it possible to calculate the number of roofs in Lisbon suitable for green roofs.

The number of potential green roofs that may be built in the most conservative scenario (no red tiles, available area equal or larger than 100 m^2, slope less or equal to 11° and sunny-shaded roofs) is 4545 with an area of 2,18 km^2. This is an increase in the city's green area of 8,5%.

Figure 8: *The dark green colour represents the potential green roof cover that can be built considering the flat and pitched green roof and shaded to sunny scenario (Santos et al. 2016).*

If all pitched and flat green roofs would be chosen, under sunny-shaded conditions, there would be an increase in the city's green area of 14,4%. This represent 14% of all the buildings in the city.

Conclusions are that there are more red tiled roofs in the historical city centre which lowers the green roof potential. Moreover, the researchers conclude that remote sensing imagery must be complemented with 3D geographical modelling in order to measure urban sustainability.

The researchers want to add a global sensitivity -and uncertainty analysis as well as adding parameters for climate change and biodiversity to increase the trustworthiness and accuracy of the method.

Rooftops, with an area lower than $100m^2$, can still be investigated for the purpose of introducing for example solar panels (Santos et al. 2016).

3.4. Summary of master's thesis: Lund

Green roofs on municipal buildings in Lund - modelling potential environmental benefits is a master thesis paper published in LUP student papers by Lund university in 2005. The author is a student at Lund university in Sweden at the department of physical geography and ecosystem analysis. The aim of the study is to theoretically apply green roofs to municipal buildings and simulate potential environmental effects. In order to do so, a pre-investigation was made with GIS and a digital camera in in order to model the roofs of the study area including roof properties such as slope (Levallius 2005).

The chosen study area is a part of Lund city where many buildings such as the University, the University hospital and several technical companies are situated.

Input data is:

- Field studies: 247 photos taken with a digital camera which makes it possible to find the roof slopes and roof cover materials. Slopes are categorised into 7 classes of five degrees intervals, between 0° and 30°.
- Orthophotos, with a resolution of 0,5 m from year 2004, are given by the city's technical administration.
- Extra orthophotos from year 2000 (only the eastern half of the area) is given by the department of physical geography and ecosystem analysis. Resolution 0,2 m.
- The technical administration also provides a datasheet of information on all buildings in Lund from 2004. The scale is 1:5000.

The slopes were categorised into 5 degrees intervals due to the properties of drainage materials and the possibility of in-site establishment on the green roof. Furthermore, the author though it would be a practical compromise between needed accuracy and measurement availability. It was sometimes too difficult to categorise a complex roof due to the time limit.

To be able to divide roofs into sections, ArcView 3.x and the freeware program fGIS[2] are used. Additional tools are Microsoft excel and MATLAB 7.0.

Chimneys, fans, loft chimneys and similar are neglected due to the time-consuming effort in extracting them. It is argued that these areas are small enough to not be considered in the model. However, this means the potential green roof area and water storage capacity are slightly overestimated.

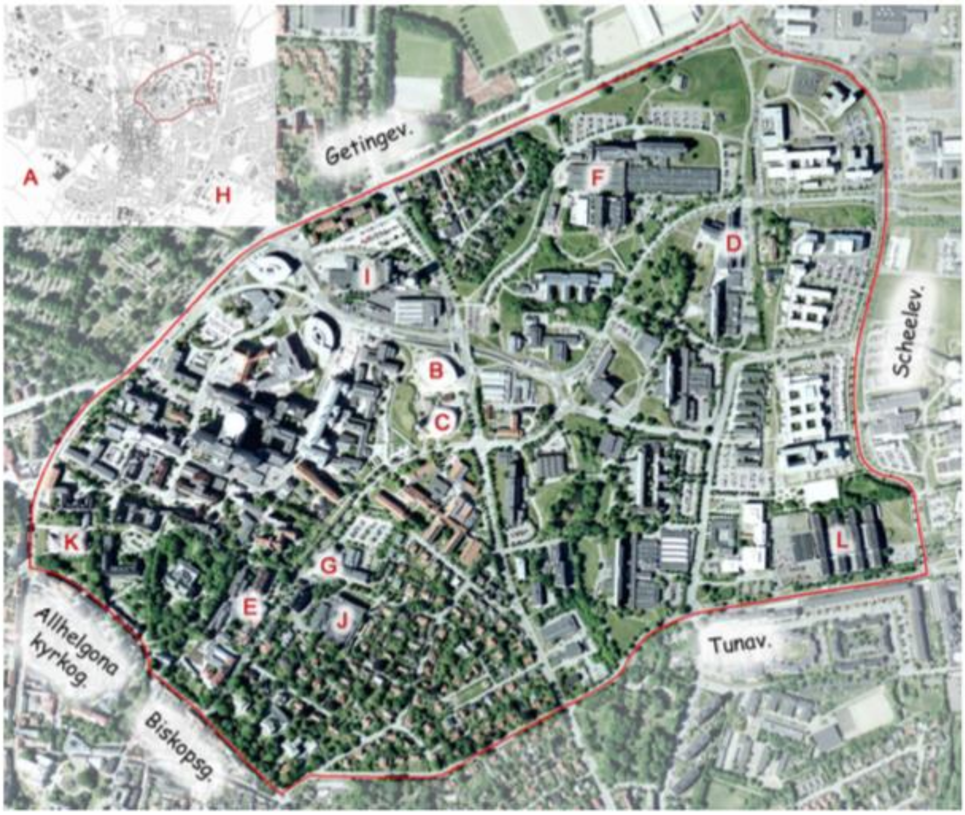

Figure 9: *An orthophoto from Lund technical administration and the red line encloses the study area (Levallius 2005).*

All in all, the model that is created contains the roof data together with climate data, solar position -and angle data, roof material properties, transmissivity, shortwave radiation, water level and evaporation, longwave radiation in and out, surface temperature, radiation and radiation balance. With all this data, many scenarios can be tested. However, in order to calculate only the number of suitable roofs for retrofitting, only a part of the model is needed. The rest is for performance estimations.

The roof area that may be greened corresponds to 85% of all roof area of municipal buildings, or almost 14% of the total study area (see figure 10). The general green space is estimated to increase from 42% to 55% if this would to be realised, roughly one third. Furthermore, a percentage of 67% of flat -or low sloped roofs are found (0° up to 5°).

It is shown that the investigated roof surfaces mostly consist of bituminous material which is a good material to construct green roofs on, according to the author. Of all suitable green roofs found, about 73% contained of this bituminous surface material. The second most common roof material is metal grey with 11,2% and thereafter comes tiled roofs. A part of the tiled roofs is considered suitable for becoming green roofs as long as they are not steeper than 25°, which is set as the limit in this study. The author writes that experiments have been made at the SGRI in Malmö which show that green roofs can be constructed directly on tiled roofs although this is not recommended.

Figure 10: *Areas suitable for green roofs are shown in green and unsuitable roofs are shown in red. Black buildings are non-municipal (Levallius 2005).*

The author describes a sensitivity analysis and the parameters that can be modified in the model for improvements. He also states that the model should be easy to use on other areas.

The author points out that even though there are many roofs in the study area of Lund that can be converted into green roofs, there should be a mix vegetation and not only sedum plants. This in order to increase biodiversity. Moreover, runoff water from the roofs can be considered for irrigation or cleaning (ibid.).

3.5. Summary of the literature study

The following two tables (1 and 2) are a summary of section 3.1 to 3.4 with the purpose to clarify and compare results.

Table 1: *A summary of the four papers chosen for the literature study in chapter three, section 3.1 to 3.4.*

Study area	**Braunschweig**	**Thessaloniki**	**Lisbon**	**Part of Lund**
Publication year	2017	2016	2016	2005
Tool(s)	GIS -ArcMap version 10, software ArcGIS, ESRI.	*GIS. *GEOBIA image analysis.	ArcGIS 10 (ESRI) software (Redlands, CA, USA).	*Field studies with digital camera. *Microsoft Excel. *GIS ArcView 3.x & fGIS2. *MATLAB 7.0.
Data input	*Digital elevation model. *Land use map. *Building ground plan. *Traffic count map. *Climate function map.	*Pre-processed orthoimages. *DSM *Building´s footprints.	*Building's footprints. *DSM * A pre-processed WV-2 image.	*Orthophotos *Slope classification from digital photos. *Datasheet about all buildings in Lund.
Data available from	Environmental agency of the city administration of Braunschweig.	*Technical authority of the municipality. *Hellenic Statistical authority.	*Lisbon Municipal map from 1998 and updated in 2006. *Municipal cartography.	*Lund's technical administration. *Department of physical geography & ecosystems analysis, Lund University.
Scenarios/categories	Green roofs were categorised into "appropriate", "limited appropriate" & "not appropriate".	Semi-intensive roofs for buildings constructed after 1980, extensive roofs for buildings constructed before 1980 plus public buildings.	Slope (flat & pitched) plus sunlight (sunny, shaded & sunny to shaded) plus area (>100m$_2$).	7 slope categories.
Green roof Potential	*14128 rooftops, or 5,7 km$_2$, in the "limited appropriate" and "appropriate" categories were found suitable for greening (14% of all buildings). Later reduced due to roof obstructions. *The denser inner city of Braunschweig has a higher potential.	*2,29 km$_2$, which corresponds to 16,7% of the gross built areas. *City centre and old town are less suitable for green roofing because of penthouse terraces and sloped roofs.	*4545 green roofs, or 2,18 km$_2$, can be built in the most conservative scenario. An increase in the city's green area of 8,5%. *Potential higher in northern part of Lisbon since the centre has more red tiled roofs.	*85% of all roof area of municipal buildings, or almost 14% of the total study area. General green space in Lund could potentially increase from 42% to 55%, roughly 1/3. *The true potential area is expected to be slightly lower since some areas of the roof are occupied by chimneys and ventilation pipes.

Table 2: *A summary of the criteria used in the four papers examined in the literature study of chapter three, section 3.1 to 3.4.*

Criterion/City	**Braunschweig**	**Thessaloniki**	**Lisbon**	**Lund**
Roof slope	Yes. Slopes less than 1° plus slopes between 1° and 5° set to “appropriate”. Slopes equal to or greater than 5° set to “not appropriate”.	Yes. Only flat.	Yes. Flat rooftops less than 11°. Pitched rooftops greater than 11° but equal to or less than 20°.	Yes. Seven categories from 0° to 30° with 25° as limit for green roofing.
Available roof area	*Yes. Minimum 10m2 required. * Buildings that have more or equal to 75% of their roof area with slopes less than 5°= “appropriate”. Roofs areas with slopes greater than 5°= “limited appropriate”. *Red tiles dismissed since most tiled roofs have a slope of more than 5°.	*Yes. Roof obstructions are extracted. (Air conditioning units and solar thermal systems are neglected - seen as movable objects.) *Red tiles extracted from the model from the beginning.	*Yes. Rooftop area greater than 100m2 considered. *Roof obstructions neglected (costly). *Red tiles extracted from the model from the beginning.	*Yes. No area restriction. *Roof obstructions neglected (time consuming). *Percentage of tiled roofs calculated. Considered for retrofitting if slope is less than 25°.
Weather conditions	No.	No.	Yes. Sunlight availability.	No.
Load-bearing capacity	No, due to lack of data.	Yes, partly. Roofs built after 1980 are considered to have a higher load-bearing capacity due to a law.	No but mentioned as good to include.	No. Mentioned but not used for the calculation of potential green roofs.
Other/extras	*Ecosystem services categories are only used to prioritize. *Points out that roof obstructions should be better analysed and extracted from the beginning.		Other criteria mentioned but not used: waterproofing membrane type and drainage conditions.	

3.6. Criteria explanations

To be able to construct green roofs one has to know whether or not it is suitable to do so and why. From this background, criteria can be chosen in order to create a green roof method. The following criteria were found in section 3.1 to 3.4 and are here explained with some background facts.

3.6.1. Roof slope

The joists of the building or the concrete deck, where the green roof structure will be built, should have a steep enough slope to ensure water runoff. An inclination of 2% to 3% is sufficient and can be built in afterwards if needed. It is possible to build on a steeper slope up to 45% degrees depending on the system provided for the vegetation, but the risk of erosion and shear forces causing drought need to be considered and solved for carefully for example by incorporating supporting modules (Grönatakhandboken 2017). Although a steeper roof makes it easier for people to actually see the vegetation, it may also limit access as well as the possibility for maintenance. These factors must therefore also be considered in the design stage (Green roof guide nd).

3.6.2. Load-bearing capacity

In order to build a green roof structure on top of the roof of an existing building, a control needs to be done to determine the load-bearing capacity. The choice of vegetation and substrate is then important in order to decide the total load-bearing capacity, which also depends on rain, wind, snow, slope, maintenance needs or recreation. As an example, a vegetation cover of 100 mm can weigh between 100-130 kg per square meter depending on whether it is dry or saturated with water (Grönatakhandboken 2017).

3.6.3. Waterproofing membrane layer

The waterproofing membrane layer is an important component. The layer needs to be in excellent condition since it is vital to avoid any leakage into the building. If the waterproofing layer is older than around five years and has not been tested, it should be replaced before the green roof will be introduced. A leak detection system can be provided during this process (Green roof technology 2019b). However, it is proven that the waterproofing layer and other properties of the underlying roof will be protected from wear and tear once the green roof is constructed on top as a cover which is an advantage (Greenroofs nd).

3.6.4. Area and roof obstructions

Another aspect to consider is the roof area of the building and how much space is available for a green roof. There may be disruptions like chimneys, air conditioning plant, water tanks, dormers, antennas, tiles etc. (Green roof guide nd).

3.6.5. Weather conditions

The conditions on top of a roof is often extreme and the plants must be able to endure a certain amount of wind, rain and sun exposure which depends on the location and point of compass. Especially green roofs with a thin substrate must tolerate drought (Dunnet & Kingsbury 2004).

Large window areas close to the green roof can cause reflections which can contribute to drought. A roof located permanently in the sun or in shadow is not recommended as it can contribute to plant death. Therefore, it is also important to look at what buildings and trees are surrounding the potential green roof areas since they affect weather conditions (Grönatakhandboken 2017).

4. Interview study

Introduction
In order to fully answer the research questions of this paper, information is required from people in Malmö with relevant knowledge on urban planning and green roof technology as well as GIS and remote sensing analysis.

The interview questions sent to the respondents can be found in appendix. These questions, and the answers to them, were all in Swedish but translated into English. Many of the respondents received follow-up questions with the purpose to clarify certain answers for a better understanding. All correspondence was made through email and in written form.

Altogether, 13 respondents are included in this interview study and they are presented in table 3 below on page 34. The acronyms used for the respondents can be found in column four. The respondents represent the following organisations: Byggros AB, Swedish University of Agricultural Sciences (SLU), MKB fastighets AB, SGRI, Sweco, Sweden Water Research, Skåne region, the City Planning Office of Malmö, Lund University, Svenska Naturtak and the Environmental Administration of Malmö City.

What hinders a faster expansion of green roofs?
All of the respondents appear to have a positive approach to green roof technology and want to see more green roofs in Malmö. However, they also state what they believe hinders a faster expansion, for example building permits (MN), finances (MN, HA, MO, UP, RW) lack of knowledge (MN, HA, UP, HJ, MO), maintenance problems (HA, MO, MB), load-bearing capacity of the underlaying roof (RW) and laws that are not up to date (MO).

MO writes "when it comes to the construction of new buildings, it is rare to find that green roofs are not included in the initial building plan. Therefore, the already existing city will end up a bit behind in development. There is a lack of knowledge about how one should go about when building green roofs on existing buildings, for example if an old roof is to be replaced with a new one with vegetation.".

JM believes "the knowledge about different solutions and substrates is so extensive today that no more research is needed. Instead, dissemination of already accumulated knowledge within the industry is what needs to be prioritized.".

The respondents were asked to explain how green roofs can contribute positively or cause problems in urban planning.
Uptake of stormwater (LR, HA, RW, MO, MB), reduction of urban heat islands (LR, RW, MO, MB) and extended lifespan of underlaying roof layers (LR) are a few positive outcomes mentioned. Additionally, biodiversity (LR, MN, RW, MO, MB), cost reduction in connection to rainfall and human health in the long run (MN) as well as improved air quality (MB) are other positive contributions.

Green roofs may create problems when it comes to lack of knowledge during operation and maintenance (LR, RW, UP), a possible increased leakage of nutrients to the storm water system (HA) and a too big focus on only sedum roofs instead of roofs with perennials and shrubs (RW). LR writes "a green roof needs to be maintained and this needs to be planned for

Table 3: *Presentation of the 13 respondents participating in the interview study. The table show the name of the respondent, his or her profession and the green roof experience of the respondent according to him -or herself. The last column represents the acronyms of the respondents with respect to their names.*

Name of respondent	**Profession**	**Green roof experience (according to him -or herself)**	**Acronym**
Lars Risberg	Technical Consultant, Byggros AB (a company selling green roofs and solutions systems).	Educated gardener. Years of experience with the construction and renovation of green roofs.	LR
Åsa Ode Sang	Researcher and teacher within digital landscape analysis, Swedish University of Agricultural Sciences.	Scientific studies on how green roofs can be used in green infrastructure strategies.	ÅOS
Mats Nilsson	Executive director, MKB fastighets AB (a housing company owned by the City of Malmö). Member of the SGRI board.	Spread knowledge about green roofs and develop Malmö.	MN
Henrik Aspgren	CEO of Sweden Water Research (the joint research -and development company of NSVA, Sydvatten and VA SYD). Member of the SGRI board.	Theoretical knowledge in connection to city planning and water services.	HA
Barzan Abdi	3D-producer, City Planning office of Malmö.	-	BA
Karin Larsson	Lecturer at the centre of geographical information systems, Lund University.	-	KL
Robert Weidacher	GIS engineer, City Planning office of Malmö.	Nothing that is directly work related. Interest in green roof technology and sustainability in general.	RW
Maria Olsbäck	Environmental building strategist, City Planning office of Malmö.	In relation to building permits and the detailed development plan of Malmö.	MO
Jonathan Malmberg	Head of project and development, SGRI.	Work at SGRI to spread knowledge about green roofs	JM
Ida Aronsson	PBL expert, Sweco (an engineering consultancy company).	-	IA
Mikael Billhagen	Cultivator, producer and constructor of green roofs, Svenska naturtak AB (a company selling green roofs and solutions systems).	-	MB
Ulrika Poppius	Project secretary, environmental administration, City Planning office of Malmö.	Strategical work. Integration of "green" solutions in the city of Malmö.	UP
Helena Johansson	Intendent/administrator, SGRI.	Educated gardener. Planted the green roof of Emporia shopping mall in Malmö. Guide, lecturer and gardener at SGRI since 2018.	HJ

right from the start. Just like we plan for maintenance of park environments. Otherwise the property owner will waste money when the original planted vegetation is destroyed". MO further adds "in the existing city, green roofs may conflict with conservation values from a cultural-historical perspective, but such a conflict is extremely rare".

In many European countries, for example Germany, laws and subsidies exist which make it easier for cities to invest in building more green roofs. The respondents were asked to describe what changes that are plausible in Sweden and in Malmö.
HA discusses that "there are currently no clear instruments in Sweden to encourage dampening of run-off from land and buildings, despite the fact that many government investigations have sought to propose such. One of the reasons why it has been difficult to implement is that the changes are needed at a state level so that this can have an impact at the municipal level." UP agrees with adding laws and subsidies to facilitate green infrastructure at a national level, since she believes many developers are troubled by the different guidelines in different municipalities. However, HJ adds that she does not believe such laws and subsidies will be introduced in the near future because of the lack of knowledge among politicians and officials in the state and local government.

Regarding green infrastructure ÅOS adds "green roof investment is a relatively expensive green infrastructure investment for limited ecosystem delivery but can pay off when other green infrastructure solutions are difficult to choose instead".

Requirements in The Swedish Planning and Building Act and the detailed development plans affect if green roofs can be built.
On January 1, 2015, a law was introduced against so called "municipal special requirements". The purpose of this was to clarify that individual municipalities cannot impose their own technical property requirements on buildings that go beyond PBL. However, the municipality can still impose special technical characteristics in cases where the municipality does not act as an authority, but instead, it acts in the role of the developer, tenant or property owner (JM). The City of Malmö has interpreted this change in law strictly and it has thus become more difficult to impose higher requirements on incorporating greenery and vegetation in connection with detailed plans and building permits (MO). However, planning architects, at the city planning office of Malmö, can put design regulations such as "green roofs" in the detailed development plan, and then the developer must follow this (RW). Such rules are not used very often because there are no national or municipal laws which require that green roofs should be built. After all, the politicians of Malmö set up the mission and the employees of Malmö municipality come up with a suggestion. Later, the detailed development plan will be discussed in the town council where the politicians decide whether or not the plan should be adopted. Many actors and different types of regulations are involved which makes the whole situation complex (RW). Additionally, regulations regarding detailed development plans only apply to new plans and not to old ones, which means that one would have to redo the old ones in order to add provisions for green roofs. This would be resource intensive (RW). JM further explains that it is possible to claim protection measures against flooding in the detailed development plan, and then couple this to green roofs. However, he has the feeling that there is a limited confidence in green roofs as a stormwater solution in Sweden compared to Germany.

JM writes an email to IA, a PBL expert at Sweco, and asks her to further explain municipal special requirements. IA, answers "the municipality can set up special requirements on technical properties of any building if special conditions on site require preventive measures, for example if there is a risk of flooding and a green roof is vital for the stormwater uptake. She further explains that it is not clear enough to write only “green roofs needed” in the detailed development plan. A preliminary investigation is needed to show that a green roof will contribute to the detention of stormwater runoff and the thickness of the plant bed must be specified. Then, this must also be written down in the part of the detailed development plan where goals and purposes are stated. Unfortunately, it is in general difficult to do follow ups to notice if decisions regarding green roofs in the detailed development plans have been realized (IA).

The respondents received a question about the need for a method, which includes maps and other data in both 2D and 3D, to calculate the green roof potential of Malmö. Such a method could possibly serve as a planning tool for identifying suitable roofs to investigate further.

Many of the respondents seem to think that such planning tool would be interesting to know more about and have heard about the development. Especially since we live in in a technical world where all information becomes more digital (LR). However, some mention the challenges. It is important to create tools so that the effects of introducing green roofs can be assessed socio-economically in order to enable long-term urban planning that dampens runoff (MN). Furthermore, as there are currently no legal or political requirements in place concerning green roofs, such a method may not yet be needed (KL). Internationally there are already existing methods and the need for them may be higher in more densely populated areas with reoccurring flood events (JM). UP mentions the so called “sun map” that can be found on the website of Malmö City and says it may be good to create something similar for green roofs. The sun map can give inhabitants and stakeholders information about the sun energy potential for different buildings in Malmö. However, she also writes about the problems in finding the load-bearing capacity of all roofs since this is not visible with remote sensing analysis.

Are necessary maps and databases available?

BA confirms that a good map, in 2D/2.5D, is available for Malmö as well as 3D data of about 60% of all the roofs of the city. Additionally, there is air-scanned laser data (20pts/m_2) from the streets of the whole city, which can generate a good DSM. KL believes that Malmö municipality can provide sufficient data such as vector map data, altitude models and aerial images. The use of GIS, remote analysis, city models and BIM are already an important part of urban planning and these tools will become more and more integrated as technology and community development is moving rapidly (KL).

It can be difficult to find information on physical properties for each building in Malmö.

RW suggests the age and the slope of the roof buildings as two factors to integrate in a potential green roof model in order to find suitable roofs. However, information about for example slope and load-bearing capacity is not listed in any technical construction record of the planning department of Malmö City. This since the primary mission of this department is to make detailed development plans. RW stresses the importance of the load-bearing capacity since a green roof holds more water which makes it heavier. Many existing houses are built to withstand normal rain and snow but not much more than that. At the time the houses were established, the discussion about modern green roofs did not exist. RW believes it is possible to contact every individual property owner in order to collect detailed information about slope, age of the building and load-bearing capacity.

ÅOS has, together with colleges, tried to create a green roof method. Unfortunately, it failed because it was too difficult to find the load-bearing capacity or the slope of all roofs, which is crucial for the potential. She explains that a research assistant did overall analyses and that the project was implemented with ArcGIS as a modelling tool to be able to look at different scenarios.

Is there a future for green roofs in Malmö?

The answers to this question sound optimistic. Green roofs are not a trend but a way of building sustainably (LR). Green roofs will become a standard (MN) and green roofs are needed as a part in creating vegetated areas for recreation and wildlife preservation (RW). Green roofs are becoming more and more normalized (UP). HJ sees more and more property owners, such as MKB and Hauschild+Siegel, choosing to invest in green roofs. This may increase the total number of green roofs in Malmö rather than laws and policies.

The green roof market in Malmö…

According to LR from Byggros AB, the demand for green roofs in Malmö is high. Large areas of green roofs on new buildings are often demanded by builders, developers and municipalities whereas private costumers often ask for smaller areas like their own carport or porch at the summer cottage. Also upgrades, or rather green roof maintenance materials, occur but in a smaller scale. MB from Svenska Naturtak AB answers that they mostly sell green roofs for apartment buildings, schools and sustainable houses and that 90% to 95% are for new constructions. He adds that there are not so many private buyers in Malmö.

Does the municipality of Malmö plan to build more green roofs?

UP says that that the municipality of Malmö has plans to build more green roofs on a strategic level but that she does not know much about the detailed level. The municipality should of course set a good example, but an even larger part of the urban construction is private real estate and they also need to build green infrastructure. She does not know how many green roofs currently exist in Malmö and has not found a good way to calculate it, neither does HJ. MN confirms that MKB will continue to establish green roofs in Malmö where there is a potential. Exactly what and where is decided within the individual projects and may depend, among other things, on cost and technical conditions.

5. Analysis

In order to answer the aim and research questions, an investigation has been made including the theory part in chapter two, a literature study in chapter three and an interview study in chapter four.

What criteria can be used, and should be used, in order to model the green roof potential of a city?

To be able to build green roofs on already existing buildings, one has to know whether or not it is suitable to do so and why. From this background, criteria can be chosen for the method.

Roof slope, available roof area, load-bearing capacity, waterproofing membrane and weather conditions are described in section 3.6 and can be seen the criteria. These criteria are used, discussed or mentioned in sections 3.1 to 3.4.

As can be seen in table 2, roof slope and available roof area are used as criteria in all of the four studies described in section 3.1 to 3.4. This is because the roof slope must be steep enough to ensure water runoff but not so steep that it causes erosion and drought of the plant bed. Although a steeper slope makes the green roof more visible, it may limit maintenance access (Green roof guide nd). Furthermore, it is because the roof area availability affects the size of the green roof to be built on top. One has to check if there are any disruptions like chimneys, antennas or tiles and decide how to solve it (Green roof guide nd). Additionally, JM points out that the roof must be safe for people to stay on, even if it is only for maintenance purposes. This means that both fire regulations and anchoring systems need to be considered, which can affect the resulting size of the green roof.

All of the four papers consider slope and area, but the Thessaloniki and Lund papers do not have any restrictions when it comes to minimum area. The Thessaloniki study only chooses flat roofs in their model.

The roof slope in the Braunschweig study is categorised into slopes less than 1°, slopes between 1° and 5° and slopes equal or greater than 5°. However, only the first two categories are allowed in order to avoid tiled roofs and these categories are called “appropriate”. Furthermore, buildings that have more or equal to 75% of their roof area with slopes less than 5° are set to “appropriate” while roofs areas with slopes greater than 5° are set to “limited appropriate”. The minimum roof area of 10 m^2 is selected.

In the Lisbon study, only rooftops with an area of a 100 m^2 or more are considered. Both flat rooftops (less or equal to 11°) and pitched rooftops (more than 11° and less or equal to 20°) are tested.

In the Lund study, slopes are categorised into 7 classes of five-degree intervals between 0° and 30°. The limit for converting a roof into a green roof is set to 25° in this study.

Although a minimum area is not chosen in the Thessaloniki study, roof obstructions and tiled roofs are extracted from the total available area of flat roofs. However, air conditioning units and solar thermal systems are neglected since these were seen as movable objects.

Chimneys, fans, loft chimneys and similar are neglected in the Lund study due to the time-consuming effort in extracting them. This is also done in the Lisbon study to avoid an increased data cost and volume of data.

Tiled roofs are mentioned in all four papers. The researchers of the Lisbon study write that they want to avoid the red tiled roofs in their method since the initially investment necessary to remove riles is too high. The Braunschweig and Thessaloniki study also state that tiled roofs are unsuitable for retrofitting. The Lund study includes tiled roofs in the model since it is possible to build green roofs on top of them although it is not recommended.

The load-bearing capacity of both the underlaying roof and the green roof need to be considered to avoid collapse. A vegetation cover will weigh much more if it is thick and saturated with water (Grönatakhandboken 2017). However, the greater the depth of the growing media the greater the water holding capacity (Grant 2012).

The maximum allowable load-bearing capacity is a priority criterion in the Thessaloniki study due to the risk of earthquakes. Studied buildings are therefore divided into before and after 1980 when an antiseismic regulation was implemented and changed building rules. The researcher did not include load-bearing capacity in the Braunschweig study due to lack of data. In the Lisbon and Lund studies it is mentioned as something that would be good to investigate.

The waterproofing membrane layer needs to be in excellent condition to avoid leakage. However, it will later be protected from wear and tear by the green roof which is positive (Green roof technology 2019b). JM stresses that there has to be good communication between all stakeholders since leakage from a green roof is more difficult to locate than on a conventional roof. The researchers of the Lisbon study mention other criteria they could have looked at, such as waterproofing membrane type and drainage conditions, but these were not tested.

The suitability is also dependent on weather conditions in the area and if wind, rain and sun allow plant growth (Grönatakhandboken 2017). The Lisbon study considers the available daily sunlight in the model and it is used in order to know which plants are suitable to grow on the roof.

The Braunschweig study uses ecosystem services as categories to further prioritize areas that may need more green roofs. This is however not used to calculate the number of green roofs that may be built.

What is the structure of the four green roof methods? What similarities and differences exist and what improvements can be made?

The three research papers and the master's thesis start by defining the study area and describe it with some background facts. However, while the three research papers use the whole urban city area of Braunschweig, Thessaloniki and Lisbon respectively, the master's thesis choses only a part of Lund City where there is a high concentration of municipal buildings.

The Braunschweig study uses GIS (ArcMap version 10, Software ArcGIS, ESRI) which is also the version used in the Lisbon study together with an extension called Feature Analyst 5 (FA). The GIS version used for Thessaloniki is not defined but GEOBIA image analysis is also used as well as eCognition Trimble (version 8.7). Considering the Lunds study, the tools used are ArcView 3.x and the freeware program fGIS2 as well as Microsoft Excel, MATLAB 7.0 and a digital camera.

The Braunschweig study takes input data from the Environmental Agency of the City Administration of Braunschweig while the Thessaloniki study uses data obtained from the Technical Authority of the Municipality and the Hellenic Statistical Authority. The Lisbon study takes data from the Lisbon Municipal as well as from remote sensed data with an unspecified distributor. The author of the Lund study uses digital photos in order to specify slopes and roof cover materials. Other data comes from Lund City Technical Administration as well as the Department of Physical Geography and Ecosystem analysis.

In all four papers, three to five input data types are used, and they vary depending on the aims of the papers. However, similarities can be seen. A digital surface model (DSM) is used both in the Lisbon study and in the Thessaloniki study. The DSM of Thessaloniki is used to decide elevation which is also the purpose of the digital elevation model of the Braunschweig study. These elevation models are created with the help from airborne scanning. Furthermore, information about the buildings and land use is collected from a building ground plan and a land use map in the Braunschweig study while the Lund and Thessaloniki studies use given datasheets with such information. Moreover, both the Lisbon and Thessaloniki study use information about the building's footprint. The Thessaloniki, Lisbon and Lund studies use orthoimages of different resolution and collected with aerial or satellite sensors.

The Braunschweig study uses additional data like the traffic count map and the climate function map in order to further categorise the green roofs into the ecosystem services model they have created. This is not used to actually count how many green roofs that potentially can be built as this is done in a previous step.

The Braunschweig study from 2017 uses data from between 2003 and 2012, which gives the researchers a problem since new housing areas are developed and built between the years. They solve this by neglecting the new housing areas in their method and only account for the areas existing in 2003. The Thessaloniki study from 2016 uses orthoimages collected in 2007 but the dates of the rest of the material is not specified. The Lisbon study from 2016 uses data originally created in 1998 but updated 2006 while the newest data is from 2010. The Lund study made in 2005 uses data between the years 2000 and 2005.

Tiled roofs are mentioned in all four papers. The Braunschweig study excludes red tiled roofs by only choosing roof slopes of 5° and less in their method. The Thessaloniki study uses image segmentation in the program eCognition Trimble (version 8.7) to identify red tiled roofs to be removed from the total available area. The Lisbon study uses the WV-2 image and building's footprints in order to classify the roof's covering material. The Lund study includes tiled roofs in the model although presenting the percentage of them found together with slopes in a resulting table. Field studies with a digital camera were used in the Lund study to identify the material covering the roofs.

In the Braunschweig study, roof obstructions (chimneys, antennas, staircases and elevator shafts) are avoided by categorising the roofs depending on the slopes of the roof areas. In the end of the study the researchers realise that many of the resulting roofs are still limited by too many roof obstructions and the calculated green roof potential area has to be lowered. In the Thessaloniki study, roof obstructions (staircases, elevator shafts, perimeter parapets, penthouse terraces and similar) are extracted from the total available roof area to be used for greening with the help of the GEOBIA approach. Air conditioning units and solar thermal systems are however neglected and not extracted since they were seen as movable objects. In the Lisbon study, roof obstructions (overhangs, chimneys, dormers and antennas) are instead neglected to avoid an increased data cost and volume. The same goes for the Lund study where roof obstructions (chimneys, fans, loft chimneys and similar) are neglected due to the time-consuming effort in extracting them. These items are seen as small enough to be excluded from the model although this means the potential green roof area is slightly overestimated.

Roof slope is modelled using ArcEsri's 3D analyst tool in the Braunschweig study. Only flat roofs are considered in the Thessaloniki study and the sloped roofs are extracted with the help of the satellite orthoimagery data. The Lisbon study uses the DSM and the location from the building's footprints in order to model the slope. In the Lund study, the author takes digital photos of all the roofs and visually divides them into slope sections.

All of the four papers suggest improvements for further research. The Braunschweig study points out that roof obstructions should be more carefully extracted from the beginning. The researchers of the Thessaloniki study want to add biodiversity, social impact, recreation, in situ measurements and field experiments to improve the accuracy of their method. The researchers of the Lisbon study conclude that remote sensing imagery must be complemented with 3D geographical modelling in order to measure urban sustainability. They further want to add a global sensitivity -and uncertainty analysis as well as adding parameters for climate change and biodiversity. The author of the Lund study writes he made a sensitivity analysis and that the parameters can be modified in the model for improvements.

Would it be possible to create a green roof method for Malmö and is there an interest for such tool among relevant stakeholders? What does the future look like for green roofs in Malmö? What hinders a faster expansion?

Malmö is not mentioned in any of the four study papers in the literature study in chapter three. However, all four study areas are found in Europe just like Malmö, and Lund City is situated only around 20 kilometres from Malmö. The author of the study conducted in Lund concludes his method and model should be easy to use in other areas as well (Levallius 2005).

None of the respondents know about a method on how to calculate how many green roofs that potentially can be built on already existing buildings in Malmö. However, many of the respondents believe it sounds interesting and could be useful. UP mentions the so called "sun map" that can be found on the website of Malmö City and says it may be good to create something similar for green roofs.

Both BA and KL confirm that good maps of Malmö can be found and that air-scanned laser data, vector map data, altitude models and aerial images of the city exist. Climate data can be collected from the Swedish Meteorological and Hydrological Institute (SMHI 2019).

KL predicts that GIS, remote analysis and similar will be increasingly integrated in urban planning. Geospatial analysis and GIS packages are under a rapid change and are improving constantly (Smith, Goodchild, & Longley 2018). However, GIS is difficult for an average individual to use without proper training and the processing of data is in general time consuming and costly. This can lead too big generalisations of data (Grind GIS 2018).

UP mentions the problems in finding the load-bearing capacity of all roofs since this is not visible with remote sensing analysis. ÅOS confirms this by saying that she and her colleges tried to create a green roof potential model, but it failed due to problems in finding the load-bearing capacity or the slope of all roofs. RW says that a register of slopes and load-bearing capacities of roofs is not available in any technical construction record of the planning department of Malmö City. He believes it is possible to contact each individual property owner in order to collect detailed information about slope, age of the building and load-bearing capacity. Although, it may be time consuming and costly.

JM suggests that there may be a greater need to create a green roof method abroad in countries with more densely populated areas often susceptible to flood events. He knows such methods exist in other countries.

All of the respondents in the interview study think green roof technology is mainly a good thing and that the future for it looks bright. Some of the respondents writes that "green roofs are not a trend" (LR), "green roofs are becoming normalized" (UP) and "green roofs will become a standard" (MN). The green roof consultants LR and MB both confirm that there is a high demand for green roofs in Malmö, although the larger part is for new building constructions. MO writes that it is nowadays rare to not include green roofs in the initial building plan of new buildings. The existing city may therefore end up a bit behind in development. In addition, the municipality of Malmö has strategic plans to build more green roofs according to UP, although she is not so involved in the details. When and how this will be realised was not answered in this study. MN says that MKB will continue to build green roofs where there is a potential.

HJ believes the number of green roofs will be increased by investing property owners such as MKB and Hauschild+Siegel architecture rather than through laws. She writes that this is due to the lack of knowledge amongst politicians and officials in the state and local government.

Both KL and RW writes about the lack of legal or political requirements on national and municipal level concerning green roofs. Therefore, a green roof method may not yet be prioritised. HA and UP wish for new laws and subsidies concerning green roofs on state level so that it can have an impact at the municipal level.

On the website of the City of Malmö it is stated that vegetated and aquatic areas should be increased in Malmö, including green roofs and walls. This in order to ensure that the area of green space will not decrease as the population grows. However, in only a few months the year will be 2020 and the goal about the development of bluegreen qualities will not be reached (Malmö stad 2019d).

The regulations of the PBL and each detailed development plan affect the building of green roofs. A municipality can only ask for extra technical property requirements on their own buildings and not on buildings owned by other property owners within the borders of the municipality (Boverket 2018a). An extra technical property requirement could be a green roof. However, IA explains that extra technical property requirements can be specified for any building if a proper investigation has been made to provide proof of the needs. RW adds that many actors and different types of regulations are involved in the process of planning green infrastructure, which makes the whole situation very complex. He says that it is therefore not so common that extra requirements are set.

The lack of laws and information about load-bearing capacities may be two things hindering a faster expansion of green roofs in Malmö. Building permits, finances and a general lack of knowledge were other things mentioned by the respondents. Furthermore, a faster expansion can also be hindered by the lack of maintenance after the implementation of the green roof. The property owner will waste money if the green roof dies off (LR). JM believes no more new research needs to be done since the knowledge about different solutions is already so profound. The knowledge just has to be distributed well.

6. Discussion

Table 4 below is a summary and a possible answer to one of the research questions “would it be possible to create a green roof method for Malmö”. It can be compared with table 1 and 2 in chapter three.

Table 4: This table is a possible answer to one of the research questions “would it be possible to create a green roof method for Malmö”. Compare it with table 1 and 2.

Study area	Malmö or part of Malmö that is of extra interest.
Tool(s)	An up to date GIS program. Other suggestions: Digital camera and perhaps a drone for photographs. Microsoft Excel or MATLAB for calculations.
Data input	Maps in 2.D/2.5D and 3D data of about 60% of all the roofs available. Air-scanned laser data (20pts/m2) from the streets of the whole city, which can generate a DSM. Vector map data, altitude models and aerial images of the city. Additional data input about physical building properties, load-bearing capacities and water proofing membranes. Climate -and weather data.
Data available from	Climate -and weather data from example SMHI. Companies selling green roof solutions may be able to provide data or share experience. Malmö municipality. City of Malmö. Property owners.
Criteria	Roof slope and available roof area (tiled roofs and roof obstructions are extracted, and a minimum area is chosen). Load-bearing capacity of the underlaying roof and waterproofing membrane layer. Weather conditions.
Scenarios/categories	A first scenario could be to investigate roofs with a slope between 0° and 5°. Additionally, a minimum roof area of 50m2 or more to limit the search.
Green roof potential	To be calculated/estimated.
Comments	A team with experts needed (on GIS, remote sensing, green roofs and gardening, buildings and construction as well as urban planning). A sensitivity analysis should be made to discover uncertainties to improve.

In a green roof method for Malmö, the study area could be the entire Malmö or just a part of it. The Lund study only chose a part of Lund where there is a high concentration of municipal buildings. A green roof method may be used for pointing out potential areas in a city to prioritize. Subsidies can be given to areas where it would be possible to build many green roofs or to those areas that need green roofs the most. This is something that is done in for example Germany.

One tool to use is, of course, an up to date GIS program. Additional tools to use can be Microsoft Excel or MATLAB for calculations. Almost all of the four green roof methods used extra programs, such as GEOBIA image analysis and eCognition trimble. The Lund study is the only study where the author goes on a field study to photograph slopes with a digital camera. I argue that remotly sensed data can be collected also with a drone, which is becoming increasingly popular to use. The drone can also catch closer photographs of a building when it is difficult to come close with a digital camera.

Since the cityscape of Malmö is changing, the input data should be closely related in time. BA and KL confirmed that there are a lot of input data to use for Malmö, but they did not specify when it was collected. The Braunschweig study used input data from 2003 and 2012, which gave the researchers a problem since new housing areas were developed and built between the years. New housing areas will continue to be built also in Malmö and after some years the created model needs to be updated. However, it may cost extra to always use the newest data.

I suggest that the input data primarily should contain roof slope and available roof area since this can be observed with maps and aerial photos in 2D, 2.5D and 3D. All of the four green roof methods used these two criteria. The next step would be to include information about the waterproofing membrane layers and load-bearing capacities. Finally, weather conditions can be included. Some areas may not be suitable for green roofs because of harsh winds or intense sun or because of the shadowing effects from other buildings. Field studies and measurements should be done.

The load-bearing capacity has in this study proven to be a very important criterion for a green roof potential method. The existing roof has to be able to support the green roof and the additional water after a rainfall, as well as the people standing on top of it. To improve biodiversity, it would be better to build more semi-intensive or intensive green roofs, but they normally weight more than an extensive green roof. However, research is made at for example SGRI where a thick but light-weighted semi-intensive green roof has been developed by gardener Peter Korn.

A collection of documentation on load-bearing capacities and slopes of all roofs in Malmö does not seem to exist today. The researchers of SLU, in collaboration with ÅOS, did not seem to find enough information when trying to create a green roof method. They gave up on the project. It should be possible to create a file with information about load-bearing capacity and slope of all buildings in Malmö, but it would most likely be a time consuming and costly investigation. Someone has to ask each property owner and calculations may have to be made. However, gathering information on load-bearing capacities and other physical properties of all buildings in Malmö could be useful for other scenarios, not only green roofs. Gardens, solar cells, solar heating systems, water harvesting, or water retention systems can also be built on top of roofs.

In the Thessaloniki study, the researchers chose to divide the buildings into categories before and after 1980 when a new law was implemented. This law resulted in buildings with a higher load-bearing capacity and it was therefore assumed that semi-intensive green roofs could be built on them. However, the age of a building is in general not directly correlated to its load-bearing capacity. The researchers could not have been sure that all buildings constructed after 1980 actually got a higher load-bearing capacity.

All of the four papers in the literature study would most likely have resulted in a lower green roof potential if the load-bearing capacity was taken into account. The same goes for including information about available and approved waterproofing membrane layers.

The green roof potential is naturally increasing in areas with a low number of tiled roofs since it seems too costly to replace the tiles. And I argue that it would not be sustainable to change a functioning roof until it needs renovation. Malmö has quite many tiled roofs, which can be observed through google maps. However, there seem to be more roofs with for example roofing felt in the outskirts of Malmö. They are easier to build green roofs on.

Roof obstructions and tiles should be extracted in the method in order to find the true available roof area. However, the Lisbon study and Lund study neglected roof obstructions to avoid increased data cost and volume as well as to save time. They thereby overestimated the green roof potential. They will have to make a more extensive field study afterwards in order to observe the suitability of the roofs in reality. The Braunschweig study did not extract the roof obstructions carefully from the beginning and stated that they want to perform this part better to improve their method.

The scenarios in the four green roof methods are pretty ambitious. I suggest a first scenario where only flat roofs, or roofs with very low inclination, are investigated. This, because it is cheaper and easier to build a green roof on a roof with little slope. It would probably also be easier to add extras to a flat green roof later, for example, a beehive or a solar cell system. Moreover, most tiled roofs are tilted, and they will therefore be excluded in the method automatically. Furthermore, the minimum roof size per roof could be $50m^2$ in order to limit the search and investigation. The more criteria and scenarios that are added in the next step, the more complicated the method will become. But it will hopefully also increase accuracy.

The GIS tool needs adequate input data in order to make accurate analyses, which can sometimes be time-consuming to collect. It can also be difficult to use for the average individual without proper training. However, GIS and other spatial analysis tools are already used in Malmö in connection to urban planning and are believed to become more and more integrated. Therefore, an expert team should be gathered in order to create a green roof method. A team with knowledge on not only GIS and remote sensing but also green roofs, gardening, buildings and construction as well as urban planning.

It should be important to add a sensitivity and uncertainty analysis when creating the green roof method. This is something the Lisbon study wants to do in the next step. The Thessaloniki study suggests in-situ measurements and field experiments to improve accuracy.

All of the respondents in the interview study think that there will be an increase of green roofs in Malmö in the future, even though they come from different backgrounds. However, what hinders expansion may not be the lack of tools to increase the number of green roofs. It is rather the lack of laws and policies as well as knowledge amongst politicians mainly. The interview answers regarding PBL and detailed development plans in connection to green roofs made me confused. The situation can become complex when many stakeholders are involved in decisions and no standard procedures exist. However, if Germany can implement policies and subsidies to increase the number of green roofs, Sweden should also be able to. For example, by adopting a similar approach as to how Germany uses ecological compensation as an argument to build more green roofs. Additionally, the southern parts of Sweden and Germany have similar climate so comparisons can be made between the zones.

Some of the respondents also thought that a faster expansion is hindered by finances and whether or not green roofs are a safe investment. The investment can become unsafe if proper maintenance of the green roof is not added. If the green roof dies off quickly it may result in even more insecure investors. This can probably be avoided by asking a professional gardener for advice.

Issues with urban heating and heavy rainfalls may be more problematic in more densely populated cities. Malmö is so far not a very big city, but it can become one in the future as the population is increasing year by year. Climate change may also cause more droughts and floods in the Malmö area. This is why it is important to use all the green infrastructure solutions that we can come up with, and green roofs are one of them.

If laws were implemented in Sweden concerning green roofs, the need for a specific green roof planning tool may become greater. One can also argue the opposite. If a green roof method was created and implemented now, we could evaluate whether or not more green roofs can be built on already existing roofs. If this results in a high number of green roofs, it could become an argument to implement supporting policies or subsidies. On the website of the City of Malmö, it is stated that vegetated and aquatic areas should be increased in Malmö, including green roofs and walls. A green roof tool may help to push decision-makers into action. It may not be possible to create a fully functioning green roof method but the investigation itself could lead to useful insights. It can be compared with a Life Cycle Analysis made on a product. It can be very difficult to find and include accurate information from all steps in the cycle and assumptions are often made. However, it is often possible to point out “red zones” where improvements surely can be made.

UP mentioned that it is nowadays common to include a green roof already in the planning process of a new building. LR and MB both confirm that there is a high demand for green roofs in Malmö, but mostly for new building constructions. It might be easier and cheaper to build a green roof when constructing a new building in order to have control of the whole process from start to end. We will surely see more green roofs in Malmö although they may not appear in old buildings.

There may be other tools and techniques to use in order to calculate the number of green roofs that can be built in a city. These were not investigated in this paper.

All in all, available information on green roof technology needs to be distributed continuously so that more people understand the concept better. Knowledge and experience exist but it is too concentrated. SGRI has developed green roof manuals for Sweden regarding vegetation, construction and the entire process. However, modern green roof technology is still a new technology developed from the 1960s and other types of roofs have been around for a much longer time. A red-tiled roof and a green roof can perhaps be compared with a petrol-powered car and a more environmentally friendly car. People are more comfortable with what has been on the market and tested for a longer time. It may take another 50 years before green roofs can be seen evenly distributed over the entire Malmö.

7. Conclusion

1. All of the four green roof methods evaluated in this study use roof slope and available roof area as criteria. Other criteria discussed in this study are weather conditions, waterproofing membrane layer and load-bearing capacity which can be added in the method. The latter is of extra importance since the roof on a building must be able to support the green roof built on top, plus additional weight from external factors.

2. The four green roof methods evaluated follow a very similar structure. Differences depends on the initial aims, which additional tools that were used as well as available input data and which scenarios were chosen.

   Three of the green roof methods use an entire city as study area, while one of the methods use only a part of a city. It can be good to divide a city into parts in order to limit the search and find priority areas.

   Most of the green roof methods use additional tools in order to calculate the green roof potential, such as an extension called Feature Analyst 5 (FA), GEOBIA image analysis, eCognition Trimble (version 8.7), Microsoft Excel and MATLAB 7.0.

   Only one of the green roof methods include a field study where slopes and roof material are identified with a digital camera. It is however concluded by one of the other methods that field studies and in-situ measurements should be added in order to improve the accuracy. Furthermore, a sensitivity -and uncertainty analysis should be performed.

   I suggest that it can be convenient to use a drone in order to collect both remote images and detailed images of buildings.

3. It should be possible to create a green roof method for Malmö in Sweden, but it will be challenging to collect all the input data to make it accurate. A lot of input data exists for Malmö, for example, maps in 2D/2.5D and other vector data, 3D data considering roofs, air scanned laser data, altitude models and aerial images. However, the difficulties in finding the load-bearing capacity of each building complicate the process, and the result would become overestimated without it.

   It seems possible to find the load-bearing capacity of each building in Malmö if one were to ask each property owner. Nevertheless, this could be time-consuming and requires investment. The result may, however, be useful in other situations, for example when planning to build solar energy systems, rainwater retention systems or gardens on top of roofs.

   The people interviewed in this study were in general positive towards green roof technology and believe the number of green roofs will eventually increase in Malmö. The Municipality of Malmö has strategic plans to build more green roofs and MKB will continue to build green roofs where there is a potential. Pioneers like Hauschild+Siegel architecture may also lead the way forward.

Some of the respondents have heard about methods on how to calculate the green roof potential in order to plan for more green roofs. However, according to answers of the respondents, such a method may not yet be needed, as no political requirements currently exist in Malmö. There are no laws, policies or subsidies in Sweden, compared to for example Germany, which clearly imply that more green roofs must be built. Depending on the development of this matter, a green roof method may prove to be useful in the future.

However, one can also argue the opposite. On the website of the City of Malmö, it is stated that vegetated and aquatic areas should be increased in Malmö, including green roofs and walls. If a green roof method was created and used in Malmö now, it could become an argument to implement supporting laws or subsidies regarding green roofs.

The lack of laws and information about load-bearing capacities may be two things hindering a faster expansion of green roofs in Malmö. Building permits, finances and a general lack of knowledge were other things mentioned by the respondents. Available information on green roof technology needs to be distributed continuously so that more people understand the concept better.

It would be interesting to do further investigations and compare laws and subsidies of Sweden and Germany. This in order to see what Sweden can learn from Germany when it comes to green infrastructure and green roofs. It would furthermore be useful to collect and compile information about psychical properties of all roofs in Malmö, including load-bearing capacities. A dense city can result in limited space for green and blue areas, and many roofs have useful empty space. Moreover, it would be interesting to follow-up if the green roof methods analysed in this study have been implemented and been useful in the chosen study areas.

"Is it not against all logic when the upper surface of a whole town remains unused and reserved exclusively for a dialogue between the tiles and the stars."
Le Corbusier (Charles-Édouard Jeanneret).

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9. Appendix

Questions for the interview study.

A list of the name acronyms can be found in table 3 in chapter four.

Question one to seven below were sent by email to all respondents except from IA. IA only got one question (about municipal technical requirements) forwarded by JM in order to help him answer the question.

Some of the respondents got extra questions depending on their profession:
Question eight was sent to BA and KL. Question nine to twelve were sent to LR and MB. Question twelve was also sent to UP, MN and HA. Questions thirteen and fourteen were sent to HA, MN and UP. Question fourteen was alto sent to HJ. Question fifteen was sent to MN and question sixteen was sent to ÅOS.

1. In what way do you have experience with green roofs? In what context?
2. There could potentially be more green roofs in Malmö. Do you think more green roofs should be built, and if so, what hinders faster expansion? If you don't think more green roofs should be built, why do you think so?
3. In what ways could green roofs contribute positively or cause difficulties, based on your perspective or your area of responsibility?
4. In several European countries, such as Germany, laws and subsidies have been introduced to make it easier for cities to invest in more green roofs. What changes are plausible in Sweden and Malmö?
5. What knowledge needs to be developed primarily to enable green roof expansion?
6. Do you see a need for a method, using maps and other data in both 2D and 3D, to calculate how many existing roofs are suitable for green roofing in a particular city? This method could serve as a planning tool for identifying suitable roofs to investigate further. Do you have anything to add about such a method?
7. Is there a future for green roofs in Malmö?
8. If one were to calculate how many green roofs that could potentially be built on already existing buildings in Malmö using GIS and remote sensing:
-How do the conditions for this look like?
-Do you think necessary maps and databases are available?
Materials used in other studies are, for example, orthoimages, information about buildings, map with the building's footprint, digital surface model, WorldView-2 photo and other information needed depending on the criteria chosen.
9. What type(s) of green roof(s) do you offer?
10. How big is the demand for green roofs in Malmö? Where does this demand come from? (Private, municipality etc).
11. Do you sell most green roofs for new buildings or are there many customers who want to upgrade their existing roofs?
12. When it is time to build a green roof in a particular location, who will find out the suitability for this? For example, the roof's load-bearing capacity, slope, available sunlight etc.
13. Does the municipality have plans to build more green roofs in Malmö?
14. How many green roofs are there in Malmö right now?
15. MKB has already built green roofs in Malmö, will it continue? What do the plans look like?
16. Annika Kruuse mentioned that you, together with colleagues, tried to do some kind of green-roof potential study. It however fell on the fact that information about load-bearing capacities could not be found. Would you like to tell me more about this method? What was the purpose of the study? What tools and criteria did you want to use?