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Master's Thesis

Exploring the possibilities of urban rooftop farming in Vienna

submitted in satisfaction of the requirements for the degree of

Diplom-Ingenieur

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by

Barbara Laa, BSc

Matr.Nr.: 00925912

under the guidance of

Univ.-Prof. Architekt Dipl.-Ing. **Christoph M. Achammer**

Dipl.-Ing. **Maeva Dang**

Institut für Interdisziplinäres Bauprozessmanagement
Industriebau und interdisziplinäre Bauplanung
Technische Universität Wien
Karlsplatz 13/234-2, A-1040 Vienna

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Kurzfassung

Diese Masterarbeit beschäftigt sich mit den Möglichkeiten von Urban Rooftop Farming in Wien. Motiviert durch die positiven Effekte von Urban Farming und Dachbegrünung auf eine Stadt und den weltweiten aktuellen Trend des Rooftop Farmings, sollen die Gegebenheiten für diese Art der urbanen Landwirtschaft in Wien analysiert werden. Ziel ist es, herauszufinden, welche Flächen dafür geeignet sind, wo sich diese befinden und wie viel Gemüse darauf produziert werden kann. Dies wird anhand einer Literaturrecherche und der Analyse von GIS-Daten der Stadt Wien bewerkstelligt.

Zuerst werden bestehende Rooftop Farming-Projekte und ähnliche Studien für andere Städte analysiert. Danach werden unterschiedliche Anbaumethoden betrachtet. Die Nahrungsmittelproduktion wird auf den Gemüseanbau beschränkt. Dafür werden die herangezogenen Anbaumethoden in zwei Kategorien eingeteilt: traditioneller Anbau in Erde an der freien Luft (als Gründach oder mit Hochbeeten umgesetzt) und Hydroponik in einem konditionierten Glashaus. Abschließend werden die Unterschiede der jeweiligen Methode in Bezug auf Ertrag, Brutto/Netto Produktionsfläche und Gewicht herausgearbeitet.

Zur Identifizierung geeigneter Flächen werden dann zuerst Kriterien formuliert, die eine Eignung des Daches für Rooftop Farming beschreiben. Dabei liegt der Fokus auf baulichen und rechtlichen Parametern. Die berücksichtigten Parameter sind Dachneigung, Verhältnis von Fläche zu Umfang, Größe, standortbezogene Faktoren, baurechtliche Aspekte, Gebäudenutzung, Tragwerk, Dachaufbau, Gebäudeinfrastruktur und finanzielle Aspekte. Diese allgemeinen Parameter werden dann anhand von fünf beispielhaften Typologien für spezifische Gebäude genauer erläutert. Die Ergebnisse dieser Erkundung werden übersichtlich in einem Handbuch zusammengefasst.

Um eine Verknüpfung der Kriterien mit der Stadtstruktur zu erhalten wird aus vorhandenen GIS-Daten der Stadt Wien ein Modell mit geeigneten Dachflächen erstellt. Die Basis hierfür bilden Daten aus Laserscanning und Realnutzungskartierung. Die Kriterien, welche in dem Modell berücksichtigt werden konnten sind Dachneigung (weniger als 5°), Größe (mehr als 1.000 m^2 flacher Bruttofläche), Nutzung und Solarpotenzial. Aus dem Modell kann dann die Gesamtfläche, die sich für Rooftop Farming eignet herausgelesen werden. Die Bruttofläche an geeigneten Dachflächen beträgt etwa 520 ha.

Die Recherche hat ergeben, dass eine maximale Produktion mittels hydroponischem Anbau gegeben ist. Pro Jahr könnten 208.422 Tonnen Gemüse produziert werden, würde man alle erfassten Flächen mit Hydroponik-Glashäusern belegen. Dadurch könnten 53,4% des Bedarfs an frischem Gemüse in Wien gedeckt werden.

Abstract

This master's thesis explores the capacity of Vienna to grow food on rooftop gardens for the nourishment of its inhabitants. Following the global trend of rooftop farming and motivated by the positive effects of urban farming and green roofs on a city, the parameters for urban rooftop farming in Vienna are being analyzed. The objective is to identify which areas are suitable for this type of urban farming, where these areas are located and how much vegetables could be produced on them. This is achieved through literature research and GIS-data analysis.

First, existing rooftop farming projects and similar studies that have been carried out for other cities are analyzed. Then, different production methods are considered. The analysis is limited to the production of fresh vegetables. The consulted production methods are divided into two categories: traditional open-air, soil-based systems that can be installed as green roofs or container gardens and hydroponics in a conditioned greenhouse. After analyzing the specifications of each method, the differences between the two methods with respect to yield, gross/net production area and additional weight are discussed.

In order to identify feasible areas, criteria that define the suitability of rooftops are formulated. The focus is set on structural and legal parameters. The study parameters that are considered are: inclination of the roof, quotient area/perimeter, size, location based factors, legal aspects, building use, building structure, building infrastructure and financial aspects. These parameters are first discussed in general and then for specific buildings with the help of five defined typologies as case studies. The results of this analysis are summarized in a practical handbook.

For the connection of the study parameters with the city matrix, existing GIS-data from the city of Vienna is utilized to develop a model of the city with suitable roof areas. The basis for this model is laserscanning and land-use data. The criteria that are considered in the model are roof inclination (less than 5°), size (more than 1,000 m^2 flat gross area), building use and solar potential. The resulting suitable area is about 520 ha gross area.

It is discovered that the maximum yield can be achieved with hydroponic greenhouses. On the identified suitable area, a yield of 208,422 t fresh vegetables per year is possible. With this amount, 53.4% of the city's demand for fresh vegetables could be met.

Contents

List of abbreviations

BDA Federal Monuments Office (*Bundesdenkmalamt*).

GIS Geographic information system.

HG Hydroponic greenhouse.

HVACR Heating, ventilation, air conditioning and refrigeration.

MA Municipality department (*Magistrabsabteilung*).

MA 19 Municipality department of Architecture and Urban Design (*Architektur und Stadtgestaltung*).

MA 22 Municipality department for environmental protection (*Umweltschutz*).

MA 37 Building police (*Baupolizei*).

MA 42 Municipality department Parks and Gardens (*Wiener Stadtgärten*).

MA 64 Municipality department for legal matters of building, energy, railway and aviation (*Rechtliche Bau-, Energie-, Eisenbahn- und Luftfahrtangelegenheiten*).

MPA Monument Protection Act (*Denkmalschutzgesetz*).

n.a. Not available.

n.d. No date.

NFT Nutrient film technique.

ÖNORM Standard of the Austrian Standards Institute.

ÖNORM B Standard for building of the Austrian Standards Institute.

ONR Rule of the Austrian Standards Institute (*Regel des Österreichischen Normungsinstituts*).

PV Photovoltaic.

TRVB Technical Guidelines for Preventive fFire Protection (*Technische Richtlinien Vorbeugender Brandschutz*).

TU Vienna Technical University of Vienna (*Technische Universität Wien*).

UHI Urban Heat Island.

UNESCO United Nations Educational, Scientific and Cultural Organization.

USD United States Dollar.

Chapter 1

Introduction

Challenges caused by increasing populations and climate change present the basic motivation for enhancing urban farming. More and more often agriculture is practiced on the existing empty surfaces of flat roofs in cities. This master's thesis aims to explore the possibilities of urban rooftop farming in Vienna. The legal and building-specific parameters that have to be considered for the installation of a rooftop farm are identified through literature research. The quantification of suitable areas and location of these areas in Vienna is achieved by a GIS (geographic information system) data analysis.

This chapter continues with a short notion on the citation style used in the thesis. Then, the motivation for this research topic is explained, followed by the formulation of the objectives, research questions, study assumptions and limitations. After that, the methodology used to answer the research questions is described. The chapter ends with information about the city of Vienna and its current practice of farming.

1.1 Citation style

In this master's thesis the author-date citation style according to The Chicago Manual of Style (2010) is adopted. Articles, papers and books will be cited with the author's last name or the name of the publishing organization and year of publication. Citations of legal texts and national standards are indicated only by the title of the text (e.g. Viennese Building Code, ÖNORM L 1131). Online sources with unknown authors are marked by the publishing company or the title of the article. In case of no available publication date, no date is mentioned for citations in the text. These sources are marked in the literature index with "n.d." (no date) instead of the year. For easier distinction the names of authors and titles are written in capital letters.

1.2 Motivation

The present master's thesis is motivated by the positive effects urban rooftop farming can have on a city. It was aimed to find out how and to what extent this practice could be implemented in Vienna. Today more than half of the world's population lives in urban environments and future population growth is expected to occur almost exclusively in cities (United Nations 2014). This entails major social, economic and ecological challenges at the present time and even more in the future. These challenges also apply to Vienna, as the city follows the global trend as a growing urban area (Vienna City Administration 1). As summarized by Grewal and Grewal (2012), urbanization in combination with globalization undermines local economic resilience and separates consumers and producers. This can result in complex and geographically dispersed supply chains and a dependence on foreign goods for basic necessities like food. The transportation of these goods, in turn, causes enormous emissions of greenhouse gases.

Urban agriculture could play a significant role in dealing with the challenges mentioned above. The supposed environmental benefits of urban farming can be summarized in the following three categories according to Goldstein et al. (2016):

1. Supply-chain efficiency
2. Urban symbiosis benefits
3. Ex-situ environmental benefits

Supply-chain efficiency includes not only shorter transportation routes from farm to consumer, so-called "food miles", but also an overall decrease of environmental burdens caused by food production and distribution. These burdens include for example the use of fertilizers, pesticides and herbicides, which can pollute the environment via agricultural runoff. Additionally high amounts of energy are needed for cooling, storage and packaging in the course of food distribution. Urban symbiosis means the interaction of an urban farm with a city's material and energy fluxes. Especially rooftop farms could have a positive influence on the building below, such as lowering the energy demand through insulation. On the other hand, a rooftop farm could benefit from the building's waste heat and use urban food waste for fertilization. Regarding the city's microclimate, urban agriculture can help reduce the Urban Heat Island (UHI) effect and hold back stormwater runoff. Many existing rooftop farms operate in closed loop systems, which saves water, reduces the need for fertilizers and stops agricultural runoff from entering natural ecosystems. This practices can contribute to the third category: ex-situ environmental benefits. Urban agriculture is supposed to have a beneficial effect, even on ecosystems beyond the city boundary. This includes carbon sequestration and reduction in agricultural land occupation.

The overall effect of urban rooftop farming on the environment is not completely understood yet. The study of Goldstein et al. (2016) compared the environmental performance of different methods of urban agriculture (including rooftop farming) to conventional rural farming in northern climates (Boston and New York City) using a life cycle analysis. The authors argue that benefits of urban farming are largely contextual and cannot be applied to cities in northern climates with cold winters and the use of fossil fuel energy sources. Six metrics as impact potentials were compared: climate change, freshwater ecotoxicity, marine eutrophication, water resource depletion, land use and mineral, fossil and renewable resource depletion. The results show that urban agriculture does not necessarily lead to reductions in land use and carbon sequestration regarding the life cycle of the farms. However, it has to be considered that the study of Goldstein et al. (2016) is not an all-encompassing approach. The study only models cradle-to-shelf: cultivation, harvesting and distribution of food to market. Therefore impacts caused by post purchase transportation and processing are not included. In summary, there are proven environmental benefits of urban farming, but more research needs to be done to get a clear image of the overall environmental impact of urban farming in northern climates.

Besides the effects on the environment, urban farming can also have social and economic benefits. Producing food inside the city increases local self-reliance, can create jobs and promote a sense of community. Since nutrients degrade with time, it is beneficial to human health to eat fresh food. Urban agriculture provides local fresh food, usually without the use of chemicals or even organic, which can contribute to the health of city residents. (Grewal and Grewal 2012, Mandel 2013)

1.3 Objectives

The objective of this master's thesis is to explore the possibilities to grow food on flat roofs of existing buildings in Vienna. This includes the identification of surfaces suitable for rooftop farming and the quantification of the potential food production capacity. For the identification of suitable surfaces, the focus was set on structural and legal criteria. In addition, it was determined to only consider the cultivation of vegetables on a commercial scale. Six research questions have been formulated. They are listed in the following and related to the proposed research method.

1. Which criteria need to be considered for installing rooftop farms?
   → will be answered through literature research

2. How big is the potential surface area that could be converted into rooftop farms?
   → will be answered through GIS data analysis

3. Where are the potential roof surfaces located?
   → will be answered through GIS data analysis

4. What is the most efficient way to grow vegetables on rooftops in Vienna?
   → will be answered through literature research

5. Which amount of vegetables could be produced?
   → will be answered through a combination of literature research and GIS data analysis

6. Which amount the city's demand for vegetables could be met with rooftop farms?
   → will be answered through a combination of literature research and GIS data analysis

Furthermore, it is desired to develop a practical handbook that can serve as a guide for anyone who would like to install a rooftop farm or is otherwise interested in the subject. This handbook should show the results in a clear and didactic way.

1.4 Study assumptions and general limitations

The thesis assumes that urban rooftop farming can play a significant role in the vegetable production for the city. This also involves the assumption that there is a considerable amount of suitable rooftops existing in Vienna.

The main limitations of the study lie in the way the GIS data has been built. It is assumed that this data is representative for the buildings in Vienna but this does not necessarily mean it maps the exact reality. Concerning the building use for example, only the given categories can be used. This makes the creation of other categories impossible an excludes certain types of mixed use. Another limitation is the date of collection of the data. The two sets of data that have been used, have been created in different years (2008 and 2009) and are relatively old. They might not fit perfectly together and the urban landscape has changed since then.

1.5 Methodology

1.5.1 Literature Review

Relevant literature was primarily provided by Maéva Dang, the supervisor for this thesis. Additional literature concerning urban rooftop farming was identified by searching academic databases and Internet search engines. The following databases and search engines were used:

- ▷ CatalogPlus of TU Vienna
- ▷ Online catalogue of BOKU Vienna
- ▷ Web of Science
- ▷ Google scholar
- ▷ google.com / google.at

The search was conducted with english and german search terms. English search terms were "urban farming", "urban gardening", "urban agriculture", "urban horticulture", "community garden", "rooftop garden", "rooftop farming", "rooftop horticulture", "green roof", "hydroponic", "aquaponic", "vertical farming". Since many english terms are used likewise in german, the german search terms were reduced to "Urbane Landwirtschaft", "Dachgarten", "Dachfarm", "Dachterrasse", "Gründach","Dachbegrünung", "Gemeinschaftsgarten", "Hydroponik", "Aquaponik", "Baugenehmigung" plus "Dachgarten", "Baugenehmigung" plus "Dachterrasse", "Denkmalschutz", "Denkmalschutz" plus "Dachgarten", 'Denkmalschutz" plus "Dachterrasse". The terms were specified to be anywhere in the title or abstract with no date or language restrictions.

The literature was then analyzed in a first phase by browsing, regarding the suitability for this thesis and the number of sources was narrowed down accordingly. In a second phase the remaining literature was studied more thoroughly. These sources present the basis for the handbook and general information given in this thesis. Four studies were found to deal with analyses similar to this thesis, for different cities. They are described in chapter 2.

1.5.2 Standards

The research also included the identification of former and current live load values required for structural analyses, in order to evaluate the load bearing capacity of existing buildings in Vienna. Former values have been taken from old Austrian standards, that were available in hardcopy at the library of the Technical University of Vienna (TU Vienna). Standards that are valid at the present have been accessed via the Austrian Standards website effects 2.0, which provides standards in full text for students under the URL *https://effects.austrian-standards.at*.

1.5.3 Other sources

Other sources that provided information that was included in the thesis were emails, a site visit and personal conversations with representatives of existing rooftop farming projects. The site visit (Site visit 2016) was a guided excursion to the Viennese rooftop farm "Gartenwerkstadt" (see section 2.8) in the course of the university class "Industrial Building" at the Technical University of Vienna (TU Vienna). The projects designed during that class have also been a source for this thesis (Industriebau 2016).

1.5.4 GIS-analysis

In order to analyze location based factors, a geographic information system (GIS) model of the city was developed. The municipality department 22 (MA 22), responsible for environmental protection, provided GIS-data about all roofs in Vienna. For the analysis the freeware QGIS in the Version "QGIS 2.18 Las Palmas" was utilized. The analysis of data exported from QGIS and the preparation of diagrams took place in Microsoft Excel. Detailed information on the analysis in QGIS and Excel can be found in chapter 5.

1.6 Information about Vienna

Vienna is the capital and largest city of Austria (in size and population) and one of the nine states of Austria, a small country in Central Europe. Figure 1.1 shows the location of Austria in Europe and the location of Vienna in Austria, highlighted in green. The city is located in the Northeast of the country, between the easternmost extension of the Alps in the West, the plain Marchfeld in the East and the Vienna Basin in the South. Coming from the North, the Danube River forms the border between the 21^{st} and 22^{nd} district and the other districts, separating the city in two parts. (Vienna City Administration)

(a) Location of Austria in Europe

(b) Location of Vienna in Austria

Figure 1.1: Maps of Europe and Austria

The city is divided into 23 administrative districts that are shown in the map in figure 1.2. The district numbers 1-9 and 20 are considered inner districts and number 10-19 and 21-23 are considered outskirts of the city.

The city has a total area of around 415 km^2. Green areas account for almost half of the city area. The percentage of green areas in the inner districts vary between 2% to 13%, whereas the western districts offer up to 70% green area. The population of the city was 1,867,582 as of January, 1^{st} 2017. (Vienna City Administration, Statistik Austria 2017)

Regarding urban farming, Vienna already produces about 1/3 of the consumed vegetables in the city. On the ground, more than 5,000 ha of the city area are used for agriculture. Thereof 870 ha account for vegetable production. 60,000 t of fresh vegetables are produced each year.

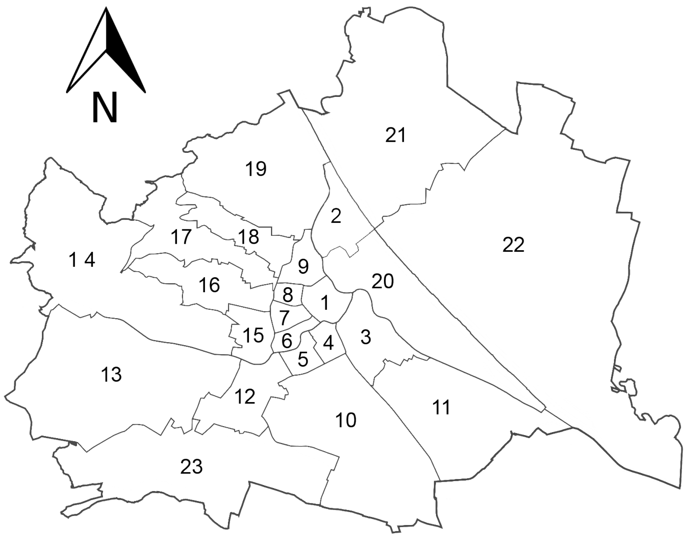


Figure 1.2: Vienna and its 23 administrative districts

The majority of agricultural area can be found in the districts number 10, 11, 19, 21, 22 and 23. Several other districts also feature farming areas, though on a smaller scale. (Vienna City Administration 10)

In 2014, the largest area could be found in the 22^{nd} district with 2,660 ha, followed by 1,120 ha in the 21^{st} district and the 10^{th} district with 892 ha. The dominating production method in these three districts was field farming. In the 11^{th} district, on the other hand, the agricultural area of 301 ha is mainly used for vegetable production. The farming area in the 19^{th} district is primarily used for producing wine. (Landwirtschaftsbericht 2015)

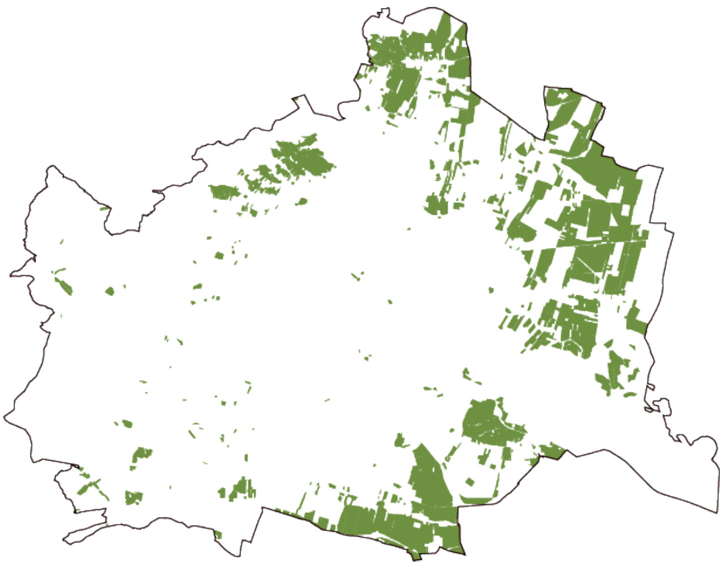


Figure 1.3: Agricultural areas in Vienna

Figure 1.3 shows the agricultural areas (fields, market gardens, orchards, vineyards) in Vienna according to the *Realnutzungskartierung* (Vienna City Administration 8).

The Vienna city administration published a city development plan as a vision for the year 2025 (Step 2025). The plan discusses challenges caused by an increasing population and climate change and shows the strategies for dealing with them. The installation of green roofs, for example, is noted as a measure against UHIs and for stormwater management.

Chapter 2

State of the art

This chapter deals with the current situation of urban rooftop farming around the world and the scientific research in this regard. Rooftop gardens that grow food are not a new invention, yet the practice of producing food on top of buildings on a bigger scale, for commercial purposes is a relatively recent development. Therefore there is no extensive knowledge or longterm experience available. The chapter starts with a short depiction of the history of urban agriculture and rooftop farming. Then, there follows a review of studies concerning similar evaluations of rooftop farming potential regarding other cities. Afterwards, a study of roof gardens in Vienna from the year 1986 is discussed, followed by an analysis of the green roof potential in Vienna. Finally, in the last section of this chapter international examples of rooftop farming projects are described.

2.1 History

Urban agriculture used to be part of ancient cities in China and Latin America with the earliest record from 3100 BCE. Rooftop farming may have a lenghty history as well. The terraced roof gardens that are known as the Hanging Gardens of Babylon are supposed to have existed around 600 BCE in Mesopotamia and might have been the first rooftop farming project. There are indications, that these gardens have been used for agricultural purposes. Furthermore, in the 1500s in Mesoamerica, the Aztecs are said to have built highly developed roof gardens in their cities, which produced food and incorporated waste management strategies. All around the developed world urban agriculture used to be a common part of cities until the Industrial Revolution, which started at the end of the eighteenth century. Farming areas had to give way to factories and urban development. Agriculture moved outside of the cities and the food had to be imported into the cities. After the industrialization, urban farming became popular again from time to time, especially in times after war when fresh food was hard to access. Today, as people recognize the benefits of local food production, urban agriculture and rooftop farming are on the rise again in cities around the world. North America and Singapore are currently the leaders in rooftop farming with a number of companies producing food on roofs on a commercial scale. (Mandel 2013)

According to Buehler and Juge (2016), the first commercial urban rooftop farm started operations in 2010 (Brooklyn Grange Navy Yard Farm). In total, the study found 15 commercial rooftop farms that existed in 2015. These were either soil-based open-air farms or hydroponic greenhouses. The majority of new farms implemented the latter method, though open-air farms still present the bulk of farming area. Most of the detected farms are situated in North America, but the authors indicated that there might be more Asian case studies available. However, information about Asian rooftop farms was either not published or only available in local languages.

2.2 Study for New York City

Ackerman et al. (2012) conducted a study for the potential for urban agriculture in New York City. Pages 40 - 42 of the study deal with rooftops and their potential farming area in particular. The authors chose the following criteria for the selection of suitable surfaces.

- Flat roof
- Location in manufacturing or commercial district
- Built between 1900 and 1970 (because of the building structures)
- Building footprint of over 10,000 square feet (ca. 929 m^2)
- Maximum 10 stories tall
- Not used for heavy industry or noxious purposes

With these criteria 5,227 private and 474 public buildings were identified, with a total roof area of 3,079 acres (ca. 1,246 ha).

Additionally, the authors determined the following factors that need to be considered, but were not included in the spacial analysis.

- Sun exposure
- Roof materials and condition
- Roof access and egress

The authors concluded that they utilized restrictive criteria and there might be even more potential rooftop farming area in New York City. For the determination of other suitable sites, they suggest an evaluation on a case-by-case basis.

2.3 Study for Rotterdam

Another similar study was carried out for the city of Rotterdam in the Netherlands (Dumitrescu 2013). On the pages 12 - 14 the study is focused on potential urban agriculture on flat roofs. The author mapped suitable rooftops, according to the following criteria.

- Flat roof
- Maximum 40 m height
- Adjacent roof of same height
- Minimum size of 500 m^2
- Building age and function
- Ownerhsip
- Water access
- District heating access

- ▷ Solar power potential
- ▷ Social criteria

Regarding the structure, the combination of building age and function was utilized to define the potential strength with respect to additional loads. According to the authors, the total potential flat roof surface in Rotterdam is about 906 ha.

2.4 Study for Bologna

A study conducted in Bologna (Orsini et al. 2014) found that the yield of urban rooftop farms would be able to cover 77% of the vegetable requirements of the city's inhabitants. The authors carried out a case study for the potential vegetable production on rooftops. To this end they performed experiments with three different growing systems: Nutrient Film Technique (NFT), hydroponic floating systems and solid substrate cultivation in wooden containers. With the obtained data, the yields of different crops could be compared by season and growing system. On this basis, the authors designed an 'optimal rooftop garden' with a combination of the three growing systems. This garden could produce a maximum yield of 41.7 g vegetables $m^{-2}d^{-1}$. Regarding the floating and solid substrate systems, the study concluded, that only 65% of rooftop space could be used as productive matter. The productivity of these systems was therefore adjusted.

In order to determine the available area, the authors identified all flat roofs and roof terraces of the city with the help of Google Earth, AutoCAD and the city technical map of Bologna. The result was 3,500 flat rooftops with a total area of about 82 ha.

2.5 Eat Up - Study for North America

Eat Up (Mandel 2013) is a comprehensive guide to rooftop farming in North America. It provides tools to help plan and realize a rooftop farm. The book includes interviews with farmers, best-practice examples, checklists and a decision tree for prospective rooftop farmers. The author makes the distinction between gardening and farming in that farming is defined as the production of agricultural goods in exchange for money. Gardening on the other hand is described as the production of these goods for self-consumption, charity or gifting. In this sense three categories of scale are presented: rooftop gardens (small-scale), rooftop farms (medium-scale) and rooftop agriculture industry (large-scale). Three different checklists for projects of the three different scales are presented. The following list includes criteria from all three checklists.

- ▷ Zoning and building code
- ▷ Proximity to consumers
- ▷ Climate
- ▷ Microclimate
- ▷ Structural capacity
- ▷ Rooftop access
- ▷ Parapet

- ▷ Waterproofing membrane
- ▷ Water hookup on the roof
- ▷ Space for amenities
- ▷ Business plan and financing

For large-scale rooftop farming, the author presents a practical decision tree (Mandel 2013, p. 201). This flowchart-like tool considers certain building characteristics and guides the user either to the farming system that fits the building best or to a dead end if the building is not suitable for farming. The four featured farming systems are containers, raised beds, row farm and hydroponics. The building characteristics taken into account are structural integrity, size, ownership, zoning, building use and location.

The decision tree starts with a cell describing three criteria that are considered mandatory:

- ▷ Flat roof
- ▷ No taller building to the south
- ▷ No vacant lot to the south

The author names four categories of use. These are residential, commercial, industrial and institutional. Further branches of the tree concern building density, roof type, construction date, size, more specific use and proximity to residential buildings (and therefore consumers). According to the author, the tree favors buildings with high dead load capacity, large acreage, supposed low rental fees, permitted agriculture according to zoning, building use related to education, food or multi-unit occupancy and location near consumers. The structural capacity is rated by construction date and roof type (concrete slab roof / metal roof). Mandel further recommends importing the tree into GIS software, to map out potential rooftop farm locations.

The book Eat Up is particularly interesting for the present master's thesis, since the decision tree in combination with the checklists is similar to the handbook created for this thesis. In addition, criteria from the handbook are combined with a GIS map of Vienna, as recommended by the author.

2.6 PAN-WIEN analysis of roof gardens in Vienna

The only resource found to the subject of rooftop farming in Vienna was a publication from 1986 of the association "PRO AUSTRIA NOSTRA - Landesgruppe WIEN". This was the Viennese committee of the predecessor of "EUROPA NOSTRA Austria", the Austrian national committee of the international association "EUROPA NOSTRA", a movement for the safeguarding of Europe's cultural and natural heritage. The publication *Forschungsvorhaben - Dachgärten Wiens* (Ehlers et al. 1986) is a study about rooftop gardens in Vienna. It includes an investigation about the existing rooftop gardens in the inner districts of the city. Additionally, there is a guide on what to take into consideration for the installation of a rooftop garden on an existing surface regarding the structure of the building and legal aspects. Though the investigation was conducted more than 30 years ago, in the years 1983-1985, many factors remain unchanged today.

In chapter 4 of the study considerations regarding the structural analysis are described. It is indicated that the structure needs to be able to bear the load resulting from the additional weight of new roof layers, consisting of: soil, drainage, filter, root barrier and the live load resulting from accessibility. The authors emphasize that the planning of a roof garden always has to start with an evaluation of the existing structure and its load-bearing capacity.

Chapter 7 of the study deals with the investigation about the existing rooftop gardens and summarizes the findings. The authors describe 107 rooftop gardens in the administrative districts 1, 3, 4, 5, 6, 7, 8, 9 and 20 (see map in figure 1.2) with areas ranging from 8 - 180 m^2. Additionally interviews with operators of 55 rooftop gardens were conducted. In those interviews it was determined if and which agricultural crops were planted. The results show, that of the 55 rooftop gardens 55% (30 gardens) grew vegetables or herbs, 13% (7 gardens) grew soft fruits and 16% (9 gardens) other culinary fruits (including fruit grown on trees). However, it is not possible to draw a conclusion regarding the total area used for agriculture. The authors knew of more than 150 roof gardens in the inner districts and roughly estimated the number for the entire city to be around some hundred roof gardens. The conclusion of the investigation was that there were almost solely private gardens as extension to apartments as roof garden projects.

2.7 Analysis of green roof potential in Vienna

The study of Vali (2011), conducted for the municipality department for environmental protection (MA 22), aimed to identify all surfaces suitable for the installation of a green roof in the city of Vienna. With the help of airborne laserscanning data, flat roofs were identified. The roofs were divided into two classes of inclination, 0 - 5° and 5 - 20°. Surfaces of the first class (until 5° inclination) are considered suitable for intensive greening. For further analysis, the author only included areas that are larger than 5 m^2 and have a quotient of area divided by perimeter $A/P > 0.3$. Structural factors, monument protection and land-use restrictions were not considered for this analysis. Some surfaces that already feature vegetation have been excluded from the potential area.

The study found a total area of surfaces that could be converted into intensive green roofs (0 - 5° inclined) of 1,068.4 ha. The results are presented for each district. Additionally, the 10 biggest continuous surfaces are shown. The GIS data obtained by the study forms the basis for the GIS-model that has been developed in the course of this thesis.

2.8 International examples of rooftop farms

Though in Vienna they are still rare today, there exist numerous successful urban rooftop farms around the world. In the remaining part of this chapter examples of Viennese and international rooftop farms are described. The selection was made in order to show a variety of the different types of buildings, management and farming systems. In order to allow for a comparison between the projects, key facts are listed in a standardized table.

Sargfabrik - Vienna, Austria

"Sargfabrik" is the name of a building in the 14th district of Vienna, which used to be a coffin factory. Since 1996 it accommodates the collaborative housing project of the association "Verein für Integrative Lebensgestaltung – VIL". The premises include an event hall, bathhouse, restaurant, playground and roof garden. The roof garden is constructed as an intensive green roof with different plants, including fruit trees and patches for vegetables and herbs. The work for the agricultural part of the garden is provided by the members of the community. (Sargfabrik, Österreichische Gartenbau Gesellschaft)

Figure 2.1: Sargfabrik roof garden (Landhotel Yspertal)

Table 2.1: Facts about "Sargfabrik" project

Location	Vienna, Austria
Building type	Residential building
Management	Community of residents
Growing system	Green roof with vegetable patches
Gross area	1,000 m^2
Products	Vegetables, herbs, fruit
Production	n.a.

Gartenwerkstadt - Vienna, Austria

Another project in Vienna is the "Gartenwerkstadt" in the 6th district. Neighbors of the publicly owned parking garage founded an association to transform the gravel covered flat roof into a community garden. In 2016 construction started with ultra-light, self-built containers made out of steel wire, fabric and osier stakes. Containers and wooden walkways were placed alongside the underlying beams to ensure the transfer of the additional load. Since the remaining surfaces were not modified and are not accessible for people, the existing structure has a sufficient load bearing capacity and no modification or reinforcement was necessary. The soil filled containers for growing vegetables are supplemented by a foil tunnel that functions as a mobile green house. In addition, the farm houses a beehive and offers workshops and courses. (Site visit 2016)

The roof has a total area of 1,900 m^2. The association plans to use only 580 m^2 of this area for their farm, with a net production area of 230 m^2. This corresponds to a net area / gross area-ratio of about 39.7%. (Site visit 2016)

Figure 2.2: Self-built containers and foil tunnel in Gartenwerkstadt (Kneidinger)

Table 2.2: Facts about "Gartenwerkstadt" project

Location	Vienna, Austria
Building type	Parking garage
Management	Community garden
Growing system	Container farm
Gross area	1,900 m^2
Products	Vegetables, herbs
Production	n.a.

ØsterGro - Copenhagen, Denmark

Figure 2.3: ØsterGro rooftop farm (Rud)

Table 2.3: Facts about “ØsterGro” project

Location	Copenhagen, Denmark
Building type	Industrial
Management	Community Shared Agriculture
Growing system	Green roof beds
Gross area	$600\,m^2$
Net area	$350\,m^2$
Products	Vegetables, honey, eggs
Production	1,960 kg vegetables
	$3.3\,kg\,m^{-2}$ gross area
	$5.6\,kg\,m^{-2}$ net area

ØsterGro farm is a rooftop farm in Copenhagen, Denmark, operating since April 2014. It was built on top of a former car auction house and has a total area of $600\,m^2$ (gross area) whereof $350\,m^2$ (net area) are used to grow food in soil filled beds. The beds are constructed as a green roof with a soil layer of 35 cm. (Haaland 2017)

In addition to the vegetable patches, the farm features four beehives, a chickenhouse and a greenhouse on the roof. The greenhouse is utilized for growing seedlings and microgreens, hosting workshops, processing the harvest and includes a small restaurant. During the production months (June to November) the farm achieves an average yield of 70 kg vegetables per week. (Haaland 2017)

The farm is organized as a Community Supported Agriculture (CSA) where the association grows vegetables for 40 members in cooperation with the farm Seerupgaard. Every week from June to November the members get a box, filled half with vegetables from ØsterGro and half with vegetables from Seerupgaard. The private owner of the building charges no rent for the roof farm, the association only has to pay operational costs. (Haaland 2017)

UpGarden - Seattle, USA

The UpGarden is a community garden on the top level of Mercer Street Parking Garage in Seattle. Installed in 2012, the garden was developed in cooperation with the city government as a temporary project, until the garage is redeveloped as part of the Seattle Center Master Plan. The garden is divided in plots for farming that are specifically assigned to community members. In the middle of the farm there is an old airstream trailer repurposed as a tool shed. (Seattle City Government)

Table 2.4: Facts about “UpGarden” project

Location	Seattle, USA
Building type	Parking garage
Management	Community, rentable plots
Growing system	Raised beds
Gross area	$2{,}300\,m^2$
Products	Vegetables, herbs
Annual yield	n.a.

Figure 2.4: UpGarden in Seattle on top of a parking garage (Higbee)

Brooklyn Grange, Navy Yard Farm - New York City, USA

Brooklyn Grange is a rooftop farming and intensive green roofing business. Founded in 2010, the company planned, built and operates two commercial green roof farms in New York City. The first, Long Island City Rooftop Farm, is around 4,000 m^2 large. The second location is called Navy Yard Farm, shown in figure 2.5, with an area of about 6,000 m^2. The farm was constructed in 2012 as a green roof with rows for farming and is complemented by a small greenhouse, used for growing microgreens. It is situated on top of Building number 3 in the "Brooklyn Navy Yard", a former shipyard. The industrial eleven-stories-building is owned by the City of New York and inhabited by different businesses. In addition to the two farms, the company manages a large-scale apiary with beehives around the whole city. In total they grow around 23,000 kg of produce per year. The products are sold at markets, to restaurants, retail stores and the 55 members of the CSA (Community Shared Agriculture) program. (Plakias 2016, Brooklyn Grange FAQ, Brooklyn Grange PressKit)

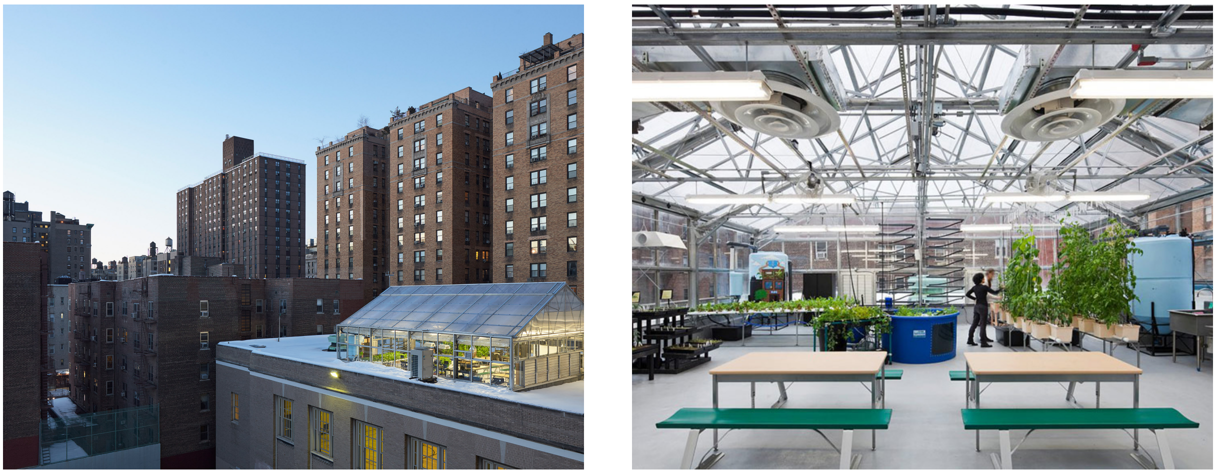
Figure 2.5: Navy Yard Rooftop Farm (Brooklyn Grange PressKit)

Table 2.5: Facts about "Brooklyn Grange Navy Yard" project

Location	New York City, USA
Building type	Industrial
Management	Commercial company
Growing system	Green roof / row farming
Gross Area	6,000 m^2
Products	Vegetables, herbs, microgreens
Production	13,800 kg
	2.3 $kg\,m^{-2}$ gross area

Manhattan School for Children - New York City, USA

The greenhouse on top of the roof of Manhattan School for Children is a science lab for educational purposes. It is used as a classroom as well as an urban farm with hydroponic, NFT and aquaponic growing systems. The area is about 140 m^2 and besides the growing systems, the greenhouse features a composting center, insect growing areas, a weather station, a rainwater collection system for irrigation of the plants and fans powered by building-integrated photovoltaic cells. Parents had the idea to install this lab where students of all grades not only learn about the new technologies in urban farming, but also how to set this in context with resource management, biodiversity and renewable energies. (Growing a Greener World 2013, Kiss + Cathcart architects)



(a) Outside view **(b)** Inside view

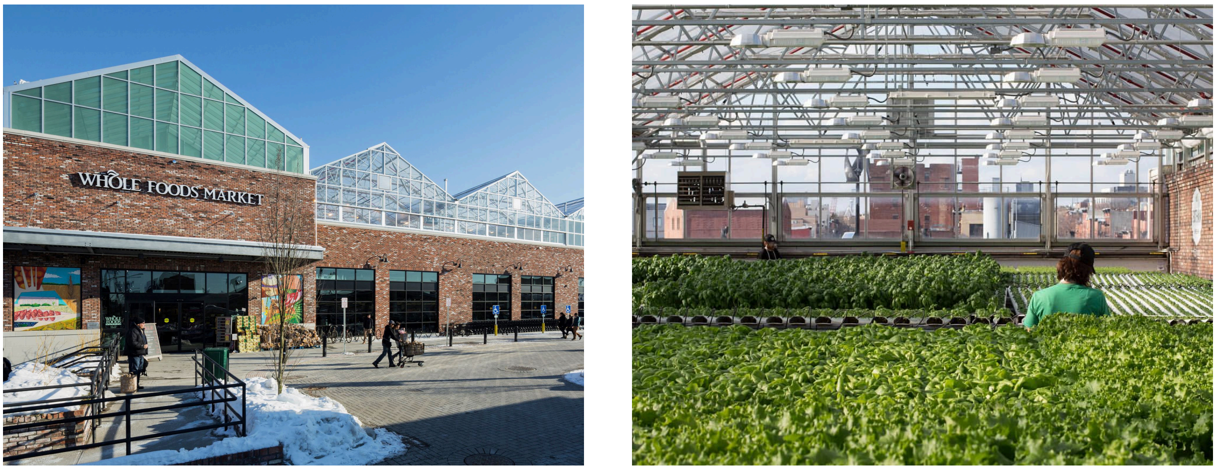
Figure 2.6: Rooftop greenhouse as a science lab at Manhattan School for Children (Kiss + Cathcart architects)

Table 2.6: Facts about "Manhattan school for children" project

Location	New York City, USA
Building type	School
Management	Educational
Growing system	Hydroponic, NFT, aquaponic greenhouse
Gross area	$100\,\mathrm{m}^2$
Products	Vegetables, lettuces, herbs
Annual yield	n.a.

Gotham Greens/Whole Foods Store - New York City, USA

Gotham Greens is a company that designs, builds, owns and operates hydroponic farms in greenhouses on rooftops in the US. They produce mainly leafy greens like lettuce, bok choy or baby kale with hydroponic NFT systems, but also herbs and tomatoes. Up until now the company operates four farms in New York City and Chicago. In Gowanus, Brooklyn Gotham Greens opened the first commercial farm on top of a supermarket. The Gowanus farm alone produces a yield of 90,000 kg each year. (Gotham Greens)



(a) Outside view **(b)** Inside view

Figure 2.7: Gotham Greens farm on top of Whole Foods Store in Brooklyn (Gotham Greens FB)

Table 2.7: Facts about "Gotham Greens Gowanus" project

Location	New York City, USA
Building type	Supermarket
Management	Commercial company
Growing system	Hydroponics in greenhouse
Gross area	$1{,}858\,\mathrm{m}^2$
Products	Leafy greens, herbs, tomatoes
Annual yield	90,719 kg $48{,}83\,\mathrm{kg\,m}^{-2}$ gross area

UF002 de Schilde - The Hague, Netherlands

UF002 is the second aquaponic rooftop farm of the Swiss company "Urban Farmers". Their pilot farm (UF001) is based in Basel, Switzerland and only 250 m^2 large. The successor started operations in 2016 in The Hague, Netherlands and is the biggest aquaponic farm in Europe with a production area of 1,500 m^2 for vegetables, 400 m^2 for fish and 300 m^2 visiting and event area. The farm is two stories high and is situated on top of a former TV and phone set factory building. On the upper level there is the retrofitted greenhouse with the vegetable growing area and an event area. The lower level, which used to be the top level of the existing building, now features the fish tanks, offices and processing areas. Figure 2.9 shows a visualization of the farm's cross section. Per year, the farm produces 45 t of vegetables and 19 t of fish, which are sold on site at the weekly rooftop market and at different gastro partners around the city. (Urban Farmers 1, Urban Farmers 2, Urban Farmers 3)

(a) Outside view

(b) Inside view

Figure 2.8: UF002 rooftop greenhouse farm in The Hague (space&matter)

Figure 2.9: Visualization of the two levels of UF002 with hydroponic growing area on top and fish tanks below (space&matter)

Table 2.8: Facts about “UF002 de Schilde” project

Location	The Hague, Netherlands
Building type	Industrial
Management	Commercial company
Growing system	Aquaponics in greenhouse
Gross area	2,200 m^2
Vegetable Production area	1,500 m^2
Fish Production area	400 m^2
Products	Vegetables and fish
Annual vegetable yield	45 t
	30 $kg\,m^{-2}$ net area
Annual fish production	19 t
	47,5 $kg\,m^{-2}$ net area

Chapter 3

Types of rooftop farms

There are different kinds of cultivation methods that can be used for growing food on rooftops. In this chapter, two main different systems are defined and specified: open-air soil-based farming and hydroponic farming in a conditioned greenhouse. Afterwards, additional features like chicken coops, beehives or small greenhouses as a supplement to open-air farms are described. Furthermore holistic design approaches to form a symbiosis between the farm and the building underneath are presented. At the end of the chapter, there is a comparison between the systems regarding crop yields, weight and area allocation.

3.1 Definition of farming systems

Each of the different growing systems that can be applied to a rooftop has their own advantages and disadvantages and is better or worse suitable for a certain building. The classification of systems can be made for instance by the medium in which the plants grow. In traditional farming the plants are grown in soil consisting of organic and inorganic matter. Nutrients have to be added from time to time in the form of fertilizers. With respect to rooftop farming, this method can be incorporated by constructing a green roof with sealing layers and soil spread on wide areas of the roof. Other possibilities are the construction of raised beds or putting the soil in smaller containers like planters, pots or recycled objects. More innovative forms of agriculture eliminate soil and soil related insects, fungi and bacteria. Nutrients are provided by a solution of water and added nutrients. The plants grow either in an inert medium, float on a reservoir of nutrient solution or are held in place by trays. These production systems can be summarized as hydroponics. There are endless possibilities for the layout of a hydroponic farm. The planters can be placed for example on the ground, benches, fixed tables, movable tables or hanging devices. In order to protect the technological equipment and to assure year-round cultivation, such systems are often placed in a conditioned greenhouse. (Shrestha and Dunn 2017)

According to Mandel (2013) the most common rooftop production methods are container gardening, raised bed production, row farming and hydroponics. Whereas the author makes no distinction between different hydroponic methods.

For this master's thesis it was decided the cultivation methods are divided into two main different categories:

- ▷ Open-air and soil-based
- ▷ Hydroponic greenhouse

This decision was taken due to several factors. First, there are similar yields attained by different soil-based production methods, which differ largely from the yields of hydroponics (see section 3.6.1). Second, hydroponic constructions are usually lightweight and cause less additional weight load on the roof than soil-based farms (see section 4.8.3). Furthermore, existing commercial rooftop farms are either soil-based and open-air or greenhouses using hydroponics (Buehler and Juge 2016).

The cultivation methods are not mutually exclusive. It is possible to have a rooftop farm with a mixture of methods. In the study for Bologna (Orsini et al. 2014) for example, the authors combined three techniques for the 'optimal garden' in order to achieve a steady productivity and grow a broader spectrum of crops.

3.2 Open-air and soil-based

3.2.1 Container farm

A container farm is characterized by the use of relatively small containers filled with soil. The containers are placed additionally on the roof, mostly without changing the existing structure. Container farms are often small-scale projects using recycled vessels like old bathtubs, plastic boxes, buckets, coffee bags, etc. to grow the plants in. Installing such a farm is relatively inexpensive and requires little effort. However, the containers present limited soil volume and therefore confined space for roots. In addition, the soil in small containers loses heat and moisture more quickly and consequently requires frequent irrigation. Furthermore, it has to be fertilized more often and the yields of container crops are lower compared to other cultivation methods. (Mandel 2013)

The study of Buehler and Juge (2016) found no commercial rooftop farms that use a container farming system. Nevertheless, there is no evidence that would suggest that it is not possible to operate a commercially successful container farm. In addition, containers could also be part of a farm that uses a mixture of production methods.

3.2.2 Raised beds

Raised beds could be described as large containers. It is possible to use prefabricated models or build custom beds on site. They can be constructed as elevated containers or placed directly on the roof structure. In order to limit the weight, it is advisable to install thin beds mades of lightweight materials like wood or metal siding. Depending on the material, the durability of the raised beds is influenced. Wood degrades quite soon and may be replaced more often than steel structures, for instance. (Mandel 2013)

Due to the load bearing capacity of the building structure, it can be necessary to place the beds over columns or beams. For example, the self-made raised beds of “Gartenwerkstatt” (see section 2.8) are specifically lightweight and placed over the supporting beams of the roof. This can significantly limit the number of beds and layout possibilities for such a farm, when a structural reinforcement of the building is unfeasible.

Raised beds also offer a number of advantages. In comparison with row farming, the equivalent distributed load at the same soil thickness is still smaller. Therefore soil layers could be thicker, which is ideal for root vegetables. As with smaller containers, aggressive plants and weeds are contained due to the limited volume. Additionally, raised beds offer better conditions for soil drainage, compaction and erosion and the soil gains heat more quickly. Nonetheless, the existing commercial farms today do not use raised beds as a production method either (Buehler and Juge 2016). (Mandel 2013, Buehler and Juge 2016)

3.2.3 Green roof / row farming

A farm constructed as a green roof, where most of the area is covered in soil, mimics the conditions of a field farm on the ground best. Different planting techniques are possible, though the most common one is row farming. Row farming means linear crop production in contiguous beds (Mandel 2013).

Knowledge and experience for green roofs is readily available. In Austria there is even a national standard, which is dedicated to green roofs, the ÖNORM L 1131. In general, a distinction is made between extensive and intensive green roofs, which differ in soil thickness. Green roofs with a soil layer equal to or larger than 15 cm are considered intensive (Getter et al. 2009). The required soil depth depends on the crop. The german green roof company ZinCo recommends a minimum depth of 20 cm for farming. 20 cm are suitable for fruits and vegetables like lettuce, onions, herbs, zucchini, eggplant, squash, cabbage, melons, strawberries and similar crops. Tomatoes, green beans, raspberries, blackberries, currants and such like, on the other hand, require a substrate depth of 28 to 40 cm (ZinCo).

Besides soil, there are further components necessary for the construction of a green roof. A typical buildup with all required layers (according to ÖNORM L 1131) is shown in figure 3.1. The different layers are discussed in the following, starting from the bottom.

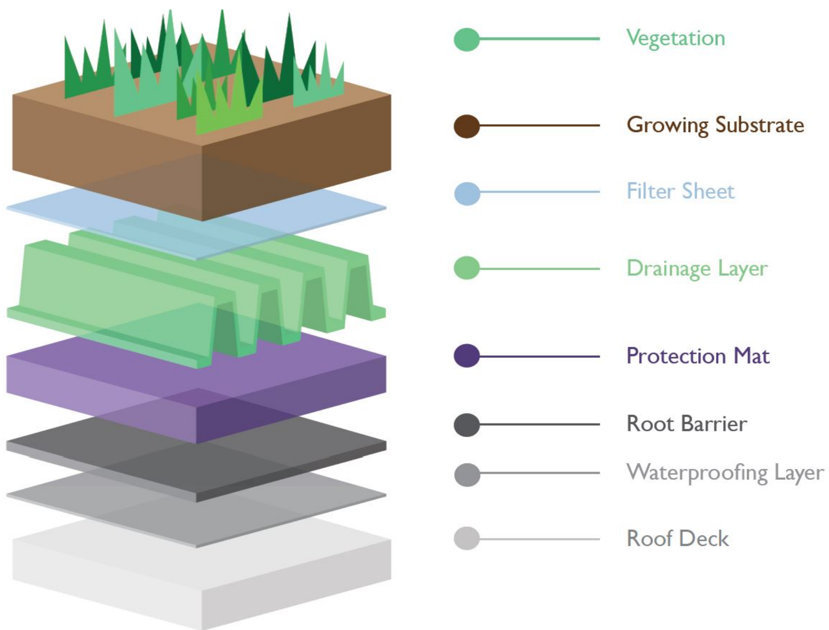


Figure 3.1: Buildup of a green roof suitable for farming (Growing Green Guide)

The waterproofing membrane on top of the roof deck should be already existing. Though before installing a green roof it should be checked for damages. In addition to the rules of ÖNORM L 1131, the design and execution of roof waterproofing is regulated in ÖNORM B 3691:2012. The root barrier serves as a protection for the roof construction and waterproofing membrane against the roots of the plants. There is no need for a separate root barrier layer if the waterproofing membrane is root resistant according to the German Standard “FLL Green Roof Guideline”.

With inverted roofs (see section 4.9) the insulation layer of the roof structure lies above the waterproofing membrane and root barrier. The protection layer is usually formed by a mat that resists perforation and prevents damage to the root barrier during the construction of the green roof. When the protection mat is thick enough, it can also be used for the retention of water and nutrients. The drainage layer is required to bring excess water to the water outlets. It can also be designed for additional functions like storing water or providing ventilation. The materials used for drainage layers on the roof are lightweight as well. Nowadays moulded rubber or plastic elements are used frequently. But it is also possible to use materials like expanded clay, gravel or lava. Above the drainage layer there is the filter layer. It is generally made of geo-textiles like fleece and serves as a separation between the soil and drainage layer. Small particles and organic matter are prevented from entering the drainage layer, so that they are available for the plants in the growing medium and do not clog the drainage layer and water outlets. The growing medium for rooftop farms is usually a special lightweight soil mixture. Mineral materials with low density but high water retention capacity and good water permeability should be included in the mixture. Such materials are lava, expanded clay, clay tiles or pumice. (International Green Roof Association, ÖNORM L 1131)

Concerning the farm layout, there are a lot of possibilities. However, it may be beneficial to include an area for congregation. Farms with such areas often rent them to external persons, for example for weddings, photo shoots or yoga classes or the operating companies hosts workshops and events themselves (e.g. Brooklyn Grange). Others included a Restaurant on the roof (ØsterGro). This can generate an additional income for a commercially operated farm.

3.3 Hydroponics in greenhouse

All existing commercial farms in rooftop greenhouses use hydroponic growing systems (Buehler and Juge 2016). Hydroponics offer many benefits. As already mentioned, soil related pests can be eliminated. Placing the food production in a greenhouse makes it independent from weather. Therefore year-round cultivation is possible, with a more predictable and reliable plant growth. With hydroponics it is also possible to easily stack crops in order to make efficient use of space. As a result much higher yields than with soil-based production methods can be achieved (see section 3.6.1). In addition, hydroponic systems usually have less weight than soil-based ones, which is a great advantage with respect to rooftop farming (Mandel 2013).

On the other hand, hydroponics require a high initial investment (see section 4.11), sophisticated technological skills and high energy input. In northern climates they are usually placed in a greenhouse to ensure a proper conditioned environment. Temperature, humidity, air circulation, nutrient output and light can be calibrated and monitored. (Mandel 2013)

Hydroponics are often praised as a sustainable technology. But hydroponics are not sustainable by nature. However, these systems make it easy to implement environmentally friendly and sustainable technologies. Some of these technologies include a symbiosis with the building underneath the farm, which are discussed in detail in section 3.5. Sustainable methods that are independent from the building are (Buehler and Juge 2016):

- Chemical Free Production
- Energy Efficiency
- Water Re-Use

Chemical Free Production means that there are no chemical containing pesticides, herbicides or fertilizers used. Measures for Energy Efficiency include the implementation of technologies and materials that increase energy efficiency, like LED lighting or highly insulating glass. The re-use of irrigation water is usually executed in a circulating system and leads to a drastic reduction of water use. These three measures are already incorporated by all of the commercial rooftop farms in greenhouses. Different hydroponic systems are described in the following. (Buehler and Juge 2016)

Passive hydroponics

Passive systems are the simplest version of hydroponics, since they do not require active irrigation. A commonly used passive system is the Wick System. The plants are placed in an inert porous growing medium like expanded clay, coconut coir, perlite, vermiculite, brick shards or wood fiber. With the help of a wick, that is connected to a reservoir of nutrient solution, the roots get access to water and nutrients by capillary action. Figure 3.2 shows a Wick System. (Shrestha and Dunn 2017)

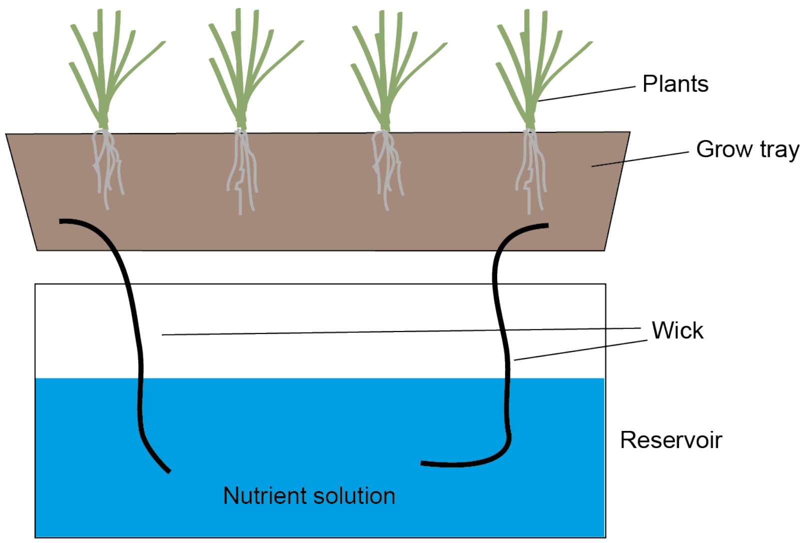


Figure 3.2: Passive hydroponic system / Wick System

Drip irrigation systems

Drip irrigation systems can be designed with or without a growing medium. Generally, a pump immersed in the nutrient solution reservoir is connected to a timer and pumps the solution to the base of each plant by a drip line. A drip irrigation system is shown in figure 3.3. (Shrestha and Dunn 2017)

Flooding systems

Flooding systems are also known under the name Ebb and Flow Systems. With this system, the grow tray is flooded from time to time with nutrient solution and is then drained again. This process is usually initiated by a pump in the reservoir that is connected to a programmed timer. (Shrestha and Dunn 2017)

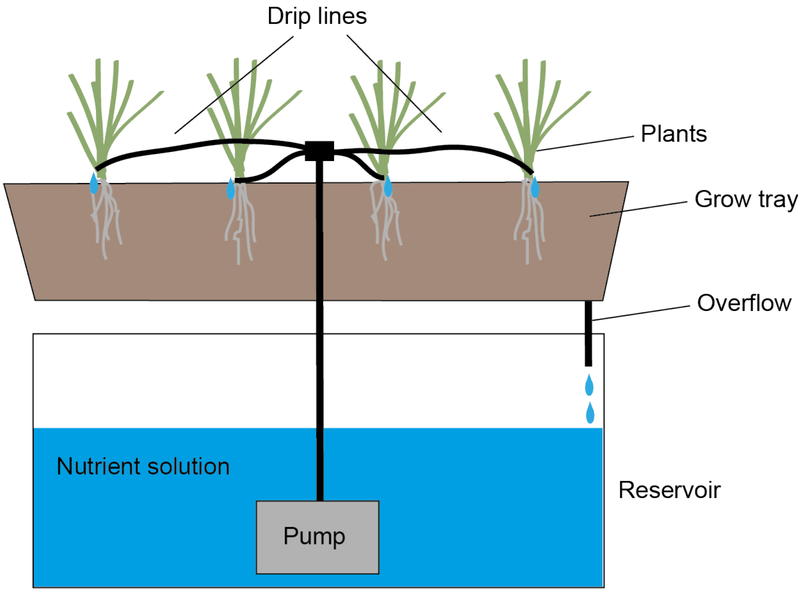


Figure 3.3: Drip irrigation hydroponic system

Floating systems

With floating systems, the plants are commonly placed on a styrofoam platform and float directly on the nutrient solution, whereby the roots are dunked in the water. To ensure the supply of oxygen to the roots, a water stone can be placed inside the reservoir. Figure 3.4 shows an illustration of a floating hydroponic system. (Shrestha and Dunn 2017)

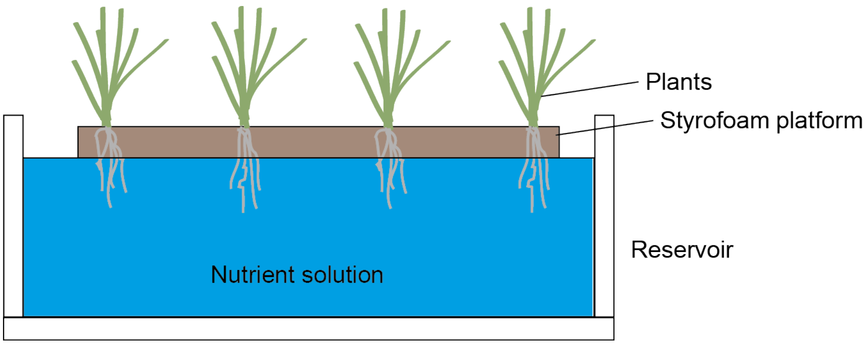


Figure 3.4: Floating hydroponic system

Nutrient Film Technique (NFT)

The Nutrient Film Technique features a shallow stream of fertilized water that is continuously flowing by the bare roots of the plants. The crops are placed on a growing tray and a pump brings the nutrient solution from a reservoir to the tray. Usually the excess water drops back to the reservoir and the water and remaining nutrients are re-used. In contrast to most other hydroponic systems, there is no timer necessary for this method. In figure 3.5 an illustration of an NFT system can be seen. (Shrestha and Dunn 2017)

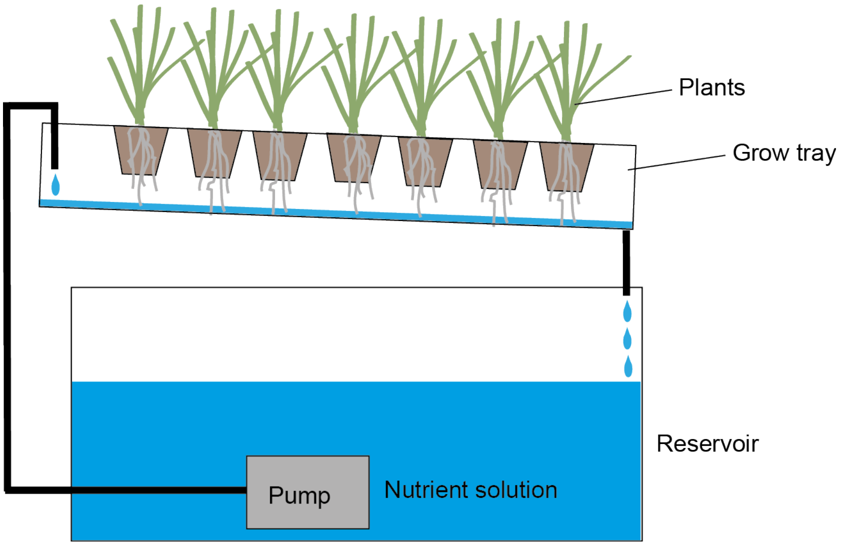


Figure 3.5: NFT hydroponic system

Aeroponics

Aeroponics are a special kind of hydroponics, where the plants are held in place by a tray or a different construction and the roots get sprayed on with a nutrient solution. The setup generally includes a reservoir of nutrient solution, a timer and a pump, as with other active hydroponic systems. In contrast to them, aeroponics feature spray jets at the roots of the plants that provide nutrients, oxygen and water. Furthermore the timer is set to supply nutrient solution for a few seconds every couple of minutes. This water-saving technique is depicted in figure 3.6. (Shrestha and Dunn 2017)

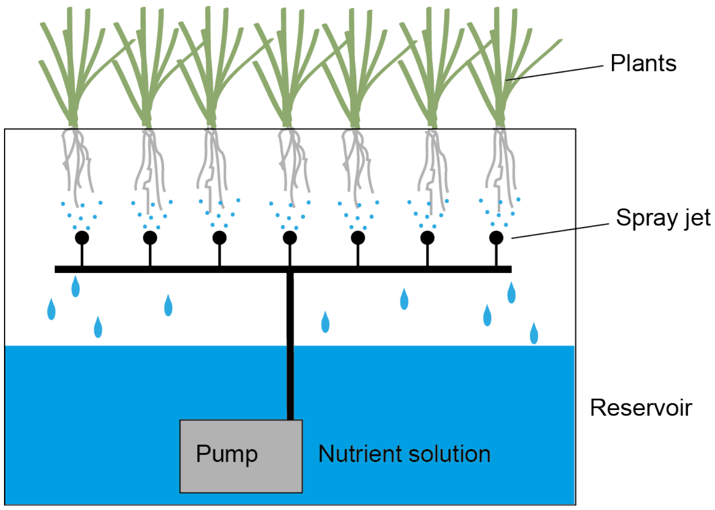


Figure 3.6: Aeroponic system

Aquaponics

Aquaponics is a combination of hydroponics and aquaculture (fish farming). It is usually constructed as a closed-loop system where the feces of the fish serve as nutrients for the plants.

Figure 3.7 shows an aquaponic system with different filters between the fish tank and growing system.

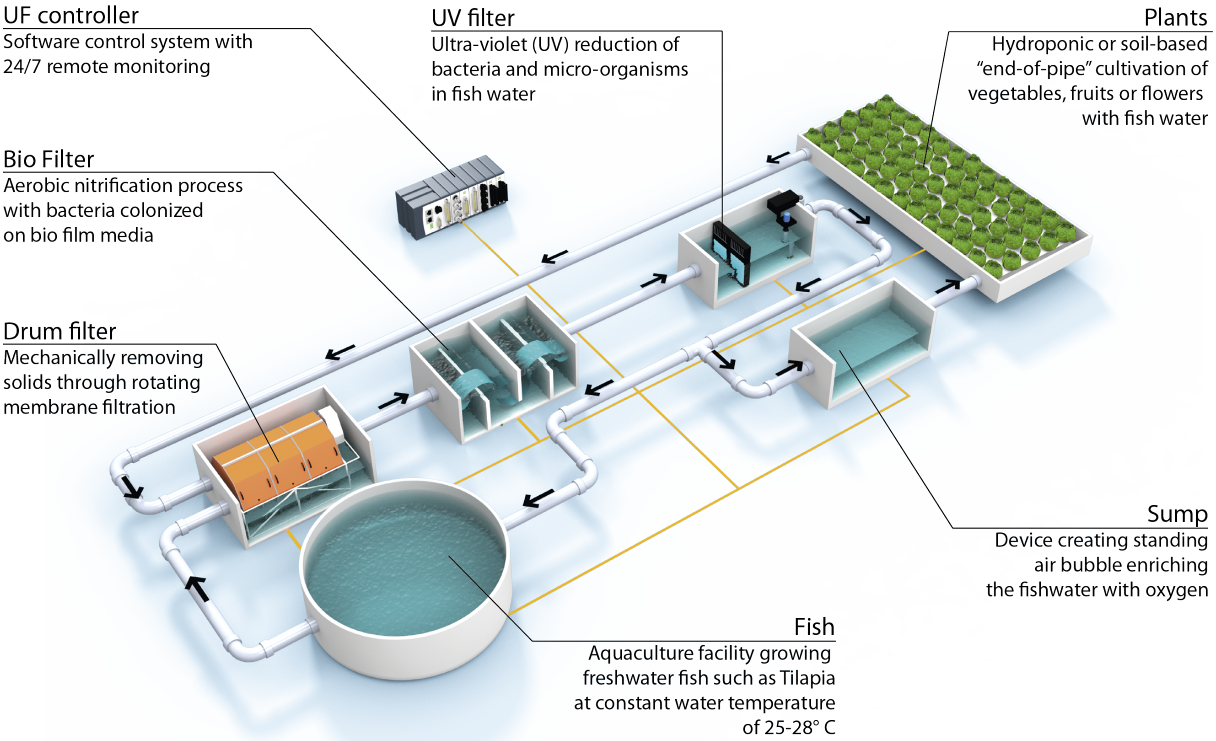


Figure 3.7: Aquaponic system (Urban Farmers 2, Urban Farmers 4)

Which hydroponic system or combination of systems are used depends for the major part on the planted crops. Short term crops like leafy greens are generally placed in recirculating systems like NFT or flood and drain gravel channels, whilst plants with a longer life cycle and crops vulnerable to root disease are mostly grown in non-recirculating, media-based systems. (Shrestha and Dunn 2017)

3.4 Supplementary features

Even though the distinction was made between soil-based open-air farms and hydroponic greenhouses, it can also be beneficial to include a small greenhouse in the layout of an open-air farm. It can be used for the cultivation of seedlings, hibernation of plants and as a work station. In the case of the ØsterGro farm, the greenhouse also houses a kitchen and restaurant.

Some open-air farms also include small animals like hens or rabbits. These animals can help removing pests and weeds from the soil, and simultaneously provide nutrients in the form of manure. In addition hens can produce eggs and poultry. They can be kept free-range or in a mobile coop. (Mandel 2013)

For open-air as well as for indoor farms, it is necessary for many crops to get pollinated. The easiest way to do this is to welcome bees or other pollinators to the farm. The additional benefit of housing a hive of honey bees is the production of honey. The alternative method is hand pollination with small brushes. Since this method requires human workforce, it influences productivity and costs. On large rooftops this can be seen as a disadvantage. (Mandel 2013)

3.5 Urban symbiosis

With regard to environmental sustainability and for reduced inputs, it can be beneficial to make use of synergies between the farm and the building underneath. Buehler and Juge (2016) formulated the following urban symbiosis methods for hydroponic farms:

- Renewable Energy
- Waste Heat
- Greywater
- Rainwater Collection
- Recycling of Nutrients
- Exchange of Gases

Though the methods were associated with hydroponic systems, some of them can also be implemented in soil-based open-air farms. Renewable energies can be used separately by the farm, but also integrated in the building. Possible technologies include photovoltaic modules, wind energy and the use of solar thermal energy. Waste heat from the building is automatically harnessed through the roof. However, it would also be feasible to connect greenhouses to the HVACR (Heating, ventilation, air conditioning and refrigeration) systems of the building underneath. This way it is not only possible to make use of excess heat, but also to exchange O_2 for CO_2 with the building. In order to reduce the use of water, the farm could use greywater from the building or collected rainwater for irrigation. Finally, recycling nutrients can be realized by circulating hydroponic systems, using fish feces in aquaponics or composting kitchen waste from the building.

In return, the farm can also give something back to the building below. Saturated soil on top of a roof insulates the building. A greenhouse also serves as a thermal buffer against heat and cold. The heat generated within a greenhouse can be harnessed and fed into adjacent stories (as well as O_2) or stored in a reservoir.

3.6 Comparison of methods

According to Mandel (2013), the main production methods in rooftop farming (container farm, raised beds, row farming and hydroponics) differ in initial investment, longevity and crop yields. Whereby container gardening is generally on the low end of the spectrum of investment, longevity and crop yields and hydroponics on the high end. Raised beds can require a small or medium initial investment and provide low to high longevity depending on the used materials. Yields per square meter are medium compared to other cultivation methods. Row farming requires a high initial investment and can generate high yields. With continuous maintenance row farms can be also long-lasting. (Mandel 2013)

Another important difference between the methods is the requirement of expertise for hydroponic systems. For the design and operation of such farms, the personnel has to be educated in these innovative systems. The time and cost for this education is much higher than training for farming with traditional soil methods.

In the following, yield, weight and allocation of area and the according differences for the two production types are discussed in more detail.

3.6.1 Yield

The crop yields of existing rooftop farms and experimental data was compared. A list of all compared projects with according yields and sources can be found in annex A. Most sources do not indicate whether the values are given for gross or net production area. Since these values form the basis for the further analysis of possible yield production of rooftop farms in Vienna, it is conservatively assumed that yields without indication refer to net area. It is assumed that the climatic conditions of the study cases for soil-based open-air systems are similar to Vienna. The yield values derived from the case study in Bologna (Orsini et al. 2014) have not been included in the comparison. This is due to the fact that they include open-air hydroponic systems, which are not relevant for this master's thesis. In addition, the values probably refer to gross area (*"In the substrate and floating system, about 35% of rooftop space was taken up with non-productive matter [...]. Therefore productivity from these systems was adjusted accordingly."* Orsini et al. (2014)). The figure in annex A (on page 2 of the annex) shows the values of the different cultivation methods. The graphic illustrates that hydroponic systems achieve a much higher yield than soil-based farms. For further calculations mean values for the yields of the two different categories are considered. The values are shown in annex A under the graphic and here, in table 3.1.

Table 3.1: Mean yields per cultivation method

Soil-based open-air	Hydroponic greenhouse
5.21 kg/m^2 net area	29.32 kg/m^2 net area

Another important factor to consider regarding possible crop yields for a certain rooftop, is the amount of nonproductive area that cannot be used for growing plants. This subject is discussed further in the next section.

3.6.2 Gross / net area

Every rooftop farm has a certain amount of productive area and nonproductive area. Unfortunately this issue is not discussed much in the available literature. For this thesis, the net area is defined according to the following equation.

$$Net\ area\ (m^2)\ =\ Gross\ area\ (m^2)\ -\ Nonproductive\ roof\ area\ (m^2)$$

Whereby the gross area corresponds to the total roof area, excluding possibly used areas under the roof. The nonproductive roof area, in turn, is defined as follows.

Nonproductive area and area for infrastructure in particular is discussed further in section 4.10.

Soil-based, open air: Nonproductive area = Walking space
+ Storage area
+ Working space
+ Event space
+ Infrastructure
+ Existing Structures

Hydroponic greenhouse: Nonproductive area = Greenhouse structure
+ Walking space
+ Storage area
+ Working space
+ Event space
+ Infrastructure
+ Existing Structures

Regarding soil-based systems, two sources have been consulted for the identification of the net area / gross area-ratio. The net area / gross area-ratio of the project "Gartenwerkstadt" (see section 2.8), which uses a container farming system, is about 39.7%. The case study of Orsini et al. (2014) was designed with a nonproductive roof surface of 35%, which corresponds to a net area / gross area-ratio of 65%. Since the "Gartenwerkstadt" is a community project without commercial interest, the net area / gross area-ratio of that project is considered not representative for commercial farming projects. Therefore, for soil-based systems, the value of Orsini et al. (2014) (65%) is adopted.

Due to the flexible layout possibilities in hydroponic systems, the definition of gross and net area is more complicated. In the course of a university class at TU Vienna (Industriebau 2016), students designed hydroponic farming projects for a university building (the case study building for the category *Education, Health, Sports, Culture*, discussed in section 4.12.2). Two trends could be observed. First, farms where everything is placed on the roof (with 69.5% nonproductive roof area) and second, layouts where some parts of the production are located under the roof (with only 27% nonproductive roof area). In order to meet these trends, the following two subcategories for hydroponic greenhouse (HG) farms have been determined.

1. **HG total-roof:** food processing surface/installations for workers are located directly in the greenhouse on the roof and a percentage of the roof surface is used for photovoltaic (PV)-modules

2. **HG part-roof:** Food processing surface/installations for workers are minimized on the roof (because space is available under the roof) and no PV-modules

The nonproductive roof area for hydroponic farms is therefore dependent on the availability of space under the roof and the implementation of PV-modules on the roof. The net area / gross area-ratios according to the different farming systems are summarized in table 3.2.

Table 3.2: Net area / Gross area-ratio according to farming systems

Soil-based, open-air	HG total-roof	HG part-roof
65.0%	30.5%	73.0%

Furthermore, for installations there is a certain amount of area required inside the building. With open-air farms, it might be possible to hook up the required installations to the existing building infrastructure. For hydroponic systems, on the other hand, it is usually necessary to add installations that can take up a significant amount of space. For more information on required building installations, see section 4.10.

3.6.3 Additional weight

Concerning structural matters, the load bearing capacity of the building determines the production method. Or in reverse, the desired production method and its weight determines which building can be used. The weight of the different structures depend on multiple factors. In general it can be said that soil-based structures are heavier than soilless systems.

For soil-based rooftop farms, usually a special lightweight soil mixture is utilized. Brooklyn Grange for instance uses "Rooflite" soil made by the company Skyland USA (Brooklyn Grange FAQ). They offer an agricultural blend that has been optimized for rooftop farming. This soil mixture has a saturated weight of 60 - 90 lbs/ft^3 which corresponds to a specific weight of about 9.5 - 14.0 kN/m^3 (Skyland USA). The agricultural soil recommended by the german company ZinCo corresponds to a specific weight of saturated soil of about 14.0 kN/m^3. For comparison, the specific weight for humid (not saturated) garden soil is 17.0 kN/m^3 (Krapfenbauer 2011). Depending on the thickness of the soil layer, the additional dead load can be calculated. The minimum depth is assumed with 20 cm. With a specific weight of 9.5 kN/m^3, the distributed load caused only by the soil is at least 1.9 kN/m^2. Increasing the depth to 40 cm and calculating the load with the high-end specific weight of 14.0 kN/m^3, the distributed load rises to 5.6 kN/m^2. Additionally, the materials necessary for the buildup of the green roof below the soil have to be considered. ZinCo indicates the total specific weight of a green roof with a minimum soil depth of 20 cm and a total depth of 25 cm with 300 kg/m^2, which corresponds to around 3.0 kN/m^2. Depending on the desired soil depth, materials and supplementary constructions, this value can rise significantly.

For containers and raised beds the same calculations can be performed. In that case, the soil depth will increase and the weight of the containers and pathway installations have to be considered. On the other hand, the soil weight is not distributed over the whole roof, but limited to the area of the containers/raised beds. They should be placed strategically on top of the underlying supporting structure (e.g. walls or beams).

Hydroponic systems are generally praised for their lightweight characteristics in comparison to soil-based systems. However, the additional loads depend largely on the incorporated systems. It has to be considered that there can be high concentrated loads caused by water reservoirs and fishtanks, when using aquaponics. Unfortunately there was not much data found in literature about the weight of hydroponic systems. Urban Farmers 2 indicate the distributed load of their hydroponic system with 200 kg/m^2, which corresponds to around 2.0 kN/m^2 and is significantly smaller than the minimum load of 3.0 kN/m^2 of the soil-based system. In contrast, the load for aquaculture is 900 kg/m^2 (ca. 9.0 kN/m^2) and the one for the required biofilter is 1,500 kg/m^2 (ca. 15.0 kN/m^2). Additionally the weight of the greenhouse, which is highly depending on the structure and materials also has to be taken into consideration. A light structure can be achieved for example by using aluminium elements and polycarbonate panels. The forces originating from the greenhouse are not distributed over the whole roof area, but transferred punctually or linear to the structure below. Furthermore, the greenhouse has to be structurally analyzed as well and needs to be securely connected to the building structure below. The design and construction of commercial production greenhouses is regulated in ÖNORM EN 13031-1. The issue of additional loads and load bearing capacity is discussed further in section 4.8.

Chapter 4

Study parameters

This chapter concerns the parameters that make rooftop farming viable. Therefore it tries to answer the first research question: *Which criteria need to be considered for installing rooftop farms?*. The objective is to determine which rooftops are suitable for farming and to develop a practical guide/handbook. In the first section, the criteria are defined and in the following sections, these criteria are discussed in more detail. The focus is set on legal and structural parameters. After the discussion of criteria, five building typologies with exemplary study cases are presented, in order to connect the defined parameters with the existing building matrix. In the last section, the development of the handbook is described.

4.1 Rooftop farming criteria

As already mentioned, the basis for the GIS analysis of potential rooftop farming area is the study regarding Viennese green roof potential of Vali (2011). The criteria of the study for roofs suitable for intensive greening are:

- Inclination - maximum surface inclination of 5°
- Quotient area/perimeter (A/P) > 0.3
- Size - minimum flat surface area of $5\,\mathrm{m}^2$

Even though they have been formulated for intensive green roofs, it is hypothesized that these criteria apply to soil-based and hydroponic greenhouse farming on roofs as well. The three criteria are adopted in this thesis with one modification: the minimum flat surface area has been increased to $1{,}000\,\mathrm{m}^2$ (as discussed in section 4.4).

In accordance with the reviewed literature, further factors have been identified that have to be taken into account when planning a rooftop farm. The additional parameters are listed below and discussed in the following sections.

- Location based factors
- Legal aspects
- Building use
- Building structure
- Roof structure
- Building infrastructure
- Financial aspects

4.2 Inclination

Only roofs that have a maximum inclination of 5° are considered viable for rooftop farming. This value has been adopted according to Vali (2011). The author argues, that surfaces with a higher pitch are not suitable for intensive green roofs, since it would be necessary to add constructions to prevent the soil from sliding off the roof. It is assumed that this is also applicable to green roofs used for agricultural purposes, as well as hydroponic greenhouses. Hydroponic systems might not use soil that can slide off, but the necessary installations would also have to be secured against sliding.

4.3 Area / perimeter quotient

The quotient of area divided by perimeter of a roof area is also adopted by Vali (2011) with $A/P > 0.3$. It eliminates surfaces that are long and narrow. The author explained that this factor was considered in order to not include unsuitable surfaces like long rain gutters or parts of facades. This parameter is primarily necessary for the identification of feasible surfaces for the GIS model. On the other hand it is also advisable to look at the shape of the roof surface regarding possible farming layouts.

4.4 Size

It was decided to limit the analysis of suitable surfaces to areas that could be turned into commercial farms. An important factor for a farm to be commercially successful is a minimum area for food production. The yields rise linearly with the amount of area, whereas the investment for singular installations and machines stays the same. In the literature, there are quite diverse values given for the smallest viable size.

In her book "The Farm on the Roof", Plakias (2016) explains that the Brooklyn Grange company was looking for buildings with an area of at least 2,300 m^2 for their flagship farm. However, they calculated this value with the assumption of generating their only income by selling produce. Nowadays a large part of their revenue is due to renting the roof for events. Nevertheless, their two operating farms are about 4,000 m^2 and 6,000 m^2 large. In the study for New York City (Ackerman et al. 2012), only buildings were considered that have a footprint larger than 10,000 square feet, which corresponds to about 929 m^2. Contrary to this, in the study for Rotterdam (Dumitrescu 2013, p. 13), the minimum acceptable surface area for suitable rooftops was assumed with 500 m^2. Furthermore, according to (Freisinger et al. 2015, p. 35) a minimum area of 1,000 m^2 is necessary for commercial hydroponic and aquaponic greenhouse farms. Finally, it was decided to choose a minimum area of 1,000 m^2. This factor was also considered for the creation of the GIS model (see chapter 5).

4.5 Location based factors

4.5.1 Climate

Regarding the general city climate, the same principles apply as with farming on the ground in the area of Vienna. The city is located in a temperate climatic zone with changing temperatures and sun hours according to the seasons. Agricultural activity is mostly carried out in spring and summer, whereas farming in winter usually occurs in conditioned greenhouses.

Concerning the microclimate of the roof, extreme heat and wind should be avoided. Though plants need enough sunlight to grow, they also have to be protected from heat stress, for example by providing shade with the help of a canopy. The wind velocity is depending on the height of the building and other factors. Ackerman et al. (2012) decided on maximum 10-story buildings for their analysis of New York City, because of the climatic conditions and the transportation of growing media, materials, and equipment. On the other hand, the study for Rotterdam (Dumitrescu 2013) decided on a maximum building height of 40 m to avoid strong winds and excessive sun exposure. For the GIS analysis for the present master's thesis it was not possible to include the building height, due to a lack of data. Mandel (2013) further suggests to avoid strong winds by choosing buildings that are shielded from rivers and other bodies of water that act as wind corridors. Additionally, she recommends to choose a site where taller neighboring buildings act as windbreaks.

4.5.2 Solar radiation

In order to find out if a roof receives enough solar radiation to operate a commercial farm without artificial lighting, it is advised to carry out a different analysis for each specific building. This can also help in finding the right layout for the farm. Nevertheless the Viennese "solar potential cadastre" (*Solarpotentialkataster*) can give some orientation in this regard. This cadastre was originally created to give information on the suitability of a roof for PV-panels or solarthermal installations. It tells if a building receives either more than 1,100 KWh/m^2 solar energy per year, more than 900 KWh/m^2 solar energy per year or less than 900 KWh/m^2 . This information was also included in the GIS-model, as described in section 5.2.

Mandel (2013) additionally recommends to choose a site where there are no taller buildings or vacant lots to the south, to ensure enough solar radiation.

4.5.3 Other location based factors

Other location based factors include the proximity to consumers and infrastructure. Although this is an important issue for some cities (as discussed by Mandel (2013)), these factors are considered insignificant for Vienna. Since the area of the city is relatively small with a high density of markets and restaurants and good infrastructure, it is assumed that these factors are no problem for any existing building in Vienna.

4.6 Legal aspects

4.6.1 Standards

In Austria compliance with standards is not required by law per se. Nevertheless some laws refer to standards, which effectively makes them legally binding (see also section 4.6.2). The publications of the Austrian Standards Institute serve as recognized guidelines and compliance with the standards can be of advantage in the case of legal problems.
Additionally compliance with standards can be the basis for subsidies. For example Vienna's Municipal Department Parks and Gardens (MA 42) supports green roofs with a grant, on condition that the installation is performed according to ÖNORM L 1131 by a horticultural company. (Vienna City Administration 2)

Austrian and international standards which are of special interest in relation to the planning, building and operation of rooftop farms, are listed below.

ONR 24009 Evaluation of load capacity of existing building constructions

ÖNORM EN 1991-1-1 Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings

ÖNORM B 1991-1-1 Eurocode 1 - Actions on structures - Part 1-1: General actions - Densities, self- weight and imposed loads for buildings - National specifications

ÖNORM EN 1991-1-3 Eurocode 1 – Actions on structures – Part 1-3: General actions – Snow loads

ÖNORM B 1991-1-3 Eurocode 1 - Actions on structures - Part 1-3: General actions – Snow loads - National specifications concerning ÖNORM EN 1991-1-3 and national supplements

ÖNORM EN 1991-1-4 Eurocode 1 – Actions on structures – Part 1-4: General actions – Wind actions concerning ÖNORM EN 1991-1-1 and national supplements

ÖNORM B 1991-1-4 Eurocode 1 - Actions on structures - Part 1-4: General actions – Wind actions - National specifications concerning ÖNORM EN 1991-1-4 and national supplements

ÖNORM L 1131 Planning, building and maintenance of green area on roofs

ÖNORM EN 13031-1 Greenhouses: Design and construction - Part 1: Commercial production greenhouses

ÖNORM B 3691 Design and execution of roof waterproofing

4.6.2 Building law

The legislative and executive jurisdiction of building laws in Austria rests in the hands of the nine federal provinces. The city of Vienna is a province on its own with several laws and regulations that have to be taken into account for construction projects. The following list gives an overview of the structure of different Viennese laws and regulations concerning construction projects. This is not a complete list of all regulations concerning construction projects, but it suffices to demonstrate the complexity of the legal system. The terms are translated by the author, the original german titles are written in parentheses, in italic. (Vienna City Administration 3)

- ▷ Viennese Building Code (*Bauordnung für Wien - BO für Wien*)
  - By-laws to the Viennese Building Code
    - Viennese Allotment Law (*Wiener Kleingartengesetz*)
    - Viennese Garage Law (*Wiener Garagengesetz*)
    - Viennese Elevator Law (*Wiener Aufzugsgesetz*)
    - Viennese Canal Law (*Gesetz über Kanalanlagen und Einmündungsgebühren*)
    - Law for the protection against construction noise (*Gesetz zum Schutz gegen Baulärm*)
  - Regulations to the Viennese Building Code (*Verordnungen*)
    - Viennese Regulations for Construction Engineering (*Wiener Bautechnikverordnung*)

    * Construction Plan Regulation (*Bauplanverordnung*)
    * Viennese Garage Regulation (*Wiener Garagenverordnung (Ausgleichsabgabe)*)

- ▷ Viennese Environmental Protection Law (*Wiener Naturschutzgesetz*)

The Viennese Regulations for Construction Engineering (*Wiener Bautechnikverordnung*) from 2015 made the Guidelines of the Austrian Institute of Construction Engineering, short OIB Guidelines (*Richtlinien des Österreichischen Instituts für Bautechnik*, short *OIB Richtlinien*) legally binding for Vienna. Since these guidelines often refer to the Eurocodes. This makes them legally binding as well.

The Viennese Building Code (*Bauordnung für Wien*) is passed by the Viennese Provincial Parliament (*Wiener Landtag*) and regulates the land-use planning, urban planning, the construction of new buildings and modifications to existing buildings. The Municipal Department MA 64 is responsible for publishing the land-use plan and the Municipal Department MA 37 (also called *Baupolizei*) is responsible for verifying the compliance with the regulations and granting the building permit. (Vienna City Administration 3)

In addition to the Viennese regulations, all federal laws have to be taken into consideration, for example the Monument Protection Act (*Denkmalschutzrecht*) and the Commercial Law (*Gewerberecht*).

4.6.3 Building permit

According to § 60 of the Viennese Building Code, new buildings and modifications and additions to existing buildings require a building permit. Included in the list of construction projects that require a building permit are vertical extensions to existing buildings and modifications that have an influence on the fire safety of a building or that can alter the exterior view of the building.

Though there is no explicit notion of green roofs or roof gardens in the Viennese Building Code, it can be assumed that for the construction of a rooftop farm, a building permit is required. The literature agrees in general to the requirement of a building permit for roof terraces (Baldia 2014), green roofs (Pendl et al. 2009) and roof gardens (Ehlers et al. 1986). Furthermore, it is assumed that a greenhouse is considered a vertical extension and most probably alters the exterior view of a building.

Requests for a building permit have to be submitted to the MA 37. The list below features documents that have to be submitted with the request. There were only documents included which are considered relevant for the construction of rooftop farms. The complete list of documents required for a request for a building permit can be found on the Viennese governmental website (Vienna City Administration 4). Descriptions of the documents are translated by the author.

- ▷ Request Form
- ▷ Building plans
- ▷ Approval of all owners registered in the Land Registry, e.g. with signatures on the building plans

- ▷ Proof of the use of high efficient alternative energy supply systems, or proof that the use is not feasible
- ▷ For new constructions, modifications or additions: confirmation that the principles of accessible design and construction are followed
- ▷ Documented calculation of the resident fees
- ▷ Proof of compliance with the parking requirement
- ▷ Structural analysis for the preliminary design
- ▷ Design concept for garden areas of the site
- ▷ Proof of the availability of sufficient water for firefighting (on the building plan)
- ▷ Location for waste containers on the building plan
- ▷ Required documents for architectural review of the Department of Architecture and Urban Design (MA 19)

Some of the required documents can be especially problematic for the construction of rooftop farms. First, the approval of all owners registered in the Land Registry is needed, for example in the form of signatures on the building plans. This could be a difficult issue if there are several co-owners and not all of them agree with the planned project, as it is often the case with residential buildings (see also section 4.6.7 and 4.12.4). Second, documents for architectural review of the Department of Architecture and Urban Design (MA 19) have to be submitted. A favorable opinion about the project from the MA 19 is necessary for receiving the building permit. By changing the roof structure and adding constructions, the appearance of the building could be modified and may not be in compliance with the cityscape anymore. This issue is discussed in further detail in section 4.6.5.

For the planning of a rooftop farm, the most significant factor usually is the building height. The minimum and maximum building heights are regulated in the land-use plan and § 75 and § 81 Abs. 4 - 6 of the Viennese Building Code. The MA 37 reviews the request and checks the accordance with the regulations. If the design is in accordance with the law, the building permit is granted.

Additionally, there is the possibility to have a simplified procedure according to § 70a of the Viennese Building Code, if compliance with the regulations is verified by a legally certified engineer (*Ziviltechniker*). The simplified procedure should lead to an earlier start of the construction works, which can start one month after the request. Over a period of three months after the request, neighbors can raise objections against the project and at the end of the period the building permit must be granted or reasons for the inadmissibility must be given.

The building permit does not substitute other possibly required permits. If the rooftop farm serves a commercial purpose, the Industrial Code (*Gewerbeordnung*) has to be considered as well. In the case of a rooftop farm, there is the possibility that an industrial operating permit (*Betriebsanlagengenehmigung*) is necessary (see section 4.6.4).

4.6.4 Industrial operating permit

According to § 74 of the Industrial Code all buildings, rooms, areas and facilities where a business is operated on a regular basis are considered an operating facility (*Betriebsanlage*). An industrial operating permit (*Betriebsanlagengenehmigung*) is required if the operating facility

(a) could present a risk for the facility owners, customers or neighbors and their property,

(b) could cause inconvenience to the neighbors,

(c) could endanger the quality of water,

(d) impairs the public transportation, or

(e) could cause inconvenience to institutions such as churches, schools or hospitals.

The responsible agency is the Vienna City Administration (*Magistratisches Bezirksamt*).

The industrial operating permit is not required prior to obtaining a building permit. Nevertheless it might be helpful to obtain the industrial operating permit first. The authority can impose conditions that must be fulfilled during the operation of the facility and it might be helpful to be able to consider the requirements in the request for the building permit. (World Bank Group)

4.6.5 Monument Protection

Regarding monument protection, there are several laws and agreements that have to be taken into account for construction projects in Vienna. The federal Monument Protection Act forms the legal basis for the protection of monuments in all of Austria. Additionally, the city of Vienna has declared protection zones in various areas of the city and there are international agreements like the UNESCO Convention on the protection of World Heritage that need to be considered as well. In the following, the different regulations are described in more detail with indication of the responsible authorities.

Monument Protection Act

The Monument Protection Act is a federal act that regulates the protection of monuments due to their historic, artistic or other cultural significance. The responsible authority is the Federal Monuments Office (*Bundesdenkmalamt*, short BDA), which keeps a public list of all protected monuments, the Denkmalverzeichnis. In 2015 there were 2,601 secular buildings and 394 sacred buildings in Vienna listed as protected monuments, according to Statistik Austria (2015). The monument status of each building in Vienna can also be viewed in the Land Registry.

The BDA has to agree to every destruction and modification of an object that can influence its appearance. Agreement is expressed in the form of a permit, granted by the Federal Monuments Office, which is independent from the building permit. Either permit can be obtained without the other, but the construction project can only be realized legally if both are obtained. (Bundesdenkmalamt)

Protection Zones

According to the "Altstadterhaltungsnovelle" from 1972, a law for the protection of the old town, the city of Vienna can declare protection zones (*Schutzzonen*). These are areas forming a characteristic ensemble that should be preserved, independent from the federal Monument Protection Act. The protection zones are displayed in the land-use plan and their protection is regulated in § 7 of the Viennese Building Code.

Construction projects are reviewed by the MA 19 regarding the modified appearance of the building and its accordance with the cityscape. This review is part of the process for obtaining the building permit and therefore no additional permit is required. There are 135 protection zones (shown in figure 4.1 a) that include more than 15,000 buildings, which represents around 9% of the Viennese building stock. (Vienna City Administration 5)

UNESCO World Heritage

The *Convention Concerning the Protection of the World Cultural and Natural Heritage* (Unesco 1972) is an international agreement of the UNESCO (United Nations Educational, Scientific and Cultural Organization). Participating parties commit themselves to the identification, protection, conservation and presentation of World Heritage sites, including taking legal measures. The responsible authority for the implementation of the convention is called *World Heritage Committee*, consisting of representatives from 21 of the States Parties to the Convention. As of 2016, the agreement was adopted by 193 states and ratified by Austria in 1992. (Unesco)

Identified and accepted sites are recorded in the World Heritage List. Vienna has two UNESCO World Heritage zones, the Palace and Gardens of Schönbrunn and the Historic Centre of Vienna (primarily the first district and Belvedere Palace). Core and buffer zones inside the city are shown in figure 4.1 b.

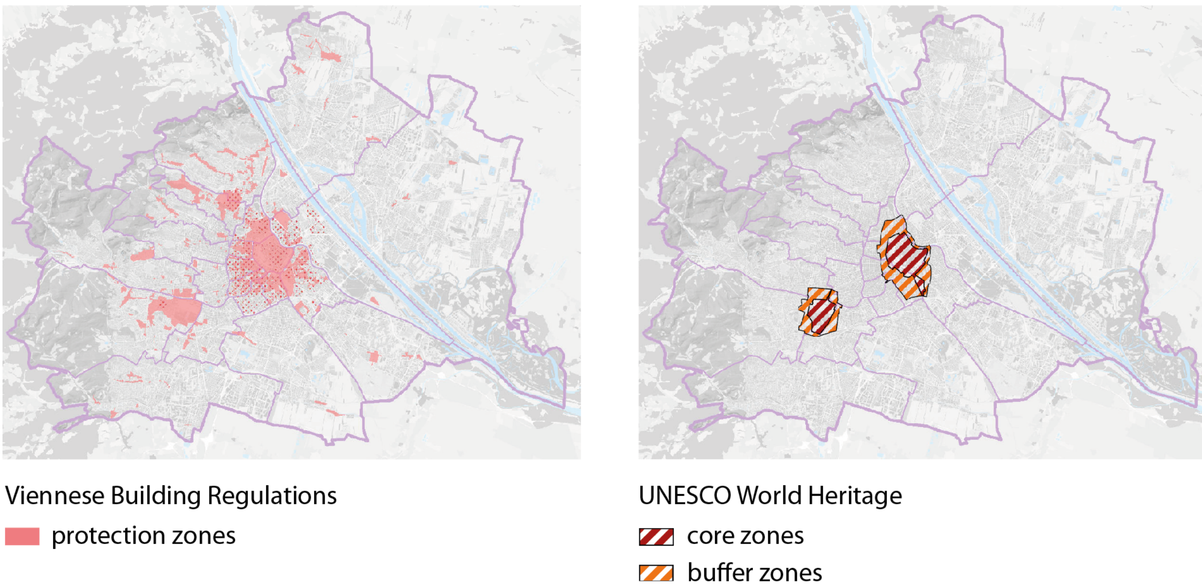


Figure 4.1: Viennese protection zones and UNESCO World Heritage zones (https://www.wien.gv.at/stadtplan/)

The areas are protected at federal and provincial level by the Monument Protection Act and the Viennese Building Code (in the form of protection zones and building regulations). Nevertheless, a construction project that conforms to the Austrian regulations but is still refused by the World Heritage Committee can lead to withdrawal from the World Heritage List.

An interesting aspect of the UNESCO World Heritage regarding the implementation of rooftop farms can be found in the *Recommendation on the Historic Urban Landscape* (Unesco 2011). In answer to changing conditions for cities faced with global challenges like demographic shifts and climate change, the organization published the additional recommendation, including the following statement.

> *"Concern for the environment, in particular for water and energy consumption, calls for approaches and new models for urban living, based on ecologically sensitive policies and practices aimed at strengthening sustainability and the quality of urban life. Many of these initiatives, however, should integrate natural and cultural heritage as resources for sustainable development."* (Unesco 2011, sec. II, para. 17)

The statement acknowledges the importance of innovations for the existing urban environment but also clarifies that the protection of heritage is an essential part of sustainability. It can be interpreted in the way that construction projects concerning the modification of monuments for environmental purposes, like rooftop farms, will be viewed as legitimate by the committee. However, these projects still have to fit the criteria for the protection of world heritage sites.

4.6.6 Health and safety

The Viennese Building Code (2016) includes requirements for health and safety which have to be fulfilled in order to obtain the building permit. This section should provide a more detailed insight into important issues concerning health and safety with respect to rooftop farms. These issues are listed below and will be further described in the following.

- Fire safety
- Fall protection
- Sanitary facilities

Fire safety

According to Pendl et al. (2009), intensive green roofs that are regularly irrigated present a low risk for fire. Nevertheless, the regulations demand a proof for the fire safety. It is assumed that for open-air farms and retrofitted greenhouses the same rules apply as for the other stories of the building. The requirements of the OIB Guideline 2, which regards fire safety, have to be fulfilled. To this end, all construction materials need a certain level of fire resistance, escape routes and the division of fire compartments have to be considered.

Another useful set of standards for planning with respect to fire safety is provided by the Austrian federal fire department association (*Österreichischer Bundesfeuerwehrverband*) under the name *Technische Richtlinien Vorbeugender Brandschutz*, short TRVB.

Fall protection

For open-air farms, a guard rail or parapet is necessary to protect people from falling off the roof. The Viennese Building Code demands that where there is a risk of falling, there has to be mounted a protection. On the roof this can be a parapet or railing. If children can access the area, the railing has to be constructed in such a way, that they cannot climb or slip through the grills. According to the OIB GUIDELINE 4, the minimum height of such a protection is 1.00 m and for a fall height of 12 m or more 1.10 m. Additionally, the railing must withstand a horizontal force according to ÖNORM EN 1991-1-1 and ÖNORM B 1991-1-1. There is also the possibility to combine a protection against falling with a wind or sun protection or as a trellis for climbing plants.

Another issue regarding fall protection is the access to the roof. Existing egresses to roofs that are only accessible for maintenance purposes are not necessarily safe to use as an entrance to a rooftop farm. For more information on safe access to the roof see section 4.10.1.

Sanitary facilities

Besides the necessary production facilities (see section 4.10.3), sanitary facilities for employees and visitors should be included in the layout of the farm. They can be situated on the rooftop or in a different story of the building and have to be scaled according to the size of the farm and number of employees.

In § 98 of the VIENNESE BUILDING CODE, it is stated that buildings with common rooms and buildings that are intended to host a larger number of people have to be equipped with sufficient sanitary facilities. These facilities have to meet the needs of the building with respect to hygiene. A similar formulation can be found in OIB GUIDELINE 3, which deals with hygiene, safety and environmental protection.

4.6.7 Ownership

In this master's thesis, a rooftop farm is considered an extension to an existing building. This building can be owned by one or more private persons, companies or a public institution. Since all co-owners of a building have to agree to the construction of a rooftop farm (see section 4.6.3), a non-cooperative owner could present a major obstacle for such a project. It is for example possible that co-owners, residents or companies that have offices in the building demand certain security measures like a separate entrance for farming personnel and visitors.

The simplest situation is definitely a single private owner who decides to realize a farming project on the roof him- or herself. Alternatively the roof area could be rented by the farm operators. In this case it has to be clearly regulated in a contract who is liable for damages. Usually the tenant (farm operator) is the liable party. A common problem is for example the damaging of the waterproof roof layer. The repairs of a damaged waterproof layer can be very expensive. Therefore this risk has to be considered by a rooftop farming company.

4.7 Building use

Before the construction of a new building, the intended use has a large effect on the building structure, installations and floor plan. In addition, the use of a building is often connected to the ownership situation. These factors, together with the available information of land use for the GIS-model (see section 5.3) led to the definition of the following five categories of use.

1. Industrial / Retail

2. Education, Health, Sport, Culture

3. Office
4. Housing / Mixed use
5. Parking

Building usages that were intentionally not included in the categories because they could pose a risk to human health or deemed unsuitable for rooftop farming are gas stations, energy related buildings and communications facilities. These types of buildings have also been excluded from the analysis of Ackerman et al. (2012) for New York City.

The details of what each category of use implicates with respect to rooftop farming are discussed in section 4.12. The categories form the basis of the five different typologies used as case studies.

4.8 Building structure

For each building, there has to be made an individual structural analysis by a certified structural engineer to show that the building can support a rooftop farm. This analysis is required for obtaining a building permit (see section 4.6.3). The evaluation of the load bearing capacity of existing building constructions is regulated in the ONR 24009. The loads that have to be considered for the construction of a rooftop farm inlcude the existing and additional loads caused by the farm (see section 4.8.3).

Generally speaking, the built structure should depend on the regulatory framework of the country. Concerning pay loads, the Viennese Building Code refers to the Austrian standard ÖNORM EN 1991-1-1, the national implementation of the European standard called "Eurocode 1", in combination with the National Annex ÖNORM B 1991-1-1. The built structure usually has been constructed according to the standards valid at the time of construction. The specified loads for the roof determine the roof structure and the pay loads for each floor determine the building structure, including the foundations.

In the past decades, the values for pay loads have changed. This is in part due to the fact that material parameters are better known today and structural calculations can be performed more exact. Therefore structures can be used more efficiently. Values for past and present pay loads are given in annex B and are discussed in the next section.

4.8.1 Comparison of historic standards

The buildings in Vienna offer a great diversity of construction dates, quality and materials. Since there is no comprehensive data available about construction dates, building materials and the status of the structures, it is difficult to draw conclusions about the structural fitness of all buildings in Vienna.

For the purpose of analyzing the city with respect to supporting structures, this thesis uses the approach of comparing the standard of imposed loads for buildings which is valid today (ÖNORM EN 1991-1-1 in combination with ÖNORM B 1991-1-1) with old standards that were valid at the time of construction. The comparison is focused on the defined pay loads, because they affect the supporting structure of the whole building, including the foundations.

The historic building regulations and Austrian standards concerning pay loads are liste below in chronological order (according to ONR 24009).

Historic building regulations:

- ▷ Circulare der k.k. Landesregierung in Erzherzogthume unter der Enns, 1829
- ▷ Verordnung des k.k. Ministeriums des Inneren vom 23.September 1859 (Bauordnung für die k.k. Reichshaupt- und Residenzstadt Wien)
- ▷ Normalien des Österreichischen Ingenieur- und Architektenvereines: Bestimmungen für die Belastung von Baukonstruktionen und Beanspruchungen von Baumaterialien, Wien 1902
- ▷ Österreichische Regierungsvorschrift vom 15.November 1907
- ▷ Vorschrift über die Herstellung von Tragwerken aus Stampfbeton oder Beton-Eisen bei Hochbauten, 1911

Unfortunately not all of the above mentioned were available to the author. Regarding the historic building regulations, only the values of *Normalien des Österreichischen Ingenieur- und Architektenvereines: Bestimmungen für die Belastung von Baukonstruktionen und Beanspruchungen von Baumaterialien* from 1902 could be obtained from KOLBITSCH (1989).

Austrian standards:

- ▷ ÖNORM B 4001:1955, Berechnung und Ausführung der Tragwerke; Hochbau; ständige Lasten und Nutzlasten im Hochbau
- ▷ ÖNORM B 4001:1962, Berechnung und Ausführung der Tragwerke; Hochbau; ständige Lasten und Nutzlasten im Hochbau
- ▷ ÖNORM B 4001:1965, Berechnung und Ausführung der Tragwerke; Hochbau; ständige Lasten und Nutzlasten im Hochbau
- ▷ ÖNORM B 4001:1974, Ständige Lasten und Nutzlasten im Hochbau
- ▷ ÖNORM B 4012:1981, Belastungsannahmen im Bauwesen; Nutzlasten im Hochbau
- ▷ ÖNORM B 4012:1988, Belastungsannahmen im Bauwesen; veränderliche Einwirkungen; Nutzlasten
- ▷ ÖNORM B 4012:1997, Belastungsannahmen im Bauwesen - Veränderliche Einwirkungen - Nutzlasten

Additionally to the standards listed in ONR 24009, the following outdated standards have been considered for the comparison.

- ▷ ÖNORM ENV 1991-1-1:1995, Eurocode 1: Grundlagen der Tragwerksplanung und Einwirkungen auf Tragwerke - Teil 2-1: Einwirkungen auf Tragwerke - dichten, Eigenlasten, Nutzlasten
- ▷ ÖNORM EN 1991-1-1:2003, Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings

- ÖNORM B 1991-1-1:2003, Eurocode 1 - Actions on structures - Part 1-1: General actions - Densities, self- weight and imposed loads for buildings - National specifications concerning ÖNORM EN 1991-1-1 and national supplements.

The available regulations and standards are compared in a table in annex B. The table illustrates that there is a high potential for structural capacities. All fields colored in red represent a higher or possibly higher pay load value than the one that has to be used today according to ÖNORM EN 1991-1-1 and/or ÖNORM B 1991-1-1. The highest potential offer industrial buildings that experienced a change of use and are therefore imposed with lower pay loads than they have been initially designed for. Other capabilities can be found within buildings with areas where people might congregate, like schools, restaurants, cafés, theaters, museums or exhibition halls.

Examples of how the information of the table can be used for the analyzation of a building can be found in section 4.12 for each case study typology.

4.8.2 Existing dead loads

The existing dead loads of the building structure have to be considered for the structural analysis. However, for the construction of a rooftop farm it can be necessary to remove parts of the roof structure, which decreases the dead load.

Typical roof structures of buildings in Vienna are also discussed in section 4.9. Considering for example a warm roof with gravel on top, the structure could be used for a rooftop farm except for the gravel. The specific weight of gravel is about $18.00\,kN/m^3$. A typical thickness of 8 cm gravel layer result in a load of $1.44\,kN/m^2$ that can be deducted from the existing dead loads. On the other hand the part of a cold roof that has to be removed weighs about $0.30\,kN/m^2$ (metal covering on timber boarding). (Krapfenbauer 2011)

4.8.3 Additional loads

For the construction of a rooftop farm, the following additional loads need to be considered.

- Dead load
- Pay load
- Wind actions
- Snow load
- Crop actions

Dead load

The additional dead load consists of all imposed loads that are relatively constant over time. The additional weight according to the type of rooftop farm is discussed in section 3.6.3 and reaches from $3.0\,kN/m^2$ for a lightweight green roof to $15.0\,kN/m^2$ for a biofilter of an aquaponic greenhouse. Permanently present machines and technical equipment have to be considered for the dead load of a rooftop farm as well. Additionally the weight of plants and crops can considered as part of the dead load (see also crop actions).

Pay load

As mentioned before, the required pay load values are regulated in ÖNORM EN 1991-1-1 and ÖNORM B 1991-1-1. The value for accessible roofs is defined as the value for the adjacent rooms according to the use categories A to G (see also annex B). There is no explicit notion of farming, though it is assumed that the according pay load value is about 3.0 kN/m^2 to 5.0 kN/m^2. Depending on the layout of the farm, it is possible to have different areas with different pay loads. Storage rooms (category E1.3) and areas with possible large crowds or physical activities (categories C3.2, C4 and C5) account for a minimum of 5.0 kN/m^2, industrial buildings and halls (category E1.2) for at least 4.0 kN/m^2 and office areas (category B2) for 3.0 kN/m^2. The farming area itself is presumed to be comparable to the categories C2 (areas with fixed seats) and C3.1 (areas with moderate frequency of people without obstacles for moving people), which account for 4.0 kN/m^2.

Wind actions

Additional wind loads have to be considered for added structures. This is evident for green houses, but should also be considered for open air farms with additional parapets or railing, trellis for climbing plants and structures for the protection of plants against wind. The calculation of the required wind load is regulated in ÖNORM EN 1991-1-4 and ÖNORM B 1991-1-4.

Snow load

The snow load may increase or decrease according to the added structures. The calculation of the required snow load is regulated in ÖNORM EN 1991-1-3 and ÖNORM B 1991-1-3. For an open-air farm, the load will stay the same. Depending on the roof shape of a greenhouse, the snow load shape coefficient μ_i influences the snow load value. A pitched roof usually accounts for a lower shape coefficient, whereas the possibility of snow accumulation increases μ_i and causes a significantly higher snow load value. A heated greenhouse also accounts for a lower snow load. The thermal coefficient C_t for heated greenhouses is given in Annex E of ÖNORM EN 13031-1. It varies between 0.6 and 0.9 depending on the roof cladding.

Crop actions

According to ÖNORM EN 13031-1, crop actions that are caused by plants and crops and which are supported by the greenhouse structure have to be taken into account as variable actions. The given minimum characteristic values for crop actions range from 0.15 kN/m^2 for crops like tomatoes and cucumbers to 1.00 kN/m^2 for crops in heavy containers.

Since there are no regulations for crop actions in ÖNORM EN 1991-1-3 and ÖNORM B 1991-1-3, it is recommended to include the weight of plants and crops in the dead load, for open-air farms and hydroponic farms where they are not supported by the greenhouse structure.

4.9 Roof structure

The supporting structure of the roof needs to be evaluated in the structural analysis. Contrary, in this section, the different roof types that are commonly found in Vienna and their feasibility for rooftop farming are being discussed. Since the existing roof structure will be changed into a floor for hydroponic greenhouses, this section is focused on soil-based farms that are constructed as a green roof. They might take advantage of the existing structure.

The flat roofs that can be found in Vienna can be divided into three different types: “cold roof” (*Kaltdach*), “warm roof” (*Warmdach*) and “inverted roof” (*Umkehrdach*). According to Pendl et al. (2009) and ÖNORM L 1131, all of the different roof types can be suitable for greening. They are described in the following. A special case is the top level of parking garages that are constructed as a parking area with an asphalt top layer. This case is discussed in section 4.12.5.

Cold roof

Cold roofs are also called ventilated roofs. In this concept, the insulation is supported by an independent ceiling, whereas the roof deck is supported by rafters. Between the two layers is a void with air supply. In order to prevent condensation between the layers, sufficient ventilation has to be provided. Figure 4.2 shows the typical layers of a cold roof. (Bauder)

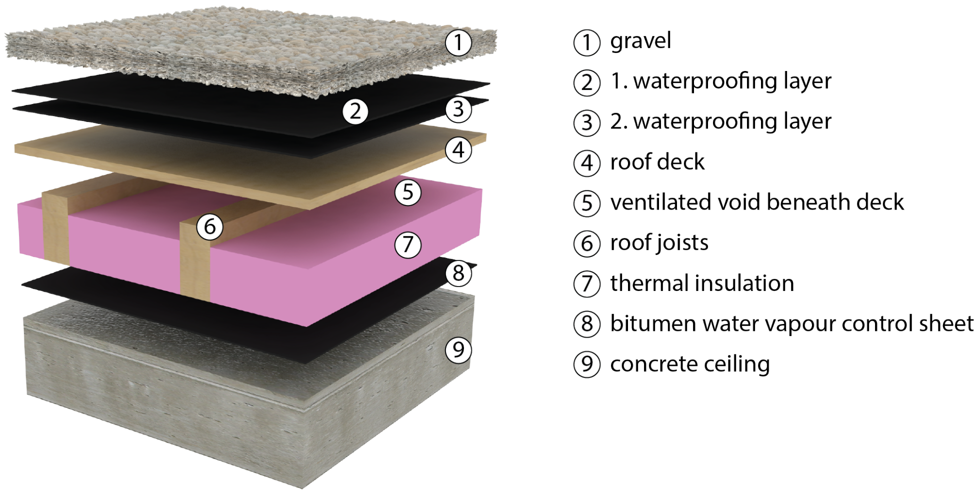


Figure 4.2: Buildup of a cold roof

According to ÖNORM L 1131 p. 8, cold roofs can be turned into green roofs, if the roof deck exhibits sufficient capacity to bear the additional load. The standard also mentions that the cooling effect of the vegetation can influence thermal processes in the structure.

Warm roof

Warm roofs are non-ventilated roofs where the waterproofing layer is located on top of the insulation. In many cases ballast or paving stones are added for the protection of the structure. They provide weight against wind actions and keep heat, sunlight and weather off the structure. A typical layer composition for a warm roof can be found in figure 4.3.

Warm roofs are also suitable for intensive greening. For this purpose the ballast or paving is removed and a root barrier has to be installed. Furthermore, it is important that the load

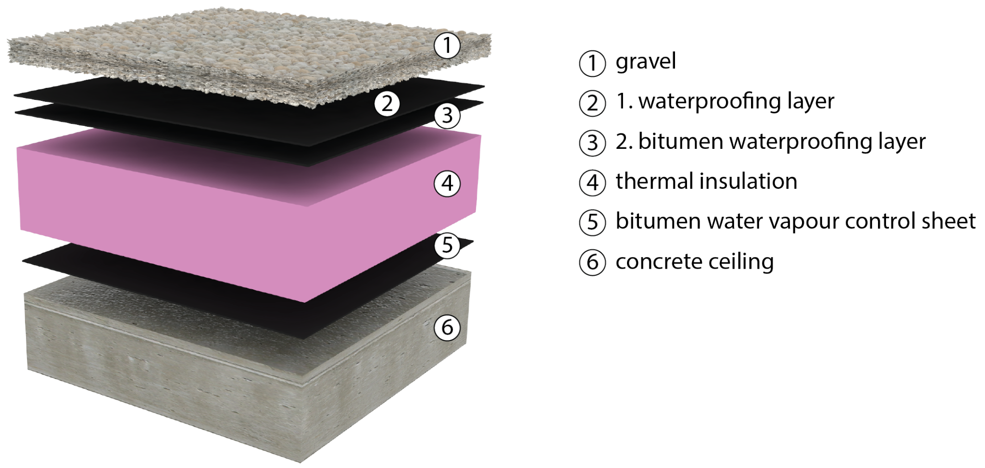


Figure 4.3: Buildup of a warm roof

capacity of the insulation is considered (ÖNORM L 1131, p.8). According to PENDL et al. (2009), the warm roof is economically best suitable for green roofs.

Inverted roof

The inverted roof is also called "protected membrane roof". With this roof, the waterproofing layer is located underneath the thermal insulation and therefore water is running through the insulation before being led to the gutter system. This kind of roof demands waterproofing membrane materials that are tolerant of supporting load and thermal insulation that is withstanding water (e.g. extruded polystyrene). As with warm roofs, ballast or paving stones are placed on top for the protection of the insulation. Figure 4.4 shows the structure of an inverted roof.

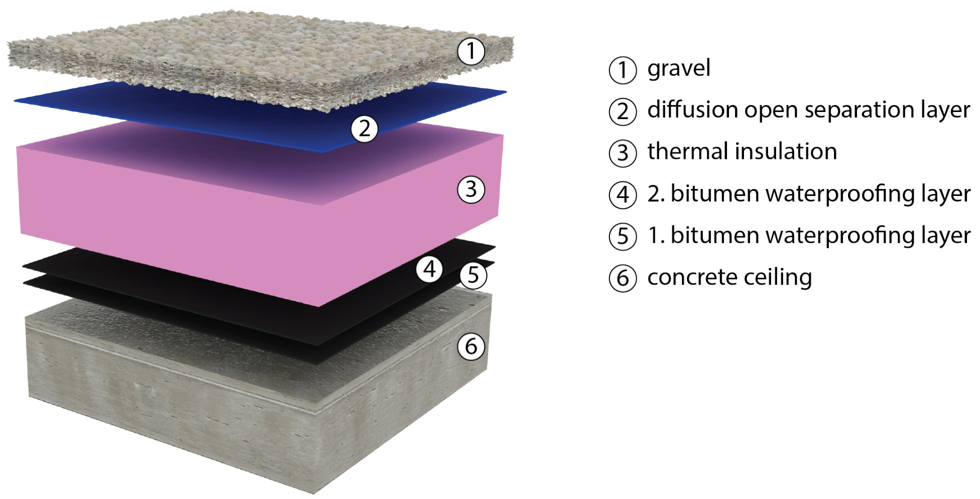


Figure 4.4: Buildup of an inverted roof

According to ÖNORM L 1131, inverted roofs are suited for intensive greening, if vapor diffusion to the outside is possible.

4.10 Building infrastructure

In this thesis, building infrastructure includes the access to the roof, building installations for water, electricity and air, and facilities necessary for the production (sanitary facilities, storage space, office space, common rooms, parking).

4.10.1 Roof access

For the installation and operation of a rooftop farm, it is necessary to have access to the roof. This access should meet certain criteria for efficient production and safety. Not only people but also material have to be transported to the roof and people, material and produce have to be transported down again. Ladders, pull-down staircases and narrow staircases do not meet the requirements of the Viennese Building Code and OIB Guideline 4. For main staircases, according to OIB Guideline 4, the minimum width is 1.20 m. In her book “Eat Up”, Mandel (2013) (p. 94) claims that the safest legal access to a roof in Philadelphia is *“through the door of a taller building story or a headhouse (a rooftop vestibule in which a staircase from the floor below exits onto the roof)”*.

It certainly is an advantage if there is an already existing staircase or elevator leading to the roof level. If not, the access has to be retrofitted. Sometimes it can also be necessary to install an additional access to the roof for reasons of security. As discussed in section 4.6.7, co-owners may demand a separate entrance for the farm. Additionally, restrictions concerning the escape route have to be considered. This is a matter of fire safety, which is described in section 4.6.6. Adding an access to the roof can be especially problematic if there are restrictions regarding monument protection (see section 4.6.5) and the buildings appearance should not be modified. A solution to this could be an exterior staircase and/or elevator on the backside of the building that cannot be viewed from the street.

With respect to accessibility, it should also be considered to design the layout of the farm in a way to provide short ways from and to the access point. This ensures maximum efficiency for farming procedures.

4.10.2 Building installations

Building installations with respect to rooftop farming include water supply and water disposal, electricity and HVACR (heating, ventilation, air conditioning and refrigeration). On the one hand, there are installations that are required by the farm, on the other hand, on most rooftops, there are existing building installations that could present an obstacle for the installation of a farm. The issue of existing installations is also discussed in the discussions of the GIS-model in section 5.7 under the title “roof installations”.

Water supply and electricity are necessary for every rooftop farm, whereas other installations depend on the farming system. Existing connections to water and electricity on the roof level are an advantage for the construction of a rooftop farm. If this is not the case, mostly, the new installations for the farm can be connected to the existing systems in the building. As discussed in section 3.5 with regard to urban symbiosis, it can be beneficial to connect a conditioned greenhouse to the HVACR-system of a building. Nevertheless, it can be necessary to install additional pipes inside the building that account for a substantial amount of space. This could pose a problem, especially in buildings with a high rental area/gross area ratio (usually residential buildings) where there is little space left for use. The extent of installations for the farm can also reduce the net farming area (see section 3.6.2). Alternatively, water supply could also be provided by rainwater collection and electricity by a source of renewable energy located directly on the roof.

4.10.3 Farming facilites

The following facilities should be considered for rooftop farms:

- ▷ Sanitary facilities
- ▷ Storage space
- ▷ Processing space
- ▷ Common room
- ▷ Kitchen
- ▷ Office space
- ▷ Parking

As mentioned in section 4.6.6, sanitary facilities should be provided for staff and visitors. Depending on the procedures of the farm, space for storage and processing must be included in the layout. Furthermore office space, changing rooms, a common room and kitchen can be beneficial to the operations of a farm. Parking for staff and visitors is optional but depending on the concept for sales and distribution, space for delivery and parking for vans or cargo bikes has to be considered. All of these facilities can be located on the roof, in other stories of the building or within close proximity to the farm. When located on the roof, the net farming area can be significantly reduced by these nonproductive areas (see section 3.6.2).

4.11 Financial aspects

A retrofitted rooftop farm is an investment with substantial construction costs. The costs are usually larger than for a rooftop farm constructed for a new building. It is difficult to give exact numbers for the construction costs for projects on existing buildings. The projects are always unique and the costs depend largely on the circumstances of the building and the design of the farm. Additionally, the existing retrofitted rooftop farms are not numerous and the construction of such farms is still not common. In general it can be said that hydroponic greenhouses are high input/high output farms. In order to produce high yields, it is necessary to make a high investment in the first place. Soil-based open-air farms on the other hand, need a smaller investment, which goes hand in hand with lower yields.

Nevertheless, to give a guideline, average construction costs for the two farming systems are presented in table 4.1. The basis for this are the construction costs of four different rooftop farming projects. The values are given in USD/m^2 at the time of construction, indexing has not been considered. Known details of the costs for each farming project are discussed in the following.

Table 4.1: Average construction costs of rooftop farms

Open-air and soil-based	Hydroponic greenhouse
∅ 79 USD/m^2	∅ 882 USD/m^2

According to Mandel (2013) (p. 188), the construction cost of Long Island City Rooftop Farm (in 2010) of Brooklyn Grange in New York City was USD 200,000, which translates to around 50 USD/m^2. Eagle Street Rooftop Farm, which finished constructions in 2009 in New York City, had a total construction cost of USD 60,000 for the green roof and around USD 3,000 for farming materials and seeds (Mandel 2013, p. 46). The size of the farm is around 557 m^2, which means construction costs of approximately 108 USD/m^2. The mean of these two projects is 79 USD/m^2. However, it has to be considered that these two farms were constructed with the help of volunteers, which reduces the construction costs significantly.

Mohamed Hage of Lufa Farms names the construction cost of their first hydroponic greenhouse farm in 2011 with about USD 2.2 million (Mandel 2013, p. 132). Since the area of the farm is aroung 2,880 m^2, this relates to about 764 USD/m^2. In their investment brochure, Urban Farmers 2 are looking for roofs with a minimum area of 2,000 m^2 and claim that the capex is approximately USD 2 million. With a minimum area of 2,000 m^2, this translates to around 1,000 USD/m^2. The mean of these two greenhouse projects is 882 USD/m^2.

Factors that can significantly increase the construction costs are the reinforcement of the building structure and the construction of an additional access to the roof.

4.12 Definition of Building Typologies

In order to give practical examples of what the parameters discussed in this chapter mean for an individual building, five building typologies have been defined as case studies. The classification of the typologies was defined on the basis of the building use, which in most cases determines the structure and ownership. According to the category of use (see section 4.7), the following five typologies were defined:

- ▷ Industrial / Retail
- ▷ Education, Health, Sports, Culture
- ▷ Office
- ▷ Housing / Mixed use
- ▷ Parking

After defining the typologies, correspondent example buildings in Vienna were chosen. The typologies and their characteristics are described in the following subsections and depicted in the classification matrices shown in table 4.3 to 4.7. The descriptions start with a short summary of the general building characteristics and continue with the classification matrix, followed by an analysis according to the parameters Structure, Ownership, Monument protection and Building infrastructure.

Real buildings will not show the exact characteristics of one typology. Nevertheless, the typologies can serve as a guideline. People who are interested in installing a rooftop farm on a specific building can analyze that building with the help of the classification matrix (table 4.2). The building characteristics should be entered in the matrix. This matrix is then compared to the typologies, to find out which typology or combination of typologies matches the building best and should be consulted.

Table 4.2: Template for the classification matrix

USE		STRUCTURE		OWNERSHIP		MONUMENT PROTECTION		ROOF INFRASTRUCTURE	
Industrial / Retail		Date of construction		Public		protection zone		stairs	
Education, Health, Sports, Culture		*before 1955*		Private		MPA		elevator	
Office		*1955-1980*		*single owner*		UNESCO		car access	
Parking		*1981-1995*		*multiple owners*				electricity	
Housing / Mixed use		*after 1995*						water supply	

4.12.1 Industrial / Retail

The key advantage of industrial buildings is the usually large area in a rectangular shape. As a bonus, synergies with respect to building installations (use heat from machines to heat the greenhouse) can benefit the farm. On the other side, existing installations on the roof could present an obstacle to the construction of a rooftop farm. Additionally, if the building is used as a supermarket or shopping center, the produce could be sold directly on place.

Classification matrix

Table 4.3: Classification matrix for the *Industrial* typology

USE		STRUCTURE		OWNERSHIP		MONUMENT PROTECTION		ROOF INFRASTRUCTURE	
Industrial / Retail		Date of construction		Public		protection zone		stairs	
Education, Health, Sports, Culture		*before 1955*		Private		MPA		elevator	
Office		*1955-1980*		*single owner*		UNESCO		car access	
Parking		*1981-1995*		*multiple owners*				electricity	
Housing / Mixed use		*after 1995*						water supply	

Structure

The *Industrial / Retail* typology is defined as a hall structure with one story, consisting of a flat slab with columns. The construction date is after 2000, so the respective standard is ÖNORM EN 1991-1-1, the standard that is valid today. If the building has been designed for current industrial use, this means that there are probably no structural reserves and the building has to be reinforced to support the additional weight.

Ownership

The typical industrial or retail building is owned by a single private owner which represents a good basis for obtaining a building permit.

Monument protection

The typology does not have any restrictions regarding monument protection.

Building infrastructure

There is no existing adequate access to the roof. A new staircase and an elevator have to be built, preferably with external access in order to not mix staff from the building and make the farm accessible on the weekends. Because of the low height of the building, the construction of the external access is relatively inexpensive.

On the roof there are some existing installations. However, they occupy only a small amount of space of the whole farmable roof area and therefore do not present a problem for the installation of a rooftop arm.

Example building

The example building for the *Industrial / Retail* typology is a supermarket at Friedrich-Engels-Platz 12, in the 20^{th} district of Vienna. The area suitable for the installation of a rooftop farm (the area called GREENAR05 according to the GIS-model) is about 1,000 m^2. This building was analyzed with respect to a rooftop greenhouse in the course of a bachelor thesis by Moysan (2017). An aerial view of the supermarket is shown in figure 4.5.

Figure 4.5: *Industrial / Retail* case study building (google maps)

4.12.2 Education, Health, Sports, Culture

This typology encompasses buildings that are publicly owned and serve one of the purposes mentioned in the name. Examples for buildings in this category are schools, universities, hospitals, nursing homes, sports halls and museums. Farms on top of such buildings could be managed as commercial farms producing food for the students, patients or inhabitants in cooperation with the facility.

Classification matrix

Table 4.4: Classification matrix for the *Education, Health, Sports, Culture* typology

USE		STRUCTURE		OWNERSHIP		MONUMENT PROTECTION		ROOF INFRASTRUCTURE	
Industrial / Retail		Date of construction		Public		protection zone		stairs	
Education, Health, Sports, Culture		*before 1955*		Private		MPA		elevator	
Office		*1955-1980*		*single owner*		UNESCO		car access	
Parking		*1981-1995*		*multiple owners*				electricity	
Housing / Mixed use		*after 1995*						water supply	

Structure

The construction date for this typology is defined in the late 1960s. The according standard is ÖNORM B 4001:1965. There might be capacity for additional loads. The pay loads in category A1 (hospital rooms), C1 and C3.1 according to ÖNORM B 4001:1965 (see table in annex B) have decreased. Pay loads of the category C2 may have decreased as well.

Ownership

This typology is owned by the state, the city or a public company. This could present an advantage if the owner him or herself is interested in a rooftop farming and promotes the development of such a project.

Monument protection

The building is located in the buffer zone of UNESCO World Heritage, but there are no legal restrictions regarding monument protection.

Building infrastructure

For this typology, there is an existing room on the same level as the majority of the roof area. This room is accessible via a staircase and an elevator. The roof area can be accessed via a broad door from the room. Additionally, it is equipped with water supply pipes and electricity. These are good conditions for the installation of a rooftop farm. No additional access is necessary. Installations for the farm can easily be hooked up to the existing ones on the roof level.
Furthermore, there are HVACR installations on the second roof level and a utility room. It is worth considering a symbiosis of the installations of a conditioned greenhouse with the existing HVACR system, as described in section 3.5.

Case study

The case study building for this typology is a university building of the TU Vienna in Gußhausstraße 27-29, in the 4th district of Vienna. It was built between 1967 - 1973 and has a GREENAR05-area of 3,077 m^2. The building was subject to the rooftop farming projects designed in the course of the university class "Industrial building" (Industriebau 2016), which have been used as a source for this thesis (as described in section 3.6.2).

Figure 4.6: *Education, Health, Sports, Culture* case study building (google maps)

4.12.3 Office building

Office buildings can have a simple ownership situation that can be beneficial for a rooftop farming project. This typology offers structural capacity, because of the changes in pay loads.

Classification matrix

Table 4.5: Classification matrix for the *Office* typology

USE		STRUCTURE		OWNERSHIP		MONUMENT PROTECTION		ROOF INFRASTRUCTURE	
Industrial / Retail		Date of construction		Public		protection zone		stairs	
Education, Health, Sports, Culture		*before 1955*		Private		MPA		elevator	
Office		*1955-1980*		*single owner*		UNESCO		car access	
Parking		*1981-1995*		*multiple owners*				electricity	
Housing / Mixed use		*after 1995*						water supply	

Structure

The *Office building* typology is defined as being constructed in the beginning of the 20th century. The standards valid at that time were the *"Normalien des Österreichischen Ingenieur- und Architektenvereines: Bestimmungen für die Belastung von Baukonstruktionen und Beanspruchungen von Baumaterialien"* from 1902. There is a high possibility that the load bearing capacity of the structure is high enough to support the additional weight, since the values for pay loads in office areas used to be higher at the time of construction. This can be seen in the table in appendix B. The value for pay loads in office areas is 4.50 - 5.50 kN/m^2 and the value today according to the

ÖNORM EN 1991-1-1 and ÖNORM B 1991-1-1 is 3.00 kN/m^2. However, since the building age is quite high, the condition of the structure - especially the foundations - has to be evaluated.

Ownership

The typology of the office building is considered as owned by a single private company. This might be an advantage, if the company is interested in supporting the farm for their public image, to present themselves as a sustainable company. But it is also possible that they want to benefit directly financially from the farm and charge a high rent.

Monument protection

This typology is defined as located in a protection zone according to the VIENNESE BUILDING CODE, as well as in the UNESCO World Heritage core zone. Additionally, it is protected by the MONUMENT PROTECTION ACT. Considering this monument status, it is advised not to alter the outer appearance and favor a construction that cannot be viewed from the street.

Building infrastructure

There are several existing headhouses where people can access the roof via staircases and elevators. No additional access has to be constructed. The roof features a lot of installations necessary for the HVACR-system of the building. The farm has to be designed in a way to avoid these installations and benefit from synergies with the building physics. Existing office areas inside the building can be rented additionally to provide the necessary facilities for production.

Case study

The case study building for the *Office building* typology is the Austrian Post Savings Bank in the first district of Vienna, the *Innere Stadt*. The address of the building, which is shown in figure 4.7, is Georg-Coch-Platz 2. The building was constructed from 1904-1912 and has a GREENAR05-area of about 2.729 m^2.

Figure 4.7: *Office building* case study building (google maps)

4.12.4 Housing / Mixed use

This typology represents buildings that are used entirely for housing or have a mixed use of housing and offices or other usages. Mixed use buildings have been included in the housing typology and not in the office typology because it is presumed that residents account for major issues (for example regarding ownership) and a large number of mixed use buildings have been designed as residential buildings in the first place. Therefore housing and mixed use buildings share more characteristics than office and mixed use buildings.

Classification matrix

Table 4.6: Classification matrix for the *Housing / Mixed use* typology

USE		STRUCTURE		OWNERSHIP		MONUMENT PROTECTION		ROOF INFRASTRUCTURE	
Industrial / Retail		Date of construction		Public		protection zone		stairs	
Education, Health, Sports, Culture		*before 1955*		Private		MPA		elevator	
Office		*1955-1980*		*single owner*		UNESCO		car access	
Parking		*1981-1995*		*multiple owners*				electricity	
Housing / Mixed use		*after 1995*						water supply	

Structure

The *Housing / Mixed use* typology is a building that has been constructed for housing between 1981 and 1995, on the basis of ÖNORM B 4012:1988. There have been no changes in pay load values concerning residential activities since then. It is therefore presumed that the structure is not capable of bearing the additional weight of a rooftop farm. Consequently, it has to be reinforced.

Ownership

As already discussed shortly in section 4.6.7, representative for this typology are multiple private owners, often living inside the building, which may not be entirely in favor of the project. This can present a big challenge for a rooftop farming project with respect to obtaining the building permit and access to the roof (see also section 4.6). The risk of opposing parties may be reduced by a planning process that includes all stakeholders.

Monument protection

This typology is located in an area that is declared a protection zone according to the land-use plan that is part of the Viennese Building Code. Therefore it is advised to design a construction that cannot be viewed from the street.

Building infrastructure

The sole access to the roof of the *Housing / Mixed use* typology is via a narrow staircase next to the elevator shaft for maintenance purposes only. Since this is not an adequate access for a rooftop farm (see section 4.10.1), it is necessary to extend the staircase or build a new access. It can be of advantage to make the access independent from the building entrance. This can help reassuring the inhabitants that there is no risk of external people gaining access to the building.

Considering the fact that this typology is located in a protection zone, it is advised to not alter the outer appearance and favor a construction that cannot be viewed from the street.

Concerning installations, the existing water supply pipes and electricity structure in the building can easily be extended to the roof.

Example building

The example building for the *Housing / Mixed use* typology is a residential building in the 7$^{\text{th}}$ district of Vienna, in Seidengasse 3. The construction date of the house is estimated in the beginning of the 90s. The building has a GREENAR05-area of 1,598 m^2. An aerial view of the residential building is shown in figure 4.8

Figure 4.8: *Housing / Mixed use* case study building (google maps)

4.12.5 Parking garage

The *Parking garage* typology is defined as a multi-story parking garage with a top level accessible for cars. This type of building might not be found too often within the city boundaries, but the few existing ones have a high potential for rooftop farming. They offer a large area with a beneficial shape and a highly advantageous existing accessibility of the roof. Additionally, the accessibility of the building within the city is usually given, since the garages are often placed directly at subway stations as park&ride facilities, at event spaces or at train stations. Furthermore, the top level of parking garages miss protection against weather. For this reason, it is presumed that customers prefer to park their cars in the other stories and the top level is underused. An example for a rooftop farming project of this kind of building is the UpGarden in Seattle, described in section 2.8.

Parking garages with flat roof that are not accessible for cars, like the project “Gartenwerkstadt” described in section 2.8, do not fall into this category. They can be considered industrial buildings in the sense of the here defined typologies.

Classification matrix

Table 4.7: Classification matrix for the *Parking garage* typology

USE		STRUCTURE		OWNERSHIP		MONUMENT PROTECTION		ROOF INFRASTRUCTURE	
Industrial / Retail		Date of construction		Public		protection zone		stairs	
Education, Health, Sports, Culture		*before 1955*		Private		MPA		elevator	
Office		*1955-1980*		*single owner*		UNESCO		car access	
Parking		*1981-1995*		*multiple owners*				electricity	
Housing / Mixed use		*after 1995*						water supply	

Structure

Pay loads for top levels of parking garages are different from the ones of conventional roofs. According to ÖNORM EN 1991-1-1, parking garages fall into the category F, for light vehicles up to 30 kN gross vehicle weight and with less than 8 seats. The floors and roof accessible for vehicles have to be imposed with a uniformly distributed pay load q_k of 2,50 kN/m^2 and a single axle load Q_k of 20 kN (ÖNORM B 1991-1-1). This single load is significantly higher than the single pay loads for different uses of buildings, which range from 2-5 kN. Therefore it is very likely that parking garages offer enough structural capacity to support the additional weight of a rooftop farm.

Regarding the roof structure, parking garages also differ from other buildings. The top level is constructed as a parking area, usually covered in asphalt or concrete. Figure 4.9 shows a possible buildup for an insulated parking level, designed as an inverted roof.

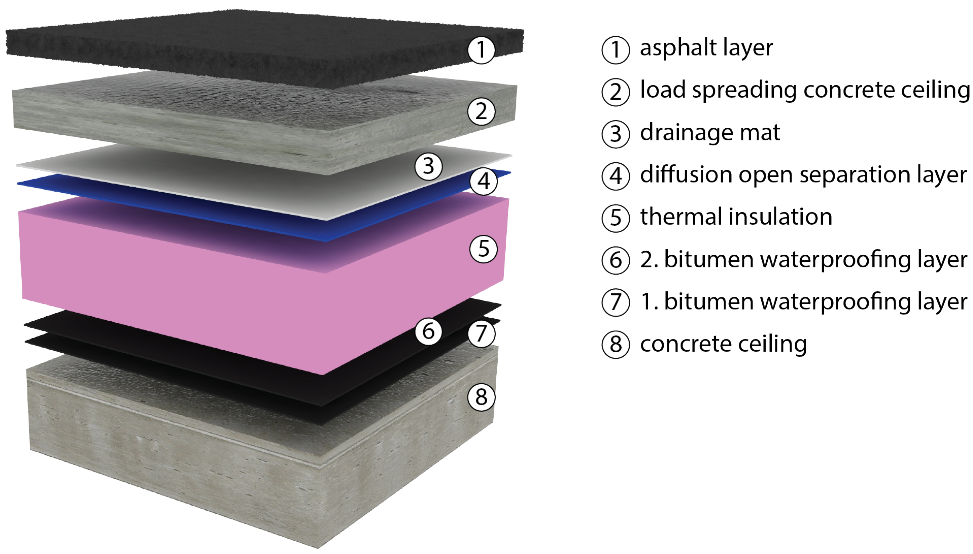


Figure 4.9: Buildup of the top level of a parking garage

In case of the construction of a green roof, it is possible that the existing roof structure of the parking garage does not have to be changed. If the covering layer serves as a root barrier and the waterproofing layer is intact, the green roof layers can be added on top of the existing structure.

The *Parking* typology is defined as being built in the 1980s, when the distributed pay load was 3,50 kN/m^2 according to ÖNORM B 4012:1981 (see annex B). Compared to the value required by ÖNORM B 1991-1-1 of 2,50 kN/m^2, this represents another possible structural reserve.

Ownership

This typology is owned by a single private company. As discussed with the *Office* typology, this can be either an advantage or a disadvantage, depending on the owner's view of the project. Owned by a single private owner, this may be a chance for him (or the company) to make extra money by renting a space that usually is not even used.

Monument protection

There are no restrictions regarding monument protection for this typology.

Building infrastructure

Accessibility to the roof is ideal for agricultural purposes. The vertical circulation is ensured by elevators, stairs and even cars and small vans can access the roof via ramps. Electrical connection is usually already available. Water supply, on the other hand, has to be retrofitted. Alternatively there is the possibility to make use of a rainwater collection system.

Case study

The parking garage next to the western train station (*Westbahnhof*) in the 15th district of Vienna represents this typology as a case study building. It is located at the end of the big shopping street Mariahilfer Straße with the address Felberstraße 1. The area that could be converted into a rooftop farm is 3,299 m^2. Figure 4.10 shows an aerial view of the building.

Figure 4.10: *Parking garage* case study building (google maps)

4.13 Handbook for Typologies

In order to visualize the results of this chapter in a didactic way, a handbook was designed. It can be found in annex C. The handbook was inspired by board games. It is a folded paper with the width of five DIN A4 sheets. In the middle, there is a cross section plan of a building, which acts like the game board. The user is supposed to start consulting the handbook at the bottom of the cross section at the “Start” circle and continue the steps to reach the rooftop farm (“Finish”). The visualization shows a greenhouse and an open-air farm with a description of the two farming systems in keywords. The steps feature different symbols that represent the criteria for the farming suitability of a rooftop. Information on the different criteria can be viewed on the left side of the handbook. With some criteria, the text refers to the five typologies and their characteristics, which are described in the right part of the handbook. When one criteria is understood and met, the user can jump to the next criteria. This continues until all criteria are met and he or she reaches the finish, and therefore his or her rooftop farm. If one criterion is not met, the user has to go back to the start and try again with a different rooftop.

Chapter 5

GIS-model

The present chapter deals with the development and analysis of the GIS-model representing the rooftops in Vienna that are suitable for farming. The objective was to link the requirements discussed in chapter 4 with the existing building matrix. Unfortunately, not all of the criteria could be represented in the model. There was no data available about the structure, construction dates and building infrastructure that could be linked to the map.

The MA 22 provided two different sets of data, which form the basis of this model. The first one represents Viennese buildings and gives information on their roof surfaces and green roof potential in particular (Vali 2011). The second one shows the land use in Vienna according to the *Realnutzungskartierung* (Vienna City Administration 8). In order to create the model, the two data sets have been combined and analyzed with the help of the software QGIS. Regarding the criteria for potential rooftops, the final model includes information on the following:

- ▷ Surface inclination (in °)
- ▷ Size (of the intensive greening potential area, in m^2)
- ▷ Quotient area/perimeter
- ▷ Use (underneath the roof)
- ▷ Sunlight exposure (kWh/m^2 solar radiation energy per year)

This chapter continues in the next section with information on the provided data that forms the basis for the model. Then, there follows a description of the analysis concerning green roof potential (section 5.2), land use (section 5.3) and size (section 5.4). Section 5.5 gives a detailed explanation on the combination of the two data sets, applied filters and creation of different layers. Afterwards the results of the analysis are presented and shortly interpreted in section 5.6. Finally, the last section of this chapter discusses problematic issues that occurred and have to be considered with respect to the GIS-model.

5.1 Basis

As mentioned before, the basis for the model includes two different sets of GIS-data provided by the MA 22. The data was available in the form of Shapefiles with polygons and associated attributes. All text parts are written in German. The two different sets of data and their characteristic parameters are shown in table 5.1. The two data sets were imported into the software QGIS in order to create the model. Additionally, the Shapefiles of city boundaries and bodies of water were downloaded at the governmental ViennaGIS website (Vienna City Administration 9) and included in the model, in order to present the polygons in context with the environment. All figures showing the model are oriented North.

Table 5.1: Characteristic parameters of the data sets

Parameter	1^{st} set of data	2^{nd} set of data
Polygons	Buildings	Land area
Attributes	Green roof potential Solar potential	Land-use
Creation year	2008	2009

In the 1^{st} set of data, the polygons represent buildings. All polygons present in this data set are shown in figure 5.1 in red. The associated attributes are listed and described in table 5.2. Figure 5.2 shows a screenshot from QGIS. One polygon of the 1^{st} data set, has been selected to show its attributes.

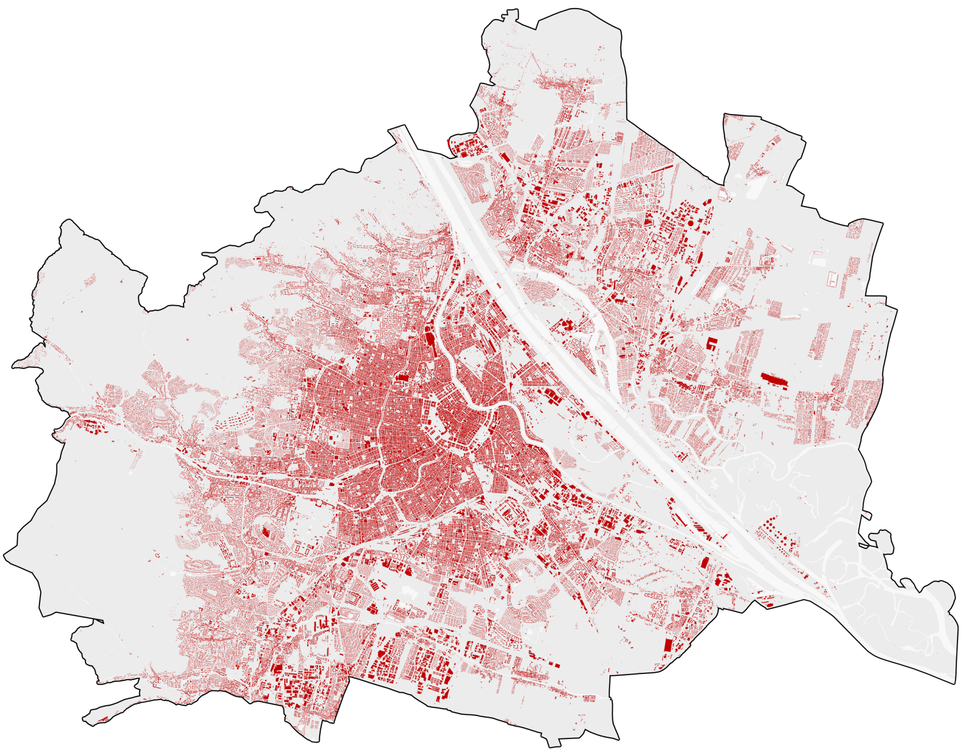


Figure 5.1: Polygons of the 1^{st} data set depicted in red

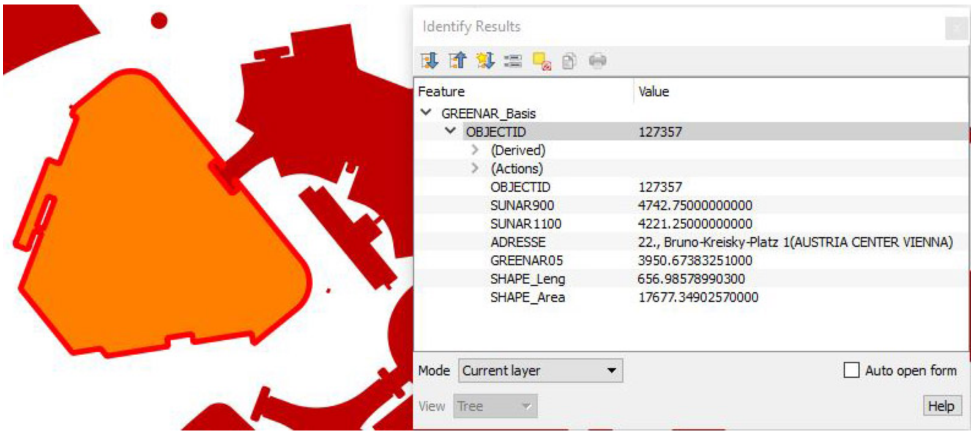


Figure 5.2: Screenshot QGIS - Building polygon with attributes

Table 5.2: Attributes of the 1st data set

Attribute name	Description
OBJECTID	identification number
GREENAR05	total area of surfaces of the polygon, that are less than 5° inclined, larger than 5 m^2 and have a quotient of A/P > 0.3, according to VALI (2011) in m^2 (see also section 4.1)
SUNAR900	area in m^2 with a minimum of 900 KWh/m^2 solar radiation energy per year
SUNAR1100	area in m^2 with a minimum of 1,100 KWh/m^2 solar radiation energy per year
ADRESSE	address of the building represented by the polygon
GREENAR05	total area of surfaces of the polygon, that are less than 5° inclined, larger than 5 m^2 and have a quotient of A/P > 0.3, according to VALI (2011) in m^2 (see also section 4.1)
SHAPE_Leng	perimeter of the polygon in m
SHAPE_Area	area of the polygon in m^2; the set of data included only areas with GREENAR05 > 5 m^2

Contrary to this, in the 2nd set of data, the polygons represent land areas with an associated use that is given in the attributes. The land use polygons of the base data are shown in figure 5.3 and the associated attributes are listed and described in table 5.3. In figure 5.4 a polygon of the 2nd data set and its attributes are shown as a screenshot from QGIS.

Table 5.3: Attributes of the 2nd data set

Attribute name	Description
OBJECTID	identification number
NUTZUNG_LE	text describing the land use, level 2
NUTZUNG___1	text describing the land use, level 1
AREA	area of the polygon in m^2

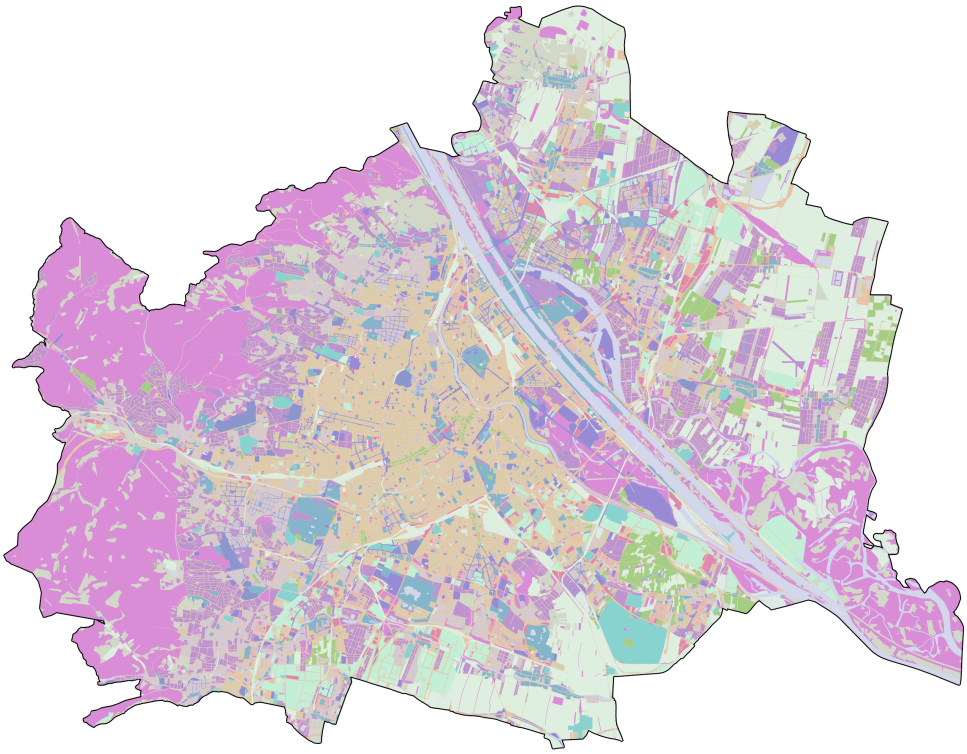


Figure 5.3: Polygons of the 2nd data set, colored according to land use

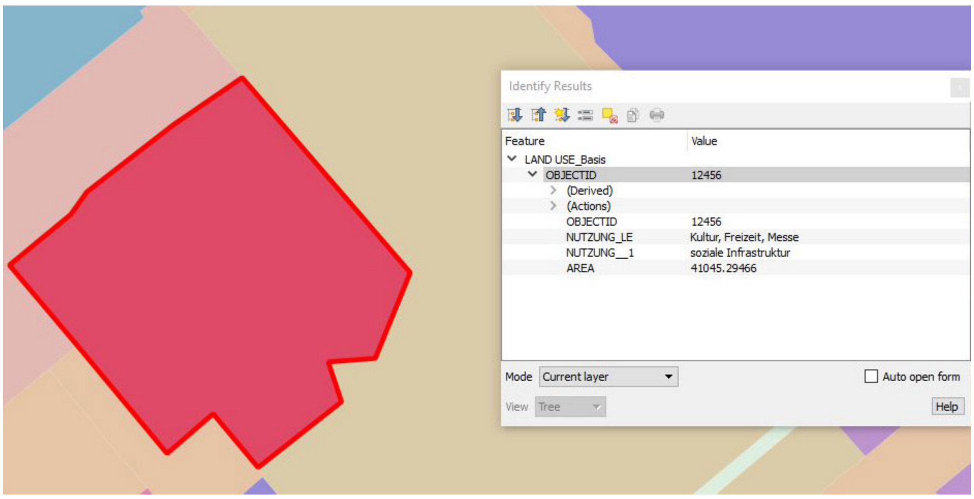


Figure 5.4: Screenshot QGIS - Land use polygon with attributes

5.2 Green roof potential

The 1st set of data was analyzed regarding the area of green roof potential and solar potential. For this purpose the following filters were created.

"GREENAR05" > 999

"SUNAR900" > 0

"SUNAR1100" > 0

First there was only the GREENAR05-filter applied, then a combination considering all areas with a potential green roof area larger than 999 m^2 and a minimum solar radiation energy of 900 kWh per year. The resulting total GREENAR05-areas are shown in table 5.4.

Table 5.4: Filters concerning potential green roof area and solar potential

Applied filters	No. of objects	Greenar05 area	%
"GREENAR05" > 999	1,966	5,456,928 m^2	100%
"GREENAR05" > 999 AND ("SUNAR900" > 0 OR "SUNAR1100" > 0)	1,943	5,424,810 m^2	99.41%

As described in section 4.4, the minimum size for a rooftop farm was defined with 1,000 m^2. Nevertheless, the filter for suitable green roofs was set to "larger than 999 m^2". This was decided in order to include the exemplary building of the *Industrial / Retail*-typology, which was analyzed by Moysan (2017) and has a potential green roof area of only 999.5 m^2 (see section 4.12.1).

The filters regarding the solar potential were applied in order to only consider polygons with an area that receives a minimum solar radiation energy of 900 kWh per year, according to the Viennese solar potential cadastre (Vienna City Administration 7), which is also discussed in section 4.5.2. The objective of this analysis was to combine the factors of surface inclination (potential green roof area) and solar radiation.
Unfortunately the data of the solar potential is not linked to the data of the green roof potential, hence the respective area does not necessarily have to be overlapping. The surface with high solar radiation could be a steep part of the roof, whereas the potential green roof area of the same polygon could be located at a shady part.
The combination of the two factors surface inclination and solar radiation is not possible with the existing data. However, table 5.4 shows that the total area of the filter combinations with consideration of the solar potential show a difference of only 0.59% in relation to the total GREENAR05-area to the areas of filters without consideration of the solar potential. It was decided that this difference is negligible and to not consider the SUNAR-layers in the further analysis of the model. Nevertheless, the information is still present in the attributes and accessible via the model.

A new shape layer file was created with the polygons filtered only by "GREENAR05" > 999. The layer was called *GREENAR05 > 999*.

5.3 Land use

The 2nd data set includes polygons covering the whole area of the city containing information about the land use. This information was used to gain more knowledge about the buildings and to eliminate unsuitable polygons. In order to arrange the data more clearly, the layer was divided into the five categories of use defined in section 4.7.
Later, it is intended to combine the information of potential green roof area and use of buildings suitable for rooftop farming (see section 5.5). For this purpose, five new layers were created with the help of filters. The filters applied to the GIS-model were defined as follows.

Industrial / Retail

"NUTZUNG_LE" ILIKE 'solitäre Handelsstrukturen'
OR "NUTZUNG_LE" ILIKE 'Transport und Logistik inkl. Lager'
OR "NUTZUNG_LE" ILIKE 'Industrie, prod. Gewerbe, Großhandel inkl. Lager'
OR "NUTZUNG_LE" ILIKE 'Bahnhöfe und Bahnanlagen'

Education, Health, Sports, Culture

"NUTZUNG_LE" ILIKE 'Bildung'
OR "NUTZUNG_LE" ILIKE 'Gesundheit und Einsatzorg.'
OR "NUTZUNG_LE" ILIKE 'Kultur, Freizeit, Messe'
OR "NUTZUNG_LE" ILIKE 'Sport und Bad (Indoor)'
OR "NUTZUNG_LE" ILIKE 'Sport und Bad (Outdoor)'

Office

"NUTZUNG_LE" ILIKE 'Büro- und Verwaltungsviertel'
OR "NUTZUNG_LE" ILIKE 'Geschäfts-, Kern- u. Mischgebiete'

Housing / mixed use

"NUTZUNG___1" ILIKE 'Wohn- u. Mischnutzung (Schwerpunkt Wohnen)'

Parking

"NUTZUNG_LE" ILIKE 'Parkplätze u. Parkhäuser'

All polygons, that did not fit these filter criteria were excluded from the model, thereby unsuitable buildings with other usages like communications facilities, electric utilities or gas stations were not included (see also section 4.7).

5.4 Size classes

According to the size of potential farming area (gross area), there were three classes defined:

- Small (up to 2,000 m^2)
- Medium (larger than 2,000 m^2 but smaller or equal 6,000 m^2)

▷ Large (larger than 6,000 m^2)

The according filters that have been applied to the model in QGIS for the creation of separate layers for each class are:

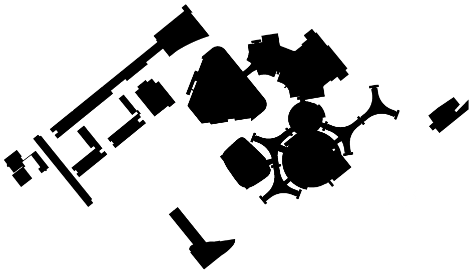
Small: "GREENAR05" <= 2000
Medium: "GREENAR05" > 2000 AND "GREENAR05" <= 6000
Large: "GREENAR05" > 6000

Maps showing the polygons of the different size classes are shown in Annex D.2 (Small), D.3 (Medium) and D.4 (Large).

5.5 Creation of combined layers

In order to link the information of land use with the information of potential green roof area and size class, combined layers had to be created. This was accomplished with the help of the 'Intersection'-tool in QGIS. The following steps were followed in order to create the 15 layers combining use, size category and roof information.

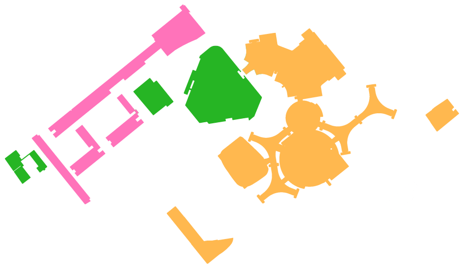
1. Filter use according to section 5.3 and save filtered polygons as five separate shape layer files.
2. Add new attribute 'use' to the attribute tables and fill in the use according to the five categories.
3. Apply the 'Dissolve'-tool to each layer with the newly created attribute 'use' to reduce errors for clipping. Save the dissolved layers as new layers.
4. Create buffer for *GREENAR05 > 999* by using the 'Buffer'-tool with a distance of -0,001 m to avoid errors with the intersection (for details see section 5.7). Save new layer.
5. Apply 'Intersection'-tool with the buffered *GREENAR05 > 999*-layer as the input layer and the dissolved use layers as the second layer. Save new layers.
6. Create new attribute field 'Poly_area' with the '$area'-function for all intersected layers.
7. To avoid double polygons (buildings with two or three different land-uses) use the filter "Poly_area" >= 1000 and save new layers.
8. At this point there were still 52 double polygons, which were regarded one by one and classified according to their use. The redundant polygons were deleted. For further details on this step see section 5.7.
9. Filter the new layers according to their size with the filters in section 5.4. Save new layers.



(a) Building polygons

(b) Land use polygons

(c) Building polygons and land use polygons



(d) Intersection of (a) and (b) - combined layers

Figure 5.5: Example of the creation of combined layers

Figure 5.5 shows an example of the intersection. Subfigure (a) shows the building polygons of the 1st data set, (b) shows the land use polygons of the same area according to the 2nd data set. In figure 5.5 (c) the building polygons are shown as a transparent layer above the land use polygons to show the spatial relation of the polygons. It can also be seen, that some building polygons cross more than one land use polygon. Figure 5.5 (d) shows the intersected layers, where the building polygons now also exhibit the land use attribute and have been cut by the borders of the land use polygons.

Figure 5.6 shows a screenshot from QGIS of a polygon after the intersection. The attributes from both data sets can be seen.

The layers were also exported to Microsoft Excel to analyze double polygons (see section 5.7) and calculate the potential farming area according to the categories.

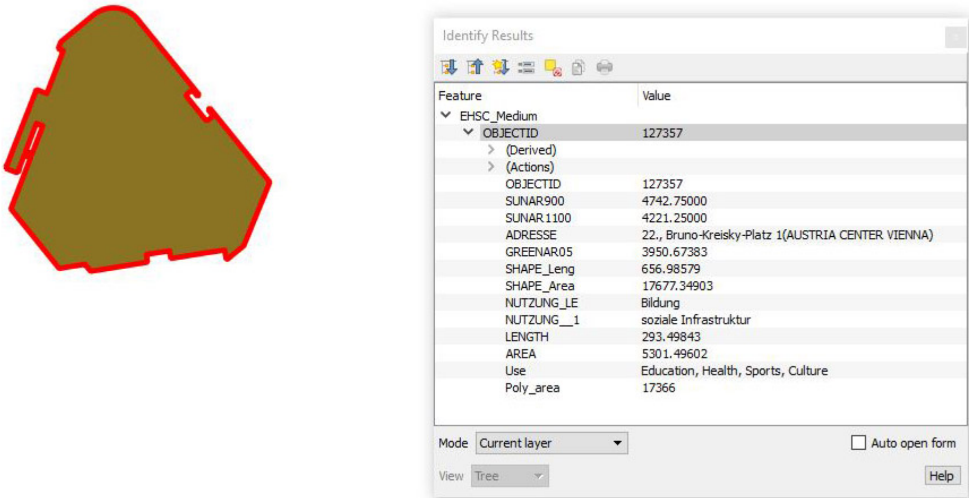
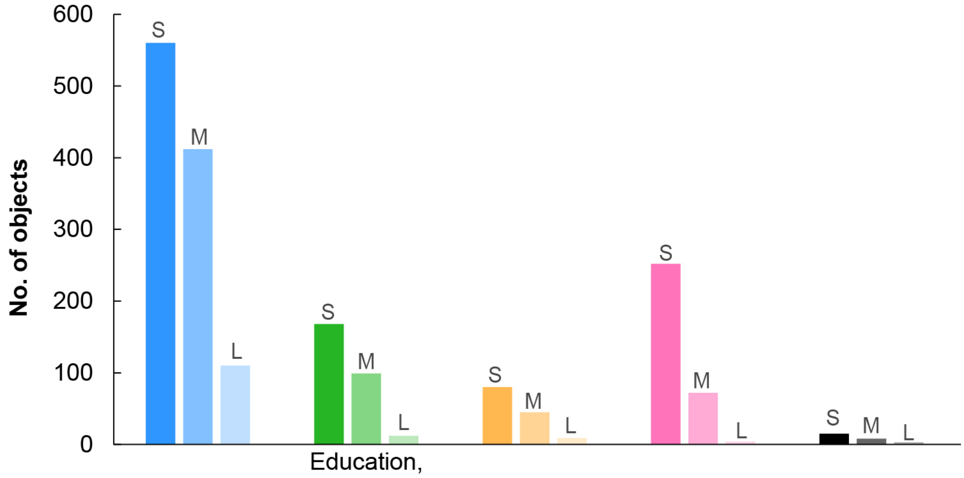


Figure 5.6: Screenshot QGIS - polygon with combined attributes

5.6 Results of GIS analysis

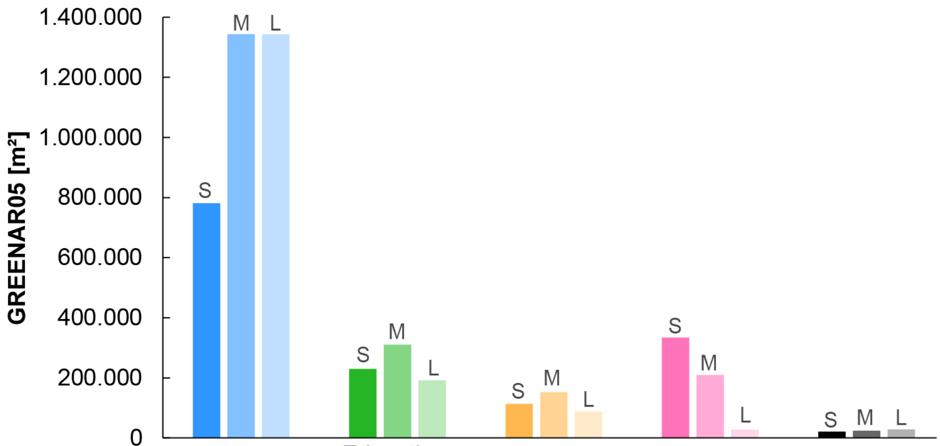
After following the steps in the section before, different maps were created to show the polygons according to their categories, size class and location. All of the maps can be found in Annex D. Annex D.1 shows the map including all layers. The maps showing only the polygons of each category of use can be found in annex D.5 to D.9.

Figure 5.7 shows the number of objects with potential green roof area according to the GIS-model. The values are presented by category of use and size class. In figure 5.8 the potential green roof area in m^2 according to the attribute GREENAR05 can be seen. For further use, the total potential rooftop farming area is rounded to 520 ha.



	Industrial / Retail	Education, Health, Sports, Culture	Office	Housing / Mixed use	Parking	Total
Small (S)	560	168	80	252	15	1.075
Medium (M)	412	99	45	72	8	636
Large (L)	110	12	9	4	3	138
Total	1.082	279	134	328	26	1.849

Figure 5.7: Number of objects with potential rooftop farming area according to category of use and size class



	Industrial / Retail	Education, Health, Sports, Culture	Office	Housing / Mixed use	Parking	Total
Small (S)	781.280	229.408	113.245	334.075	20.935	1.478.943
Medium (M)	1.343.401	310.499	152.215	209.144	24.020	2.039.279
Large (L)	1.342.991	191.543	88.071	27.402	28.329	1.678.335
Total	3.467.672	731.450	353.530	570.621	73.284	5.196.557

Figure 5.8: Potential rooftop farming area in m^2 according to category of use and size class

Looking at the values in figure 5.7 and 5.8, it can be seen, that the majority of buildings with potential green roof area and the majority of that area can be found in the category *Industrial / Retail*. The maps in appendix D.5 show, that the majority of these buildings are situated on the outskirts of the city. Buildings in the categories *Education, Health, Sports, Culture* and *Housing / Mixed use* are dispersed over the whole city (see appendix D.6 and D.8), whilst the *Office*-polygons are slightly more clustered in the inner parts of the city, as can be seen in appendix D.7. The parking garages are shown in appendix D.9. They are few in number and can be found in inner and outer parts of the city, since they are often located at train stations as 'Park & Ride' facilities.

As mentioned before, the maps according to the size class can be found in appendix D.2, D.3 and D.4. Additionally, the graphs in figure 5.9, 5.10 and 5.11 show the percentages of potential rooftop area regarding the category of use for each size class.

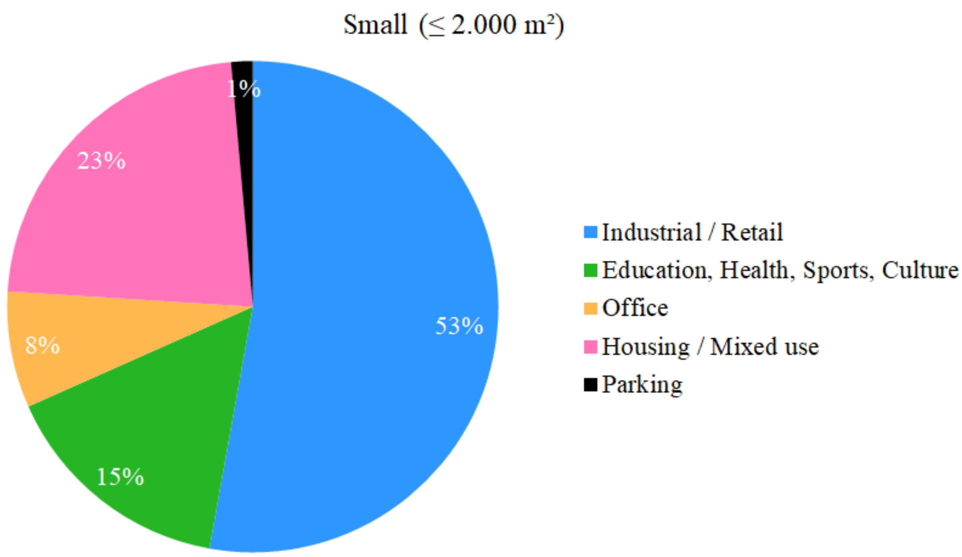


Figure 5.9: Distribution of potential rooftop area in the size class 'Small' according to the five categories of use

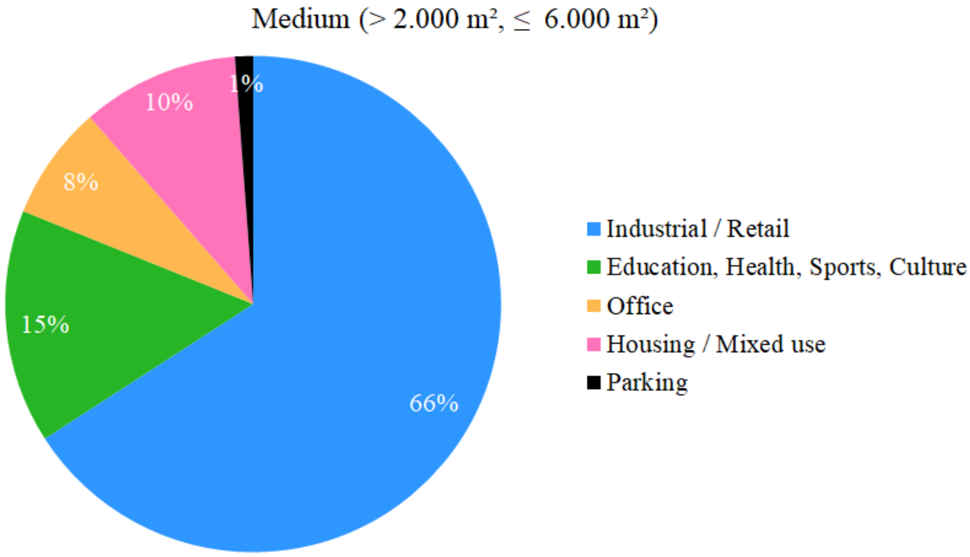


Figure 5.10: Distribution of potential rooftop area in the size class 'Medium' according to the five categories of use

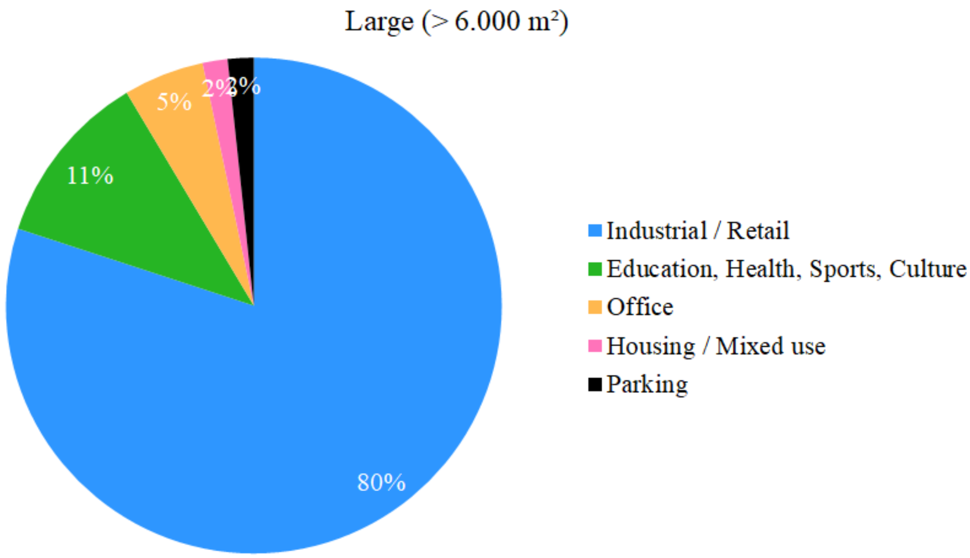


Figure 5.11: Distribution of potential rooftop area in the size class 'Large' according to the five categories of use

Category *Industrial / Retail* represents the majority in each of the size classes. Buildings in the *Housing / Mixed use* category represent a significant part of the area of small rooftops with 23% of the total potential green roof area, as shown in figure 5.9. Regarding the 'Medium'-size class, these buildings are still represented with a considerable percentage of 10%, see figure 5.10. In contrast to this, the percentage shrinks to 2% in the class 'Large'. Buildings belonging to the other three categories show a rather consistent percentage throughout the different size classes.

5.7 Discussions

It is important to understand that the GIS-model is not a perfect depiction of reality and there are some issues that have to be considered when working with data that has been derived from the model. On the one hand, some polygons that are part of the model do not represent rooftops that can be used as urban farms and on the other hand there are existing buildings, which would be suitable for rooftop farming but are not part of this GIS-model.

In order to find out if the polygons actually represent buildings with rooftops suitable for rooftop farming according to the considered parameters, a plausibility check was carried out. The polygons that remained after applying the filters were visually examined by sampling. Different parts of the city were regarded in detail and suspicious polygons were compared with satellite images provided by the governmental map of Vienna (Vienna City Map) and google maps (available at: http://maps.google.at).

The problematic issues that appeared, are listed below and described more detailed in the following.

- ▷ Already used areas
- ▷ Non-existing buildings
- ▷ Roof installations
- ▷ Double polygons
- ▷ Buffer tool

Although these problematic issues have to be kept in mind, they are all considered negligible for the purpose of this study, which seeks to gain an overview of the potential farming area on a level of detail that is not affected by these problems.

Already used areas

It is debatable whether already used areas should be taken into account for the analysis. Some of those areas are existing green roofs, utilized terraces and parking decks. The latter is discussed detailed in section 4.12. Regarding the others, on the one hand these areas already serve an ecological or social purpose and are maybe less likely to be converted into farming spaces. On the other hand they still represent potential surfaces for food production that could easily be adapted for agriculture. Therefore it was decided to consider these surfaces in the model.

Another part of the already used areas are surfaces, which are occupied by special usages. Such an example would be railway lines. Figure 5.12 shows the example of a railway line, that has been identified as a suitable rooftop, but is used for public transportation trains. The railway line can be seen on the right of the images, crossing the Danube canal.
Since the polygons of railway lines are long shaped, it was tried to avoid this issue with the same measure as Vali (2011) filtered long and narrow areas, by using the area to perimeter (A/P) quotient (in that case $A/P > 0.3$).
However, the A/P quotients of the railway line polygons range from 3.9 to 7.9 and do not differ significantly from the value of building polygons with suitable rooftops. Therefore it was not

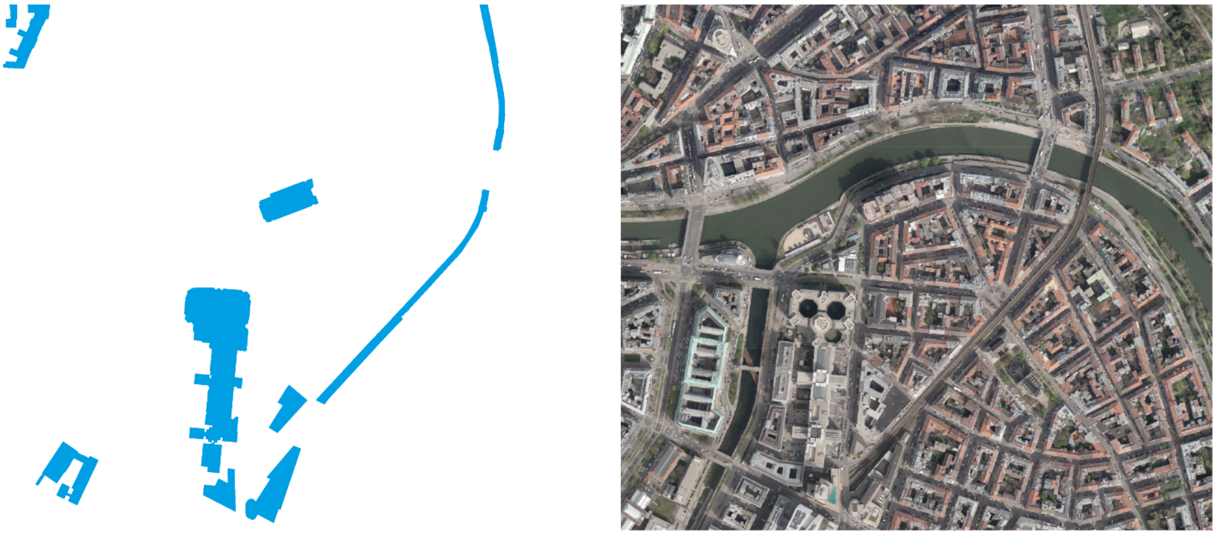


Figure 5.12: Comparison of the polygons in the GIS-model (left) and the aerial view according to https://www.wien.gv.at/stadtplan/ (right)

possible to eliminate these areas with a filter depending on the ratio of area to perimeter.

Another idea to avoid these polygons was to not consider the correspondent use of the attribute NUTZUNG_LE '*Bahnhöfe und Bahnanlagen*', which translates to 'railway stations and railway constructions'. Thereby there would have been eliminated numerous railway and U-Bahn stations with roofs suitable for rooftop farming. Ultimately it was decided to accept these polygons as part of the GIS-model, since the area was insignificant compared to the area of suitable surfaces.

Non-existing buildings

The data used for the analysis was collected in 2008. Since cityscapes change over time, some of the buildings have changed or are not existing anymore and new buildings have been built. Since there was no newer data available, this issue cannot be avoided. On the other hand, it is presumed that there are also newly constructed buildings with potential rooftop farming areas, that are not considered in the data. However, it cannot be said whether there is a balance between demolished and new buildings.

Roof installations

Some roofs detected as flat by laser scanning have multiple large installations on top of them, mostly HVACR machines like refrigeration vents. These buildings often present a challenge for the installation of rooftop farms, as mentioned by Ackerman et al. (2012) on page 42, who excluded supermarkets from their analysis of New York City because of this reason. It was decided to keep buildings with such installations and supermarkets in particular, in the GIS-model, since there already exist multiple successful farms on top of supermarkets (for example Gotham Greens, see section 2.8) and supermarkets present a perfect location regarding transportation and sale of produce.

Double polygons

As mentioned in section 5.5, during the combination of layers some polygons were doubled. This happened because these buildings are located on more than one land use polygon and maybe house different usages. The majority of cases could be eliminated by deleting all polygons that were smaller than 1,000 m^2 (for clarification: this is the total size of the polygon, filtered by the attribute 'Poly_area', not the size of potential green roof area, attribute 'GREENAR05'). Thereby, smaller pieces of the building polygons crossing a different land use polygon were deleted.
The remaining double objects were identified in the course of an analysis in Microsoft Excel according to their potential green roof area. The 52 remaining objects were regarded one by one in google maps. According to their appearance and information provided by google, a significant use for each building was decided. A complete list of the objects and decisions can be found in Annex E.

Buffer-tool

For the creation of combined layers the 'Intersection'-tool was utilized (see section 5.5). When first trying to apply this tool, the following error message appeared.

> *"Input layer A contains invalid geometries (Feature 38). Unable to complete intersection algorithm."*

This problem was also encountered by other users of QGIS and described and solved in an internet forum (accessed 10.07.2017 via: *https://gis.stackexchange.com/questions/112687/fixing-geometry-validity-errors-in-qgis*). One solution is the creation of a small buffer for the problematic layer, as described in step 4 in section 5.5.

Although applying this buffer solves the above mentioned error, it also implies a new issue. The comparison between the original *GREENAR05 > 999*-layer and the buffered layer shows, that some polygons of the original layer are not included in the buffered version. This affects seven polygons that represent buildings and one polygon representing a railway line. As discussed with the already used areas, it is of interest to not include railway lines in the model. Concerning the buildings, the affected polygons are listed in table 5.5.

Table 5.5: Building polygons lost due to buffer

Address	GREENAR05	Use
13., Schönbrunner Schloßstraße 47(BETRIEB)	3.866	Education, Health, Sports, Culture
9., Strudlhofgasse 4(PHYSIKALISCHES INSTITUT)	1.247	Education, Health, Sports, Culture
10., Davidgasse 92-94	1.673	Housing / Mixed use
20., Aignerstraße 1	1.561	Housing / Mixed use
3., Würtzlerstraße 25/1(PENSIONISTEN-WOHNHAUS)	3.039	Housing / Mixed use
11., Svetelskystraße 4(SCHULE)	5.345	Education, Health, Sports, Culture
Total	**16.731**	

The object described in the first line of table 5.5 represents Schönbrunn castle, which is protected by all of the three kinds of monument protection that are described in section 4.6.5 and therefore does not represent an ideal building for rooftop farming. The GREENAR05-area of these polygons sums up to 16,731 m^2, which equals 0.32% of the total potential farming area of 520 ha.

Chapter 6

Results and conclusion

This chapter starts with the final results of the food production capacity according to the previous analysis. Then, the research questions that have been formulated in section 1.3 are answered. Afterwards, a discussion of the results follows. The chapter ends with an outlook concerning future research and possible developments with regard to the research topic.

6.1 Food production capacity

6.1.1 Potential yield

The total potential rooftop farming area of Vienna is 520 ha. This area corresponds to the gross area defined in section 3.6.2. The net area, on the other hand, depends on the farming system. According to the net area / gross area-ratios in 3.2, the net area for Vienna would be 336 ha (65.0%) for soil-based open-air farms, 158.6 ha (20.5%) for HG where everything is located on the roof and 379.6 ha (73.0%) for HG where part of the production is located under the roof.

The maximum yield is possible with a conditioned HG where part of the production is located under the roof, since this system offers the highest net area and the highest possible yield per area (see section 6.1.1). Using all of the available area for this method would result in about 111,299 t of vegetables per year (see equation below).

$$3,796,000\, m^2 \ \cdot \ 29.32\, kg/m^2 \ = 111,298,720 \ kg \mathrel{\widehat{=}} 111,299\, t$$

Table 6.1 gives a sensitivity analysis, showing the minimum and maximum potential yields depending on the implemented farming systems. On the left, the percentage of roof area used for each production method or for no production ("Not used") is indicated. In the right column the total yield is calculated. The rows are sorted from lowest to highest possible yield. The potential yields range from 0 t/a to 111,299 t/a, starting at the top with 100% of the suitable farming area not being used. The maximum yield is shown at the bottom. As already mentioned, this yield can be achieved by using all of the suitable area for the HG part-roof method. In between there are different combinations of use for the rooftop area.

Table 6.1: Sensitivity analysis showing the potential yield depending on the production methods

Percentage of gross area used for				Yield in t/a
Soil-based, open-air	HG total-roof	HG part-roof	Not used	
0%	0%	0%	100%	0
50%	0%	0%	50%	8.805
10%	10%	10%	70%	17.541
100%	0%	0%	0%	17.610
0%	50%	0%	50%	23.251
20%	20%	20%	40%	35.082
25%	25%	25%	25%	43.853
0%	100%	0%	0%	46.502
30%	30%	30%	10%	52.623
0%	0%	50%	50%	55.649
0%	0%	100%	0%	111.299

6.1.2 Nutritional needs of the citizens

According to Statistik Austria (2016), the per capita consumption of fresh vegetables for the agricultural period of 2015/16 (1^{st} August, 2015 - 31^{st} July, 2016) was 111.6 kg. Accordingly, the demand for fresh vegetables is assumed with 111.6 kg per person and year. With a population of 1,867,582 (Statistik Austria 2017), this corresponds to a total demand for fresh vegetables of 208,464 t, as shown in the equation below.

$$1,867,582 \;\cdot\; 111.6\,kg \;=\; 208,422,151\,kg \mathrel{\widehat{=}} 208,422\,t$$

Thus, the percentage of demand met can be calculated as shown in the next equation.

$$\frac{111,299\,t}{208,422\,t} \;=\; 0.5340 \mathrel{\widehat{=}} 53.40\%$$

53.40% of the demand for fresh vegetables of Vienna's inhabitants could be met with rooftop farming.

6.2 Answering of research questions

1. Which criteria need to be considered for installing rooftop farms?

The criteria that have to be considered for the installation of a rooftop farm, as determined in section 4.1, are listed below.

- ▷ Inclination - maximum surface inclination of 5°
- ▷ Quotient area/perimeter (A/P) > 0.3

- ▷ Size - minimum flat surface area of 1,000 m^2
- ▷ Location based factors
- ▷ Legal aspects
- ▷ Use
- ▷ Building structure
- ▷ Roof structure
- ▷ Building infrastructure
- ▷ Financial aspects

The criteria included in the GIS-model (see chapter 5), which formed the basis for the further analyses, included the following criteria:

- ▷ Inclination - maximum surface inclination of 5°
- ▷ Size - minimum flat surface area of 1,000 m^2
- ▷ Quotient area/perimeter (A/P) > 0.3
- ▷ Use

2. How big is the potential surface area that could be converted into rooftop farms?

This question was also analyzed in chapter 5. According to the developed GIS-model, the potential rooftop farming area is 520 ha (gross area). Depending on the farming system, the net area varies between 158.6 ha and 379.6 ha (see section 6.1.1).

3. Where are the potential roof surfaces located?

As shown on the maps in annex D and discussed in section 5.6, the suitable surfaces are dispersed over the whole city. Though looking at the categories of use, some patterns become visible. The largest part of the potential rooftop farming area can be found on buildings of the category *Industrial / Retail*. These buildings are located mostly in the outer districts of Vienna. Suitable office buildings are rather concentrated in the inner parts of the city. The other categories show potential areas all over the city. Buildings of the category *Housing / Mixed use* tend to be smaller units.

4. What is the most efficient way to grow vegetables on rooftops in Vienna?

As shown in section 3.6.1, the maximum yield could be achieved using hydroponics in conditioned greenhouses.

5. Which amount of vegetables could be produced?

With hydroponics in conditioned greenhouses, a vegetable yield of 29.32 kg/m^2 can be achieved (see section 3.6.1). As calculated in section 6.1.1, the maximum possible yield is 208,422 t of fresh vegetables per year.

6. Which amount the city's demand for vegetables could be met with rooftop farms?

As calculated in section 6.1.2, 53.40% of the city's demand for fresh vegetables could be met with urban rooftop farming.

6.3 Handbook

The developed handbook is attached as annex C to this master's thesis.

6.4 Discussion of results

The results show that more than half of the demand for fresh vegetables in Vienna could be met with commercial urban rooftop farming. Though it is not likely that all of the suitable surfaces will be turned into hydroponic greenhouse farms, the analysis shows that this significant amount is theoretically possible. In combination with different urban farming concepts and considering the fact that Vienna already produces 1/3 of the demanded fresh vegetables inside the city (Vienna City Administration 10), it is assumed that a high level of self-sufficiency regarding vegetables can be achieved. Table 6.1 shows the importance of using hydroponic greenhouses for a high yield. For example using all of the suitable area for soil-based, open-air farming results in about half of the potential yield (17,610 t/a) that could be achieved when using 20% of the available area for each of the three production methods and 40% for no production at all (35,082 t/a).

The interest to install a rooftop farm can be largely dependent on the construction costs and doubts about the profitability of such a project. Whilst soil-based open-air farms are relatively inexpensive, hydroponic greenhouses require a high initial investment Additionally they consume a considerable amount of energy and have high operational costs. Yet, regarding profitability, greenhouses offer the advantage of being able to grow almost any kind of products directly in the city, including rare and pricey ones. Examples for such products are:

- ▷ tropical and exotic products
- ▷ products that cannot be produced in open-air farms throughout the year
- ▷ pharmaceutical products
- ▷ fragile products

Besides that, both rooftop production methods (open-air and HG) benefit from being able to deliver local fresh produce. This stands in contrast to a wide range of products available in the supermarket, which have been produced far away, might have been harvested early to mature in containers or have been frozen. Furthermore, rooftop farms can generate income from other sources than the sale of produce. For example parts of the area can be rented to customers. The unusual setting makes it an appealing location for photo shoots, workshops and various events. To conclude the issue of profitability, existing rooftop farms show that such projects can be profitable (e.g. Lufa Farms, Gotham Greens, Urban Farmers, Brooklyn Grange).

This thesis should be seen as a first analysis for rooftop farming in Vienna. There are many factors that had an impact on the analysis, where assumptions were made because of a lack of data. Concerning production methods, the practice of rooftop farming and especially hydroponic farming is still new. For example, the information regarding potential crop yields and construction costs are derived from only a few innovative projects. More field data has to be acquired in order to obtain more reliable values.

With respect to legal aspects, there are also some uncertainties. Today, there is no notion of rooftop gardens or agriculture as a part of buildings in the Viennese Building Code (2016). Therefore the legal requirements are not entirely clear. Though there is a national standard concerning green roofs (ÖNORM L 1131), it does not deal with green roofs for agricultural purposes. The same applies to greenhouses, which are not commonly put on roofs and hence, have no specific regulations as part of buildings.

Regarding the GIS-model, the result is a map that features all of the defined parameters that could be located in the city. It would have been desirable to include more parameters in the model, but often the data information could not be connected with the map. This applies to microclimate, building structure, roof structure and building infrastructure. Further issues concerning the GIS-model are discussed in section 5.7.

6.5 Outlook

This thesis can be viewed as an initial analysis for the potential of rooftop farming on existing buildings in Vienna. Though many parameters have to be analyzed individually for each building, the overall analysis for the city could be refined as well. With the acquisition of data that connects building parameters missing in the GIS-model with the location in the city, the model could be expanded and become more accurate.

Additional research could be executed in the field of rooftop farming on new constructions. In Vienna there are still undeveloped areas where new buildings will be constructed. When designing a new building with farming area on the roof, the construction costs for the farm should be lower than for retrofitted farms, since additional loads and structures can be considered from the start. Furthermore these areas have not been included in this analysis and therefore present additional farming area. The same applies to old buildings that will be demolished and give way to new constructions. Another interesting potential for additional farming area is the conversion of attics to farming areas. In the past years it has become common in Vienna to convert old attics into high priced apartments. Alternatively, these areas or parts of them could be turned into farming area.

Concerning the level of self-sufficiency, it could be interesting to analyze the potential urban farming area on the ground. Another option for the enhancement of food self-sufficiency would be the construction of vertical farms within the city boundaries. To this end it could also be interesting to expand the analysis to include not only vegetables but also other types of food.

Regarding legal aspects, as already mentioned, today there is no explicit notion of roof gardens and farming areas as part of buildings in the legal texts. It is desirable that the Viennese Building Code includes these terms to ensure a clear legal situation. It is presumed that this will happen with a rising number of urban rooftop farming projects and further research in that field.

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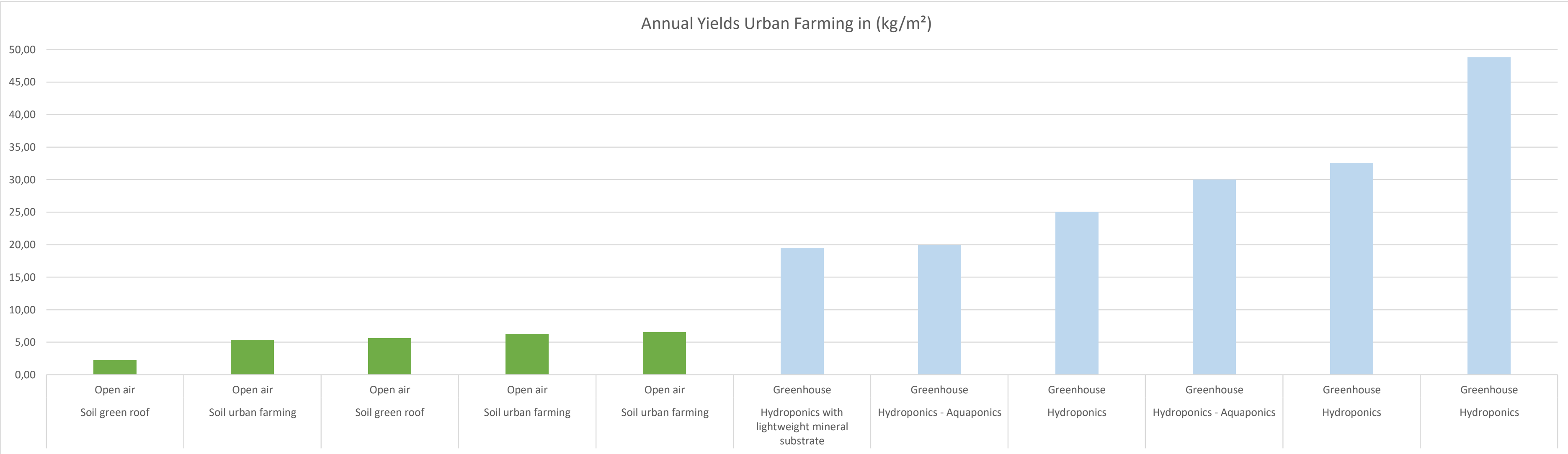
Appendix A

Yields in urban (rooftop) farming

YIELDS URBAN (ROOFTOP) FARMING

Cultivation method	Open air / greenhouse	Annual yield in (kg/m²)	Crop	Location	Source	Remark
Soil green roof	Open air	2,25	'Produce' (assumed produce = vegetables)	New York City, US	Brooklyn Grange PressKit, accessed via *https://www.brooklyngrangefarm.com/electronic-press-kit*	43,000 square foot + 65,000 square foot 50,000 lbs of produce per year -> 0,46 pounds per sq ft -> 2,25 kg/m²
Soil urban farming	Open air	5,40	Vegetables	Montreal, Canada	Duchemin, E., Wegmuller, F., & Legault, A. -M. (2008). Urban agriculture: Multidimensional tools for social development in poor neighborhoods. Field actions science report (Vol. 1, No. 1). *http://factsreports.revues.org/index113.html*	'intensive'
Soil green roof	Open air	5,60	Vegetables	Copenhagen, Denmark	Private email communication with Livia from Ostergro company	average 70 kilos every week from may to november on 350 m² 70*7*4/350=5,60; per net area
Soil urban farming	Open air	6,30	Vegetables	Seattle, Us	McGoodwin, M. (2009) P-patch vegetable gardening for fun and proft. Via *http://www.mcgoodwin.net/pages/ppatch.html* calculated by Grewal (2011)	'intensive'
Soil urban farming	Open air	6,50	Vegetables	Tucson, Arizona, US	Cleveland, D. (1991). Are urban gardens an efficient use of resources? via *https://cals.arizona.edu/OALS/ALN/aln42/cleveland.html*	'intensive'
Hydroponics with lightweight mineral substrate	Greenhouse	19,53	Vegetables	Cleveland or Bay area,US; not clear	Grewal, S.S., & Grewal, P. S. Can cities become self-reliant in food? J. Cities (2011) cites Bay Localize (2007) http://www.baylocalize.org/files/Tapping_the_Potential_Final.pdf which cites Charles Schultz, "Soilless in Singapore," Growing Edge Magazine, http://www.growingedge.com/magazine/back_issues/view_article.php3?AID=170324 (accessed April 1, 2007). (not accessible anymore) and Juan Izquierdo, FAO. Personal communication with Brian Holland, DC&E, May 2007.	Grewal (2011): 19,53 kg/m² Bay Localize: 4 pounds per sq ft
Hydroponics - Aquaponics	Greenhouse	20,00	Vegetables	Basel, Switzerland	Urban Farmers *https://urbanfarmers.com/projects/basel/*	5 t vegetables, 250 m² -> 20 kg/m²
Hydroponics	Greenhouse	25,00	Tomatoes	Barcelona, Spain	Sanyé-Mengual, E., J. Oliver-Solà, J. I. Montero, J. Rieradevall. An environmental and economic life cycle assessment of rooftop greenhouse (RTG) implementation in Barcelona, Spain. Assessing new forms of urban agriculture from the greenhouse structure to the final product level (2015), Int J Life Cycle Assess (2015) 20:350–366.	value taken from unpublished work from ICTA, conventional greenhouse in same geographic context, 11 months crop period
Hydroponics - Aquaponics	Greenhouse	30,00	Vegetables	The Hague, Netherlands	Urban Farmers *https://urbanfarmers.com/projects/the-hague/*	45 t vegetables, 1500 m² -> 30 kg/m²
Hydroponics	Greenhouse	32,57	Leafy greens	NYC, US	Gotham greens *http://gothamgreens.com/our-farms/greenpoint*	100,000 lb, over 15,000 sqft -> 6,67 lb/ft² -> 32,57 kg/m²
Hydroponics	Greenhouse	48,83	Leafy greens, herbs, tomatoes	NYC, US	Gotham greens *http://gothamgreens.com/our-farms/gowanus*	200,000 lb, over 20,000 sqft -> 10 lb/ft² -> 48,83 kg/m²



Arithmetic means:

Hydroponic greenhouse	29,32 kg/m²
Soil-based open-air	5,21 kg/m²

kg = lb/2,2046 lb = pounds

m² = ft² / 10,764 ft² = square feet

1,00 lb	0,45 kg
2,20 lb	1,00 kg
1,00 ft²	0,09 m²
10,76 ft²	1,00 m²
1,00 lb/ft²	4,88 kg/m²
23,73 lb/ft²	1,00 kg/m²

input
result

Appendix B

Comparison of standards regarding pay loads

Category	Specific Use	Example	ÖNORM EN 1991-1-1: 2011 09 01 in combination with ÖNORM B 1991-1-1: 2017 02 01	ÖNORM EN 1991-1-1: 2003 03 01 in combination with ÖNORM B 1991-1-1: 2003 09 01	ÖNORM ENV 1991-1-1: 1995 03 01	ÖNORM B 4012: 1997 04 01	ÖNORM B 4012: 1988 11 01	ÖNORM B 4012: 1981 09 01	ÖNORM B 4001 11/1974	ÖNORM B 4001 09/1965	ÖNORM B 4001 10/1962	ÖNORM B 4001 03/1955	NORMALIEN 1902
			q_k in [kN/m²]	q_k in [kN/m²]	q_k in [kN/m²]	q_k in [kN/m²]	q_k in [kN/m²]	q_k in [kN/m²]	q_k in [kN/m²]	q_k in [kN/m²]*	q_k in [kN/m²]*	q_k in [kN/m²]*	q_k in [kN/m²]*
A	Areas for domestic and residential activities	A1: Rooms in residential buildings and houses; bedrooms and wards in hospitals; bedrooms in hotels and hostels, kitchens and toilets	2,00	2,00	2,00	2,00 - 3,00**	2,00 - 3,00**	2,00 - 3,00**	2,00 - 3,00**	2,00 - 3,00**	2,00	2,00	2,50
B	Office areas	B2: Office areas in office buildings (access areas and staircases C3.1)	3,00	3,00	3,00	≥ 3,00	≥ 3,00	≥ 3,00	≥ 2,00	≥ 2,00	≥ 2,00	≥ 2,00	4,50 - 5,50
C	Areas where people may congregate	C1: Areas with tables, etc. (areas in restaurants, cafés, schools)	3,00	3,00	3,00	4,00	4,00 - 5,00	4,00 - 5,00	4,00	4,00	4,00	4,00	3,00 - 5,50
		C2: Areas with fixed seats (areas in churches, theaters, cinemas, lecture halls)	4,00	4,00	4,00	4,00	4,00 - 5,00	4,00 - 5,00	4,00 - 5,00	4,00 - 5,00	4,00 - 5,00	4,00 - 5,00	4,00
		C3.1: Areas with moderate frequency of people without obstacles for moving people (areas in museums, exhibitions)	4,00	4,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00	4,00
		C3.2: Areas with possibly high frequency of people without obstacles for moving people (access areas in public buildings, schools, hotels, hospitals)	5,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00	4,00
		C4: Areas with possible physical activities (dance halls, gymnastic rooms, stages)	5,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00	4,00
		C5: Areas susceptible to large crowds (concert halls, sports halls)	5,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00	5,00	4,00
D	Shopping areas	D1: Areas in general retail shops	4,00	4,00	5,00	4,00	4,00 - 5,00	4,00 - 5,00	4,00 - 5,00	4,00 - 5,00	4,00 - 5,00	4,00 - 5,00	4,50 - 5,50
		D2: Areas in department stores	5,00	5,00	5,00	4,00	5,00	5,00	5,00	5,00	5,00	5,00	4,50 - 5,50
E1	Areas susceptible to accumulation of goods, including access areas and industrial use	E1.2 Industrial buildings and halls	≥ 4,00	≥ 4,00	6,00	≥ 4,00	≥ 4,00	≥ 4,00	≥ 4,00	≥ 4,00	≥ 4,00	≥ 4,00	4,50 - 5,50
		E 1.3 Storage rooms and halls	≥ 5,00	≥ 5,00	6,00	≥ 5,00	≥ 5,00	≥ 5,00	≥ 4,00	≥ 4,00	≥ 4,00	≥ 4,00	4,50 - 5,50
		E 1.4 Collections of books and archives	≥ 5,00	≥ 5,00	6,00	≥ 5,00	≥ 5,00	≥ 5,00	≥ 5,00	≥ 5,00	≥ 5,00	≥ 5,00	4,50 - 5,50
F	Traffic and parking areas for light vehicles (≤ 30 kN gross vehicle weight and ≤ 8 seats not including driver)	Garages; parking areas, parking halls	2,50	2,50	2,00	2,50	2,50	3,50	3,50	3,50	3,50	3,50	-
G	Traffic and parking areas for medium vehicles (> 30 kN, ≤ 160 kN gross vehicle weight, on 2 axles)	Access routes; delivery zones; zones accessible to fire engines (≤ 160 kN gross vehicle weight)	5,00	5,00	5,00	2,50	2,50	3,50	3,50	3,50	3,50	3,50	-
H	Roofs not accessible except for normal		1,00	1,00	0,75	0,50	0,50	1,50	1,00	1,00	1,00	1,00	-
I	Roofs accessible with occupancy according to categories A to G		as adjacent rooms, see A - G	as adjacent rooms, see A - G	as adjacent rooms, see A - G	as adjacent rooms, ≥ 2,00	as adjacent rooms, ≥ 2,00	as adjacent rooms, ≥ 3,00	3,00	3,00	3,00	3,00	-
Uniformly distributed load according to self weight of movable partitions			0,50 - 1,20	0,50 - 1,20	-	0,50 - 1,00	0,50 - 1,00	1,00	1,00	0,75	0,75	0,75	-

*original values in kg/m², conversion 100 kg/m² ≙ 1 kN/m²

** 3,00 kN/m² for hospital rooms

higher value than today

lower value than today

Appendix C

Handbook

Roof inclination

Rooftop farms can only be installed on flat roofs. Flat means that the maximum inclination of the surface is 5°. Above that, the soil would slide down and working on the roof would be more difficult and dangerous.

Size

The minimum area for a commercial farm is assumed with 1.000 m².

Location based factors

Microclimate
The microclimate on the roof needs to be suitable for plants. Strong winds and excessive sun exposure (heat stress) should be avoided. Canopies and windbreaks can help to make the microclimate more plant-friendly. Very tall buildings usually account for high wind velocity and are not suited for rooftop farming.

Solar radiation
Plants need enough solar radiation to grow. Areas for rooftop farms should be faced to the south and free from shading caused by surrounding buildings. The Vienna solar potential cadastre can serve as a guideline for solar radiation. It shows how much solar energy every roof in the city receives per year. If there is not enough solar radiation, artificial lighting could be implemented.

Proximity to consumers and infrastructure
The building needs to be in proximity to consumers (markets, restaurants, residential buildings). Connection to the road network of the city and other infrastructural installations (water supply, sewage, electricity) has to be provided.

Structure

For each individual building there has to be made an evaluation by a structural engineer about the load-bearing capacity of the building. It is possible that a building offers enough structural capacity to support the additional weight caused by a rooftop farm. If not, the building has to be reinforced, which can result in high costs. Additional loads that need to be considered are dead load, pay load, wind actions, snow load and crop actions. They depend on the cultivation system and construction. Depending on the date of construction, different laws and standards dictated different pay loads. Due to this fact and possible changes of use, there might be structural reserves.

Construction date

before 1955	-> see typology C
1955 - 1980	-> see typology B
1981 - 1997	-> see typology D, E
after 1997	-> see typology A

Roof structure
Flat roofs in Vienna can be divided into cold roof, warm roof and inverted roof. All of these three can be suitable for greening, if the structure is able to bear the additional load. A special case is the top level of parking garages that are constructed as a parking area with an asphalt top layer (-> see typology E).

§ Legal aspects

Ownership

public	-> see typology B
single private owner	-> see typologies A, C
multiple private owners	-> see typology D

Building permit
A building permit for the construction of the rooftop farm has to be obtained. For this, there has to be made a structural analysis, all owners of the building have to agree to the project and sign the building plans and the farm has to meet the requirements according to the land use plan, including building height. In addition, the Viennese Regulations for Construction Engineering (OIB Richtlinien) and the standards they refer to, have to be followed. In some cases an industrial operating permit has to be obtained as well.

Monument protection -> see typology C
- protection zones according to the Viennese Building Code
- federal Monument Protection Act
- UNESCO World Heritage

Health and safety
All construction materials need a certain level of fire resistance, escape routes and the division of fire compartments have to be considered. For open-air farms, a guard rail or parapet with a minimum height of 1.10 m is necessary to protect people from falling off the roof. The railing has to be constructed in such a way, that children cannot climb or slip through the grills. Sanitary facilities for employees and visitors should be included in the layout of the farm. They can be situated on the rooftop or in a different story of the building and have to be scaled according to the size of the farm and number of employees.

Building infrastructure

Roof access

Existing access to the roof:		
	None	-> see typology A
	Stairs	-> see typologies C, D
	Elevator	-> see typology B
	Car ramp	-> see typology E

Installations
Required installations are: electricity, water supply, waste water disposal

Farming facilities
Requried farming facilities are: processing space, sanitary facilities, office space

€ Financial aspects

For soil-based open-air farms, construction costs of about 79 USD/m² can be expected. The construction costs for hydroponic greenhouse farms amount to about 882 USD/m². Factors that can significantly increase the construction costs are the reinforcement of the building structure and the construction of an additional access to the roof.

Hydroponic greenhouse

Soilless cultivation method in conditioned environment

minimum additional dead load
g_k = 2,0 kN/m²

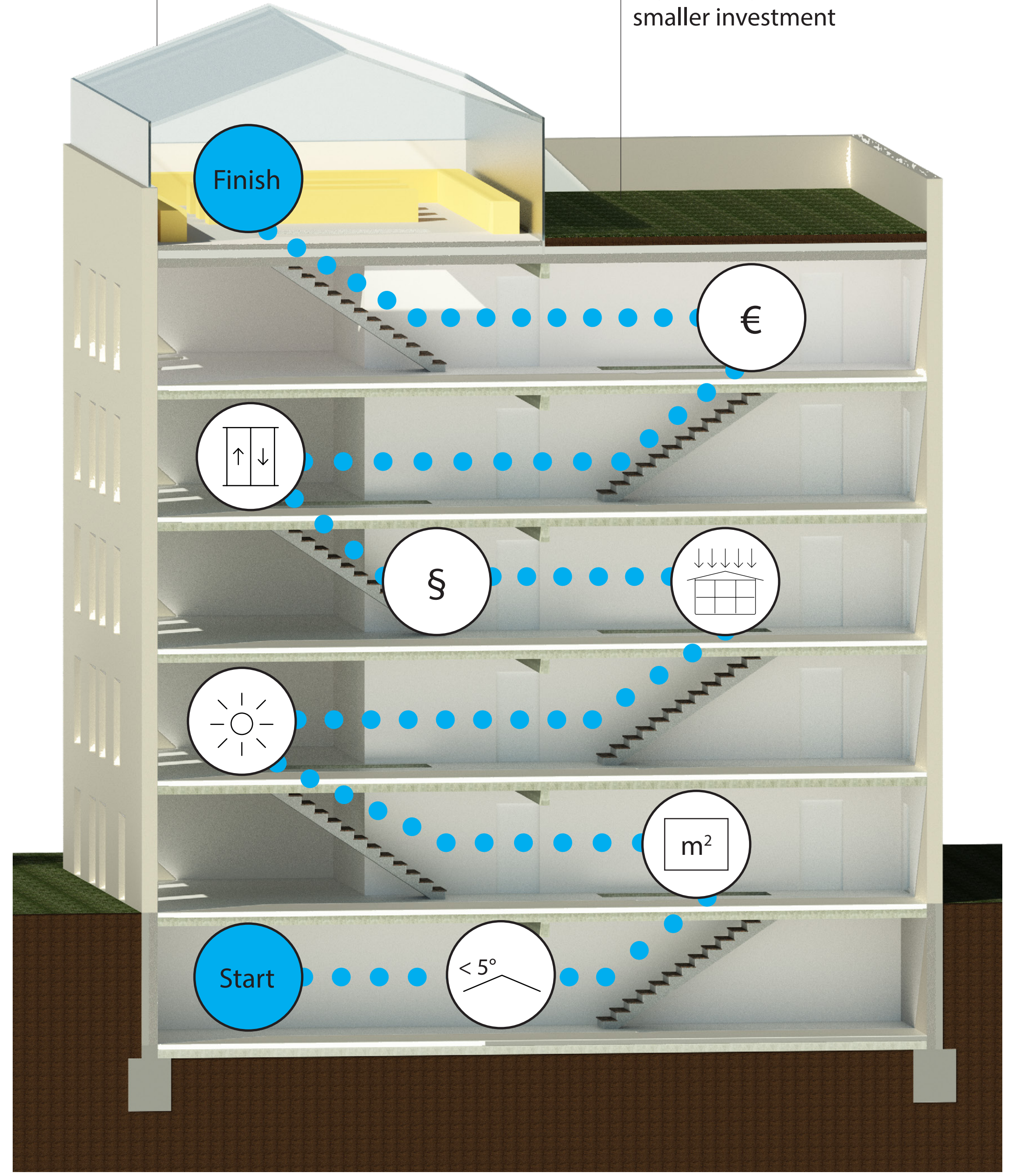
high yields
high input
low weight
large investment

Soil-based open-air

The whole roof is constructed as a green roof with lightweight soil

minimum additional dead load
g_k = 3,0 kN/m²

low yields
low input
higher weight
smaller investment



A Industrial / Retail

Construction date:	After 1995
Roof access:	None
Ownership:	Single private owner
Example building:	Supermarket, Friedrich-Engelsplatz

Industrial buildings usually offer a large rectangular area, which is an advantage for the farm layout. Synergies with respect to building installations can benefit the farm. But existing installations on the roof could also present an obstacle to the construction of a rooftop farm. If the building is used as a supermarket or shopping center, the produce could be sold directly on place. The Eurocode 1 was valid at the time of construction. If the building has been designed for current industrial use, there are probably no structural reserves and the building has to be reinforced to support the additional weight. The typical industrial or retail building is owned by a single private owner which represents a good basis for obtaining a building permit. There is no existing adequate access to the roof. A new staircase and an elevator have to be built, preferably with external access in order to not mix staff from the building and make the farm accessible on the weekends. Because of the low height of the building, the construction of the external access is relatively inexpensive.

B Education, Health, Sports, Culture

Construction date:	Between 1955 - 1980
Monument protection:	Buffer zone UNESCO World Heritage
Roof access:	Stairs, elevator
Ownership:	Public owner
Example building:	University building, Gusshausstraße

This typology encompasses buildings that are publicly owned and are for example schools, universities, hospitals, nursing homes, sports halls or museums. The construction date for this typology is defined in the late 1960s. The according standard is ÖNORM B 4001. Since the pay loads for such building uses have decreased, there might be capacity for additional loads. This typology is owned by the state, the city or a public company. This could present an advantage if the owner him or herself is interested in a rooftop farming and promotes the development of such a project. The building is located in the buffer zone of UNESCO World Heritage, but there are no legal restrictions regarding monument protection. The roof is accessible via a staircase and an elevator and is equipped with water supply pipes and electricity. These are good conditions for the installation of a rooftop farm, since no additional access is necessary and installations for the farm can easily be hooked up to the existing ones. It is worth considering a symbiosis of the installations of a conditioned greenhouse with the existing HVACR system.

C Office Building

Construction date:	Before 1955
Monument protection:	UNESCO World Heritage, Protection zone, Monument according to MPA
Roof access:	Stairs, elevator
Ownership:	Single private owner
Example building:	Office, Georg-Coch-Platz

The Office building typology was constructed in the beginning of the 20th century. There is a high possibility that the load bearing capacity of the structure is high enough to support the additional weight, since the values for pay loads in office areas used to be higher at the time of construction. But the building age is quite high and the condition of the structure - especially the foundations - has to be evaluated. The house is owned by a single private company, which might be an advantage, if the company is interested in supporting the farm for their public image, to present themselves as a sustainable company. But it is also possible that they want to benefit directly financially from the farm and charge a high rent. Considering the monument status, it is advised not to alter the outer appearance and favor a construction that cannot be viewed from the street. Access to the roof is given via staircases and elevators. The farm has to be designed in a way to avoid HVACR installations and may benefit from synergies with the building physics. Existing office areas inside the building can be rented additionally to provide the necessary facilities for production.

D Housing / Mixed use

Construction date:	Between 1981 - 1995
Monument protection:	Protection zone
Roof access:	Narrow stairs
Ownership:	Multiple private owners
Example building:	Residential building, Seidengasse

The building has been constructed for housing between 1981 and 1997, on the basis of ÖNORM B 4012. Since there have been no changes in pay load values concerning residential activities since then, it is presumed that the structure is not capable of bearing the additional weight of a rooftop farm and has to be reinforced. Representative for this typology are multiple private owners, often living inside the building, which may not be entirely in favor of the project. This can present a big challenge for a rooftop farming project with respect to obtaining the building permit and access to the roof. The risk of opposing parties may be reduced by a planning process that includes all stakeholders. It is advised to design a construction that cannot be viewed from the street, because of the location in a protection zone. Since there is only a narrow staircase available to access the roof, it is necessary to extend it or build a new access. It can be of advantage to make a new access that is independent from the building entrance. This can help reassuring the inhabitants that there is no risk of external people gaining access to the building. Concerning installations, the existing water supply pipes and electricity structure in the building can easily be extended to the roof.

E Parking garage

Construction date:	Between 1981 - 1995
Roof access:	Stairs, elevator and car ramp
Ownership:	Single private owner
Example building:	Parking garage, Felberstraße

Multi-story parking garages with a top level accessible for cars offer a large area with a beneficial shape and a highly advantageous existing accessibility of the roof. They are designed for very high single axle loads and therfore offer high structural capacity to support the additional weight of a rooftop farm. This typology was constructed after 1995, when the distributed pay load was lower than today, which represents another possible structural reserve. The top level is constructed as a parking area, usually covered in asphalt or concrete. If the covering layer serves as a root barrier and the waterproofing layer is intact, green roof layers can be added on top of the existing structure. Accessibility to the roof is ideal for agricultural purposes. The vertical circulation is ensured by elevators, stairs and even cars and small vans can access the roof via ramps. Electrical connection is usually already available. Water supply, on the other hand, has to be retrofitted. Alternatively there is the possibility to make use of a rainwater collection system.

Appendix D

Maps

D.1 All layers

D.2 Size class - Small

D.3 Size class - Medium

D.4 Size class - Large

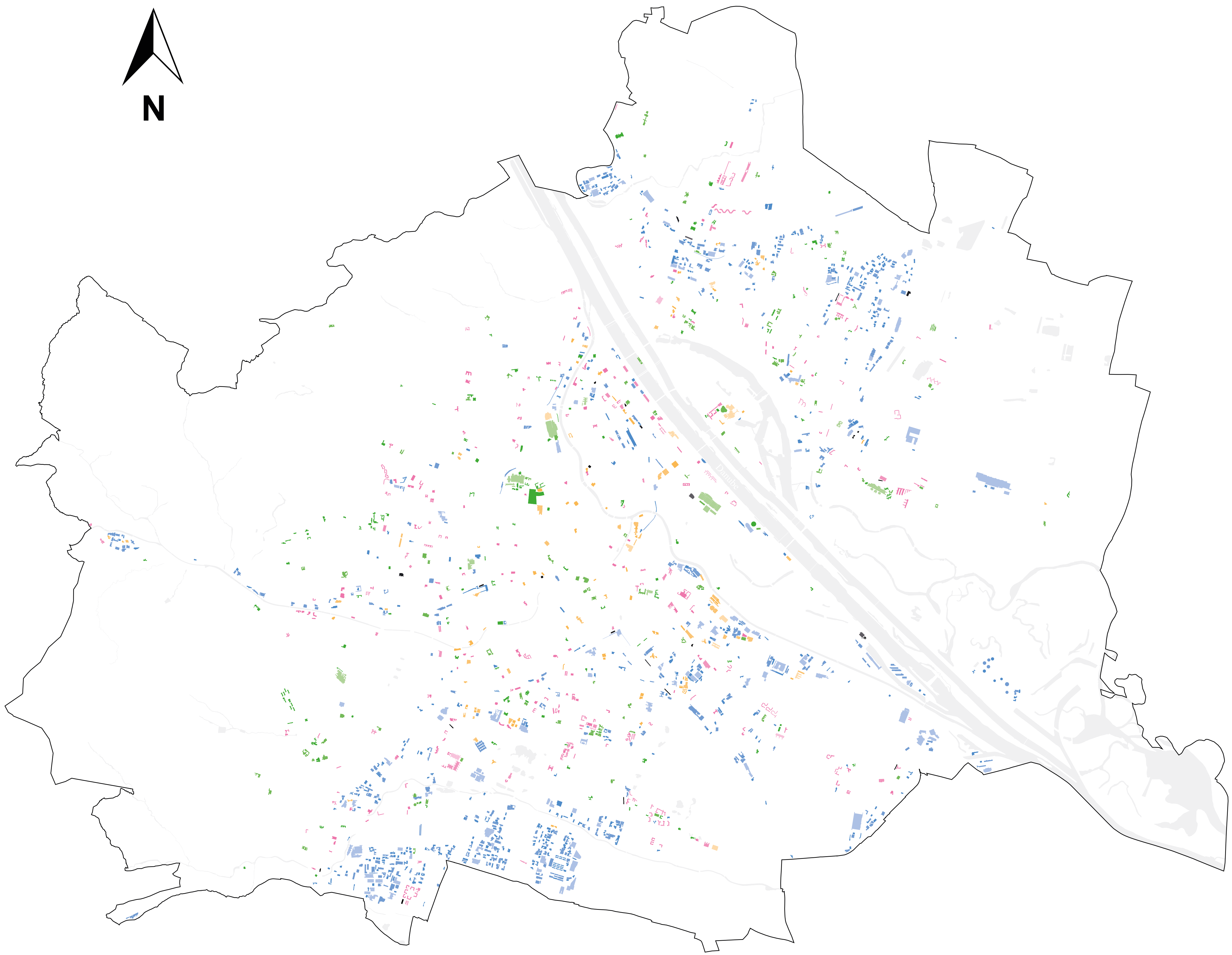
D.5 Category Industrial / Retail

D.6 Category Education, Health, Sports, Culture

D.7 Category Office

D.8 Category Housing / Mixed use

D.9 Category Parking



LEGEND

- Industrial / Retail - Small
- Industrial / Retail - Medium
- Industrial / Retail - Large
- Education, Health, Sports, Culture - Small
- Education, Health, Sports, Culture - Medium
- Education, Health, Sports, Culture - Large
- Office - Small
- Office - Medium
- Office - Large
- Housing / Mixed use - Small
- Housing / Mixed use - Medium
- Housing / Mixed use - Large
- Parking - Small
- Parking - Medium
- Parking - Large

Small: ≤ 2.000 m²

Medium: > 2.000 m², ≤ 6.000 m²

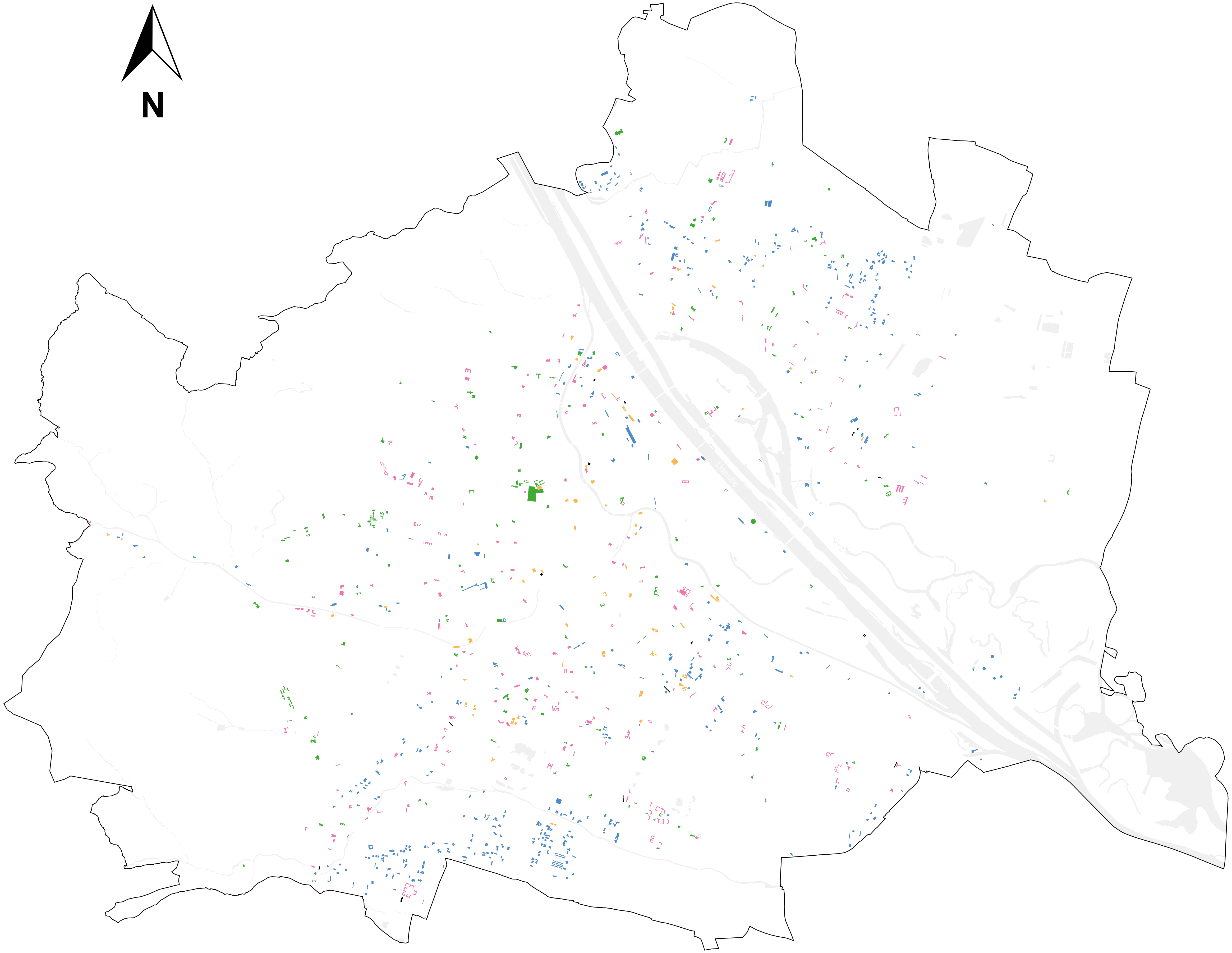
Large: > 6.000 m²

Map of Vienna

GIS-model

All layers

Scale 1:100.000



LEGEND

Industrial / Retail - Small

Education, Health, Sports, Culture - Small

Office - Small

Housing / Mixed use - Small

Parking - Small

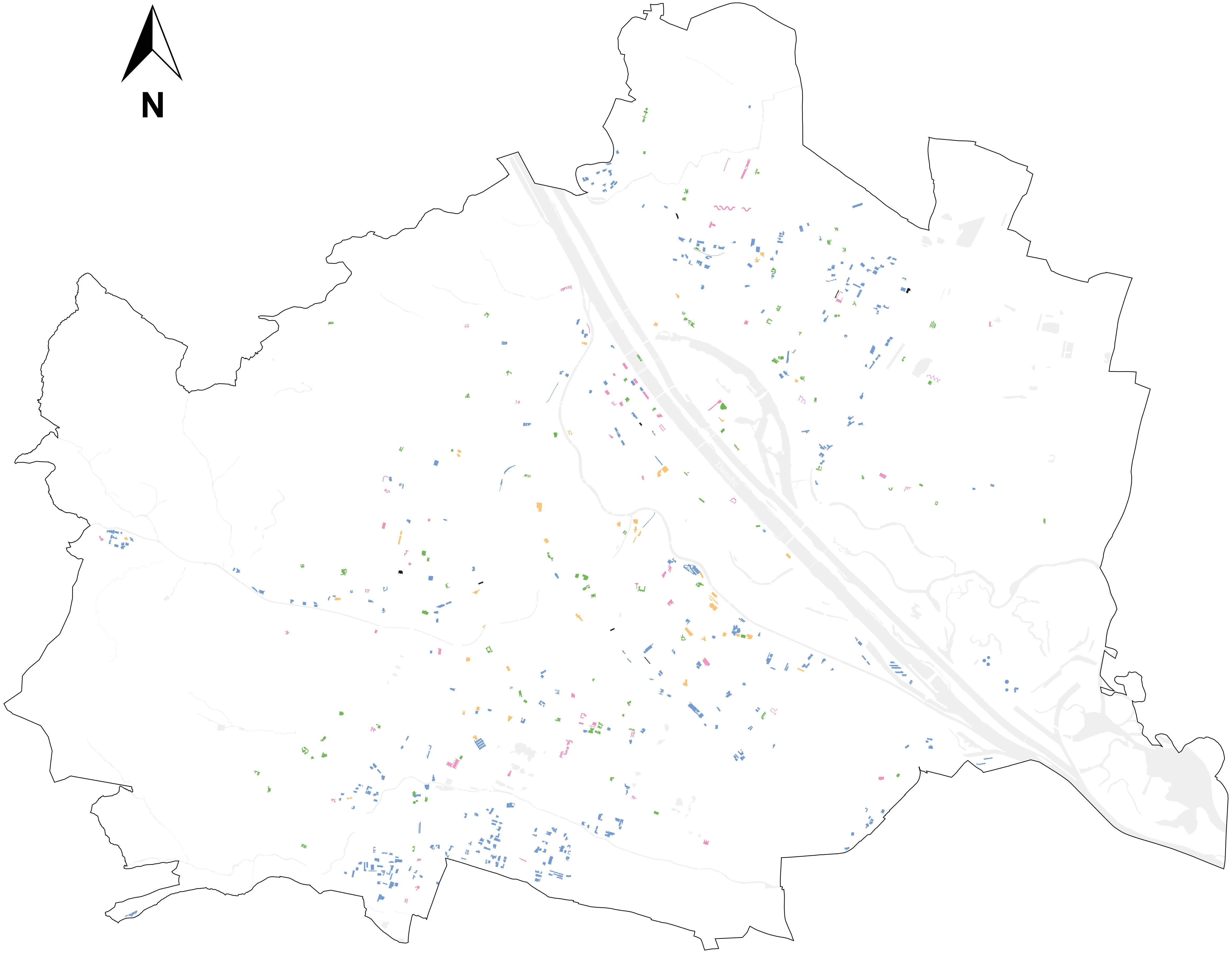
Small: ≤ 2.000 m²

Map of Vienna

GIS-model

Size class - Small

Scale 1:100.000



LEGEND

Industrial / Retail - Mediu

Education, Health, Sports,nCulture - Medium

Office - Medium

Housing / Mixed use - Medium

Parking - Medium

Medium: > 2.000 m², ≤ 6.000 m²

Map of Vienna

GIS-model

Size class - Medium

Scale 1:100.000

LEGEND

Industrial / Retail - Large

Education, Health, Sports, Culture - Large

Office - Large

Housing / Mixed use - Large

Parking - Large

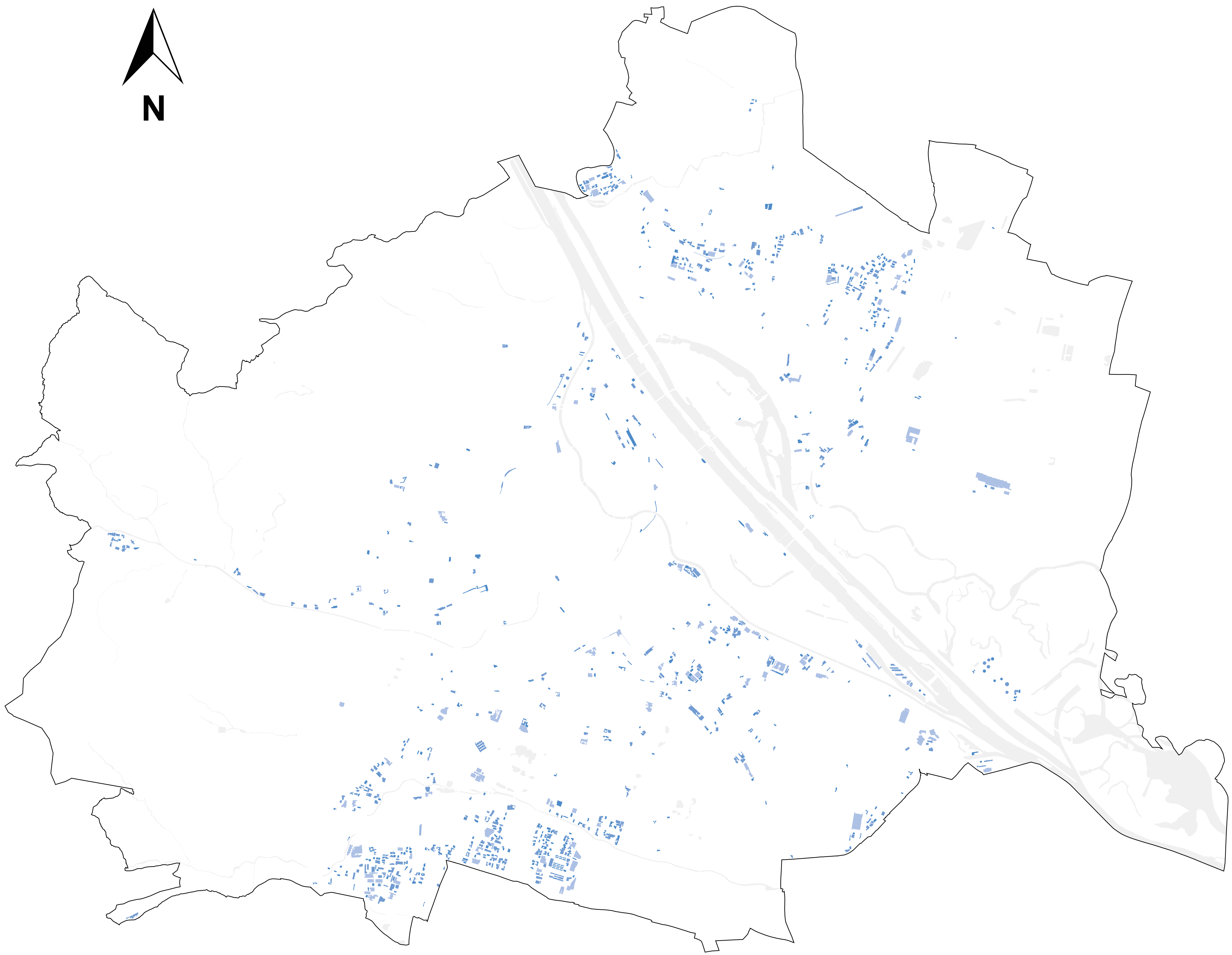
Large: > 6.000 m²

Map of Vienna

GIS-model

Size class - Large

Scale 1:100.000



LEGEND

Industrial / Retail - Small

Industrial / Retail - Medium

Industrial / Retail - Large

Small: ≤ 2.000 m²

Medium: > 2.000 m², ≤ 6.000 m²

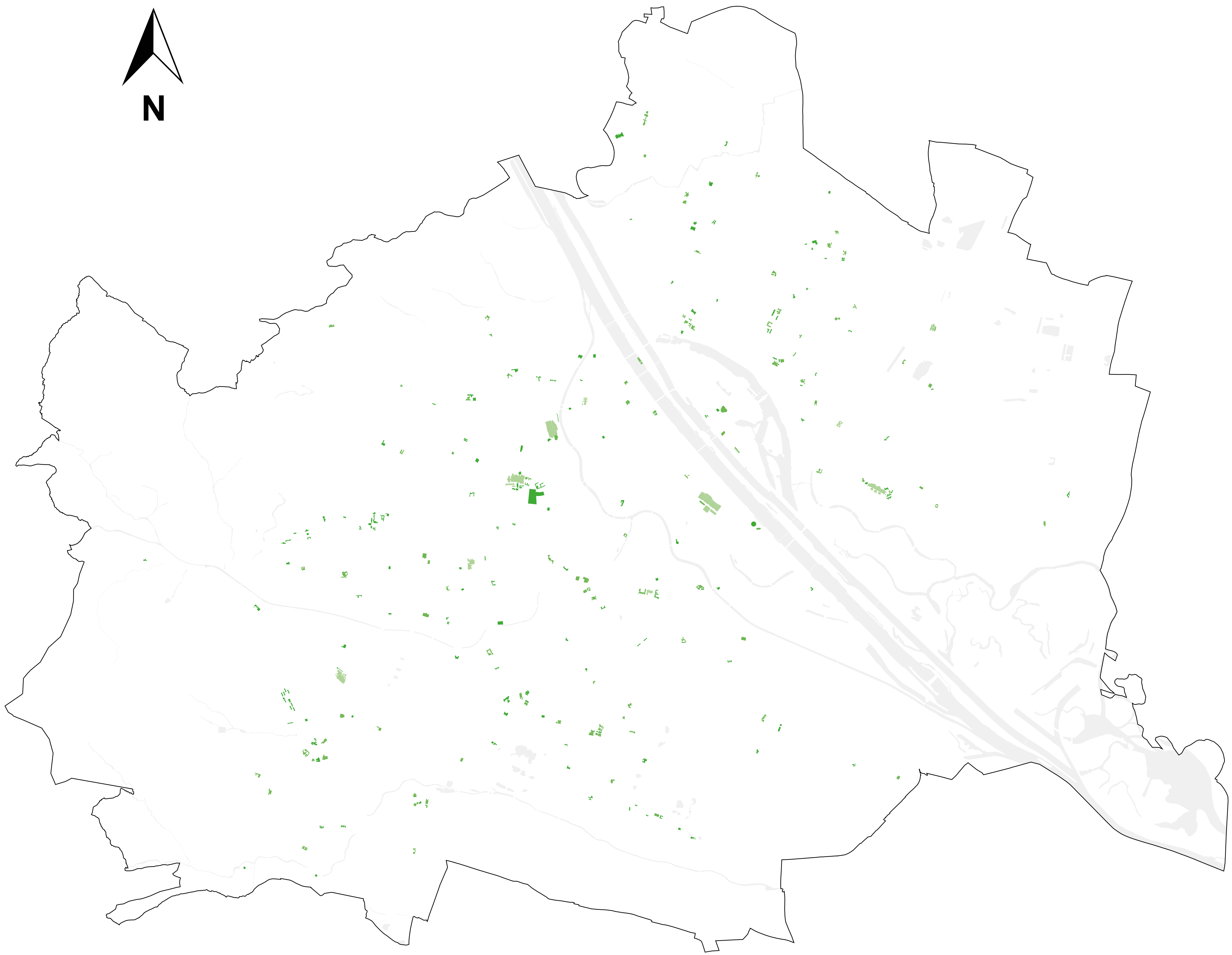
Large: > 6.000 m²

Map of Vienna

GIS-model

Category *Industrial / Retail*

Scale 1:100.000



LEGEND

Education, Health, Sports, Culture - Small

Education, Health, Sports, Culture - Medium

Education, Health, Sports, Culture - Large

Small: ≤ 2.000 m²

Medium: > 2.000 m², ≤ 6.000 m²

Large: > 6.000 m²

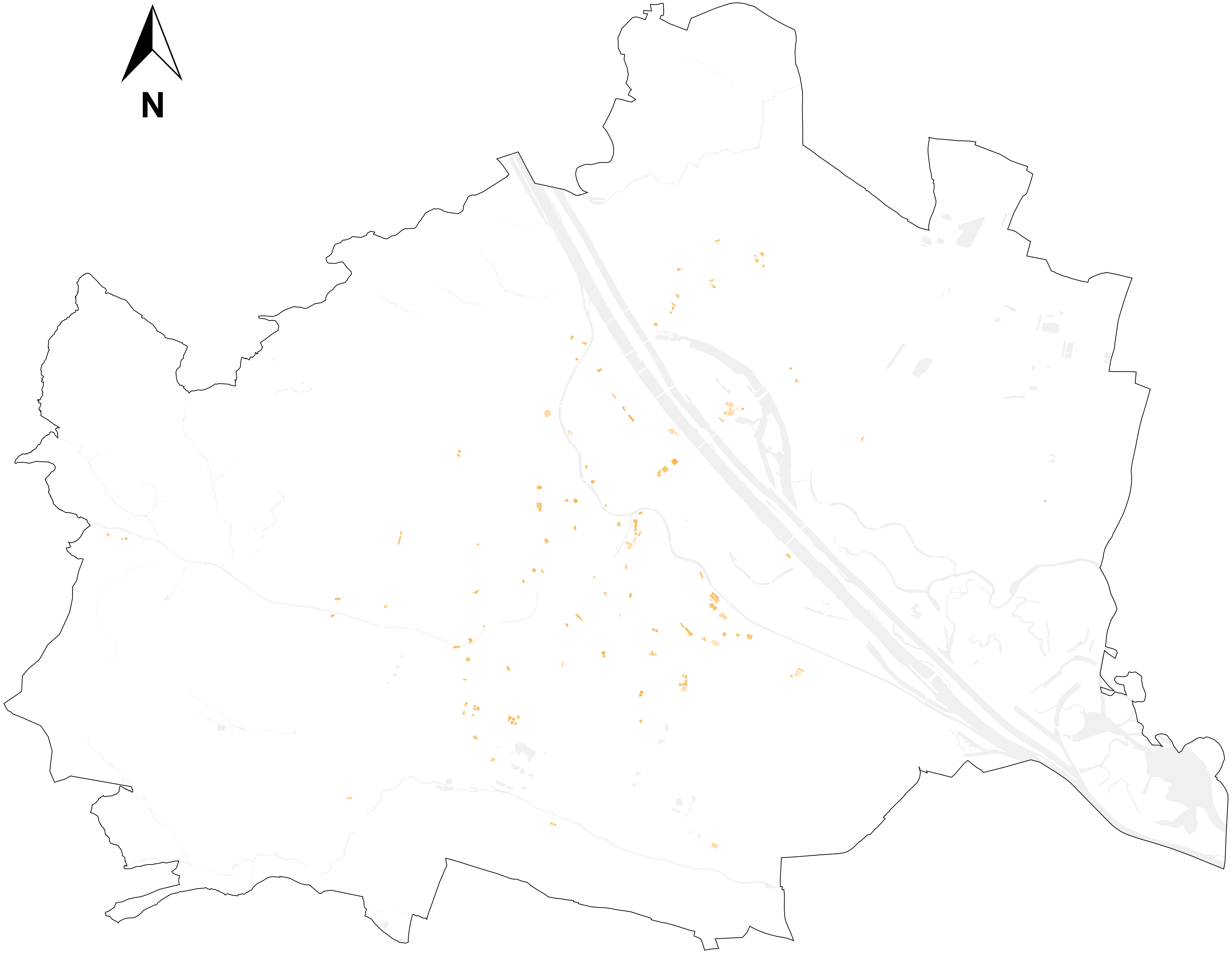
Map of Vienna

GIS-model

Category

Education, Health, Sports, Culture

Scale 1:100.000



LEGEND

Office - Small

Office - Medium

Office - Large

Small: ≤ 2.000 m²

Medium: > 2.000 m², ≤ 6.000 m²

Large: > 6.000 m²

Map of Vienna

GIS-model

Category *Office*

Scale 1:100.000

LEGEND

Housing / Mixed use - Small

Housing / Mixed use - Medium

Housing / Mixed use - Large

Small: ≤ 2.000 m²

Medium: > 2.000 m², ≤ 6.000 m²

Large: > 6.000 m²

Map of Vienna

GIS-model

Category *Housing / Mixed use*

Scale 1:100.000

LEGEND

Parking - Small

Parking - Medium

Parking - Large

Small: ≤ 2.000 m²

Medium: > 2.000 m², ≤ 6.000 m²

Large: > 6.000 m²

Map of Vienna

GIS-model

Category *Parking*

Scale 1:100.000

Appendix E

List of double polygons

OBJECTID	ADRESSE	GREENAR05	Use	No.	Decision	Remark	MD
207007	12., Gertrude-Wondrack-Platz 5/1	1.004	Housing / mixed use	2	delete		
207007	12., Gertrude-Wondrack-Platz 5/1	1.004	Parking	2	keep	Residential building and parking garage; I would take the parking, because the polygon is bigger and the area is better suitable than the roof of the house	ok
60762	19., Döblinger Hauptstraße 83	1.332	Education, Health, Sports, Culture	2	keep	I think the best suitable part of this polygon is a school	ok
60762	19., Döblinger Hauptstraße 83	1.332	Housing / mixed use	2	delete		
100547	6., Damböckgasse 4	1.495	Office	2	keep	majority of area probably office	ok for office (but in reality mainly VHS)
100547	6., Damböckgasse 4	1.495	Housing / mixed use	2	delete		not defined as housing / surface used for Parking (ca. 5850m²) and VHS (bildung)
61661	20., Unterbergergasse 1(SCHULE)	1.569	Education, Health, Sports, Culture	2	keep	School = education	ok
61661	20., Unterbergergasse 1(SCHULE)	1.569	Housing / mixed use	2	delete		
170519	18., Kreuzgasse 74	1.613	Industrial / Retail	2	keep	majority of area is roof of supermarket	ok (+ building structure does fits with industrial object)
170519	18., Kreuzgasse 74	1.613	Housing / mixed use	2	delete		actually really not housing where it is flat - USI sport on one of the lot
202530	15., Tellgasse 3/3	1.652	Education, Health, Sports, Culture	2	keep	MA 51 sports hall	ok
202530	15., Tellgasse 3/3	1.652	Housing / mixed use	2	delete		
119626	10., Doerenkampgasse 3	1.716	Industrial / Retail	3	keep	same area, but not double	ok
119400	15., Schwendergasse 41(HAUS DER BEGEGNUNG)	1.716	Education, Health, Sports, Culture	3	keep	majority of area HDB and library = education&culture	ok
119400	15., Schwendergasse 41(HAUS DER BEGEGNUNG)	1.716	Housing / mixed use	3	delete		
155974	10., Neilreichgasse 111(SCHULE)	1.869	Education, Health, Sports, Culture	2	keep	School = education	ok
155974	10., Neilreichgasse 111(SCHULE)	1.869	Housing / mixed use	2	delete		
8442	6., Windmühlgasse 22	1.877	Housing / mixed use	2	delete	Parking garage (Gartenwerkstatt)	
8442	6., Windmühlgasse 22	1.877	Parking	2	keep	Parking garage (Gartenwerkstatt)	ok
102510	15., Graumanngasse 7(BETRIEB)	2.124	Office	2	keep	majority of area is office building	ok (almost all surface is office!)
102510	15., Graumanngasse 7(BETRIEB)	2.124	Housing / mixed use	2	delete		
107715	10., Jagdgasse 23(SCHULE)	2.135	Education, Health, Sports, Culture	2	keep	School = education	ok
107715	10., Jagdgasse 23(SCHULE)	2.135	Housing / mixed use	2	delete		
103719	20., Höchstädtplatz 3	2.246	Industrial / Retail	2	keep	industrial building	ok because bigger surface industrial
103719	20., Höchstädtplatz 3	2.246	Office	2	delete		
133459	13., Hietzinger Hauptstraße 10-16(HOTEL)	2.377	Industrial / Retail	2	delete		
133459	13., Hietzinger Hauptstraße 10-16(HOTEL)	2.377	Housing / mixed use	2	keep	majority of area in housing; hotel	ok
107595	20., Pasettistraße 96-98	2.382	Industrial / Retail	2	delete		
107595	20., Pasettistraße 96-98	2.382	Parking	2	keep	majority of area is parking deck of ÖAMTC	ok
187123	9., Nordbergstraße 15(UNIVERSITÄT)	2.488	Industrial / Retail	2	delete		
187123	9., Nordbergstraße 15(UNIVERSITÄT)	2.488	Education, Health, Sports, Culture	2	keep	majority of area UZA 4 (part of university of Vienna)	ok

125446	21., Julius-Ficker-Straße 91 BETRIEB	2.810	Industrial / Retail	2	keep	same area, but not double	ok
158300	22., Lobgrundstraße 2(OMV)	2.810	Industrial / Retail	2	keep	same area, but not double	ok
105028	10., Klausenburger Straße 25(SCHULE)	3.040	Education, Health, Sports, Culture	2	keep	School = education	ok
105028	10., Klausenburger Straße 25(SCHULE)	3.040	Housing / mixed use	2	delete		
204579	20., Hellwagstraße 34	3.190	Office	2	delete		
204579	20., Hellwagstraße 34	3.190	Housing / mixed use	2	keep	mixed use, but mostly housing on top levels	ok
10293	8., Landesgerichtsstraße 11	3.435	Office	2	keep	Prison and public prosecutor's office	ok
10293	8., Landesgerichtsstraße 11	3.435	Housing / mixed use	2	delete		
37796	14., Guldengasse 2	4.448	Industrial / Retail	2	keep	OBI department shop with parking garage, but majority of area is for the department store	ok
37796	14., Guldengasse 2	4.448	Parking	2	delete		
223855	22., Wagramer Straße 81	4.554	Industrial / Retail	2	keep	shopping mall Donauzentrum	ok
223855	22., Wagramer Straße 81	4.554	Parking	2	delete		
141098	22., Attemsgasse 10-12	4.725	Industrial / Retail	2	keep	majority of area is industrial	ok
141098	22., Attemsgasse 10-12	4.725	Housing / mixed use	2	delete		
106971	19., Muthgasse 64	5.996	Office	2	delete		
106971	19., Muthgasse 64	5.996	Housing / mixed use	2	keep	mixed use, but mostly housing on top levels	ok
13066	10., Gudrunstraße 159	6.186	Industrial / Retail	2	keep	depot for trams	ok
13066	10., Gudrunstraße 159	6.186	Housing / mixed use	2	delete		
178506	21., Trillergasse 4(TRILLERPARK)	12.569	Industrial / Retail	3	delete		
178506	21., Trillergasse 4(TRILLERPARK)	12.569	Housing / mixed use	3	delete		
178506	21., Trillergasse 4(TRILLERPARK)	12.569	Parking	3	keep	shopping mall with parking on the roof, majorit of usable area is parking	ok
Total	**52**	**171.949**					