Rooftop parks in Amsterdam:

Potential for an elevated layer of public urban green space?

Identifying and assessing the suitability of roofs for rooftop park retrofitting in Amsterdam

MSc Thesis

MSc Metropolitan Analysis Design and Engineering, joint degree WUR & TU Delft

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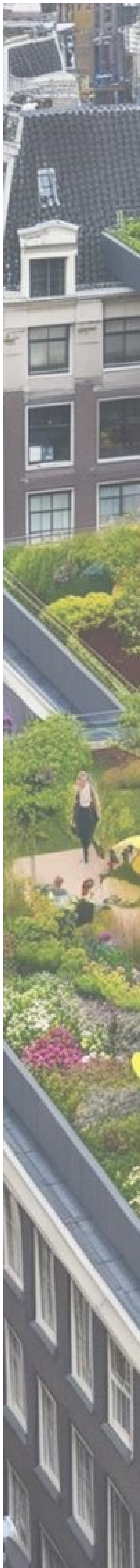

Abstract

The increasing densification in cities in the Netherlands has led to a growing competition for space, which places significant pressure on urban public and green spaces. Evident in Amsterdam, this raises questions concerning the city's ability to sustain the wide range of benefits public green spaces can provide. However, with limited horizontal space still available, the city should explore innovative solutions to create new space in the urban landscape. In this context, retrofitting existing rooftops has sparked significant interest and the concept of rooftop parks has emerged as the ultimate solution. This study explores the suitability of the existing roof stock in Amsterdam for retrofit into rooftop parks, as an elevated layer of public urban green space. Employing a mixed-method approach, it defines the concept of rooftop parks within the city's context, establishes guiding principles for rooftop parks, presents a holistic framework to assess roof suitability based on 11 key building and urban contextual criteria and analyses the application of this framework. In this way, an answer is ultimately provided as to the extent to which roofs in Amsterdam are suitable for rooftop park retrofitting. Adding to existing rooftop development perspectives, findings support informed future decision-making, ultimately contributing to Amsterdam's commitment to creating a more sustainable, liveable and climate-resilient city for all residents.

Keywords: Rooftop parks, roof retrofitting, green roof, Amsterdam, public urban green space, urban parks, criteria, suitability assessment, urban sustainability

Visualisation of a rooftop park in Amsterdam, automatically generated by Dream Lab Canva

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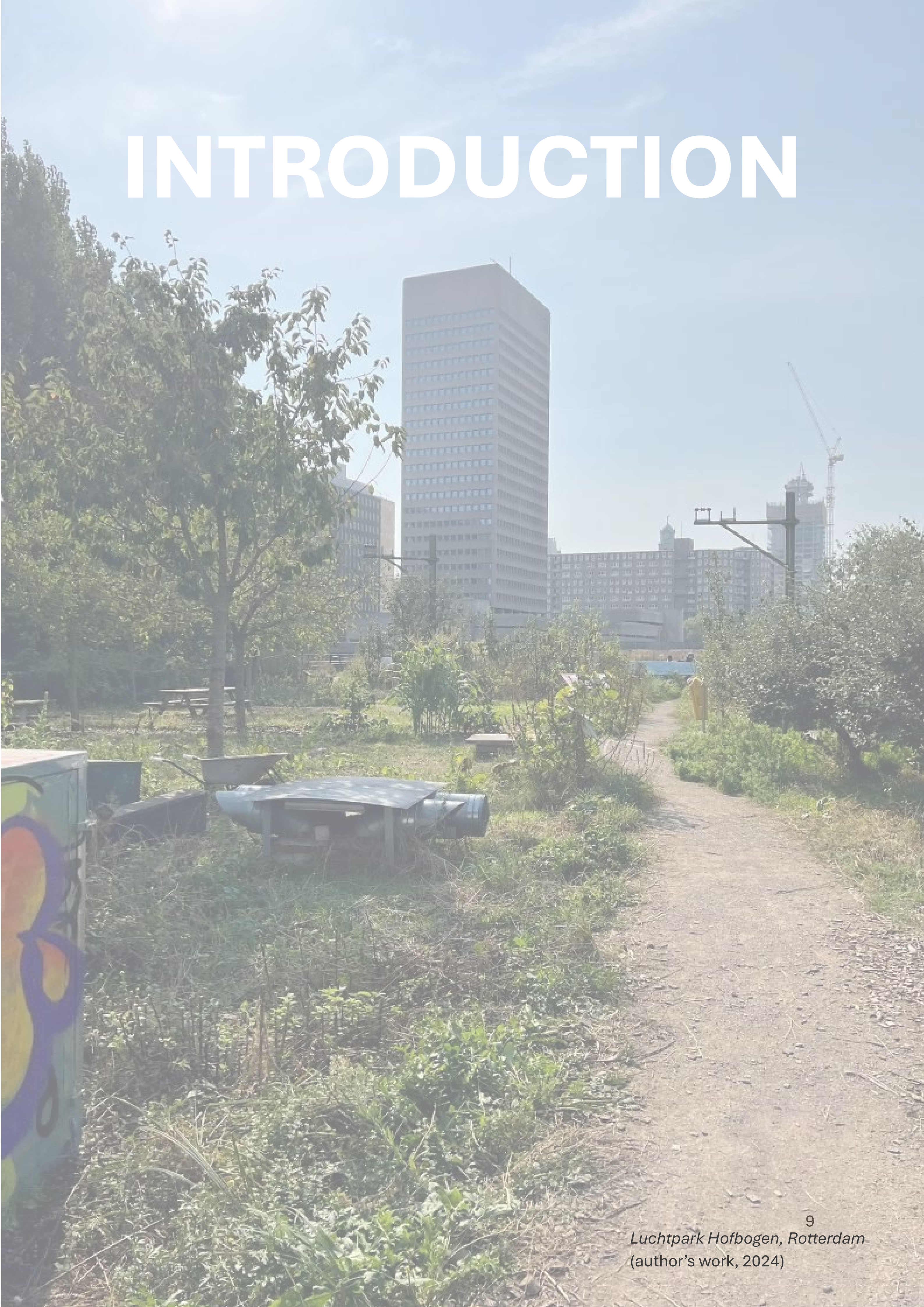
GI	Green Infrastructure
POPS	Privately Owned Public Space
PUGS	Public Urban Green Space
UGS	Urban Green Space

INTRODUCTION



Luchtpark Hofbogen, Rotterdam
(author’s work, 2024)

1 Introduction

1.1 Background

Over the last decades, the increasing densification in cities across the Netherlands has led to rising land prices and growing competition for space, which has placed significant pressure on urban public and green spaces (Hop & Hiemstra, 2013). Research has shown that the surface of public green space per household in large and medium-sized cities has decreased by 24% over the last five years (Penders, 2024). Acknowledging that high spatial competition is evident in various towns and cities, Amsterdam faces particular challenges, as revealed by the Floor Space Index (FSI) (Common Affairs, n.d.). Moreover, the impact of this pressure on Amsterdam's public green spaces is also evident. Despite a population increase of 7.5% between 2018 and 2023, the city witnessed a reduction of 2% in public green space, equivalent to a loss of 159 hectares (Gemeente Amsterdam, 2024c).

This reduction in public urban green space raises questions regarding Amsterdam's ability to sustain the wide range of benefits these spaces are known to provide, which play a critical role in fostering urban sustainability and liveability (Kasim et al., 2019). In terms of well-being, urban green spaces may contribute to psychological relaxation and stress alleviation, promote social cohesion as well as encourage physical activity, in this way enhancing overall physical and mental health (de Jong et al., 2012; Irvine et al., 2009; Maas et al., 2009; Madureira et al., 2015; Pereira et al., 2012; Seeland et al., 2009; Takano et al., 2002; WHO, 2016). Moreover, public urban green spaces provide cooling benefits, can help mitigate the urban heat island (UHI) effect and provide opportunities for water retention, air pollution reduction, and biodiversity conservation (Baró et al., 2014; Bowler et al., 2010; Lepczyk et al., 2017; Shishegar, 2014; Yang et al., 2015).

Nevertheless, the effectiveness of urban green spaces in delivering these benefits depends on their configuration, including factors such as their accessibility, type of green, and size (Hop & Hiemstra, 2013; Stessens et al., 2017). While all types of green spaces, including private gardens, can offer ecological benefits to some extent depending on the type of vegetation, public green spaces in particular, play an important role in enhancing cultural and social aspects in the city (Breuste et al., 2013). Public green spaces, such as parks, are vital as they are accessible and multifunctional, offering nature experiences to all residents and serving as a hub for recreation and community gatherings (Kasim et al., 2019). Therefore, prioritising the development and maintenance of public green spaces is essential to maximise urban greenery's social and environmental benefits. Despite the decline in urban green space, the municipality of Amsterdam also recognises that preserving and expanding public green spaces is essential, not only for maintaining the city's liveability and residents' well-being but also for ensuring sustainability and resilience of Amsterdam's urban environment in the long term (Gemeente Amsterdam, 2020).

However, with limited horizontal space available for traditional urban development, cities like Amsterdam must explore innovative solutions to create new spaces in the urban fabric. In this context, retrofitting rooftops, as often underutilised spaces, has sparked significant interest (Todeschi et al., 2020). Green roofs, particularly, characterised by vegetation based on a substrate layer, have gained prominence in academic literature and practical applications (Kotze et al., 2020). Beyond the increasing recognition of the benefits similar to other green spaces in cities (Hop & Hiemstra, 2013; Kotze et al., 2020), green roofs are also popular due to their potential economic advantages. These include reduced energy costs for heating and cooling, extended roof longevity, and increased real estate value (Rosasco & Perini, 2019; Zhang & He, 2021). By implementing green roofs, cities can add green spaces without disrupting vital services for citizens or their daily routines, while enhancing resilience at both the building and city scales (Silva et al., 2017).

However, while green roofs may offer benefits similar to ground-level urban green spaces (Silva et al., 2023), their effectiveness depends on factors such as vegetation typology and design (Hop & Hiemstra, 2013; Langemeyer et al., 2020; Silva et al., 2017). Moreover, most green roofs are either inaccessible or restricted to building residents, thus constraining social benefits akin to ground-level public green spaces. In addition to green roofs, rooftop spaces are also explored to serve other new purposes, such as energy generation (yellow), water retention (blue), and recreational activities (red) (ISSO, 2022; Nationaal Dakenplan, n.d.). Given the variety of benefits associated with green roofs and the greater potential for multifunctionality, the concept of rooftop parks emerges as the ultimate solution (ISSO, 2022). By transforming rooftops into public urban green spaces, rooftop parks could, among others, address the accessibility and visibility limitations of existing rooftop greenery (Williams et al., 2019).

In Amsterdam, space may be scarce but roofs could still offer up to 12 square kilometres, equal to 25 Vondelparks, available for retrofitting (Van Zoelen, 2022). The municipality acknowledges the advantages of green roofs and considers them a key component of the city's future green infrastructure (Gemeente Amsterdam, 2020). Simultaneously, they advocate for integrated, multifunctional rooftop planning, which could benefit the living environment in the city to a larger extent (Gemeente Amsterdam, 2023b; ISSO, 2022). While emphasising that rooftops should not replace ground-level public spaces, they recognise their potential to address urban challenges and provide additional public space (Gemeente Amsterdam, 2020). This growing recognition of rooftops as valuable spaces for urban development highlights the need for innovative solutions and sets the stage for exploring rooftop parks as a promising solution to address space scarcity and enhance public green areas in Amsterdam.

1.2 Problem statement and knowledge gap

While the municipality of Amsterdam recognises the potential of rooftops to address diverse urban challenges, their potential for retrofitting as multifunctional rooftop parks remains underexplored. To fulfil the potential for this purpose, the key challenge lies in determining which rooftops are suitable for such transformations.

Although green roofs have gained popularity in urban sustainability discussions, and literature on the topic expanded significantly in recent years, terminology remains confusing and highly intertwined (Kotze et al., 2020). Moreover, studies primarily focus on environmental benefits, with limited research addressing their potential as public spaces. Although various examples of rooftop parks exist in the Netherlands and abroad, and the concept may share similarities with rooftop gardens or sky gardens, there is no clear or consistent definition of what constitutes a rooftop park. This lack of clarity complicates efforts to understand their potential and scalability within Amsterdam's dense urban environment or other cities. Moreover, while frameworks exist for evaluating rooftop suitability for rooftop greening (Brudermann & Sangkakool, 2017; Gohari et al., 2022; Karteris et al., 2016; Mahdiyar et al., 2018; Rosasco & Perini, 2019; Sangkakool et al., 2018; N. Xu et al., 2020), these primarily emphasise technological and structural building aspects (ISSO, 2022; Silva et al., 2017; Slootweg et al., 2023; Todeschi et al., 2020). However, defining the suitability of rooftops for rooftop park retrofitting requires a more holistic perspective, incorporating broader and social functions comparable to those of ground-level public parks (Ariff et al., 2023; Gwak et al., 2017; Joshi et al., 2020; Langemeyer et al., 2020; Li et al., 2022; Pouya, 2019).

1.3 Research aim and objectives

Building on the identified knowledge gaps, the overarching aim of this study is to advance understanding of roof suitability for retrofitting into rooftop parks, and in this way provide insights for decision-making processes on public urban green spaces and rooftop transformations in the future. Specifically, this study focuses on assessing the potential of Amsterdam´s rooftops to serve as rooftop parks, addressing the challenges posed by spatial scarcity and the reduction of public green space in the city.

Three objectives are formulated to achieve this overarching research aim:

1. To establish an understanding of rooftop parks and their functions within the context of Amsterdam.
2. To identify and develop a comprehensive set of criteria for assessing the suitability of rooftops for retrofitting as parks.
3. To apply and map the developed criteria and assess the suitability of Amsterdam's rooftops for retrofitting into rooftop parks.

1.4 Research questions

To fill the knowledge gaps, and achieve the research aim, this study centres on the following main research question:

SRQ3 *SRQ2*

"To what extent and based on what criteria are roofs in Amsterdam suitable for potential retrofit as rooftop parks?"

SRQ1

To answer the main research question, the following sub-questions are formulated:

1. How can rooftop parks be defined in the context of Amsterdam, and how does this align with the existing body of literature?
2. What criteria on both the building-level and urban contextual level can be identified and developed to assess the suitability of roofs for retrofit as rooftop parks in Amsterdam, considering guiding principles of rooftop parks?
3. How and to what extent are the developed suitability criteria applicable to available building and geographical data from Amsterdam, and what do outcomes reveal about the potential for retrofitting roofs into rooftop parks?

1.5 Relevance

By exploring how the concept of rooftop parks can be defined, a term that has not yet been established in the literature, this study contributes to the existing body of literature on rooftop usage. Addressing this knowledge gap improves the understanding of the potential role of rooftop spaces within the broader context of urban green infrastructure. Additionally, the study adds to existing (green) roof retrofitting studies and frameworks through a holistic approach by integrating environmental, social, and spatial perspectives. This offers new knowledge into the potential of rooftop spaces to serve as public green areas, which broadens their scope and relevance in urban development.

Considering its societal relevance, this study supports Amsterdam's efforts to enhance urban greening and promote the integrated utilisation of rooftop spaces (Gemeente Amsterdam, 2020, 2023b). By critically evaluating the potential of rooftops as public green spaces, this research provides valuable insights for future decision-making processes in urban planning and development. Ultimately, it contributes to the municipality's commitment to create a more sustainable, liveable and climate-resilient city for all residents of Amsterdam (Gemeente Amsterdam, 2020, 2021a, 2023b).

1.6 Scope

The scope of this study is tailored to Amsterdam's context and urban fabric, considering the city's specific characteristics and needs (Gemeente Amsterdam, 2023b). The findings are particularly relevant to Amsterdam but may not directly apply to other cities with different urban challenges since the conceptual understanding as well as suitability of retrofitting rooftops as rooftop parks may vary with local conditions (ISSO, 2022; N. Xu et al., 2020). Furthermore, since existing buildings constitute the majority of urban space and feature vital but underutilised rooftop areas (Silva et al., 2017; Wilkinson & Dixon, 2016), this study concentrates on retrofitting rooftops in Amsterdam. This means that the conditions of existing buildings in the city and their potential for transformation are evaluated rather than considering new developments. Moreover, the study does not look into specific design elements or technical details, such as plant selection or detailed engineering solutions. Instead, it focuses on the exploration of the broader principles of rooftop parks' functionality and their role within Amsterdam. Finally, financial feasibility and in-depth analysis of regulations are also beyond the scope of this study, although these factors eventually influence their implementation. However, the focus is on conceptual and functional aspects of rooftop parks and the criteria needed to determine their suitability as public green spaces. Through this focused scope, the study aims to provide helpful insights that will inform future decision-making, which on its turn contributes to the development of a sustainable green infrastructure in Amsterdam.

1.7 Reading guide

The next chapter introduces the city of Amsterdam as the research context, focusing on the historic and future urban layout, green infrastructure and rooftop development. Chapter 3 presents the methodology of the research, elaborating on the different research phases. Chapter 4 defines the concept of rooftop parks in Amsterdam, based on both theoretical and empirical perspectives. Chapter 5 then presents the development of criteria for roofs to assess whether they are suitable for rooftop park retrofit, also based on theoretical and empirical evidence. The application analysis of these criteria and their implications is presented in Chapter 6. Following this, Chapter 7 discusses the results concerning the main research question, including the research limitations. Lastly, Chapter 8 presents the conclusions and recommendations.

RESEARCH CONTEXT

ROEF dakpark, Amsterdam
(author's work, 2024)

2 Research context: The city of Amsterdam

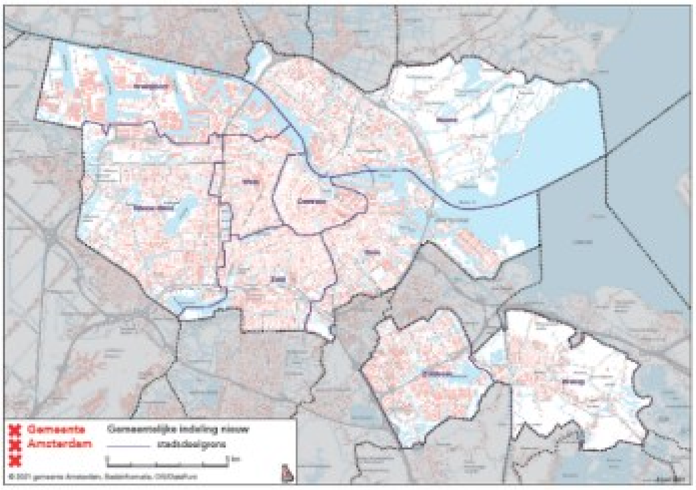


Figure 1: Map of Amsterdam and its districts (Overheid.nl, 2022)

Amsterdam, the capital of the Netherlands, serves as the context of this research. The city stretches over 24.365 hectares and is home to 935.000 residents (Maps Amsterdam, 2024). The population is characterised by its diversity and youthfulness and distributed across eight districts ('stadsdelen'), see Figure 1 (Overheid.nl, 2022), each subdivided into areas ('gebieden'), neighbourhoods ('wijken') and quarters ('buurten') (Gemeente Amsterdam, 2024a). This chapter provides an overview of Amsterdam as the research context, focusing on the historic development of its urban layout and green infrastructure, as well as the city´s current state and future initiatives related to public green spaces and rooftop development. This sets the stage for a detailed exploration of rooftop parks and their potential to shape Amsterdam's future urban landscape.

2.1 Historical development

Amsterdam's current urban form is deeply rooted in its historical development and continuous expansion. Extending beyond the layout of buildings, every phase of urban development in Amsterdam since the 16th century has been accompanied by planned investments in green infrastructure (Gemeente Amsterdam, 2020). During the significant urban expansion marked by the construction of the historic canal belt in the 17th century, greenery was predominantly introduced through private gardens and trees along the canals. When the city expanded further during the 19th and early 20th century with the construction of working-class neighbourhoods, the importance of public green spaces for health and well-being was increasingly recognised, which led to the creation of parks such as Vondelpark and Westerpark. After World War II, the General Expansion Plan ("Algemeen Uitbreidingsplan"), including a city-wide green system, introduced a lobed structure with city expansion extending like fingers from the city centre along green wedges. New urban developments, such as the Western Garden Cities, marked a clear shift towards integrating public green space into urban planning.

While the city continued to grow, the introduction of the Main Green Space Infrastructure ("Hoofdgroenstructuur") in 1996 further sparked increased use and interest in Amsterdam's public green spaces, which are recognised for their wide variety of benefits. However, since 2008, Amsterdam has experienced rapid and unanticipated growth with an average increase of 10.000 new residents yearly. As the city has focused on densification rather than outward expansion, this growth has placed major pressure on the city and its historic public green spaces, raising the question of how to effectively use the limited urban space (Gemeente Amsterdam, 2020).

2.2 Current state and future development

To accommodate the city's expected ongoing growth within the limited space, the municipality developed the **Comprehensive Vision Amsterdam 2050** in 2020 (Gemeente Amsterdam, 2021b), "A Human Metropole," which aims for an inclusive, sustainable, vital, healthy, and liveable

Amsterdam by 2050. In this vision for Amsterdam in 2050, urban green spaces and rooftop development play central roles, as elaborated below.

2.2.1 Urban green spaces

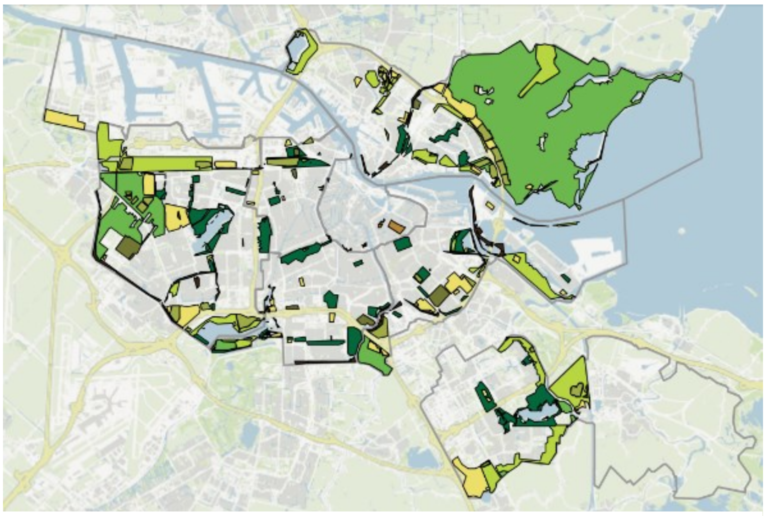


Figure 2: Main Green Space Infrastructure Amsterdam Gemeente Amsterdam, n.d.-b)

Despite the continuous growth of the city, the municipality aims for an even greener city in 2050 by choosing rigorous greening as one of the overarching strategic choices (Gemeente Amsterdam, 2021b). To align with this vision, the designated areas with green and recreational functionalities, formalised as part of the **Main Green Space Infrastructure** ("Hoofdgroenstructuur"), were revised in 2022 (Gemeente Amsterdam, 2023a). However, due to public opposition, the proposed updates were not incorporated. As a result, the most recent version of the Main Green Space Infrastructure remains the one from 2011 (Figure 2; Gemeente Amsterdam, n.d.-b).

Building onto the 2050 comprehensive vision of the city, the **Green Vision 2020-2050** particularly sets out how the city works from the current state of green towards 2050 (Gemeente Amsterdam, 2020). Guided by the 'green, unless' principle, the municipality envisions that public space will predominantly be green unless other functions, such as infrastructure, require different. At the same time, the municipality aims to enhance public access to new and existing green spaces throughout the city. By coupling further densification with expanding and improving green spaces, the goal is for every resident to have green in the direct surroundings of their homes. Furthermore, driven by four key values of green, including health, social well-being, climate adaptation, and nature, the Green Vision 2050 outlines a strong urban green structure, consisting of various interconnected green elements, including green buildings and park areas, Figure 3 (Gemeente Amsterdam, 2020). Considering population growth and densification, the city aims to strengthen all green elements, and for instance, new parks will be developed in areas currently lacking green spaces.

Figure 3: Green elements in Amsterdam in the Green Vision 2020-2050 (Gemeente Amsterdam, 2020) (f.l.t.r. Green buildings and facades, neighbourhood green, green connections, park areas and landscape surrounding the city)

In light of this research, focusing on the element of green buildings, the city recognises the underutilised potential of roofs, and the increasing importance of these spaces due to densification. By 2050, green roofs are expected to contribute to biodiversity, reduce heat stress and support water management (Gemeente Amsterdam, 2020). Moreover, these spaces are recognised to become especially vital if they are made more accessible, thereby serving as green public spaces.

2.2.2 Rooftop development

While further densification should contribute to a sustainable city, it also increases competition for the already limited space available (Gemeente Amsterdam, 2021b). In response, the **Comprehensive Vision Amsterdam 2050** identifies the exploitation and development of roofs as pivotal creative solutions to address the increasing pressure on urban space.

Figure 4 illustrates the steady increase in the number of roofs with green or multifunctional purposes over recent decades (Gemeente Amsterdam, n.d.-a). However, the majority of roofs in Amsterdam remain unused for additional functionalities. The colours depicted in the figure are further discussed in Chapter 4. Despite this underutilisation, the municipality acknowledges that rooftops hold vast potential to contribute to key objectives outlined in the vision, including climate adaptation, biodiversity, energy transition, social functions, and urban expansion (Gemeente Amsterdam, 2021b).

Rather than prioritising a single specific function, the municipality emphasises the importance of rooftop multifunctionality. This approach is thoroughly detailed in the **Integrated Rooftop Landscape Manual** ("Handreiking Integraal Daklandschap") (Gemeente Amsterdam, 2023b), which explores the diverse opportunities and key considerations for rooftop development in the city. In the context of this research, the manual is a valuable source to explore the rooftop park concept in Amsterdam, as develop criteria for suitable roofs for such transformations.

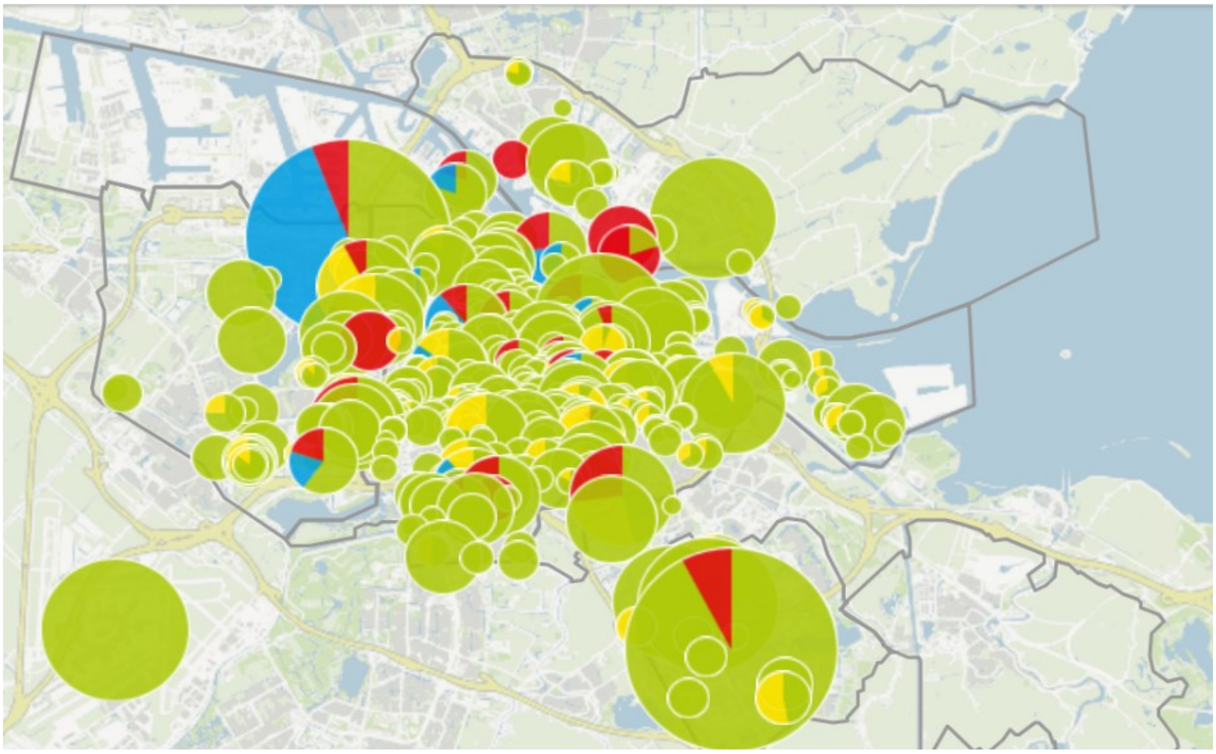


Figure 4: Green and multifunctional roofs in Amsterdam (Gemeente Amsterdam, n.d.-a)

Roofs are depicted with colours indicating different types of multifunctionality. The size of the circles refers to the size of the roofs. Most roofs are either single-function green roofs or combined green roofs with solar panels.

METHODOLOGY

De Groene Kaap, Rotterdam
(author's work, 2024)

3 Methodology

This chapter presents the research methodology adopted to address the research questions in this study. First, it describes the research design. Then, the various steps of data collection, data analysis and data integration are outlined.

3.1 Research design

A mixed-method case study approach was employed, encompassing both qualitative and quantitative methods to study the topic in depth (Subedi, 2016). Specifically, it followed an exploratory sequential design, beginning with a qualitative phase for initial data collection and analysis, followed by quantitative data collection and analysis, and eventual integration of findings (Subedi, 2016). In this research, this design was used to be able to, first, establish a definition for rooftop parks in Amsterdam and identify retrofit suitability criteria, and then test these qualitative findings in a quantitative matter. This approach allowed for data triangulation, ensuring a thorough understanding and interpretation of the research questions.

Figure 5 provides a visual overview of the research process with the different phases and their alignment with the three sub-research questions and the methods employed. The remainder of this Chapter, Chapter 3, explains the different research phases and collection methods in the approximate chronological order of completion. In terms of the set-up of the rest of the report, Chapter 4 focuses on Phase A in relation to SRQ1, Chapter 5 examines Phase A in relation to SRQ2, and Chapter 6 describes Phases B and C, addressing SRQ3 and the overall main research question.

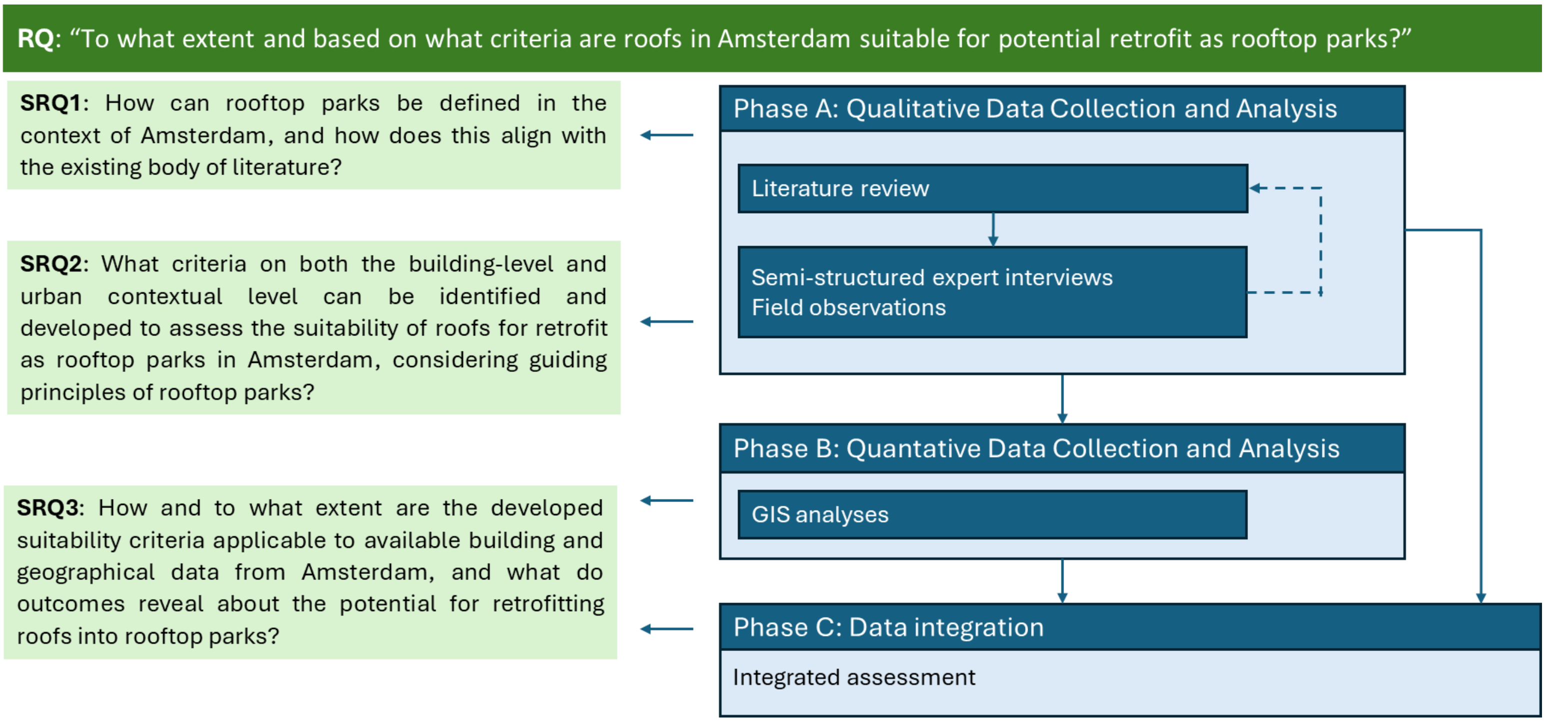


Figure 5: Research design (author's work)

3.2 Phase A: Qualitative data collection and analysis

3.2.1 Literature review

First, a literature review was performed to build a foundation to answer SRQ1 and SRQ2 in the context of existing knowledge (Snyder, 2019). While academic literature, primarily retrieved via Google Scholar, provided a broad, general understanding of the research questions, grey literature was considered to retrieve insights into the specific context of Amsterdam.

For SRQ1, the literature review involved examining academic literature to explore existing definitions of rooftop parks and establish an understanding based on related concepts including public and urban green spaces, urban parks, and rooftop typologies. Search queries included *Roof* park, urban green spaces, UGS, public space, hybrid space, urban park, roof* garden, intensive green roof, accessible roof, social roof, public roof, red roof,* and *multifunctional roof*. Then, grey literature was consulted to obtain advanced understanding into Dutch rooftop (park) development, employing reports and online resources, such as the Nationaal Dakenplan website. Additionally, municipal documents and reports about public green space and rooftop development were analysed to gain knowledge into how these spaces were classified and defined in the specific context of Amsterdam.

After a theoretical understanding of the concept of rooftop parks was established for SRQ1, an initial exploration was performed to address SRQ2, again drawing upon academic literature and review of additional grey literature. The latter included a range of non-peer-reviewed sources such as reports, policy documents, and industry publications to ensure that criteria could be tailored to the unique characteristics of the Amsterdam urban environment. Search queries included similar concepts as for SRQ1 adding terms including *suitability*, *criteria, indicators, factors, retrofit potential, decision analysis, assessment, building selection* and *location selection*. Based on this initial literature review for SRQ2, a preliminary list of criteria was created, which formed a base for conducting expert interviews and performing field observations as described in 3.2.2 and 3.2.3.

3.2.2 Semi-structured expert interviews

Following the initial review of the literature, empirical primary data was collected through semi-structured interviews with experts engaged in the development of rooftop retrofitting projects and public green spaces in Amsterdam, including designers, constructors, and municipal officers.

This qualitative research method facilitates the retrieval of information on predetermined topics while offering flexibility for additional exploration through open-ended questioning (Kallio et al., 2016). In this study, insights retrieved from these interviews add to the theoretical findings from SRQ1 and SRQ2. The literature review provided the foundation for the topic list and questions (Appendix A).

During the initial phase of the interviews, experts were invited to share their firsthand experiences and insights regarding the development of rooftop parks. This phase aimed to capture an understanding of their involvement in rooftop park projects. Subsequently, experts were asked to describe their perspectives on rooftop parks' functionalities and physical appearance. This sought to uncover the experts' definition of rooftop parks (SRQ1). Following, the interviews transitioned into identifying and prioritising criteria relevant to developing rooftop parks (SRQ 2). Experts were invited to come up with and evaluate criteria for the building and urban context for rooftop parks, based on their perceived importance for rooftop suitability in Amsterdam. The interview topic list was tailored according to the expert's main expertise; for example, constructors provided insights primarily on building criteria. Each interview lasted between 30-60 minutes and was recorded with consent.

The sampling of relevant experts was facilitated through collaboration with Rooftop Revolution, a foundation dedicated to accelerate roof development and retrofitting. Initially, based on the recommendations of the team, various partners of Rooftop Revolution were approached. Subsequently, experts were selected through snowball sampling which contributed to the incorporation of a diverse range of experts with relevant experience. The sampling continued until no significant new themes were mentioned, which indicates that theoretical saturation has been reached (Bekele & Ago, 2022). Table 1 provides an overview of the 12 consulted experts. Their roles represent a range of perspectives essential to capture diverse aspects of rooftop park retrofitting. The number of consulted experts also aligns with qualitative research standards (Bekele & Ago, 2022). Experts 1 through 11 were interviewed, while Expert 12 was consulted after analysis of the findings to validate the prioritisation process of the criteria.

Expert no.	Role and expertise
Expert 1	Associate architect with expertise in sustainable urban design and green building practices.
Expert 2	Manager of a firm specialising in the design, supply, and installation of green roofs and rooftop gardens.
Expert 3	Municipal program manager with expertise in developing multifunctional rooftop spaces.
Expert 4	Architect and researcher with expertise in public space design.
Expert 5	Municipal policy advisor for urban green with expertise in rooftop development.
Expert 6	Director of a design studio specialising in innovative roof architecture.
Expert 7	Municipal designer for public space with expertise in rooftop development.
Expert 8	Municipal policy advisor with experience in climate adaptation and development of rooftop programs.
Expert 9	Construction engineer at a consultancy firm, specialising in innovative rooftop solutions.
Expert 10	Specialist in developing creative and multifunctional concepts for rooftop spaces.
Expert 11	Municipal urban ecologist and policy advisor specialising in green infrastructure
Expert 12	Director of an organisation specialising in integrated sustainable rooftop development.

Table 1: Overview of consulted experts

For the analysis, all interviews were transcribed to ensure an accurate record of the expert's responses. Then, the transcriptions were coded with the help of the software ATLAS.ti, which allows for systematic organisation and management of qualitative data. Thematic analysis was used to examine and interpret patterns within the interview data (Proudfoot, 2023). The coding process was primarily deductive, which means that codes were established before the interviews, based on the themes that were found during the initial literature review. At the same time, the analysis also allowed for inductive coding, with new themes emerging as the data was collected and coded. This flexibility contributed to a better understanding of the topic and, eventually, this approach ensured a detailed interpretation of the interview data.

3.2.3 Field observations

In addition to the semi-structured expert interviews, empirical data was collected through field observations in existing (semi-)rooftop parks in Amsterdam and Rotterdam. These observations helped to enhance the understanding of rooftop parks and were used to address SRQ1 and SRQ2.

The field observations involved on-site visits to qualitatively assess the rooftop parks' functionalities and physical characteristics (Copland, 2018). A structured observation framework was applied to ensure systematic data collection and comparability across locations (see Appendix B). Guided by the literature review and findings from the expert interviews, the observations focused on several key aspects. First, general site information was documented, including the name, location and, if known, goals associated with the rooftop park's implementation. To assess the parks' functionalities, observations followed an existing colour-coded categorisation system commonly used in rooftop utilisation. Each rooftop park's 'green' function and appearance were documented focusing on the type, form, and variety of vegetation present. Social or 'red' functions, relating to the public aspect of the rooftop parks, were evaluated by considering accessibility, amenities and users. Additionally, other observed functions beyond green or social elements were noted to capture the full range of rooftop park variations. Beyond the parks' functionalities at a building level, their relationship with the broader urban context was examined, including a description of the surrounding environment, considering factors such as urban form, connecting infrastructure and adjacent urban green spaces. Additional qualitative remarks were documented to capture any unique aspects or unexpected findings during the visits and pictures were taken during the visits for further documentation. Field observation notes and pictures per location are provided in Appendix B.

The cases for field observations were selected based on a combination of expert suggestions and insights from the literature review. This ensured that they represented a broad spectrum of rooftop park types in various urban settings. Although this research focuses on rooftop parks in Amsterdam, several examples from Rotterdam were included due to the limited availability of rooftop parks in Amsterdam itself. While Rotterdam's examples may not directly reflect Amsterdam's urban landscape, they offer relevant ideas into rooftop park retrofitting within the broader Dutch urban context. Table 2 and Figure 6 below provide an overview of the visited rooftop parks.

The observations were conducted within a limited timeframe of about 30 minutes per visit, and primarily aimed to get a better general understanding of the concept of rooftop parks. By examining real-world examples and their appearance and functionalities, the research sought to strengthen the credibility and reliability of the study's findings. Similar to the expert interviews, the data collected from the field observations were analysed using thematic analysis. Using the observation framework, the researcher identified patterns, focusing on key similarities and differences between the rooftop parks. These insights were then compared and linked to the insights from the literature and expert interviews, enriching the understanding of the parks' appearance and functionalities.

N#	Name	Location	Date of visit
1	Orlyplein	Amsterdam	09/08/2024
2	Dakpark Vivaldi	Amsterdam	04/09/2024
3	Dakpark de Boel	Amsterdam	04/09/2024
4	Rhapsody Jan van Schaffelaarplantsoen	Amsterdam	04/09/2024
5	Dakpark Vierhavenstrip	Rotterdam	18/09/2024
6	Luchtpark Hofbogen	Rotterdam	18/09/2024
7	De Groene Kaap	Rotterdam	18/09/2024
8	DakAkker	Rotterdam	18/09/2024
9	NEMO	Amsterdam	22/09/2024
10	ROEF Dakpark	Amsterdam	29/09/2024

Table 2: Overview of field observation locations

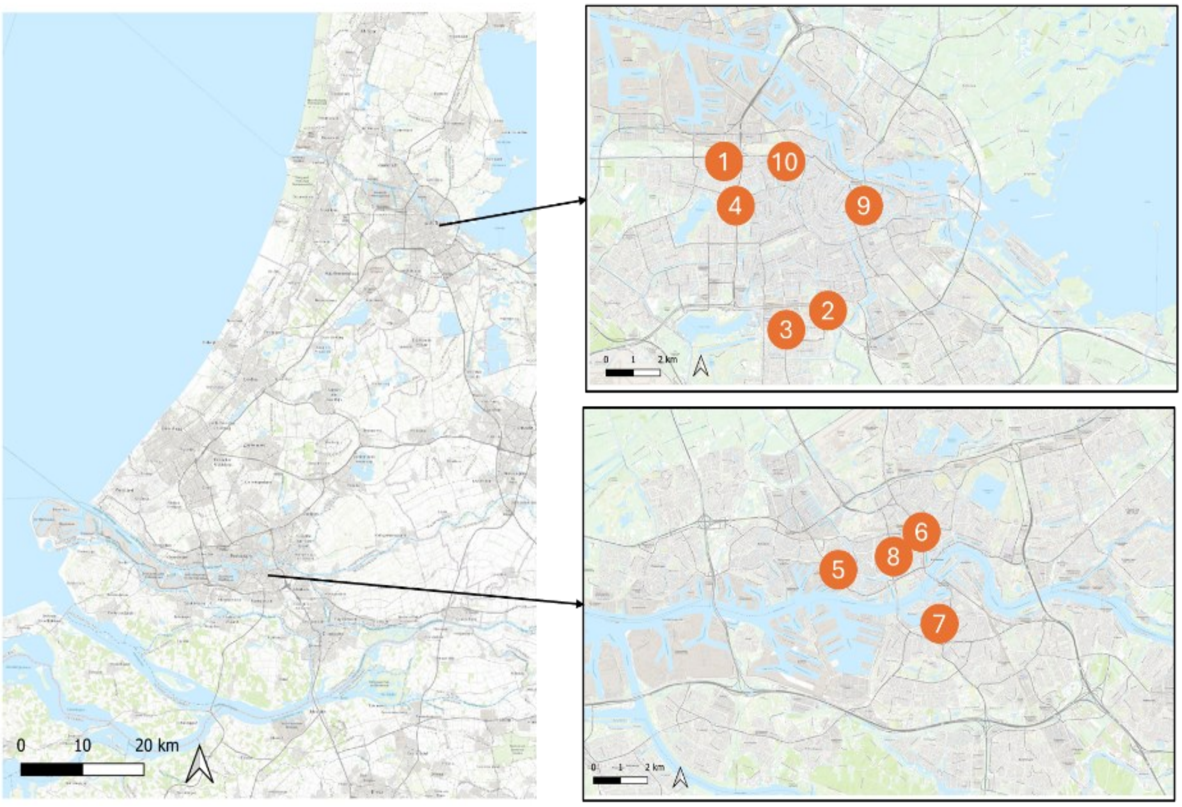


Figure 6: Overview of field observation locations (author's work)

3.2.4 Qualitative data integration

After the expert interviews and field observations were analysed, an additional round of literature review was carried out for SRQ2 to further support the criteria that emerged during the empirical research. This step formed part of the iteration in the study (see Figure 5), where the findings from the expert interviews and field observations were connected and integrated with existing knowledge from the literature.

In this step of integration, search queries combined the new themes that were identified from the interviews and observations with the information derived from the initial literature review. This allowed for a more refined understanding of rooftop parks and facilitated the development of guiding principles and the formulation of a definition that addresses SRQ1. Furthermore, this process helped to identify and refine the building-level and urban-contextual criteria (SRQ2) and corresponding indicators and thresholds needed to assess the suitability of roofs for retrofit as rooftop parks in Amsterdam. By grounding the developed criteria in both empirical data and established research, the study ensured the robustness of the suitability criteria framework. This paved the way for Phase B.

3.3 Phase B: Quantitative data collection and analysis

In Phase B, the qualitative data collected and analysed in Phase A informed the subsequent quantitative data collection and analysis. Building upon the criteria framework developed during Phase A, relevant spatial data was gathered from available datasets provided by the municipality of Amsterdam, primarily via the Maps Amsterdam website. Spatial data was considered relevant when it contained information aligning with the criteria and corresponding indicators identified in Phase A. To clarify, for instance, insights derived from expert interviews, field observations and urban green space literature regarding the required scale and available roof area for rooftop park retrofit guided the search for a dataset containing this information (DAKEN_BAG3D, table 3). The specific attribute in this dataset related to the roof size was then used to assess and filter roofs that met the established qualitative criterion and indicator threshold.

Table 3 provides an overview of the datasets that were selected in this phase of the research. Additionally, data concerning the population and the building stock per neighbourhood was retrieved via the municipal dashboard for research and statistics (Gemeente Amsterdam, 2024a). Chapter 6 elaborates in more detail on which datasets and attributes are linked to the specific criteria and indicators identified during the research process.

Dataset	Description	Link
INDELING_WIJK	Neighbourhood division	https://maps.amsterdam.nl/gebiedsindeling/
DAKEN	Green and multifunctional roofs	https://maps.amsterdam.nl/dakenlandschap/
DAKEN_BAG3D	Flat roofs, organised by building property	https://maps.amsterdam.nl/plattedaken/
ECOLOGISCHE_STRUCTUUR	Ecological structure	https://maps.amsterdam.nl/ecopassages/
HOOFDGROENSTRUCTUUR	Main green infrastructure	https://maps.amsterdam.nl/hoofdgroenstructuur/
PARKPLANTSOENGROEN	Parks in Amsterdam	https://maps.amsterdam.nl/stadsparken/
WELSTAND_NIVEAUS	Levels of aesthetic standards	https://maps.amsterdam.nl/welstand/
HOEGROOT	The contours of Amsterdam	https://maps.amsterdam.nl/hoegroot/
FUNCTIEKAART	Non-residential building functions	https://maps.amsterdam.nl/functiekaart/
Bodemgebruik groen gebieden	The type of land use per area	https://onderzoek.amsterdam.nl/dataset/groen-in-amsterdam
Afstandgroen hex100	Distance to green areas per hexagon	

Table 3: Overview of selected datasets

After relevant spatial data was collected, this data was mapped in ArcGIS Pro. This is a GIS software tool that is widely used for spatial analysis and visualisation. With this tool, the retrieved statistical data was also linked to the spatial data. Subsequently, various spatial queries and spatial overlay techniques were used to identify and assess suitable rooftops based on the established criteria framework. Spatial queries were primarily used to filter roofs based on building-level criteria, while overlay techniques combined multiple datasets and were particularly helpful for evaluating urban contextual criteria. With the evaluation of available building and geographical data in Amsterdam and the spatial GIS analyses performed with this data, this phase addressed SRQ3.

3.4 Phase C: Data integration

Following the quantitative analysis in Phase B, Phase C of this study integrated all findings from both qualitative and quantitative phases. In this phase, the criteria and indicators identified in Phase A that lacked spatial data were combined with the findings of Phase B. This integration ensures a more comprehensive evaluation of the suitability of roofs for retrofit and transformation into rooftop parks in Amsterdam.

While Phase B focused on spatial data and its quantitative analysis, Phase C built on this by considering additional qualitative criteria and indicators generated in Phase A which could not be captured by spatial data (alone). Visual assessments were conducted using satellite imagery and Google Street View to enrich this process. These tools allow for a holistic assessment of the rooftops, particularly for elements that were not easily quantified yet identified as crucial in Phase A to assess rooftop park retrofit suitability. The visual assessments based on satellite imagery and Google Street View brought a valuable extra layer of context, supporting the quantitative findings with a real-world perspective.

By integrating these multiple data sources, Phase C further addressed SRQ3 and the overall main research question. This ensured that the final assessment of the suitability of roofs for retrofitting into rooftop parks in Amsterdam was based on a well-balanced evaluation of both qualitative and quantitative criteria and indicators.

DEFINING ROOFTOP PARKS

Dakpark Vivaldi, Amsterdam
(author's work, 2024)

4 Defining rooftop parks

This research studies rooftop parks as a new concept in urban space, focusing on their potential to address social and environmental needs in cities. Vargas-Hernández (2020) describes urban space as *"the proper space of a city, that is, of a population grouping of high density (...) characterized by having an infrastructure so that this large number of people can cope harmoniously in their daily lives"*. In this regard, rooftop parks are considered part of this urban infrastructure. To define rooftop parks, it is helpful to consider them in relation to existing concepts within urban space. Therefore, this chapter aims to explore how rooftop parks can be conceptualised and how they may align with or differ from traditional urban green spaces and established rooftop typologies.

The concept of rooftop parks is developed through theoretical and empirical lenses, see Figure 7. The discussion first draws on academic literature to investigate key concepts, including urban green spaces, parks, public and hybrid spaces, and rooftop typologies in 4.1. Then, section 4.2 presents the empirical insights from field observations and expert interviews. Finally, in 4.3, these perspectives are brought together and a definition as well as guiding principles are formulated to capture the meaning and potential of rooftop parks in Amsterdam.

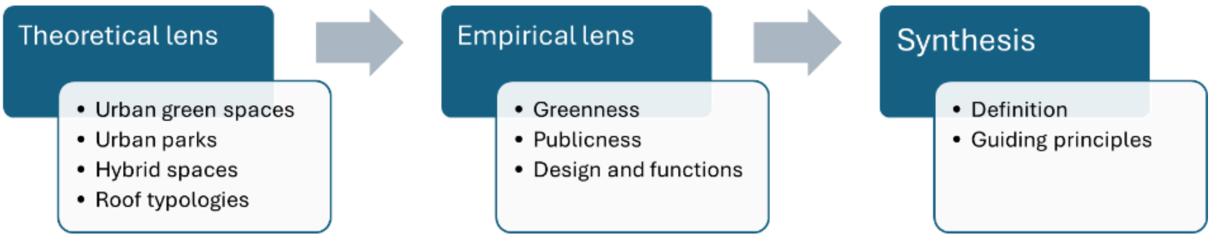


Figure 7: Set-up of Chapter 4 (author's work)

The decision to use this synthesis framework, combining both theoretical and empirical perspectives instead of creating a theory-based definition, was made to develop a holistic understanding of rooftop parks in Amsterdam. As rooftop parks are not yet defined in literature but real-world examples exist, literature in this case provides conceptual context while empirical insights contribute to the relevance and applicability of the research. The theoretical lens outlines multiple key concepts relevant to define and position rooftop parks, while the empirical lens builds onto this by examining how rooftop parks (are expected to) manifest in reality. Terms like greenness, publicness, and design and functions are explored empirically because they are practical descriptors for how rooftop parks function in a real-world context. These terms serve as an overarching reflection of the various theoretical concepts and capture their relationship with rooftop parks in practice. This approach forms the basis for the subsequent research stages, which include identifying criteria and assessing the suitability of rooftops for the development of this concept in Amsterdam.

4.1 Theoretical lens

4.1.1 (Public) urban green spaces

To gain a full understanding of rooftop parks, it is important to situate them within the broader context of urban green spaces (UGS), which generally refers to all surfaces of the urban environment with vegetation, such as grass, trees and shrubs (Taylor & Hochuli, 2017). Depending on the specific configuration, research has shown that these spaces can play a vital role in cities providing environmental benefits, such as reducing urban heat islands, improving air quality and promoting biodiversity (Bowler et al., 2010; Breuste et al., 2013; Irvine et al., 2009; Kasim et al., 2019; Madureira et al., 2015). Considering these roles and the interconnectivity between green spaces in cities, they are often also recognised as part of a broader urban green infrastructure (GI).

As previous studies have noted (Boulton et al., 2018; Taylor & Hochuli, 2017), there is considerable confusion in the literature regarding the definition of urban green spaces (UGS). The concept of UGS is defined differently among disciplines and may also include private green such as residential gardens (Taylor & Hochuli, 2017). Among others, urban green spaces can be defined by their size, ownership, access, variety of green and amenities (Taylor & Hochuli, 2017). However, this study focuses specifically on urban green spaces intended for public use (Reyes-Riveros et al., 2021), hereafter referred to as public urban green spaces (PUGS), to inform the definition of rooftop parks. As a remark, the term public urban green space is often used interchangeably with other terms like urban green space (excluding privately owned green urban areas) or open green space in the literature, which can lead to confusion (Boulton et al., 2018). Nonetheless, literature widely acknowledges that PUGS encompass a broad spectrum of areas, including small neighbourhood parks, cemeteries, sporting fields, larger nature reserves, and also public green roofs (Davern et al., 2016).

As beforementioned, all UGS may play important environmental roles in cities, but PUGS are also specifically known for their potential contribution to human well-being and additional social benefits resulting from their public nature, such as improving mental and physical health and providing space for human interaction and contact with nature (Kasim et al., 2019; Madureira et al., 2015; Reyes-Riveros et al., 2021; Seeland et al., 2009). While recognising the potential significance of these spaces sets the stage for viewing rooftop parks as a new and innovative form of PUGS in this research, it is important to acknowledge that research also indicates that the environmental and social benefits of (P)UGS are not guaranteed, and can be highly contingent on how (P)UGS are designed, planned and integrated into the city lay-out (Baycan et al., 2002; Biernacka & Kronenberg, 2019; Breuste et al., 2013; Hunter & Luck, 2015; Kasim et al., 2019; Lepczyk et al., 2017; Reyes-Riveros et al., 2021; Taylor & Hochuli, 2017).

In Amsterdam, the Main Green Space Infrastructure ('Hoofdgroenstructuur'*)* maps the key urban green spaces that have a dominant green function and serve functions beyond the neighbourhood level, holding significant value for people, plants and animals (Gemeente Amsterdam, n.d.-b). Although not all green spaces in the city are part of this network, the Main Green Space Infrastructure serves as a guiding instrument for green space planning. All included areas are publicly accessible to varying degrees. The official guiding version from 2011 as well as the reclined revision from 2022 distinguish eight different types of green spaces. While there are some differences in terminology, functions, and assigned values, both versions share a common focus on preserving and protecting valuable green spaces (see Table 4).

Distinguished green types in Main Green Space Infrastructure	
2011 (official) (Gemeente Amsterdam, 2011)	2022 (reclined revision) (Gemeente Amsterdam, 2023a)
Curiosities ('Curiosa')	City park ('Stadspark')
Corridor ('Corridor')	City pocket park ('Stadsplantsoen')
Rough nature ('Ruigtegebied of struinnatuur')	Nature park ('Natuurpark')
Urban fringe polder ('Stadsrandpolder')	Sports park ('Sportpark')
City park ('Stadspark')	Garden park ('Tuinpark')
Cemetery ('Begraafplaats')	Memorial park ('Gedenkpark')
Allotment/school garden	Landscape ('Landschap')
Sports park ('Sportpark')	Green connection ('Groene verbinding')

Table 4: Overview of green types in the Main Green Space Infrastructure of Amsterdam

Although rooftop parks are neither formally defined nor explicitly included within the Main Green Space Infrastructure, they may represent a potential new form of green space that could align with the broader objectives of urban greening in Amsterdam (Gemeente Amsterdam, 2020). While not directly included in either the 2011 or 2022 versions of the Main Green Space Infrastructure, rooftop parks may fulfil similar functions and values as traditional urban green spaces, such as supporting biodiversity and offering recreational space (Gemeente Amsterdam, 2011, 2023a). As such, they may potentially complement the existing city's green space infrastructure.

4.1.2 Urban parks

Urban parks appear as the most frequented, recognisable and well-managed public urban green spaces in the vast majority of cities, and are recognised as central components of urban green structures (Biernacka et al., 2020; Konijnendijk et al., 2013). By examining the form and function of 'traditional' ground-level urban parks, we can better understand and define rooftop parks. This comparison allows for the adaptation of established park features and functions to rooftop environments, helping to shape the desired characteristics and multifunctionality of this new emerging type of urban green space.

Lynch (1995) may have provided the simplest definition of parks, referring to parks as the pieces of green-coloured land on planners' maps, but this does not encompass the range of forms, functions, and significance of parks nowadays. While national parks may stretch over hundreds of square kilometres in rural areas, this research focuses specifically on urban parks, within the city limits. According to Konijnendijk et al. (2013), urban parks are *"delineated open space areas, mostly dominated by vegetation and water, and generally reserved for public use. Urban parks are mostly larger, but can also have the shape of smaller 'pocket parks'. Urban parks are usually locally defined (by authorities) as 'parks'. "* Similar to other (P)UGS, urban parks have been extensively studied for their diverse environmental, social, and economic contributions to cities, including enhancing biodiversity, improving air quality, providing cooling effects, promoting health and well-being, fostering social cohesion, and positively influencing property values (Chiesura, 2004; Konijnendijk et al., 2013). While the specific benefits can vary depending on the size and configuration of the park, parks are generally recognised as key elements in promoting quality of life and sustainable cities (Talen, 2010).

In Amsterdam, the concept of parks is interpreted through various types of urban green spaces, each serving distinct primary functions, such as sports or memorial purposes (Table 4). Among these, the city parks are the most prominent. Defined as green, park-like environments in the urban context, these areas welcome residents and visitors of all ages and feature a wide range of facilities (Gemeente Amsterdam, 2011, 2023a). Depending on the park's size, they have a zoning ranging from intensive to extensive use. The priority value of these parks is nature, but other main values include recreation, social, and health. In the 2022 revision, city pocket parks were distinguished as compact parks which form an essential link in the urban green structure, based on their location, scarcity or size, creating green oases and serving as the city's public gardens (Gemeente Amsterdam, 2023a).

While rooftop parks may ideally offer similar functions to these types of ground-level parks, public usage may set them apart. This distinction will be explored further in the next section, which examines the concept of hybrid urban spaces to help clarify the unique characteristics of rooftop parks.

4.1.3 Hybrid (green) spaces

While traditional ground-level parks are typically public, rooftop parks may blur the boundaries between public and private, introducing a hybrid green form that combines elements of both. According to Kohn (2004), public space has three core components: ownership, accessibility, and intersubjectivity. Based on this, she states that public space is usually defined as a place that "is owned by the government, accessible to everyone without restriction, and fosters communication and interaction".

Traditional public spaces typically include streets, plazas, squares, and the aforementioned 'ground-level' parks (Carmona, 2010), and play a vital role in any sustainable urban environment (D. Lee, 2022). On the contrary, private spaces refer to areas owned by individuals where access is limited and controlled, such as the individual's house. However, over the last decades, the definition of public space, and its distinction with private space, has become increasingly difficult, as there is a growing category of 'hybrid' spaces (Carmona, 2010; Kohn, 2004; D. Lee, 2022). These hybrid spaces meet some, but not all of the criteria outlined by (Kohn, 2004) and encompass all kinds of public, semi-public, semi-private, and private spaces. Based on this, Carmona (2010) identified twenty urban space types, ranging from clearly public to entirely private spaces, see Table 5.

These categories illustrate the varying degrees of publicness urban spaces can have, and help to define where rooftop parks might fit within this spectrum. When considered simply as a part of an individual's private home, a roof can be seen as an example of a strictly private urban space, based on the criteria outlined above. Nevertheless, depending on the type of building, roofs can also be considered public to some extent, for example, if the building is owned by the government or accessible to everyone. However, in this study, roofs are not viewed merely as functional structures that protect buildings from wind and weather, but as distinct elements of urban space that can serve broader purposes beyond the building beneath.

Consequently, when examining rooftop parks as roofs serving a public function akin to ground-level parks, regardless of the predominant private building use, the hybrid form described by Carmona (2010) as public 'private' space becomes particularly relevant. This space is characterised as a *"Seemingly public external space, in fact privately owned and to greater or lesser degrees controlled"*. In other literature, this form of hybrid space is similar to the more known concept of Privately Owned Public Space, hereafter POPS.

This type of hybrid space demonstrates that public space does not necessarily have to be owned by the public. POPS are typically managed and owned by private developers or individuals and, in agreement with the local government, these spaces must be accessible to the public (D. Lee, 2022). Generally, POPS typically arise when the government cannot provide public services and goods, stimulating the private market to offer these services with profit in mind (Banerjee, 2001). While owners may be required to follow certain regulations posed by the government (D. Lee, 2022), Smithsimon (2008) notes that these regulations, as well as the physical composition of these spaces, cater to the private interest of the owner rather than the government. In this context, owners can impose restrictions about how the space is used and by whom, while keeping it technically open to the public. The specific nature of these regulations and restrictions may vary depending on local regulations governing such hybrid spaces.

Space type	Distinguishing characteristics	Examples
	'Positive' spaces	
1. Natural/semi-natural urban space	Natural and semi-natural features within urban areas, typically under state ownership	Rivers, natural features, seafronts, canals
2. Civic space	The traditional forms of urban space, open and available to all and catering for a wide variety of functions	Streets, squares, promenades
3. Public open space	Managed open space, typically green and available and open to all, even if temporally controlled	Parks, gardens, commons, urban forests, cemeteries
	'Negative' spaces	
4. Movement space	Space dominated by movement needs, largely for motorized transportation	Main roads, motorways, railways, underpasses
5. Service space	Space dominated by modern servicing requirements needs	Car parks, service yards
6. Left over space	Space left over after development, often designed without function	'SLOAP' (space left over after planning), Modernist open space
7. Undefined space	Undeveloped space, either abandoned or awaiting redevelopment	Redevelopment space, abandoned space, transient space
	Ambiguous spaces	
8. Interchange space	Transport stops and interchanges, whether internal or external	Metros, bus interchanges, railway stations, bus/tram stops
9. Public 'private' space	Seemingly public external space, in fact privately owned and to greater or lesser degrees controlled	Privately owned 'civic' space, business parks, church grounds
10. Conspicuous spaces	Public spaces designed to make strangers feel conspicuous and, potentially, unwelcome	Cul-de-sacs, dummy gated enclaves
11. Internalized 'public' space	Formally public and external uses, internalized and, often, privatized	Shopping/leisure malls, introspective mega-structures
12. Retail space	Privately owned but publicly accessible exchange spaces	Shops, covered markets, petrol stations
13. Third place spaces	Semi-public meeting and social places, public and private	Cafes, restaurants, libraries, town halls, religious buildings
14. Private 'public' space	Publicly owned, but functionally and user determined spaces	Institutional grounds, housing estates, university campuses
15. Visible private space	Physically private, but visually public space	Front gardens, allotments, gated squares
16. Interface spaces	Physically demarked but publicly accessible interfaces between public and private space	Street cafes, private pavement space
17. User selecting spaces	Spaces for selected groups, determined (and sometimes controlled) by age or activity	Skateparks, playgrounds, sports fields/grounds/courses
	Private spaces	
18. Private open space	Physically private open space	Urban agricultural remnants, private woodlands,
19. External private space	Physically private spaces, grounds and gardens	Gated streets/enclaves, private gardens, private sports clubs, parking courts
20. Internal private space	Private or business space	Offices, houses, etc.

Table 5: Overview of urban space types (Carmona, 2010)

Within the Dutch context of public space, Melik & Krabben (2016) argue that POPS and other forms of co-production of space, defined as *"the sharing of costs, rights, and responsibilities of public space amongst a wide range of stakeholders, ranging from the market to civil society and individual citizens"* are still relatively uncommon. Nevertheless, the private sector is expected to play a more significant role in the future redevelopment of urban areas in the Netherlands, due to changing market conditions including financial pressure for municipalities, and a shift towards a neoliberal political attitude (Melik & Krabben, 2016).

So, unlike traditional ground-level parks, which are typically fully public, rooftop parks may primarily be developed in a hybrid form, blending predominant private ownership of urban buildings with public accessibility of their roofs. As a potential new form of Privately Owned Public Spaces (POPS), rooftop parks would require private owners to balance their ownership interests with public access, potentially regulated through agreements with local governments. While rooftop parks may theoretically be established on any suitable rooftop, they would require careful planning to ensure they function as shared, semi-public spaces that align with the broader principles of urban parks and public space.

4.1.4 Rooftop typologies

To further refine the concept of rooftop parks, rooftops are not only recognised as building structures but as integral elements of the urban infrastructure. Traditionally, roofs served as functional cover providing shelter from the weather. However, with increasing urban density, limited ground-level space, high property prices, and an increasing demand for accessible green areas, rooftops present a valuable solution. By re-envisioning roofs as the fifth façade, they can serve as platforms for multiple purposes with potential transformation effects on the urban area, providing social and environmental benefits (Todeschi et al., 2020).

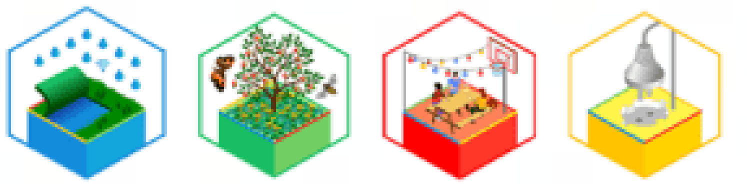


Figure 8: Colour-coded roof typologies (Nationaal Dakenplan, n.d.)

Literature categorises rooftops into various typologies based on their potential functions (Todeschi et al., 2020). In the Netherlands, these typologies are commonly distinguished by employing different colours, see Figure 8 (ISSO, 2022; Nationaal Dakenplan, n.d.). Although rooftop typologies are typically categorised based on singular functions, they can also serve multiple purposes simultaneously, providing additional benefits (ISSO, 2022; Nationaal Dakenplan, n.d.). This was exemplified by MVRDV's rooftop catalogue (MVRDV, 2021), which describes 130 different potential multifunctional rooftop typologies. To further evaluate, MVRDV's typologies consider the degree of densification, busyness, public access, and their impact range.

For this study, recognising rooftop parks as public green urban spaces, it is essential to acknowledge their multifunctionality (ISSO, 2022; Nationaal Dakenplan, n.d.). Building upon a study by the Urbanisten (De Urbanisten, 2015), this study conceives rooftop parks as spaces that may integrate green (vegetation), red (social/recreational) and blue (water management) functions. While rooftops may also support other (multi-)functions, such as energy production (categorised as "yellow"), these are excluded from the rooftop park scope in this study, as they do not align with the primary goals of providing public urban green spaces. The green, red and blue functions associated with rooftop parks are explored in terms of their characteristics and implications.

Green roofs

Acknowledging rooftop parks as urban green spaces, green roof terminology serves as a foundation for comprehending the construction of rooftop parks. Green roofs, also referred to as eco-roofs, living roofs, or roof gardens, are the most widely known function of roofs, and are generally acknowledged as vegetated rooftops based on a substrate layer (Kotze et al., 2020; Zhang & He, 2021). Retrofitting buildings with green roofs is an emerging practice and provides various building benefits, such as energy savings, noise reduction and enhanced real estate value (ISSO, 2022).

Generally, two types of green roofs are distinguished, namely extensive and intensive systems, as illustrated in Figure 9 (Brudermann & Sangkakool, 2017). Although extensive green roofs are widely adopted and offer several benefits, they are characterised by thinner substrate layers and a limited variety of vegetation (Pérez & Coma, 2018). In contrast, intensive green roof systems feature thicker substrate layers and can support a wider variety of vegetation (ISSO, 2022).

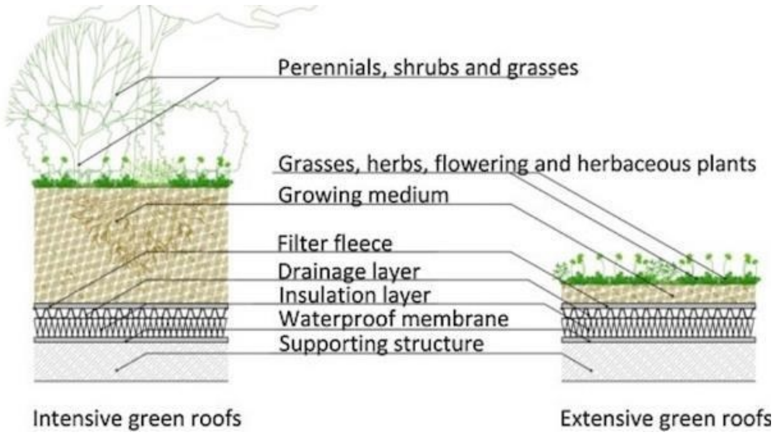


Figure 9: Schematic overview of intensive versus extensive green roof types (Brudermann & Sangkakool, 2017).

To support vegetation similar to ground-level parks, an intensive green roof system is required when developing rooftop parks. Accordingly, this study focuses on intensive green roofs to inform the definition of rooftop park, as these may, depending on their design, provide benefits to some extent akin to those of traditional urban parks, including air purification, increasing biodiversity, and cooling (Hop & Hiemstra, 2013; ISSO, 2022; Shafique et al., 2018). However, intensive green roofs also require higher load-bearing capacities of buildings, have higher costs, and demand greater maintenance than extensive green roofs (Pérez & Coma, 2018).

While the term ‘intensive’ primarily refers to the construction approach of the multilayer composition (Kotze et al., 2020), existing terminology on vegetation, substrate, and functions is highly intertwined. In that regard, intensive green roofs are also occasionally considered accessible spaces for people, yet mainly for the building's occupants (Pérez & Coma, 2018; Pouya, 2019). However, in this study, the term ‘intensive green roof’ is used to refer to the construction approach and requirements allowing for park-like vegetation.

Red roofs

While green roofs primarily offer environmental benefits, red roofs emphasise human use, making them particularly relevant for defining rooftop parks as public spaces. Red roofs are designated as user or social spaces, offering recreational areas for social interaction and relaxation, with examples including sports facilities and terraces (ISSO, 2022; Nationaal Dakenplan, n.d.). In international literature, the term red roof is non-existent and may be generally referred to as an accessible roof (Ariff et al., 2023).

Combining red roofs with intensive green roofs, often called rooftop gardens or sky gardens, is an emerging practice (Kotze et al., 2020; Li et al., 2022). This functional mix provides additional benefits similar to other public green urban spaces, such as positive impacts on mental and physical health and facilitating social interactions (Hop & Hiemstra, 2013; ISSO, 2022; Kotzen, 2018; Williams et al., 2019). However, the trend toward the privatisation of rooftop spaces means that most existing red-intensive green roofs are accessible exclusively to building occupants (Pomeroy, 2012). In studying rooftop parks as public elevated urban green spaces, accessibility may be considered a key differentiator between rooftop or sky gardens and true rooftop parks, mirroring the distinction between private and public green spaces at ground level.

Blue roofs

Finally, blue roofs are designed to retain rainwater temporarily, which relieves pressure on the urban drainage system and contributes to cooling the building (Nationaal Dakenplan, n.d.). While blue roofs can exist without vegetation, they are often incorporated into green roof systems. In this way, the captured rainwater can be used for irrigation. This is particularly valuable because vegetation on rooftops can be vulnerable to drought (ISSO, 2022). However, constructing combined blue-green roofs is more complex than green roofs due to the additional infrastructure that is required for water retention and management (ISSO, 2022). As this study focuses on rooftop parks as emerging public urban green spaces, blue roofs, despite their benefits in enhancing sustainability, are not considered a core component of rooftop parks. Instead, they are viewed as an optional, complementary feature that can be integrated into rooftop parks where water management is a concern.

4.1.5 Conceptual understanding

Figure 10 provides an overview of the previously discussed concepts through the theoretical lens. The darker coloured boxes and the arrows indicate which concepts are considered relevant to inform the definition of rooftop parks in this study.

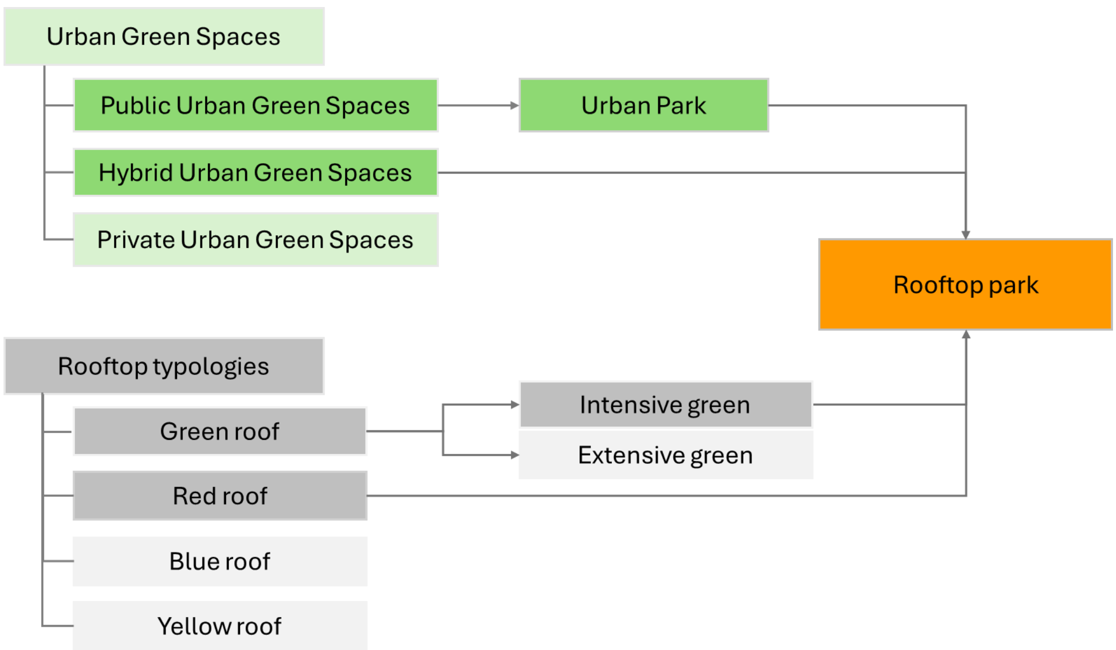


Figure 10: Conceptual understanding of rooftop parks in Amsterdam (author's work)

4.2 Empirical lens

4.2.1 Greenness of rooftop parks

While all stakeholders in this research were familiar with existing (variations of) rooftop parks, their ideas and perceptions of future rooftop parks as new urban green spaces varied considerably. Expert 3 humorously observed that a roof could technically be considered ‘green’ even if painted, underscoring the importance of distinguishing between the visual presence of greenery and its functional value. Nevertheless, despite the varying perceptions, all experts agreed that a rooftop park should include some degree of vegetation. As Expert 6 remarked, “*Otherwise you call it a square”.*

However, the type of vegetation that stakeholders envisioned for rooftop parks differed. Some emphasised that the presence of trees is essential for creating shade for visitors and the general feeling of being in a park (Experts 1 and 11). Expert 2, on the other hand, suggested that even a sedum roof with plant pots could provide enough greenery to foster the experience of a rooftop park as an elevated public green space, stating, "*I think the overall experience is sufficient; you don’t necessarily need to have a large Amelanchier standing next to you."* This variation in opinions may be linked to the familiarity of experts with existing rooftop parks and their understanding of construction feasibility, such as the height of vegetation and the need for an intensive green roof system to support larger plants (Experts 2, 9 and 11).

Furthermore, some experts mentioned the DakAkker in Rotterdam (Figure 11) as a rooftop park, which shows that agricultural vegetation may also be considered park-like green.

While Expert 11 highlighted the general preference for native plants from an ecological point of view, Expert 10 expressed a preference for biodiverse greenery but stressed that this could vary depending on the project context. The latter reflects the specific design may be flexible based on specific project goals or site characteristics. Expert 3 also highlighted that creating a green rooftop park does not necessarily depend on vegetation alone but rather on the user’s perspective and park value, questioning whether a park can truly be considered ‘green’ if it primarily serves people and not nature.

Figure 11: The DakAkker, Rotterdam (author’s work)

In differentiating rooftop parks from other rooftop typologies, such as rooftop gardens, Expert 6 suggested that the defining characteristic of a rooftop park is its public nature rather than its degree or type of greenness. Nevertheless, Expert 1 noted that while plant pots may remind the atmosphere of a roof terrace, vegetation planted directly into the ground may align more closely with the feeling of being in a park. Moreover, compared to ground-level parks, the level of greenness on rooftops may be shaped by the growth conditions on the roof, such as drought, the level of maintenance and how the park connects with its surrounding environment (Expert 1 and 11).

The diverse greenness perceptions of experts were also reflected in the observational case studies conducted for this research, which reveal significant variations in configuration and vegetation. During site visits, vegetation ranged from grasses and flowers to large bushes and fully-grown trees. Additionally, while some rooftop parks showcased a high diversity in vegetation with multiple planting layers and different levels, others appeared more uniform in their design, see Figure 12 and Appendix B.

Figure 12: Diverse vegetation in rooftop parks (author's work) (l-r: ROEF dakpark, Dakpark Rotterdam, De Groene Kaap)

Overall, the variation in vegetation as observed in the case studies and the discussion in the interviews highlights that the level of greenness of rooftop parks does not define the 'park' aspect, as it can vary depending on the intended function, which is further discussed in section 4.2.3.

4.2.2 Publicness of rooftop parks

The interviews and observations conducted in this research reveal that the publicness of rooftop parks is a key feature that makes them particularly interesting, unique, and valuable compared to other rooftop typologies. However, the envisioned publicness of rooftop parks also represents complexity, involving balancing open access with practical constraints regarding management, ownership, safety and exclusivity.

Several experts emphasised that a rooftop park's public function hinges on its accessibility, and the added value for public urban space by *"just being able to be there" (*Expert 2). Among others, Expert 1 stressed the importance of allowing users to visit and stay in rooftop parks, stating that, *"the use of the roof is an important aspect, that it is accessible and usable, not just for maintenance or viewing, but as a place where you, as a user, can go and stay"* (Interview 1). However, opinions varied on the degree of access that is required for a rooftop park to serve its public function.

Time-restricted access
One of the frequently mentioned considerations defining publicness in terms of accessibility is the opening hours of rooftop parks. Several experts referred to the practical challenges of keeping rooftop parks open at all times and suggested that a rooftop park may not need to be open 24/7 to maintain its public function (3,5,8). Instead, timed access could help manage potential issues such as security and noise (Expert 3, Expert 8). This time restriction was also illustrated in existing rooftop parks (see Figure 13): NEMO as well as Hofbogen en Dakpark close at night, at de Groene Kaap access is restricted for the public to Wednesdays and the weekend to cope with nuisance issues, and ROEF Dakpark was only opened at set times during a couple weeks in September. The question posed by Expert 3 - *"As far as I know, they close Vondelpark as well, right?"*- suggests

that time-restricted access might not significantly differentiate rooftop parks from ground-level parks in terms of public functionality. Moreover, as suggested by Expert 2, time-restricted access could offer other flexible user forms as well, where a rooftop garden typically reserved for employees opens to neighbourhood residents on Friday afternoon, or a rooftop garden for residents opens up to employees during office hours.

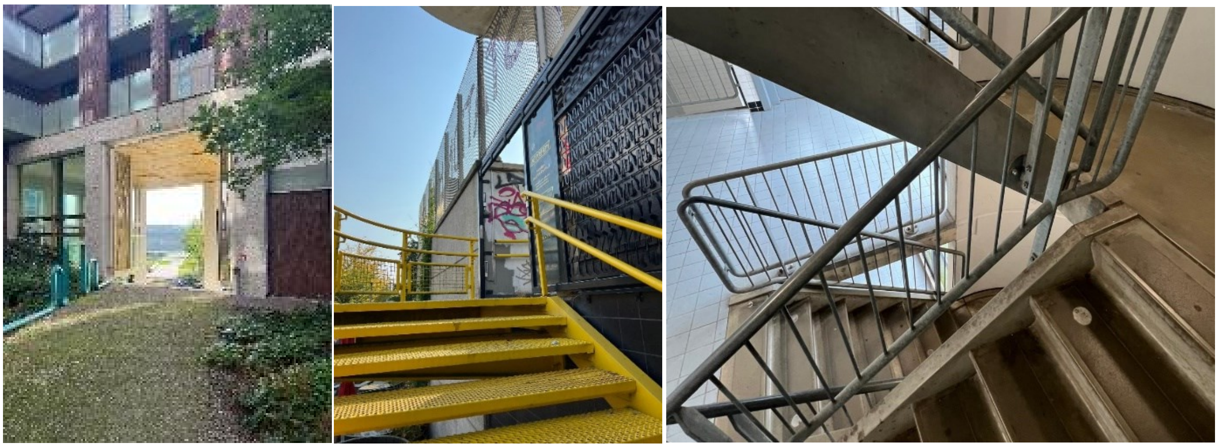


Figure 13: Public rooftop parks with restricted access (author's work)

User exclusivity

Besides time restrictions, the publicness of rooftop parks may be determined by who can access them. While some experts argued for full public access in rooftop parks, others proposed semi-public models where access is restricted to certain user groups, such as local residents. For example, Expert 2 suggested that the development of a rooftop park would be more feasible if only nearby apartment blocks and specific residents have access via a key system. However, this raises questions about the exclusivity of rooftop parks. As Expert 6 pointed out, there is a risk that rooftop parks could become exclusive spaces, much like in South America where rooftop gardens are often reserved for the wealthy. The challenge in developing rooftop parks is therefore to ensure that they remain accessible to all social groups, to benefit the broader city. This contrasts with ground-level parks, which are generally open to everyone without such restrictions.

Looking into the existing examples of rooftop parks, we also recognise that the envisioned range of users of the rooftop park varies: While at de Boel, the rooftop park is restricted to access for the apartment residents, and at rooftop park Vivaldi the area is open for employees in the building, rooftop park Orlyplein is open for all users. Moreover, at de Groene Kaap, the rooftop park is primarily meant to serve residents of the apartment block but also open for visitors (at restricted times).

Commercial restrictions

Furthermore, a significant aspect raised during the interviews was the costs associated with accessing rooftop parks. While, for example, Experts 2 and 10 elaborated on the potential benefits of commercial activities on the roof, such as a café, Expert 4 argued that if access to a rooftop park requires consumption, it undermines the idea of a public space: *"If it involves mandatory consumption, I do not consider it a park"*. She concluded that *"Publicly accessible, public, means accessible to everyone without the obligation to consume or pay."* This points to the importance of free or low-cost access in establishing a rooftop park as a genuine public space. From the observational study, we learn that, while the majority of existing rooftop parks are free to enter without an entrance fee, some have entrance restrictions based on commercial activities. At the Dakakker, you have to pass through a café to enter the garden, whereas at the Boijmans van

Beuningen Depot, you can only enter for free after the museum is closed and if the restaurant on the roof is open.

Ownership

Finally, in addition to the operational aspects, the ownership of rooftop parks may also complicate the definition of their public character. As Expert 4 noted, roofs are, when strictly speaking, not part of public spaces like ground-level parks, which adds complexity to the development of public rooftop parks. Expert 8 illustrated this by stating: *"We all want something with the roofs, but it is never ours, except for our own individual roof"*. This issue of ownership was also mentioned by Expert 4, who highlighted access and maintenance issues and introduced the term Privately Owned Public Roofs (POPR). This term suggests that rooftop parks, even if they have a public function, would primarily exist within privately owned spaces. This was also recognised by Expert 3. Ultimately, this indicates that ownership will have a significant influence on decision-making and shape the public character of rooftop parks, as can be seen in the case studies. For example, Orlyplein (co-created on municipal land) is generally open to all, reflecting a public park model. In contrast, access and maintenance at Hofbogen, where the roof is municipally owned but the building is privately owned, remain topics of discussion. At de Groene Kaap, which is owned by a residents' association (VVE), the rooftop park was closed due to complaints from nearby residents about nuisance from youth, illustrating how private ownership can affect public access.

Overall, the results indicate that the publicness of rooftop parks is defined by a combination of physical access as well as management structures. While fully public, open-access rooftop parks, similar to ground-level parks, are ideal in theory, practical constraints can often lead to semi-public models. Although time and ownership may not directly limit the publicness of rooftop parks, exclusivity based on costs or restricted access to user groups can.

4.2.3 Design and functions of rooftop parks

Apart from the greenness or publicness, the empirical lens provides insights into the envisioned design and functions of rooftop parks that contribute to a refined understanding of the concept.

Elevation

First of all, from a design perspective, the elevation of rooftop parks seems to be a defining element that sets them apart from ground-level parks and other types of urban green spaces. Expert 2 pointed out that many existing rooftop parks are actually located at ground level atop underground parking garages, raising the question of whether these can truly be considered 'real' rooftop parks, as they do not create new urban space. Moreover, several experts highlighted that especially the view and sensation of being in an elevated space contribute to the unique experience of rooftop parks compared to urban green spaces on ground level. This is underscored by expert 7, who noted *"for me, the roof is the freedom you often do not feel at ground-level (...) it is really something different"*. Observational studies supported this, comparing the view offered by Orlyplein and spaces like de Groene Kaap. These insights suggest that a rooftop park should be elevated with regard to its surroundings to qualify as a new and distinct type of Public Urban Green Space (PUGS). Nevertheless, as pointed out by Expert 2, height also introduces risks and calls for stricter safety standards, not typically required in ground-level parks.

Scale

In addition to elevation, while the observed existing rooftop parks varied widely in scale, experts generally agreed that a rooftop park should meet a certain minimum scale to be considered a true park. While Expert 3, 5, and 6, 7 emphasise that this scale is essential to meaningfully contribute to the existing public green space in the city and to enable rooftop parks as multifunctional spaces in general, Expert 11 (Urban ecology) noted this may also be required to specifically ensure ecological functions can coexist next to user functions, with little disruption. Considering a minimum scale as a defining aspect of rooftop parks may ensure the park's multifunctionality.

Programming

Furthermore, similar to other green urban spaces, experts recognised that rooftop parks should cater to diverse user needs within a limited space and therefore need certain amenities, such as benches. However, Expert 10 and Expert 3 highlighted that rooftop parks, in contrast to ground-level parks, may require more intentional programming to become successful public urban green spaces, attract visitors and establish a sustainable business model. Besides, Expert 2 stressed that the additional safety considerations that are inherent to elevated spaces, may also lead to more organised and controlled activities compared to informal gatherings seen at ground-level parks. Importantly, as noted by Expert 11, it is essential to balance the programming with ecological considerations to avoid disrupting the park's environmental functions.

Multifunctionality

Empirical insights reveal that the potential functions of rooftop parks can be widely interpreted. Generally, experts envisioned rooftop parks as a valuable opportunity to add public green space in densely built areas where space at ground level is limited. This issue of space scarcity is repeatedly highlighted as the particularly relevant function of rooftop parks in the context of Amsterdam. Furthermore, the multifunctionality of rooftop parks is widely recognised by experts and is also evident in the existing rooftop parks observed during the study (Figure 14). Expert 10 even envisions rooftop parks as (not yet existing) spaces where urban society can work on integral problem-solving. From a social perspective, experts highlighted that rooftop parks can offer a variety of benefits, including a place for quietness, an experience of the city from another perspective and space for social gathering. In terms of environmental functions, experts recognised three key benefits of rooftop parks: enhancing biodiversity, providing space for water retention, and mitigating urban heat island effects. However, Expert 5 also recognised that ground-level parks may achieve a more significant environmental impact due to their greater soil volume and natural interactions.

Despite the recognition of multifunctionality as a defining element of rooftop parks and both the potential for social and environmental benefits, experts also emphasised that not all rooftop parks need to serve the same functions or combine every possible function. As Expert 8 put it, designs can be tailored to focus on specific aspects, such as enhancing biodiversity or attracting visitors. Therefore, the multifunctionality of rooftop parks should be adjusted based on the context and the specific goals of each rooftop park project.

Figure 14: Multifunctionality in rooftop parks: Greenhouse, playground, seating area (author's work)

4.3 Synthesis

In the previous sections, theoretical and empirical lenses have been explored to build an understanding of rooftop parks. Table 6 summarises key insights from both perspectives regarding the concept of rooftop parks and in relation to existing concepts in urban space.

Theoretical lens	
(P)UGS	• UGS are all surfaces of the urban environment with vegetation, such as grass, trees, and shrubs. While all UGS may play crucial environmental roles in cities, PUGS are also specifically known for their social benefits. • The *Main Green Space Infrastructure* of Amsterdam consists of 8 types of existing green spaces that have a dominant green function and serve functions beyond the neighbourhood level, holding significant value for people, plants and animals.
Urban parks	• Urban parks are recognised as central components of urban green structures. They appear as the most frequented, recognisable and well-managed public urban green spaces in the vast majority of cities. • *"Urban parks are delineated open space areas, mostly dominated by vegetation and water, and generally reserved for public use. Urban parks are mostly larger, but can also have the shape of smaller 'pocket parks'. Urban parks are usually locally defined (by authorities) as 'parks'.* " (Konijnendijk et al., 2013) • In the city of Amsterdam, the concept of parks is interpreted through various types of urban green spaces, each serving distinct primary functions.
Hybrid urban (green) spaces	• Public space is usually defined as a place that *"is owned by the government, accessible to everyone without restriction, and fosters communication and interaction"* (Kohn, 2004) • When examining rooftop parks, the hybrid form of public 'private' space becomes particularly relevant. This space is characterised as a *"Seemingly public external space, in fact privately owned and to greater or lesser degrees controlled"* (Carmona, 2010) • As a potential new form of Privately Owned Public Spaces (POPS), rooftop parks would require private owners to balance their ownership interests with public access, potentially regulated through agreements with local governments.
Rooftop typologies	• Recognising rooftop parks as public green urban spaces, it is essential to acknowledge their multifunctionality. • To support vegetation similar to ground-level parks, an intensive green roof system is required when developing rooftop parks. • The mix of intensive green and red functions provides additional benefits similar to other public green urban spaces.
Empirical lens	
Greenness	• A rooftop park must include some degree of vegetation, but the level of greenness may vary, depending on the project context. • The greenness of rooftop parks does not define the 'park' aspect, as it can vary depending on the intended function of the rooftop park.
Publicness	• While fully public, open-access rooftop parks, akin to ground-level parks, are ideal in theory, practical constraints may often lead to semi-public models. Although time and ownership may not directly limit the publicness of rooftop parks, exclusivity based on costs or restricted access to user groups can.
Design and functions	• A rooftop park should be elevated to its surroundings to qualify as a new and distinct type of Public Urban Green Space (PUGS). • A rooftop park should meet a minimum scale to be considered a true park. • In Amsterdam, rooftop parks can be particularly valuable and relevant to adding public green space in densely built areas where space at ground level is limited • Rooftop parks, in contrast to ground-level parks, may require more intentional programming and controlled events to become successful yet safe public urban green spaces. • Rooftop parks might replicate the social and ecological roles of ground-level parks but with a focus on maximising multifunctionality within limited areas. • Rooftop parks can function as multifunctional intensive green–red roofs, but it is crucial to consider and balance the desired social and environmental benefits based on their location. Therefore, designs can be altered based on the context and the specific goals of each rooftop park project.

Table 6: Summary of key insights on the concept of rooftop parks in Amsterdam

4.3.1 Definition

Building on, by synthesising the insights from existing related concepts in literature along with expert interviews and observations, a broad new definition for rooftop parks in Amsterdam was specifically formulated for this research. Grounded in both theoretical and empirical perspectives, this original definition is as follows:

> *In the context of Amsterdam, rooftop parks are publicly accessible elevated green spaces of a certain scale, located on building rooftops and designed to function as multifunctional hybrid spaces that offer both environmental and social benefits, complementing existing urban green spaces in densely built areas.*

4.3.2 Guiding principles

Moreover, to further operationalise the concept of rooftop parks in Amsterdam in this research and clarify its relation to the existing body of literature, four guiding principles have been distinguished. These principles are derived from a synthesis of the theoretical concepts and empirical insights discussed in this chapter and reflect the core of the concept: **multifunctionality, accessibility, environmental performance and spatial integration (**see Figure 15).

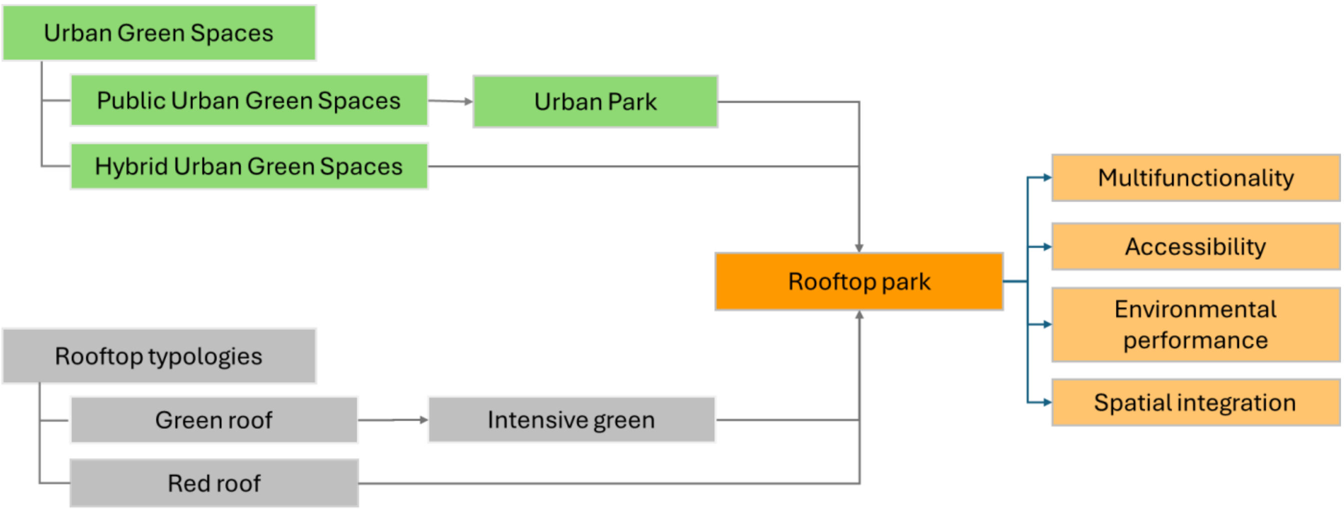


Figure 15: Linking theoretical concepts and guiding principles for rooftop park (author's work)

With this definition and operationalisation, SRQ 1 is addressed, focusing on defining and conceptualising rooftop parks within the Amsterdam context. Ultimately, the guiding principles, as described in more detail below, form the link to developing suitability assessment criteria for rooftop park retrofitting in Amsterdam, which is discussed in the subsequent chapter.

Multifunctionality

Multifunctionality was identified as a fundamental principle for rooftop parks in Amsterdam, with these spaces serving multiple purposes simultaneously while using the space effectively. While empirical insights depicted that the specific functions may vary depending on the setting, it is evident that a rooftop park should serve both people and the ecosystem. This aligns with the idea of multifunctional rooftop typologies, wherein rooftop spaces supporting multiple functions offer greater benefits to the city compared to single-function spaces (ISSO, 2022). Furthermore, this principle reflects Amsterdam's integrated approach to rooftop development and its recognition of the diverse objectives achieved by other green spaces in the city (Gemeente Amsterdam, 2020, 2023b). Although site visits showed that rooftop parks could fulfil similar functions to some extent to other types of UGS and urban parks in Amsterdam, which are also designed and known to accommodate a variety of functions (Konijnendijk et al., 2013), empirical insights from this study highlighted that planning for multifunctionality and ensuring a balance between functions is particularly necessary for rooftop parks due to the size limitations of roofs.

To ensure multifunctionality, green infrastructure planning stresses that these functions should be explicitly considered instead of being a product of chance (Madureira & Andresen, 2014). Embracing multifunctionality as a guiding principle for rooftop park retrofit in this study, suitability criteria should therefore be carefully developed to ensure that these spaces could provide opportunities for both human and ecological needs. Besides, this principle emphasises a balanced approach, integrating insights from user perspectives and ecological considerations equally.

Accessibility

Accessibility forms the second fundamental guiding principle identified for rooftop parks in Amsterdam. Accessibility in this regard refers to how easily rooftop parks in Amsterdam could be accessed by the public, both physically and socially, ensuring successful implementation. Theoretical and empirical insights highlight that restrictions in accessibility may form a barrier to the potential successful development of rooftop parks. Therefore, this principle emphasises the need for rooftop parks to be developed in a way that makes them usable for everyone. To some extent, the accessibility of rooftop parks can be viewed similarly to other UGS and urban parks at ground level, where accessibility is considered a primary quality determinant, including factors such as proximity, design and physical obstacles (Biernacka et al., 2020; Corley et al., 2018). This is also reflected in Amsterdam's Green Vision 2050, where accessibility is a central component in the city's strategy for its future green infrastructure (Gemeente Amsterdam, 2020). However, as also revealed by experts, rooftop parks introduce additional perspectives due to their elevation, making physical access particularly relevant. Similarly, literature on roof development as well as the municipality recognises the role of building architecture in enhancing accessibility for rooftop utilisation (Ariff et al., 2023; Gemeente Amsterdam, 2023b).

Moreover, as supported by empirical insights, rooftop parks are often hybrid spaces, further complicating accessibility. While they may be intended public spaces in terms of access, their location on building rooftops often links them to privately owned public spaces (POPS) (Carmona, 2010; D. Lee, 2022). As experts pointed out, this introduces complexities related to ownership and management, potentially restricting access. In the context of existing rooftop typologies, the development of rooftop parks in Amsterdam should take these hybrid characteristics into account. While other red or green rooftops are more likely to be private (ISSO, 2022; Kotze et al., 2020; Nationaal Dakenplan, n.d.), rooftop parks need to challenge these restrictions to promote access for all users. By embedding accessibility as a guiding principle for development and further analysis, rooftop parks in Amsterdam have the potential to contribute to creating usable urban green spaces, while balancing their hybrid nature.

Environmental performance

Next to multifunctionality and accessibility, environmental performance is considered a fundamental guiding principle for rooftop parks in Amsterdam. This principle emphasises that rooftop parks are not only envisioned to serve recreational purposes but also to contribute positively to the environment, similar to ground-level urban parks in Amsterdam (Gemeente Amsterdam, 2020, 2023a). Although the type of greenness of rooftop parks was not perceived as the defining aspect and varied per visited rooftop park, overall, environmental performance remains integral to their function.

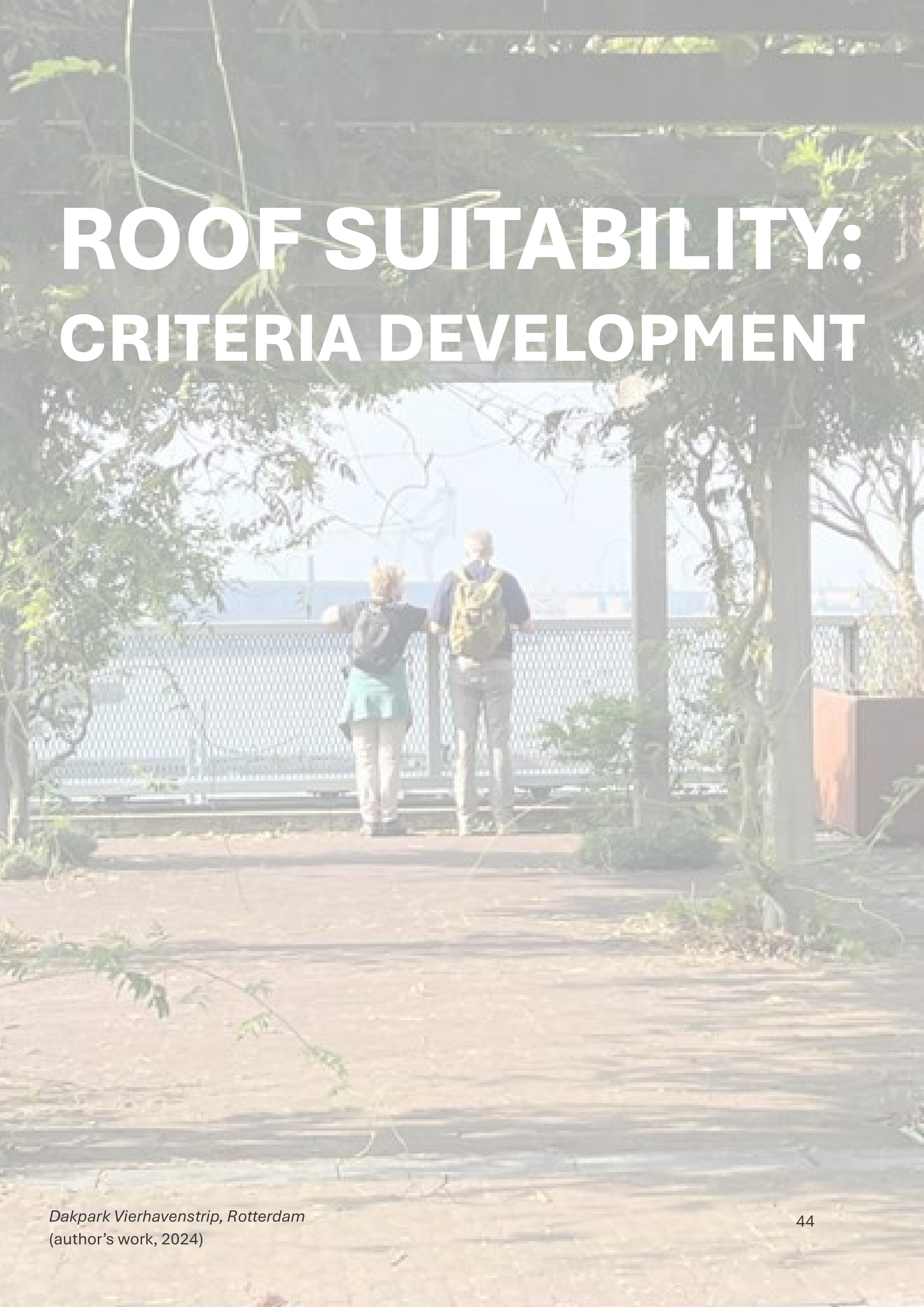
Despite challenges such as harsher weather conditions at elevation and construction requirements, empirical insights revealed that the environmental performance of rooftop parks can be considered key in making them a valuable addition to the city's green infrastructure, providing benefits similar to other UGS and parks, such as enhancing biodiversity and reducing heat stress (Hop & Hiemstra, 2013; Hunter & Luck, 2015). Adding to the complexity, while green roofs are often designed for their environmental functions (Bowler et al., 2010; Zhang & He, 2021), rooftop parks need to balance these ecological goals with their use as publicly accessible spaces. As a result, rooftop parks in Amsterdam must be developed with careful consideration of both environmental and social benefits, making environmental performance an essential guiding principle for their success.

Spatial integration

Finally, spatial integration was found as the fourth guiding principle for rooftop parks in Amsterdam. For successful eventual development, empirical evidence highlighted that rooftop parks in Amsterdam should be effectively integrated into the surrounding urban fabric. In the context of UGS and ground-level parks, spatial integration often refers to the horizontal connectivity between the green space and its surroundings (Corley et al., 2018; Talen, 2010). For rooftop parks, however, spatial integration extends beyond this, and similar to other rooftop typologies (K. Lee et al., 2024; Willemsen, 2018), may also incorporate the vertical connection between the park and the city considering its elevation. By considering both horizontal and vertical spatial integration, rooftop parks could eventually form a complementary and connected element in Amsterdam´s existing urban green infrastructure (Gemeente Amsterdam, 2020).

Together, these four guiding principles provide a holistic approach to the meaning, potential role and development of rooftop parks in Amsterdam. In the subsequent chapter, these principles are linked to the criteria to assess the suitability of roofs for rooftop park retrofitting. This connection ensures that insights from theory and practice translate into an effective framework and tool for informed decision-making for retrofitting rooftop parks in Amsterdam.

ROOF SUITABILITY: CRITERIA DEVELOPMENT



Dakpark Vierhavenstrip, Rotterdam
(author's work, 2024)

5 Roof suitability: Criteria development

To eventually effectively develop rooftop parks as a solution to address space scarcity and the reduction of public urban green spaces in Amsterdam, it is essential to identify criteria that define whether roofs are suitable for retrofitting into these new public urban green spaces, addressing SRQ2..

Therefore, this chapter presents a comprehensive assessment criteria set for the suitability of roofs for rooftop park retrofit, informed by an iterative process that integrated both theoretical and empirical insights from literature, policy, expert interviews, and observations. This set reflects a holistic approach and understanding of suitability for rooftop park retrofitting in Amsterdam.

These criteria are categorised into two distinct scales, similar to how Silva et al. (2017) approaches the large-scale assessment of green roof retrofitting: building-level criteria and urban contextual criteria.

- **Building-level criteria** are directly related to characteristics of the building or roof itself, including roof flatness, available roof area, willingness of building stakeholders, construction capacity, compatibility with building function, roof elevation and ease of access.
- **Urban contextual criteria** extend to consideration at a larger urban scale, including compatibility with existing urban green infrastructure, quality of view, visibility, and urban density.

In total, 11 key criteria have been identified for roofs to assess the suitability of roofs for rooftop park retrofit, including 7 building-level criteria and 4 urban contextual criteria. While some criteria can be directly measured, other criteria are informed by multiple indicators. Applicable threshold values are considered for each indicator to inform the suitability assessment. Furthermore, each criterion is tailored specifically to the unique context of developing rooftop parks in Amsterdam and linked to the guiding principles outlined in Chapter 4.

Table 6 provides a visual overview of the criteria set, illustrating how each criterion is linked to the guiding principles and corresponds to specific indicators (in *italic*) and thresholds for measurement. As the set addresses considerations specific to the Amsterdam setting, the assessment process is practical and context-sensitive. The following sections go deeper into the underpinning of every criterion, the indicators and thresholds. Based on prioritisation, Section 5.3 present the eventual criteria framework for assessment.

Scale	Criterion		Link to guiding principles*			
	Title	**Description**	**M**	**A**	**EP**	**SI**
Building	**Roof flatness**	Roofs should be flat to be considered suitable for rooftop park retrofit in Amsterdam, usually measured through a *roof slope* below 10 degrees.	X	X	X	
	Available roof area	Roofs should have sufficient available roof area to be considered suitable for rooftop park retrofit in Amsterdam. 500 m2 is deemed as a fitting minimum threshold for *individual roof size*. *Potential for clustering* and *existing roof use* further refine the criterion.	X	X	X	
	Construction capacity	Roofs should have sufficient overall construction capacity to be considered suitable for rooftop park retrofitting. The *building year* and *building type* offer proxies for interlinked load-bearing capacity, building quality and building structure. Buildings constructed between 1960 and 1990 are deemed to have the highest potential for rooftop park retrofit in the existing building stock of Amsterdam, excluding industrial halls.	X	X	X	
	Willingness building stakeholders	Building stakeholders should be initially willing for transformation for roofs to be considered suitable for rooftop park retrofitting. *The type of ownership* and *number of owners* can give an initial indication: public or commercial ownership and a single owner are considered more suitable. Nevertheless, eventually, willingness is more complex and *direct stakeholder engagement* is necessary for measuring willingness.	X	X		
	Compatibility building function	The *building function* should be compatible with the intended use of the rooftop park to ensure suitability for retrofitting. Public and commercial buildings offer advantages for integration, but residential roofs may still hold untapped potential for broader green infrastructure development.		X		X
	Roof elevation	Buildings with a *roof height* lower than 15 metres are more suitable for rooftop park retrofit in Amsterdam, but careful consideration is required.	X		X	
	Ease of access	Roofs should be easily accessible from ground level to be considered suitable for rooftop park retrofitting, primarily informed by the existing *type of access*. Roofs with direct access from the street and an *active frontage* are considered more suitable for rooftop park retrofit.		X		X
Urban context	**Urban density**	Roofs in dense urban areas are more suitable for rooftop park retrofit. Urban density in this study is primarily informed by *population density* measured by inhabitants per km2. Areas with more inhabitants than average and slow traffic flows are deemed more suitable.		X		X
	Compatibility green infrastructure	Roofs are more suitable for rooftop park retrofit if compatible with existing green infrastructure. Relevant indicators include the *distance to existing public green spaces*, *public green space per resident* and *linkage to ecological corridors*. Areas further than 10 minutes walking, less than 9 m2 green space per inhabitant, and linked to ecological corridors are deemed more suitable.	X		X	X
	Quality of view	Roofs are more suitable for rooftop park retrofit if the quality of view is high. While roof height may inform the quality of view on a building level, the level of *unblocked* and *interesting surroundings* serve as indicators in the urban context.				X
	Roof visibility	Roofs are more suitable for rooftop park retrofit when there is *visual contact from the ground level and surrounding buildings*. *Landmarks* may add additional value in terms of visibility, drawing public attention and interest. However, any assessment should take into account the varying levels of *aesthetic standards* across the city, particularly protected zones.		X		X

Table 7: Overview of suitability criteria, corresponding indicators and relation to guiding principles

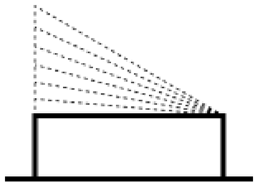
**Link to guiding principles as introduced in Chapter 4:*
M = multifunctionality, A = accessibility, EP = environmental performance, SI = spatial integration

5.1 Building-level criteria

In literature, the assessment of large-scale rooftop retrofitting at building-level is predominantly contingent upon construction-related factors, such as illustrated by various studies (Hong et al. (2019; Joshi et al., 2020; Slootweg et al., 2023; N. Xu et al., 2020; Y. Xu et al., 2021). While these theoretical insights provided an initial foundation, this section presents a more comprehensive set of building-level criteria, in no particular order. Each paragraph begins with a short textbox summarising the criterion, followed by a detailed explanation in the section below.

5.1.1 Roof flatness

Criterion: Roofs should be flat to be considered suitable for rooftop park retrofit in Amsterdam, usually measured through a roof slope below 10 degrees.

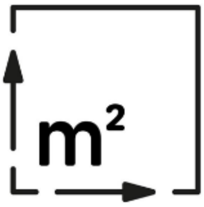


First of all, roof flatness, generally measured through the roof slope, was identified as a key criterion for assessing the suitability of a roof for rooftop park retrofitting in Amsterdam. Theoretical and empirical research consistently underscored that flat roofs, usually considered as roofs with a roof slope below 10 degrees (Joshi et al., 2020; Slootweg et al., 2023; N. Xu et al., 2020), can be generally considered most suitable for rooftop park retrofit for various reasons. As Expert 2 mentioned, the required greening for rooftop park retrofit could technically be applied to roofs of any slope, as illustrated by the Dakpark in Rotterdam. However, insights from various construction and design experts and literature review presented significant challenges, including the need for additional fixing measures to prevent vegetation from shifting, increased maintenance complexity, higher investment costs, and potential difficulties in maintaining plant health (Hong et al., 2019; Joshi et al., 2020; Karteris et al., 2016; Silva et al., 2017; Slootweg et al., 2023; Todeschi et al., 2020). Beyond structural and vegetation considerations, roofs with a smooth slope provide more inclusive accessibility, promoting public use of rooftop parks by people of all ages and backgrounds (Ariff et al., 2023). Based on these insights and aligning with the stance of the Municipality of Amsterdam that emphasises the development of flat roofs for multifunctional use (Gemeente Amsterdam, 2023b), roof flatness is considered a crucial aspect for later assessment in this study.

In other studies, a specific threshold value for the roof angle is considered to assess roof flatness and suitability (Hong et al., 2019; Joshi et al., 2020; Slootweg et al., 2023; N. Xu et al., 2020). However, in this study, considering the data availability, roof flatness was determined based on the modelled dataset. Finally, although the significance of this criterion may not differ substantially between Amsterdam and other cities, the building types identified by the municipality (Gemeente Amsterdam, 2023) as well as experts' insights (Experts 1, 5 and 8) highlighted that Amsterdam's historical architecture, characterised by many steeply sloped roofs, makes this criterion particularly relevant as an eliminating factor when assessing roof suitability for rooftop park retrofit in the city.

5.1.2 Available roof area

Criterion: Roofs should have sufficient available roof area to be considered suitable for rooftop park retrofit in Amsterdam. 500 m2 is deemed as a fitting minimum threshold for *individual roof size*. *Potential for clustering* and *existing roof use* further refine the criterion.



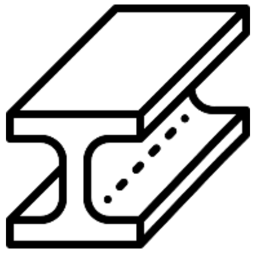
Next to roof flatness, the available roof area was identified as a key criterion to incorporate when assessing roofs for rooftop park retrofit suitability. Theoretical and empirical insights highlighted that a meaningful and functional rooftop park requires substantial space, primarily informed by the roof size. As Expert 11 stated: *"When I think of a (rooftop) park, I really imagine a large, ideally continuous, but at least a large area."* Although there is evidence that small urban green spaces and roofs can provide environmental and social benefits (Egerer et al., 2024; Mesimäki et al., 2019), a variety of studies suggest that the size of urban green spaces, including urban parks, is positively correlated with their benefits, such as biodiversity, cooling, exercising and relaxing (Konijnendijk et al., 2013; Lepczyk et al., 2017; Rey Gozalo et al., 2019). Additionally, larger green areas are generally considered more accessible (Biernacka & Kronenberg, 2019; Corley et al., 2018). Furthermore, one expert (Expert 5) pointed out that larger roofs could prevent overcrowding in rooftop parks. In general, with regard to multifunctionality, various experts noted that larger roofs would offer more space to accommodate a variety of functions simultaneously, such as user areas alongside undisturbed ecological zones, as mentioned by Expert 11. Besides, larger roofs could also help overcome constructional barriers, as Expert 9 observed that *"the larger the roof, the more you can play with load-bearing capacity and different functions."* Moreover, retrofitting larger roofs was perceived as more financially advantageous (Expert 8). Finally, the Municipality of Amsterdam also highlights the importance of roof size for rooftop utilisation in the city, stating that the larger the roof, the more favourable the ratio between detailing and the total square meters of the new roof function (Gemeente Amsterdam, 2023b). Overall, the available roof area was considered a critical factor in assessing suitability for both functional and practical purposes.

However, determining a specific minimum size proved to be challenging. Theoretical evidence for specific minimum sizes to facilitate functionalities in rooftop parks was limited and unanimous. For example, for ecological scaling effects, while Hong et al. (2019) propose 200 m2 as a minimum required available area for rooftop greening, expert 11 (Urban ecologist) highlighted that defining a threshold remains challenging as different species operate at varying scales, in line with other studies (Konijnendijk et al., 2013; Lepczyk et al., 2017). Furthermore, while the municipality of Amsterdam categorises roofs over 500 m2 as the largest category roofs, compared to small and medium-sized ones, Hermans (2022) suggests that a minimum of 500m2 is required to make significant impact and enable public access. Empirical insights offered additional perspectives, with the smallest rooftop park visited (DakAkker, Rotterdam) measuring 1000 m2 and the largest exceeding 8 ha (Dakpark Vierhavensstrip, Rotterdam). Most experts agreed on a minimum size of a couple hundred square metres as a threshold for individual roof sizes. However, Expert 6 argued that a roof should ideally be several thousand square meters, and Expert 3 questioned: *"Is 1,000 square meters really a park? I think with 1,000 square meters, you're not getting anywhere if it's supposed to be a park*." Considering the specific context of Amsterdam, it was also noted that especially in the city centre, roof sizes could form a restraining factor (Experts 3 and 8). Eventually, balancing experts' suggestions with theoretical insights and aligning with the categorisation of roof sizes by the municipality, individual roof areas over 500 m2 were deemed generally most suitable for rooftop park retrofitting in Amsterdam.

Nevertheless, although the available roof area is informed primarily through the individual roof size, considerations concerning roof clustering and existing roof uses can form refining factors to assess this criterion. Multiple experts mentioned that connecting roofs could offer opportunities for the size constraints of individual roofs while also increasing dynamics and connectivity. A notable example of this is de Groene Kaap in Rotterdam. Based on these insights, roof clustering is favoured in the later assessment, and whenever applicable, roof sizes between 200m2 and 500m2 are also considered suitable additions. On the contrary, roofs already used for other purposes are considered a limiting refinement for the available roof area and therefore manually excluded when assessing the suitability of Amsterdam's roofs for rooftop park retrofit (Hong et al., 2019; Karteris et al., 2016). Eventually, while roof clustering is deemed to contribute to the roof suitability for rooftop park retrofit, roofs that are already used reduce the suitability of the roof.

5.1.3 Construction capacity

Criterion: Roofs should have sufficient overall construction capacity to be considered suitable for rooftop park retrofitting. The *building year* and *building type* offer proxies for interlinked load-bearing capacity, building quality and building structure. Buildings constructed between 1960 and 1990 are deemed to have the highest potential for rooftop park retrofit in the existing building stock of Amsterdam, excluding industrial halls.



Often considered a traditional criterion for general rooftop utilisation and green roof retrofitting (Hong et al., 2019; Joshi et al., 2020; MVRDV, 2021; Slootweg et al., 2023), construction capacity is considered one of the key criteria for assessing rooftop park retrofit suitability on the building level. Constructional considerations are multifaceted, wherein the required load-bearing capacity of a building is closely interlinked with the building structure, quality, building type and age. As illustrated by the Rooftop Catalogue (MVRDV, 2021) and emphasised by multiple experts, constructional capacity is especially relevant yet challenging for rooftop park retrofit, as it requires the existing roof to have sufficient reserved load capacity to support the addition of weight of the park-like vegetation and intensive green roof system as well as visitors and park infrastructure amenities, involving both static loads (e.g., vegetation and infrastructure) and dynamic loads (e.g., people and events) (Expert 2). In this way, adequate construction capacity is essential to enable multifunctionality, ensure access, and enhance environmental performance.

While determining specific load-bearing capacities requires extensive structural analysis at the individual level, some general rules of thumb can be followed. Previous studies and construction expert insights underscored that buildings constructed from concrete tend to be more suitable for rooftop park retrofit given their inherent strength compared to brick, wood or steel structures (Hong et al., 2019; Joshi et al., 2020; MVRDV, 2021). Therefore, industrial halls, while often large flat roofs yet constructed from steel, are usually non-suitable (Joshi et al., 2020; MVRDV, 2021) and, interlinked with the building structure, only 8 out of the 16 building types identified by the municipality of Amsterdam would have the potential for rooftop park retrofitting (Gemeente Amsterdam, 2023b). Furthermore, although Hong et al. (2019) and expert 3 noted that buildings should generally be in good condition, renovation could also create opportunities for coupling rooftop park retrofit (Experts 6 and 9; Joshi et al., 2020). Although these insights regarding building structure, type and quality are insightful, no spatial data is available for these indicators of construction capacity in Amsterdam.

Therefore, similar to previous studies (Hong et al., 2019; Joshi et al., 2020; Silva et al., 2017; Slootweg et al., 2023), the building year is conceived as a general proxy for large-scale assessment of the construction capacity. Tailoring this to Amsterdam, buildings built between 1960 and 1990 were found to have the highest potential for rooftop park retrofit. Concrete became increasingly popular in the Netherlands and Amsterdam after WWII but, based on the introduction of regulations, 1960 marks the wider adoption in building structures (Gijsbers, 2012). Unlike Rotterdam, however, concrete buildings are less common in the inner city of Amsterdam (Expert 9). Pre-1990 buildings are considered more suitable due to the introduction of more advanced technology and stricter building requirements, also found by Joshi et al. (2020). Therefore, as Expert 9 explained, buildings built before 1990 are more likely to have structural reserved capacity as they were built with broader safety margins and less precise calculation models. Besides, buildings constructed during this time period may also require renovation (Joshi et al., 2020).

Although these insights are valuable for assessing the rooftop park retrofit potential, they may not provide the full picture. It is deemed necessary to remark that for the development of large-scale projects, such as a rooftop park with significant additional loads, the potential reserved load capacity is most likely insufficient and structural reinforcement is inevitable, which may entail substantial effort and financial investments (Expert 6; MVRDV, 2021). Acknowledging this, the constructional capacity analysis aims to pinpoint buildings with the highest potential for rooftop park retrofit in Amsterdam, as a starting point rather than a definitive assessment.

5.1.4 Willingness of building stakeholders

Criterion: Building stakeholders should be initially willing for transformation for roofs to be considered suitable for rooftop park retrofitting. *The type of ownership* and *number of owners* can give an initial indication, where public or commercial ownership and a single owner are considered more suitable. Nevertheless, eventually, willingness is more complex and *direct stakeholder engagement* is crucial for measuring willingness.

The successful retrofitting of roofs into rooftop parks depends not only on the physical suitability aspects of buildings but also willingness of building stakeholders was identified as a key criterion in the suitability assessment for rooftop park retrofit in Amsterdam. Next to the construction capacity, Zhang & He (2021) describe individual willingness as one of the key barriers to successful green roof development, a perspective widely supported by experts for rooftop park development.

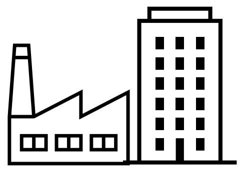
Nevertheless, while crucial for rooftop park retrofit, this willingness was found multifaceted and complex. To ensure public access to rooftop parks, literature and experts emphasised that the building occupants' acceptance of sharing their space is essential (Pomeroy, 2012). However, eventually, the building owners are the primary decision-makers for all rooftop development, as recognised by the municipality of Amsterdam (Gemeente Amsterdam, 2023b) and various experts. As Expert 7 noted, *"If you don't have that (willing owner), you can keep talking to residents or even the manager of such a property, but it will have to be the owner who agrees to this new function, the investment around it, and how it's organised."* While this illustrates the diversity in stakeholders, this statement also highlights that willingness extends beyond allowing a new multifunctional shared space; it also encompasses required financial investment and organisational aspects. This was further exemplified in the observational study and highlighted by other experts during the interviews, who raised questions regarding maintenance, responsibility and legal procedures.

Despite the complexity, indicators were identified to help assess stakeholder willingness. Firstly, the type of ownership can serve as an indicator, as each type of owner has its priorities, decision power and financial possibilities (Gemeente Amsterdam, 2023b). In Amsterdam, ownership is categorised by the municipality into owners' associations, housing associations, and public owners such as municipal real estate, and private and commercial property (Gemeente Amsterdam, 2023b). According to Expert 4, owners' associations are often resistant to change. Furthermore, experts highlighted that commercial or public ownership may align better with the required roof sizes, and financial and organisational capacity of large-scale projects such as rooftop park retrofit, making these types of buildings more suitable. This aligns with previous studies (Hong et al., 2019; N. Xu et al., 2020), which prioritise roof greening on publicly and commercially owned buildings over privately owned properties. Secondly, various experts also pointed out that single-ownership models simplify decision-making. Consequently, the number of owners, whether fragmented within a building or across clustered roofs, could also serve as an indicator. In general, fewer owners were assumed to increase the likelihood of rooftop park development, making such roofs more suitable for retrofitting.

Nevertheless, although the type of ownership and number of owners can serve as indicators of a roof's suitability for rooftop park retrofit, assessing stakeholder willingness ultimately requires direct engagement and must be conducted on a case-by-case basis. As experts noted, visionary stakeholders could make a significant difference in overcoming other barriers. As Expert 6 stated, *"That is what such a roof needs, you just need a weirdo who says: this is awesome, we are going to do this."* Moreover, experts stressed that stakeholder willingness is never static and is formed by, among others, the attitude of stakeholders toward the potential of rooftop development, and value appreciation concerning cost-benefit analyses. Furthermore, while policy and regulation may often act as barriers to rooftop development (Zhang & He, 2021), incentives or supportive measures could also positively affect stakeholder willingness for rooftop park retrofit (Experts 2, 5 and 10). Nevertheless, owners should have at least an initial willingness to rooftop park retrofit for roofs to be suitable.

5.1.5 Compatibility of building function

Criterion: The *building function* should be compatible with the intended use of the rooftop park to ensure suitability for retrofitting. Public and commercial buildings offer advantages for integration, but residential roofs may still hold untapped potential for broader green infrastructure development.



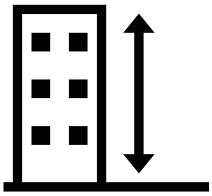
Often closely linked to the willingness of building stakeholders, the compatibility of the building function was identified as an important factor in assessing the suitability of roofs for rooftop park retrofit. Several experts expressed that a logical relationship between the building function and rooftop park retrofit is key for successful development. Public and commercial buildings were frequently identified as more compatible with rooftop parks than residential buildings, as their functions often better align with the opportunities and demands of such retrofits.

Notably, adjacent building functions, such as a hospital or restaurant, were recognised as having the potential to significantly enhance rooftop park usage (Experts 1 and 7, Gemeente Amsterdam, 2023). Besides, as Expert 7 pointed out, public, commercial or utility buildings could benefit from enhanced visibility and branding, using rooftop parks to strengthen their (public) profile or offer complementary services. For example, Expert 2 referred to a ground-level restaurant with an extension of its terrace on the roof, and Expert 10 suggested that places like the Stopera, Amsterdam's town hall, are ideal candidates for rooftop parks where the municipality could set an example of innovative public green space. This opportunity for public buildings as benchmark cases for rooftop greening was also recognised in the literature (Silva et al., 2017).

Additionally, Experts 2 and 9 pointed out that buildings with public and commercial functions could be favoured for rooftop park retrofit because these may cause fewer concerns about nuisance for residents. Nevertheless, while buildings with public or commercial buildings offer advantages for rooftop park retrofit, focusing exclusively on them in the suitability assessment may limit the overall impact. As noted by Expert 3, if the aim is to create large-scale public urban green spaces, excluding buildings with residential functions outright in the assessment may not be feasible, as these locations might especially require such a park. Therefore, while compatibility with the building function is relevant in the suitability assessment, it is not considered decisive.

5.1.6 Roof elevation

Criterion: Buildings with a roof height lower than 15 metres are more suitable for rooftop park retrofit in Amsterdam, but careful consideration is required.



Roof elevation, assessed through roof height in meters, was found to play a complex yet relevant role in evaluating the suitability of roofs for rooftop park retrofit in Amsterdam. It influences multiple considerations, including environmental performance, accessibility and overall integration within the urban fabric. Firstly, higher roof elevations could pose challenges for rooftop park ecosystems and benefits. Experts (1 and 7) and literature highlighted that green roofs on taller buildings experience increased exposure to weather conditions, such as solar radiation and wind speed, which can hinder plant growth and habitat value (Hong et al., 2019; Lepczyk et al., 2017). Other studies negatively correlate roof height with fly richness, the use of trap nests by bees and wasps, and the abundance of bugs and beetles on green roofs (Dromgold et al., 2020; MacIvor, 2016; Madre et al., 2013). These environmental impacts suggest that buildings with lower roof elevations may be more suitable for rooftop park retrofits.

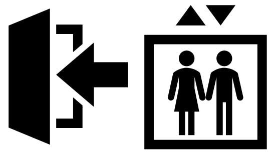
Furthermore, considering its multifunctionality, studies and experts suggested that lower roof elevations can enhance the general accessibility of rooftop parks for people. Studies and experts agree that lower heights enable an easy transition from ground level, increase visibility and encourage visitor engagement (Ariff et al., 2023; Hermans, 2022; Hong et al., 2019; Willemsen, 2018; Y. Xu et al., 2021). Notably, while Expert 2 and a study by Joshi et al. (2020) also observed that roof elevation could serve as a proxy for construction capacity, this aspect was not considered in this study, aligning with constructional insights from Expert 9.

Although clear general threshold values for roof height in terms of environmental performance remain rather inconclusive, this can partly be explained by the varying effects of elevation on different species, as noted by expert 11. Academic literature offers a range of threshold suggestions, from 15 to 40 metres (Hong et al., 2019; MacIvor, 2016). Moreover, Amsterdam's nature-inclusive building practices reflect this variability, including interventions for species ranging from 10 to 120 meters (Gemeente Amsterdam, 2019). Accessibility considerations offer more practical benchmarks for rooftop park retrofit. In line with insights from Willemsen (2018) for the city of Rotterdam, and reflecting the average height of Amsterdam's inner city, this study supports the perspective of Expert 6, who noted, "*I think you need to consider what the city is. And it is mostly buildings that are about 15 meters high, so five residential floors. I think you need to look at that level. Then the distance to the city is not that great either*". Consequently, a maximum elevation of 15 meters was identified as a suitable threshold, balancing ecological and accessibility considerations for rooftop park suitability.

Nevertheless, while lower elevations have advantages, dismissing higher roofs outright could limit opportunities. As pointed out by Expert 3, "*it is not that you can say everything low is better than everything high*". Higher roofs could provide quiet, unique park spaces with panoramic views, offering distinct values to visitors (Expert 3), which is addressed in 5.2.3. Besides, they may also be accessed from lower roofs (Hermans, 2022; Willemsen, 2018). Additionally, Expert 12 questioned how many buildings in Amsterdam would be too tall in practice, as the highest building is 'only' 150 metres. Therefore, although roof elevation is a key consideration for rooftop park retrofitting, it should not be viewed as a decisive criterion. Ultimately, careful evaluation is required, balancing its interplay with other factors and tailoring assessments to each building's context.

5.1.7 Ease of access

> **Criterion**: Roofs should be easily accessible from ground level to be considered suitable for rooftop park retrofitting, primarily informed by the existing *type of access*. Roofs with direct access from the street and an *active frontage* are considered more suitable for rooftop park retrofit.



Ease of access was identified to play a crucial role in evaluating roof suitability for rooftop park retrofits, complementing roof elevation in enhancing accessibility and vertical spatial integration. Both theoretical and empirical insights revealed that a successful rooftop park, as a new public space, depends heavily on effective access and connectivity to the surrounding urban fabric. Unlike ground-level parks and urban green spaces, the ease of access for rooftop parks is primarily determined by the existing type of access to the roof.

While examples such as NEMO in Amsterdam and Vierhavensstrip in Rotterdam illustrate how building design through gradual slopes can enhance ease of access for humans, plants and animals, this study is focused on retrofitting the existing building stock, where access may be more constrained. In this context, similar to previous studies (Hermans, 2022; Li et al., 2022), the municipality of Amsterdam recognised several types of roof access in the city, each with distinct implications for rooftop park retrofit: roofs accessible through an individual house, those accessible via a shared staircase or elevator for building users, and roofs accessible via a staircase or elevator accessible to everyone from the street. Roofs with direct street access were identified as most suitable for rooftop park retrofitting. Such access allows for a potentially high amount of pedestrian crowd (Ariff et al., 2023) and, according to experts, minimises concerns about privacy and nuisance for residents and enhances the open character of the park, making the space more welcoming and functional for a broader range of visitors. In contrast, roofs with individual access were considered less suitable, as they restrict the potential for broad public access.

In addition to the type of access, an active frontage, referring to a building's ability to provide engagement with the street, could also form an indicator of the ease of access (Ariff et al., 2023). As noted by Expert 6, *"It should be a kind of logic, I am walking here, and now I walk upwards."*

Buildings with active frontages such as cafes or community spaces may create a more natural connection from street level to the rooftop park, enhancing accessibility and the park's role as a public space (Ariff et al., 2023).

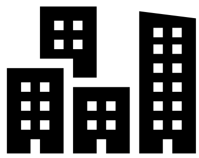
Nevertheless, despite active frontages, experts noted that in many existing buildings, few roofs are currently accessible, and even fewer have direct access from the street. As such, new constructions would often be essential, requiring sufficient ground-level space (Willemsen, 2018). Besides, experts also pointed out that ease of access could be organised in alternative ways, for example through a dedicated staircase or a special button in the elevator which would directly lead to the roof. These solutions could potentially make rooftop parks accessible even in buildings where public access from the street is not feasible.

In summary, ease of access remains a key criterion in rooftop park retrofit suitability. Although roofs with direct street access and active frontages are most ideal for enabling broad public access, alternative solutions for access could make a wider range of buildings suitable for retrofitting. The potential for interventions should be recognised to overcome challenges in the current building stock. Therefore, ease of access should be considered a flexible criterion in the suitability assessment for rooftop park retrofits.

5.2 Urban Contextual Criteria

5.2.1 Urban density

Criterion: Roofs in dense urban areas are more suitable for rooftop park retrofit. Urban density in this study is primarily informed by *population density* measured by inhabitants per km2. Areas with more inhabitants than average and slow traffic flows are deemed more suitable.



Urban density was identified as one of the key criteria for assessing the urban context regarding the suitability of rooftop park retrofit. As space scarcity is highest in urban dense areas, experts generally agreed that areas with the highest density would be most suitable for rooftop park retrofitting, with Expert 6 stating, *"the greatest need is in the busiest area of the city"* and Expert 5 noting, *"where it is most densified"*.

While urban density can be assessed using various indicators, in this study, population density was identified as the primary factor for evaluating this criterion. Population density, measured in inhabitants per square kilometre, is closely tied to urban density and space scarcity and areas with higher population density generally have a greater need for new green and public spaces, such as rooftop parks (Silva et al., 2017; Talen, 2010). As Expert 3 questioned: *"in a place like the Zuidas, which is a beautiful area where no one lives, but there are a lot of square meters, do you actually need a rooftop park there?"* While the entire city of Amsterdam could be considered densified, these insights suggest that areas with higher population density, such as the city centre and Amsterdam West, are more likely to benefit from rooftop park retrofits, making them more suitable due to their greater space scarcity and stronger demand for public and green spaces.

As urban and population density may vary significantly across different cities, this study adopts a benchmark based on the density of Amsterdam for assessment. In this regard, areas with a population density above the urban average of 5079 inhabitants/km2 (Gemeente Amsterdam, 2024b), are considered to have a heightened demand for public green space, and therefore more suitable for rooftop park retrofitting. Eventually, prioritising urban dense areas for rooftop park retrofit may contribute to better spatial integration in the city and enhance accessibility.

In addition to population density, slow traffic flows, particularly pedestrians, at the street level could be considered for enhancing accessibility and spatial integration. As various experts highlighted, a roof may be more suitable for retrofitting into a rooftop park, when *"there is already a lot of movement (at ground level), which you can then bring up onto the roof"* (Expert 5). As Expert 7 further explained, "*a place that is part of a logical route... Where people would naturally come anyway."* These insights suggest that areas in urban dense areas that are well-trafficked routes or hubs are more likely to support rooftop parks, such as on the Orlyplein in Amsterdam, as people are already moving through the area and can easily be drawn to the rooftop space.

5.2.2 Compatibility with green infrastructure

Criterion: Roofs are more suitable for rooftop park retrofit if compatible with existing green infrastructure. Relevant indicators include the *distance to existing public green spaces*, *public green space per resident* and *linkage to ecological corridors*. Areas further than 10 minutes walking, less than 9 m2 green space per inhabitant, and linked to ecological corridors are deemed more suitable.

Next to the urban density, the compatibility of roofs with the existing green infrastructure has been defined as an important aspect to consider in the urban context to assess the suitability of roofs for rooftop park retrofit. Compatibility, as revealed by theoretical and empirical insights, may be informed by various factors.

Overall, experts generally agreed that areas lacking existing greenspace could benefit more from rooftop park retrofitting, and were therefore considered more suitable. As pointed out by Expert 1, *"if there is enough green space around, I wouldn't immediately create a park on every roof."* While some experts and previous studies (Gwak et al., 2017; Langemeyer et al., 2020) suggested incorporating specific functions of rooftop parks, such as heat stress or water retention, to determine the most suitable roofs, this study adopts a more general approach. Considering the overlap between existing green space and its functions and multifunctionality as a guiding principle, three indicators have been identified reflecting this approach.

Firstly, aligning with expert insights and based on Silva et al. (2017), the overall public green space coverage was found to be informative. As norms for Amsterdam have not been clearly established yet, the percentage of public green surface per inhabitant based on widely used WHO norms was identified as an indicator, acknowledging the overall environmental and social benefits of greenspace for cities. This threshold depicts that every urban citizen should have at least 9m2 of public green space available (Snep & Goossen, 2022). Secondly, leveraging the importance of accessibility and spatial integration, the proximity of public green spaces was used as another indicator (Corley et al., 2018; Talen, 2010). In alignment with Amsterdam's urban vision to ensure that every resident is within a 10-minute walk of a park-like public environment (Gemeente Amsterdam, 2020), this walking distance to existing green spaces was deemed as a threshold value. Finally, the potential linkage of rooftop parks to ecological corridors was included as an indicator, reflecting their potential to enhance biodiversity and integrate into broader green infrastructure networks. As noted by Experts 3 and 11, rooftop parks may fulfil a role as a stepping stone in the existing green infrastructure.

Assessing roofs based on these indicators not only ensure that rooftop parks complement existing green infrastructure, but also maximise their multifunctionality and spatial integration.

5.2.3 Quality of view

Criterion: Roofs are more suitable for rooftop park retrofit if the quality of view is high. While roof height may inform the quality of view on a building level, the level of *unblocked* and *interesting surroundings* serve as indicators in the urban context.

Linked to the building elevation, the quality of view was identified as a critical factor in the urban context to assess the suitability of rooftop park retrofit. As mentioned in Chapter 4, experts recognised that high-quality views significantly enhance the unique character of rooftop parks compared ground-level spaces, playing an essential role in integrating rooftop parks into the city. Referring to the potential restorative effects of panoramic views, Expert 6 stated, *“within the contours of the city, the only place you actually encounter that is on the roof.”* This statement aligns with previous studies (K. Lee et al., 2024; Mesimäki et al., 2019) that noted that views of cityscapes and the sky were positively valued by green roof visitors.

While the relationship between roof elevation and quality of view has been emphasised, this does fully reflect the complexity of this criterion. In the urban context, the quality of view also depends on having an unblocked view from the roof, as incorporated in previous roof assessments (MVRDV & Superworld, 2022). This implies that the roof should not be surrounded by taller buildings obstructing the view. Moreover, as Expert 1 expressed when discussing ideally suitable roofs: *“You should have a roof (…) with an interesting view towards its surroundings where there is also something to see”.* Based on this insight, a roof would be more suitable for retrofitting a rooftop park if the surroundings offered an interesting view. While the perception of what constitutes an “interesting” view can vary significantly among individuals, several factors may be informative. Interesting may refer to the complexity or processes visible (K. Lee et al., 2024), be informed by the number of new view lines that are not visible from street level (Willemsen, 2018) or, as mentioned by Expert 6, the visible number of landmarks in the city. Collectively, these insights suggest that a rooftop’s suitability for park retrofitting increases when it offers diverse, unobstructed views providing a high-quality view.

5.2.4 Roof visibility

Criterion: Roofs are more suitable for rooftop park retrofit when there is *visual contact from the ground level and surrounding buildings*. *Landmarks* may add additional value in terms of visibility, drawing public attention and interest. However, any assessment should take into account the varying levels of *aesthetic standards* across the city, particularly protected zones.

In addition to the quality of the view from the rooftop park, the visibility of the roof itself emerged as a critical factor in evaluating its suitability for a rooftop park retrofit, further enhancing accessibility and spatial integration. Consistent with the findings of (Ariff et al., 2023), multiple experts emphasised that for a rooftop park to become highly accessible, it must be visible to some extent from the street level, such as at the Boijmans van Beuningen Depot in Rotterdam. This allows people to know about its presence, which generates public interest. This is particularly relevant for rooftop parks in comparison to ground-level public green spaces, because, as Expert 7 explained: *"On ground level, you just walk past as you go somewhere, but the roof is a specific place you have to deliberately go to."* While Ariff et al. (2023) describe a strategy where you could see a glimpse of the green roof, Experts 1 and 8 highlighted that creating a clear entrance at ground level could also foster this visual connection.

Furthermore, roof visibility from surrounding buildings may also contribute to a rooftop park's appeal. Although not discussed during the expert interviews, it is known that the visibility of green spaces has positive effects (Wang et al., 2022). Therefore, visibility from surrounding buildings, as seen in locations such as the Jan van Schaeffelerplantsoen and the Groene Kaap, may also be considered in assessing suitability (MVRDV & Superworld, 2022). Nevertheless, the overall positive impact may be smaller than that of ground-level green spaces and interfere with the unobstructed view as an indicator for quality of view.

Visibility can also be tied to the prominence of the rooftop park's location. As pointed out by Expert 10, and illustrated by existing rooftop parks such as Hofbogenpark in Rotterdam, while these locations can become landmarks themselves, they are also more visible and thus accessible when situated on existing landmarks in the city. Therefore, landmarks such as the Amsterdam Central Station may offer additional value as suitable locations for rooftop park retrofits. However, one important remark regarding visibility, particularly in Amsterdam, which was mentioned multiple times, concerns the varying levels of aesthetic standards across the city. Amsterdam places strong emphasis on preserving its visual identity, particularly when it comes to alterations to heritage zones and the city skyline (Gemeente Amsterdam, 2021b, 2023b). Experts noted that while rooftop parks are valuable for enhancing public green space, current regulations on aesthetic standards may hinder development due to alterations of visible elements of buildings. As Expert 5 mentioned, future rooftop developments will require more flexibility in these regulations. However, at present, especially buildings in areas with the highest aesthetic standards may be less suitable for rooftop park development. This highlights that finding a balance between innovation and preservation will be essential to unlock the potential of rooftop parks.

5.3 Prioritised criteria assessment framework

While all criteria described in this chapter are considered highly relevant to assess roofs in Amsterdam for rooftop park retrofit suitability, not all are considered equally important. Therefore, prioritisation was applied to criteria and indicators based on the relevance with regard to the problem statement, the frequency with which each criterion and indicator was mentioned and its alignment with the guiding principles of multifunctionality, accessibility, environmental performance and spatial integration. This prioritisation formed the foundation of a structured suitability assessment framework.

Table 8 lists the prioritised criteria, corresponding indicators and assessment thresholds, aligning with the discussions in the previous sections, while Figure 16 visually presents this framework. This visual representation shows the prioritisation of the building and urban context criteria on the left (blue blocks). By following the pathways based on the indicators (white blocks), rooftops in Amsterdam can be systematically assessed for suitability for rooftop park retrofit. The application of this framework is further analysed in Chapter 6.

A distinction was made between decisive and non-decisive criteria (see Table 8), following the study of N. Xu et al. (2020). Decisive criteria can independently determine whether a rooftop is unsuitable for a park retrofit. Based on theoretical and empirical findings, this study identifies roof flatness, available roof area, the willingness of building stakeholders and construction capacity as decisive criteria. These criteria and corresponding indicators are given the highest priority in the framework, are therefore also assessed first, and may directly lead to a "non-suitable" outcome (red blocks in Figure 16). Once these decisive building-level criteria are met, the non-decisive criteria are addressed (Table 8), which help to identify preferred roofs and reflect the differences in the degree of suitability for rooftop park retrofitting based on the corresponding indicators and assessment thresholds. In Figure 16, outcomes in orange blocks (not meeting assessment thresholds) indicate that there are potential challenges or obstacles, while outcomes in green blocks suggest that a roof meets a suitability criterion for rooftop park retrofit considering assessment thresholds. Eventually, the more 'green' outcomes a roof has, the higher its suitability with minimal adjustments required. A greater number of 'orange' outcomes in an assessment lowers overall suitability. Additionally, considering the prioritisation, the higher an orange block appears in the framework, the more critical its impact.

Acknowledging the importance of both building-level and urban contextual criteria, a balanced prioritisation approach was adopted (Table 8). While Expert 3, echoing some previous studies such as Langemeyer et al. (2020), suggested identifying priority areas before assessing individual buildings, the majority of experts stressed, aligning with other studies (Gwak et al., 2017; Hong et al., 2019; Silva et al., 2017; N. Xu et al., 2020), the greatest challenges arise when evaluating individual buildings and therefore building assessment should be prioritised. They argued that rooftop parks can still positively contribute to the city when applied to suitable buildings, regardless of their exact location. This highlights why it is crucial to prioritise building-level criteria at the start of the assessment. To ensure a balanced approach, this assessment starts with decisive building-level criteria (Table 8, Figure 16). Once these are evaluated, two important urban contextual criteria, namely urban density and compatibility with green infrastructure, are considered. These help to assess the broader potential for integration into the city. Then, building-level considerations related to compatibility with building function and ease of access are evaluated, followed by two more urban contextual criteria: roof visibility and quality of view. This process reflects the need to balance both the building's characteristics and integration within the wider urban context while prioritising the most important considerations at the building level.

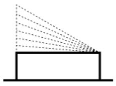
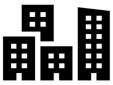
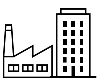
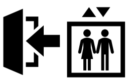
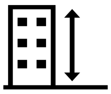
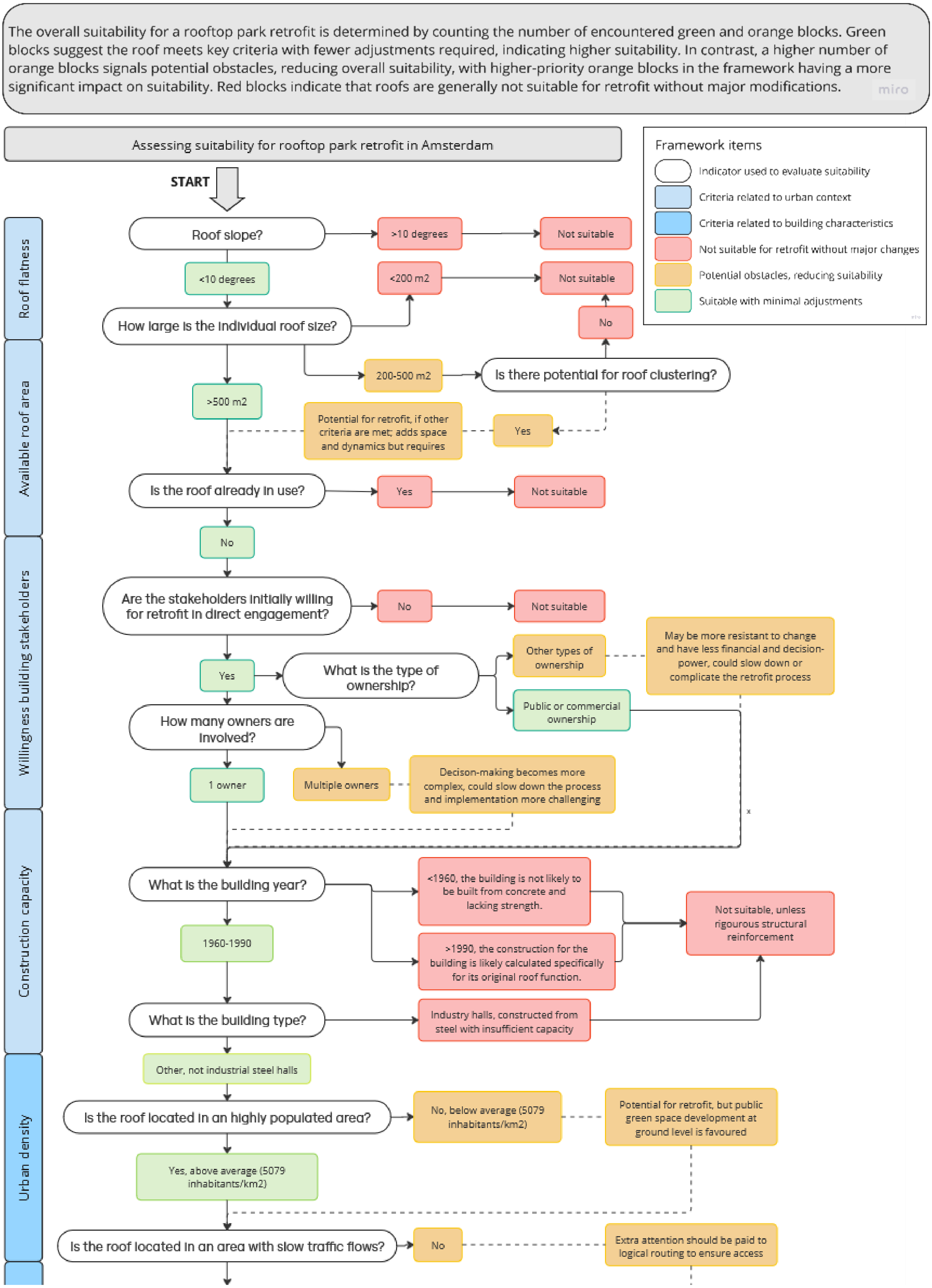
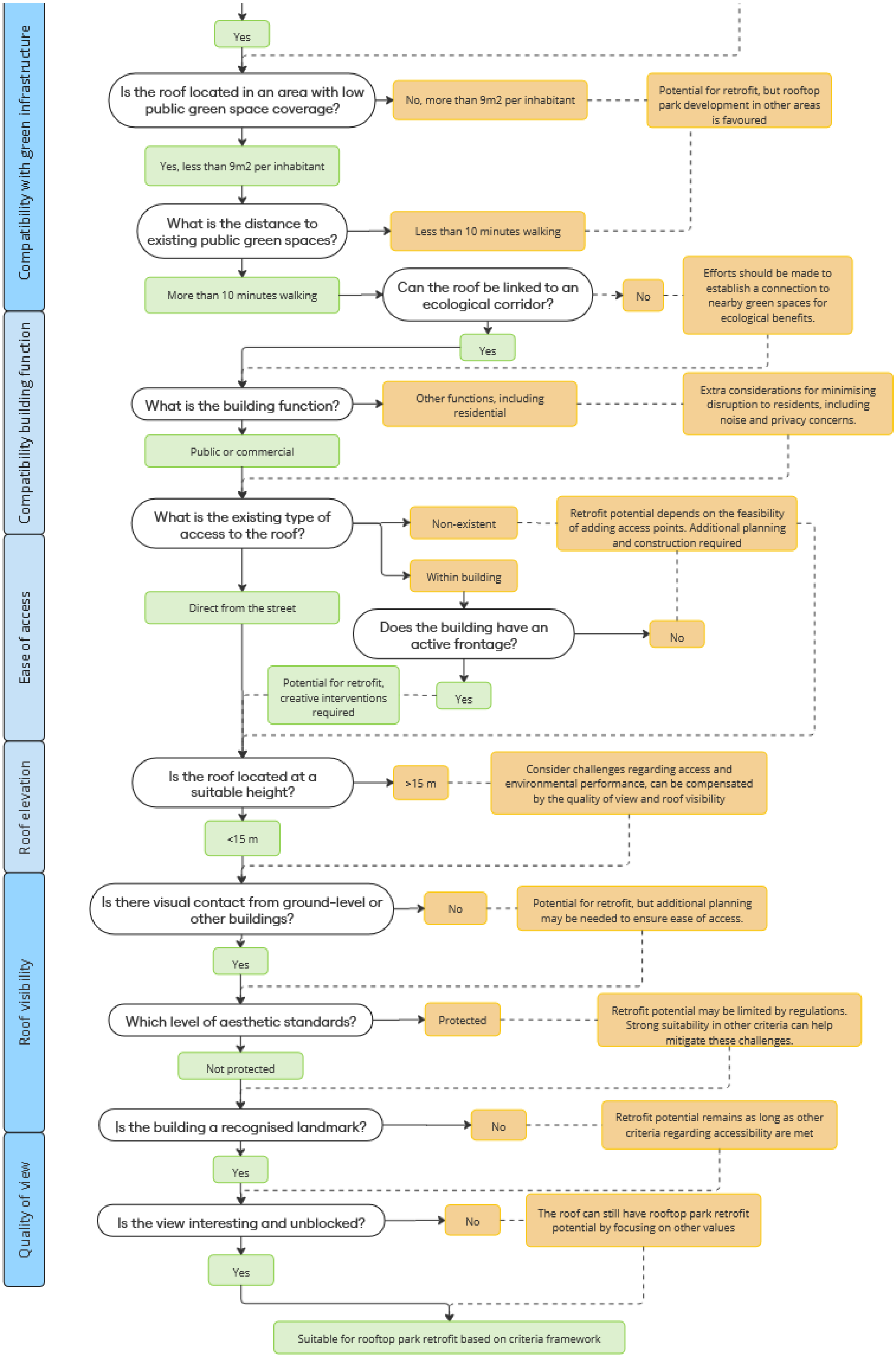
Suitability criteria (prioritised)		D/ND	Scale	Indicators	Assessment threshold
	Roof flatness	D	B	*Roof slope*: What is the roof slope?	< 10 degrees
	Available roof area	D	B	*Individual roof size*: How large is the individual roof size?	> 500 m², or >200 m² if potential for clustering is positive
				Existing use of roof: is the roof already in use?	No, roofs are not already used for other purposes
				Potential for clustering: is there potential for roof clustering?	Yes, connecting roofs compensate for the size constraints of individual roofs
	Willingness building stakeholders	D	B	*Direct stakeholder engagement*: Are the stakeholders initially willing for retrofit in direct engagement?	Yes, owners have an initial willingness to rooftop park retrofit for roofs
				Type of ownership: What is the type of ownership?	Public or commercial ownership
				Number of owners: How many owners are involved?	Single ownership
	Construction capacity	D	B	*Building year*: What is the building year?	1960-1990
				Building type: What is the building type?	Other than industrial steel halls
	Urban density	ND	UC	*Population density*: Is the roof located in a highly populated area?	Yes, above average (> 5079 inhabitants/km2 in the neighbourhood)
				Slow traffic flows: Is the roof located in an area with slow traffic flows?	Yes, well-trafficked routes or hubs for slow mobility
	Compatibility green infrastructure	ND	UC	*Public green space coverage:* Is the roof located in an area with low public green space coverage?	Yes, < 9 m2/inhabitant in the neighbourhood
				Distance to park-like green space: what is the distance to existing public green spaces?	> 10 minutes walking (850 m)
				Linkage to ecological corridors: Can the roof be linked to an ecological corridor?	Yes, it can form a stepping stone
	Compatibility building function	ND	B	*Building function*: What is the building function?	Public or commercial functions
	Ease of access	ND	B	*Type of access:* What is the existing type of access to the roof?	Direct from the street, existing access
				Active frontage: Does the building have an active frontage?	Yes, the building provides engagement with the street
	Roof elevation	ND	B	*Roof height*: Is the roof located at a suitable height?	< 15 m
	Roof visibility	ND	UC	*Visual contact*: Is there visual contact from the ground or surrounding buildings?	Yes, you can see the roof from the street/other buildings overlook the roof
				Landmark location: Is the building a recognised landmark?	Yes, the roof is located on a building that stands out from its surroundings
				Level of aesthetic standards: What is the level of aesthetic standards?	Not protected, the roof is not located in a protected zone
	Quality of view	ND	UC	*Unblocked view*: Is the view unblocked?	Yes, no higher surrounding buildings
				Interesting view: is the view interesting?	Yes, complexity, processes, landmarks or new view lines visible

Table 8: Overview of prioritised suitability criteria and corresponding indicators

Suitability criteria (prioritised): *Order of criteria assessment*
D/ND*: Decisive (D) determines the (un)suitability of roofs; Non-decisive (ND) refines the degree of suitability of roofs.*
B/UC*: Building (B) versus Urban Contextual (UC) criteria.*
Indicators*: Measurable factors with defined assessment thresholds that help assess suitability criteria for rooftop park retrofit*
Assessment Threshold: *specify the value for a roof to meet the corresponding indicator for the suitability criterion*

Figure 16: Rooftop park retrofit suitability criteria framework (author's work)





Compatibility with green infrastructure
Yes
Is the roof located in an area with low public green space coverage?
No, more than 9m2 per inhabitant
Potential for retrofit, but rooftop park development in other areas is favoured
Yes, less than 9m2 per inhabitant
What is the distance to existing public green spaces?
Less than 10 minutes walking
More than 10 minutes walking
Can the roof be linked to an ecological corridor?
No
Efforts should be made to establish a connection to nearby green spaces for ecological benefits.
Yes
Compatibility building function
What is the building function?
Other functions, including residential
Extra considerations for minimising disruption to residents, including noise and privacy concerns.
Public or commercial
Ease of access
What is the existing type of access to the roof?
Non-existent
Retrofit potential depends on the feasibility of adding access points. Additional planning and construction required
Within building
Direct from the street
Does the building have an active frontage?
No
Potential for retrofit, creative interventions required
Yes
Roof elevation
Is the roof located at a suitable height?
>15 m
Consider challenges regarding access and environmental performance, can be compensated by the quality of view and roof visibility
<15 m
Roof visibility
Is there visual contact from ground-level or other buildings?
No
Potential for retrofit, but additional planning may be needed to ensure ease of access.
Yes
Which level of aesthetic standards?
Protected
Retrofit potential may be limited by regulations. Strong suitability in other criteria can help mitigate these challenges.
Not protected
Is the building a recognised landmark?
No
Retrofit potential remains as long as other criteria regarding accessibility are met
Yes
Quality of view
Is the view interesting and unblocked?
No
The roof can still have rooftop park retrofit potential by focusing on other values
Yes
Suitable for rooftop park retrofit based on criteria framework

APPLICATION ANALYSIS

Dakpark de Boel, Amsterdam (author's work, 2024)

6 Application analysis

This chapter applies the suitability criteria framework outlined in Chapter 5 to assess the potential for retrofitting roofs into rooftop parks in Amsterdam. Therefore, to begin, an overview of the applicable and available data for each criterion and corresponding indicators was created, addressing SRQ3 (see Table 7). Based on data availability and each indicator's (non-)decisive character, the appropriate assessment approach was determined (Table 7), further elaborated upon in the following sections.

While the integrated framework presented in Figure 16 would ideally be step-by-step applied to the entire roof stock in Amsterdam to assess the suitability of all roofs for rooftop park retrofitting, the feasibility of such a large-scale assessment across the city is constrained by the need for qualitative assessments (Table 7). These require visual or subjective evaluations, which are time-consuming. Given the high number of roofs in Amsterdam, performing such a detailed visual analysis city-wide was not feasible within the available timeframe. To address this, the strategy chosen for applying the criteria framework in this study first focuses on the quantitative filtering of suitable roofs based on the identified decisive criteria, followed by the identification of promising areas, and the eventual integrated assessment of a subset of three promising roofs. This strategy, outlined in Figure 17, aligns with the prioritisation and framework presented but simplifies the process for practical purposes. By implementing this strategy, this analysis chapter provides insights into the city-wide suitability of roofs for rooftop park retrofit in Amsterdam, while also demonstrating how the framework can be applied in a detailed assessment of specific roofs.

In section 6.1, I first evaluate at a city-wide scale which roofs in Amsterdam may be considered suitable for rooftop park retrofit based on the identified decisive building-level criteria and corresponding indicators. Considering the large scale, this initial assessment relies on the decisive indicators for which quantitative data is available, including the roof slope, individual roof size, and building year. This allows for efficient filtering of roofs that meet the basic requirements for rooftop park retrofit to a large extent. After the initial filtering of roofs, in Section 6.2, promising areas in Amsterdam for rooftop park retrofit are identified to support the targetedselection of roofs for further investigation. This step is also conducted on a city-wide scale, by assessing the urban density and compatibility of green infrastructure based on the quantitative thresholds for population density, green space coverage, and the distance to existing urban green spaces. In Section 6.3, three specific roofs from the initial filtering in 6.1, located in promising areas identified in 6.2, are selected for a zoomed-in, detailed and integrated assessment. This step involves running through the entire criteria framework, integrating both quantitative and qualitative data and insights, including visual assessments. The integrated assessments of these promising roofs serve as illustrative examples, providing comparative insights and demonstrating the application of the entire framework.

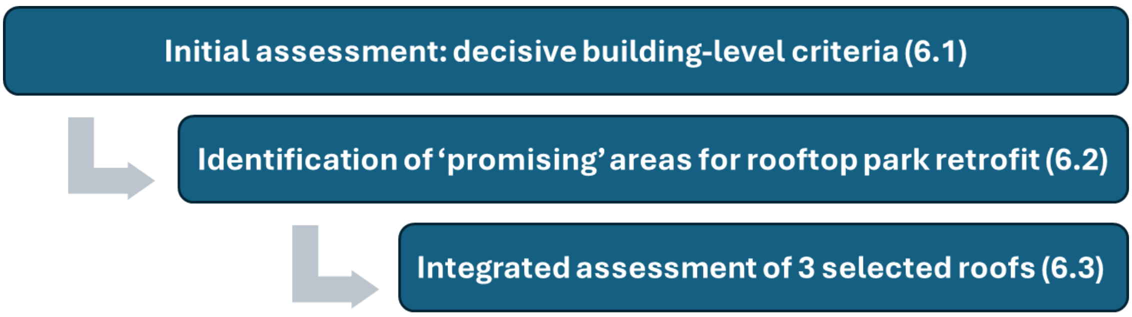


Figure 17: Application analysis strategy (author's work)

Criteria	Indicators	Assessment	Data availability
Roof flatness	Roof slope	Quantitative	Attribute B3_opp_dak_plat in dataset DAKEN_BAG3D
Available roof area	Individual roof size		
	Existing use of roof	Qualitative (visual)	ESRI satellite images, Dataset DAKEN
	Potential for clustering	Qualitative (visual)	Attribute B3_opp_dak_plat in dataset DAKEN_BAG3D
Willingness building stakeholders	Direct stakeholder engagement	Qualitative (feedback)	Not available, requires direct interaction
	Type of ownership	Qualitative (categorical)	Map only available online (Gemeente Amsterdam, n.d.-c)
	Number of owners	Qualitative (estimation)	Informed by the type of ownership, and Google Maps
Construction capacity	Building year	Quantitative	Attribute oorspronkelijkbouwjaar in dataset DAKEN_BAG3D
	Building type	Qualitative (visual) Qualitative (estimation)	Google Street View, ESRI satellite images
Urban density	Population density	Qualitative (quantitative threshold)	Dataset INDELING_WIJK and municipal statistics
	Slow traffic flows	Qualitative (visual)	Google Street View
Compatibility with green infrastructure	Public green space coverage	Qualitative (quantitative threshold)	Attribute opp_recreatiefgroen_ha in Dataset Bodemgebruik groen gebieden, Dataset INDELING_WIJK, municipal statistics
	Distance to park-like green space	Qualitative (quantitative threshold)	Attribute Gem_afstand_parkachtig_groen in dataset Afstandgroen hex100, dataset HOOFDGROENSTRUCTUUR
	Linkage to ecological corridors	Qualitative (estimation)	Dataset ECOLOGISCHE_STRUCTUUR
Compatibility building function	Building function	Qualitative (visual, categorical)	Google Street View Dataset FUNCTIEKAART
Ease of access	Type of access	Qualitative (visual)	Google Street View, Google Earth ESRI satellite images
	Active frontage	Qualitative (visual)	Google Street View
Roof elevation	Roof height	Qualitative (quantitative threshold)	Attributes B3_h_max *and* B3_h_maaiveld in *d*ataset DAKEN_BAG3D
Roof visibility	Visual contact from ground level or surrounding buildings	Qualitative (visual)	Google Street View ESRI satellite images
	Landmark location	Qualitative (visual)	Google Street View
	Level of aesthetic standards	Qualitative (categorical)	Dataset WELSTAND_NIVEAUS
Quality of view	Interesting view	Qualitative (visual)	Google Street View, Google Earth ESRI satellite images
	Unblocked view	Qualitative (visual)	Google Street View, Google Earth ESRI satellite images

Table 9: Data availability and assessment for each criterion and corresponding indicators

Table 8

Blue shades refer to building and urban context criteria

Assessment labels refer to:

Quantitative:	Objective assessment based on numeric data.
Qualitative (visual):	Subjective assessment based on visual observations.
Qualitative (categorical):	Assessment based on categorical classifications.
Qualitative (estimation):	Assessment where an estimate is made, based on perception or experience.
Qualitative (feedback):	Assessment based on subjective feedback.
Qualitative (quantitative threshold):	Assessment that combines both qualitative aspects and a numerical threshold. This means a specific numerical threshold must be met for the assessment to be categorised.

6.1 City-wide initial assessment: decisive building-level criteria

As described, the first step of this application analysis of the criteria framework evaluates the roofs in Amsterdam at a city-wide scale, focusing on the decisive building-level criteria for rooftop park retrofit suitability while filtering only based on the indicators for which quantitative data was available. Figure 18 gives an overview of this process (based on the criteria framework, Figure 16), which is further explained below.

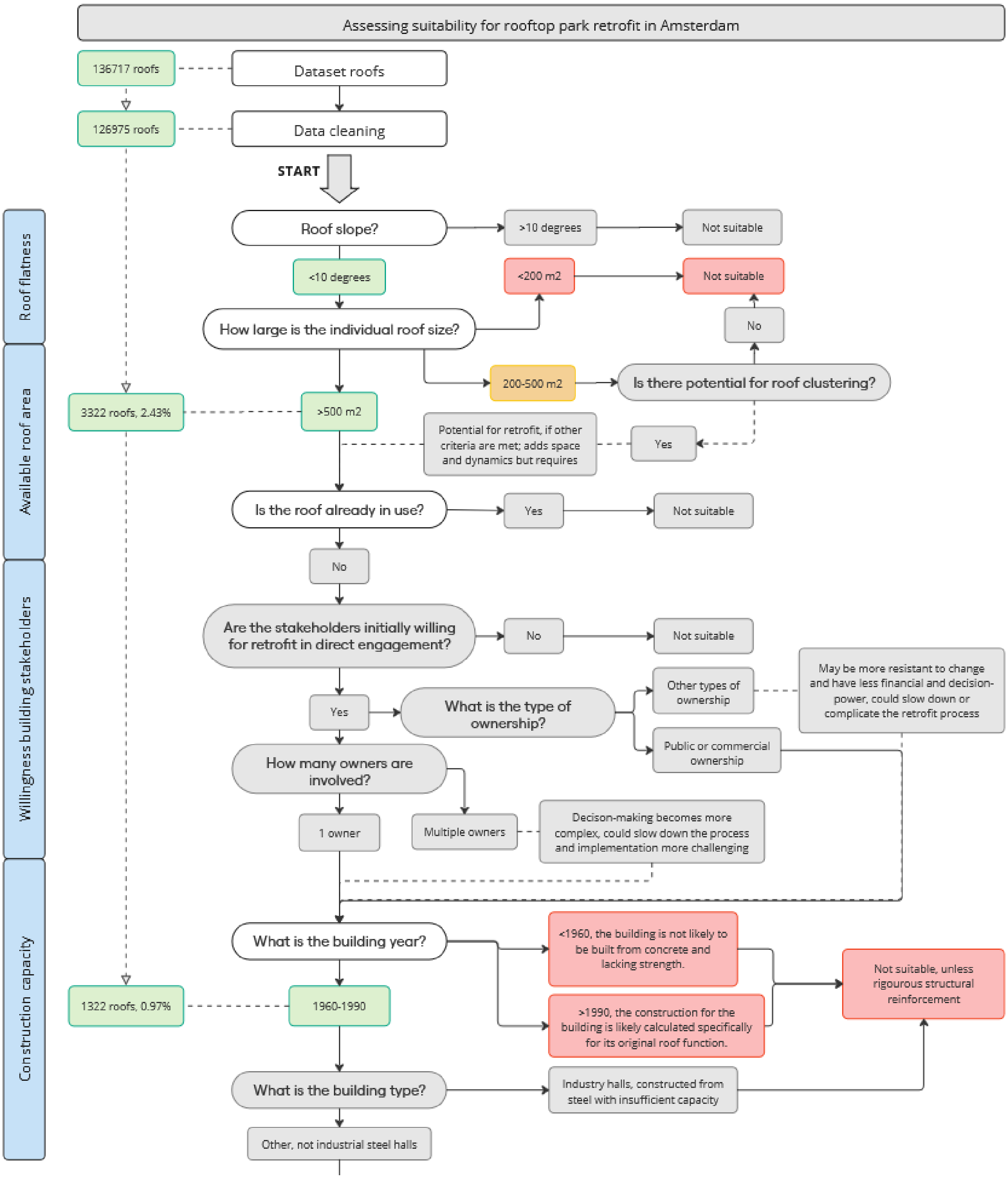


Figure 18: City-wide assessment of decisive criteria, based on quantitative filtering (author's work)

Grey blocks indicate that the indicator was not applied in this step of city-wide initial assessment

Outcomes of the filtering process of suitable roofs are presented on the left in the green corresponding blocks

Starting the assessment

The dataset with roofs in Amsterdam was first added to QGIS. This dataset (DAKEN_BAG3D) included 136717 polygons, each representing an individual roof in Amsterdam. Then, the starting point of the assessment was cleaning the data. In that regard, buildings with overlapping surfaces and for which data was marked in the dataset as either outdated or insufficient were eliminated, resulting in 126975 roofs with accurate data.

Roof flatness and Available roof area

Flat roof surface	# of roofs
Flat <200m2	118940
Flat 200-500m2	4713
Flat >500m2	3322

Table 10: Analysis of flat roof surfaces

Following the cleaning of the data and in line with the prioritisation in the criteria framework, the roofs were first assessed based on the roof's flatness. However, as data for the *roof slope* was not available in the dataset separately, the assessment of the ***roof flatness*** was coupled with the evaluation of the ***available roof area*** criterion. In this context, the surface of the roof which is flat (Attribute dataset: B3_opp_dak_plat) was utilised to filter the dataset, as a combined criterion for the *roof slope* and *individual roof size* indicators.

Table 9 presents the findings of applying the defined thresholds at this stage. The majority of roofs had a flat roof surface below 200 m^2 and were therefore considered unsuitable. 4713 roofs were found to have a flat surface between 200-500 m2 with potential suitability, while 3322 roofs were found suitable with a flat roof surface area of over 500 m^2 (2.43% of all roofs). Although Figure 16 implies that roofs between 200 and 500 m^2 require further analysis of the potential for clustering, assessment of the *existing use of the roof* and *potential for clustering* require visual assessment which was only carried out in this strategy in the later zoom-in phase of the analysis (Section 6.3). Therefore, for now, this large-scale assessment focused on the selection of 3322 roofs, as they were deemed to have the highest potential suitability based on their flat roof size of over 500m2.

Willingness of building stakeholders

Aligning with the criteria framework, the ***willingness of building stakeholders*** appears as the next decisive criterion in the assessment. However, data for *direct stakeholder engagement* is not available and requires direct engagement with building owners. Maps regarding the *type of ownership* were found online on the municipality website, but data was not managed to retrieve for own usage in QGIS. Additionally, data for the *number of owners* is lacking and may be based on the type of ownership or requires visual assessment. Therefore, the evaluation of these indicators was only incorporated in the integrated zoom-in assessment of a subset of roofs in 6.3.

Construction capacity

To evaluate the fourth decisive criterion, **construction capacity**, the roof dataset was filtered based on the building year (attribute: Oorspronkelijk bouwjaar). Of the 3322 flat roofs larger than 500 m2, 1322 were constructed between 1960 and 1990, representing 0.97% of all roofs in Amsterdam and covering about 231 ha. The remaining 2000 roofs were deemed not suitable for rooftop park retrofit at this stage and excluded. Figure 19 presents a map of Amsterdam, showing the spatial distribution of the 1322 roofs identified as initially suitable based on the applied indicators.

Figure 19: Suitable roofs based on the initial large-scale assessment of decisive building criteria (author's work)

Before proceeding, it is noteworthy that due to a lack of data concerning the *building type*, it was impossible at this scale to systematically exclude steel halls, which were considered unsuitable as described in Chapter 5. Nevertheless, previous insights (Gemeente Amsterdam, 2023b) indicate that many roofs in the Western Harbour District are likely to be steel halls. Consequently, although roofs in this area are included and standing out in the map visualisation, it is expected that a high proportion of unsuitable roofs is prevalent here, despite meeting other indicators of decisive criteria.

6.2 Identification of 'promising' areas for rooftop park retrofit

After the filtering of initially suitable roofs based on the quantitative assessment of decisive building-level criteria, 'promising' areas in Amsterdam for rooftop park retrofitting were identified to support the informed and targeted selection of roofs for the integrated assessment in 6.3. The analysis of these 'promising areas' focused on assessing the urban density and compatibility with green infrastructure criteria, using available large-scale data for the corresponding indicators (see Figure 20). While these criteria also align with the prioritisation outlined in the criteria framework, this step in the application strategy was specifically applied in response to the challenges highlighted in the study's introduction, referring to the growing pressure on public green spaces due to increasing urban densification in Amsterdam. While roofs in other areas may also be suitable for retrofit, identifying these 'promising' areas can be viewed as a pre-assessment, providing a practical foundation for selecting specific roofs. This strategy ensures that the integrated assessment phase focuses on roofs located in areas relevant to addressing space scarcity and reducing public green space in the city, ultimately supporting valuable insights and recommendations.

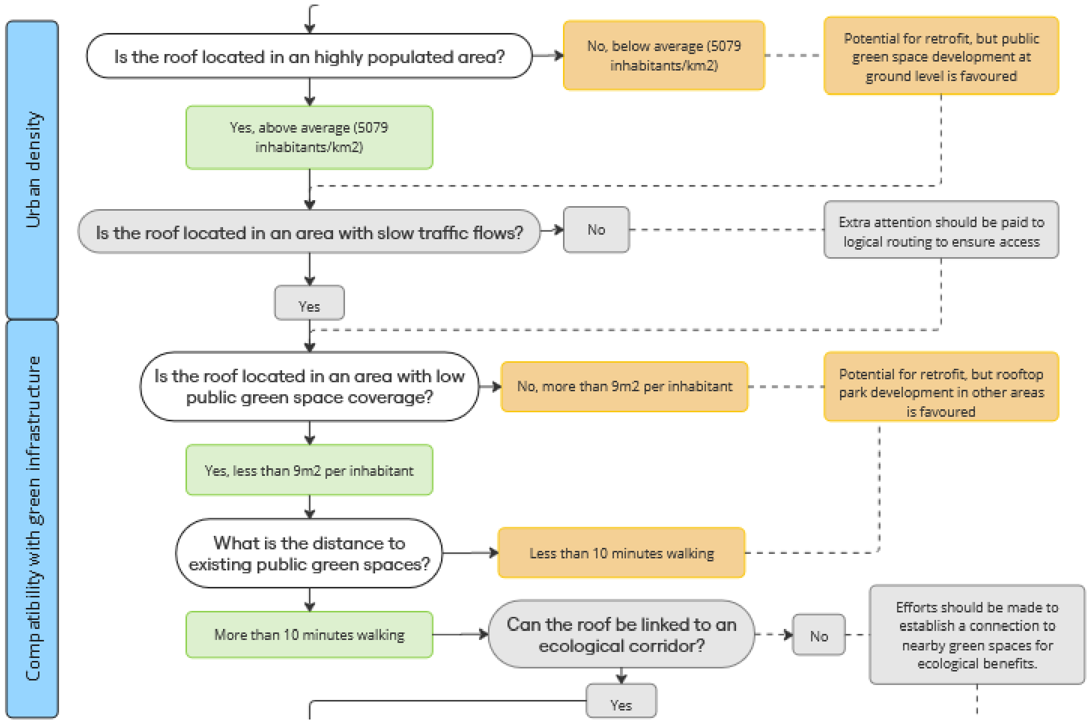


Figure 20: Applied criteria and indicators for identification of 'promising' areas (author's work)

Grey blocks indicate that the indicator was not applied in this step of city-wide assessment

Urban Density

To inform the identification of promising areas based on ***urban density***, statistical data of the *population density* was first coupled with a neighbourhood division dataset (INDELING_WIJK) to visualise the variations in population density across the city by neighbourhood (see Figure 21), in which the distinction between categories by the municipality was used (Gemeente Amsterdam, 2024b). The two lighter colours indicate areas with population densities lower and around the urban average, while the two darker colours highlight neighbourhoods with high or very high population density. Based on the quantitative threshold for population density identified in Chapter 5 (5079 inhabitants/km2), particularly neighbourhoods located in the city centre and Amsterdam West may be favoured for rooftop park retrofitting. *Slow traffic flows* as an indicator were not considered in this large-scale assessment, as this was considered to require visual assessment.

Compatibility with green infrastructure

To further inform the promising areas, areas and their compatibility with green infrastructure were evaluated. Therefore, in the dataset with land use surface (Bodemgebruik groen gebieden), the surface of recreational green (defined as areas part of the Main Green Space Infrastructure) (Attribute: opp_recreatiefgroen_ha) was coupled with the neighbourhood division dataset (INDELING_WIJK), and municipal statistics of the number of inhabitants to calculate the *public green surface coverage per inhabitant* by neighbourhood (See Figure 22). Based on the threshold of 9m2/inhabitant as presented in Chapter 5, light green areas may be favourable for rooftop park retrofit over dark green areas. Furthermore, the walking distance to park-like green spaces is presented in Figure 23, based on the Afstandgroen hex100 dataset. Considering the threshold discussed in Chapter 5, red areas with a walking distance of over 10 minutes may be favoured for rooftop park retrofit, particularly located in the city centre and Amsterdam West. As no quantitative threshold was identified for the *linkage to ecological corridors,* this is not incorporated to inform promising areas in this step but is further assessed in the integrated assessment.

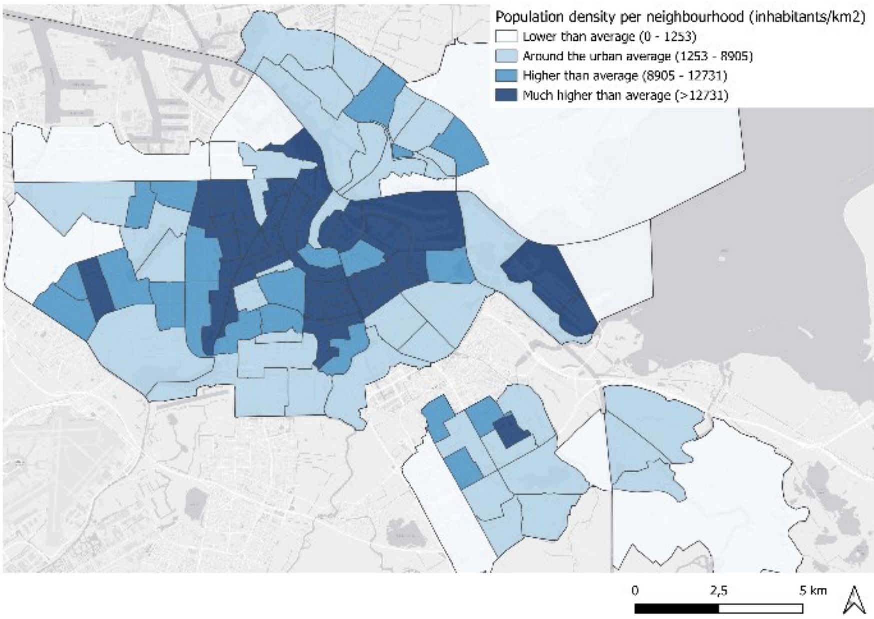


Figure 21: Population density per neighbourhood (author's work)

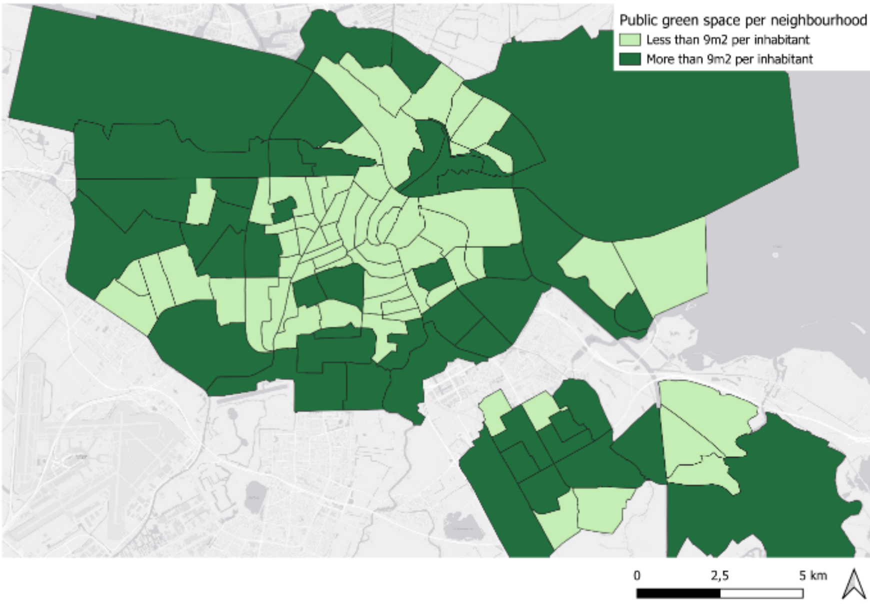


Figure 22: Public recreational green space per inhabitant per neighbourhood (author's work)

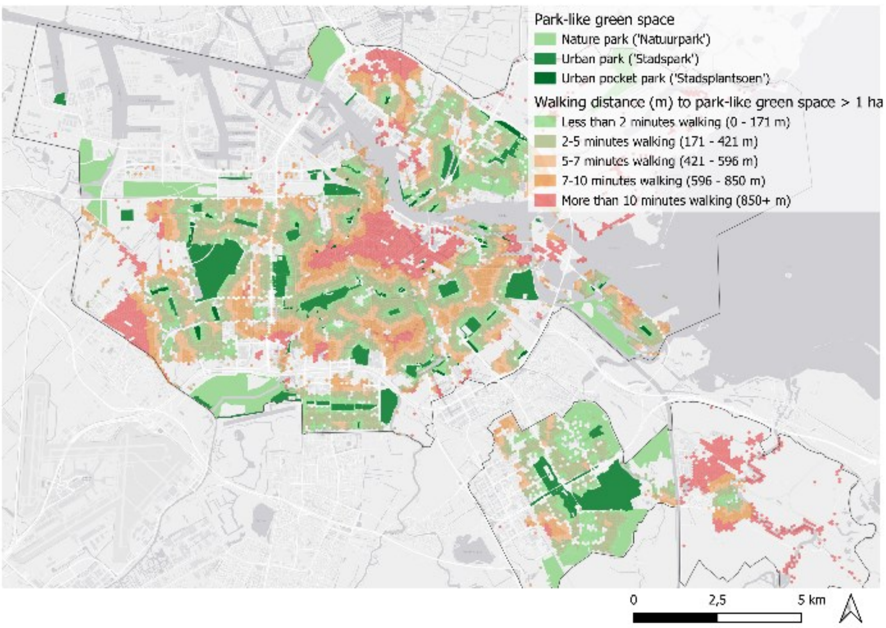


Figure 23: Walking distance to park-like green space (author's work)

By overlaying and combining the three datasets in QGIS (urban density, public green space coverage per inhabitant, and walking distance to park-like green spaces), ‘promising’ areas for this study were identified as areas that met all of the three established thresholds for these indicators, see Figure 24.

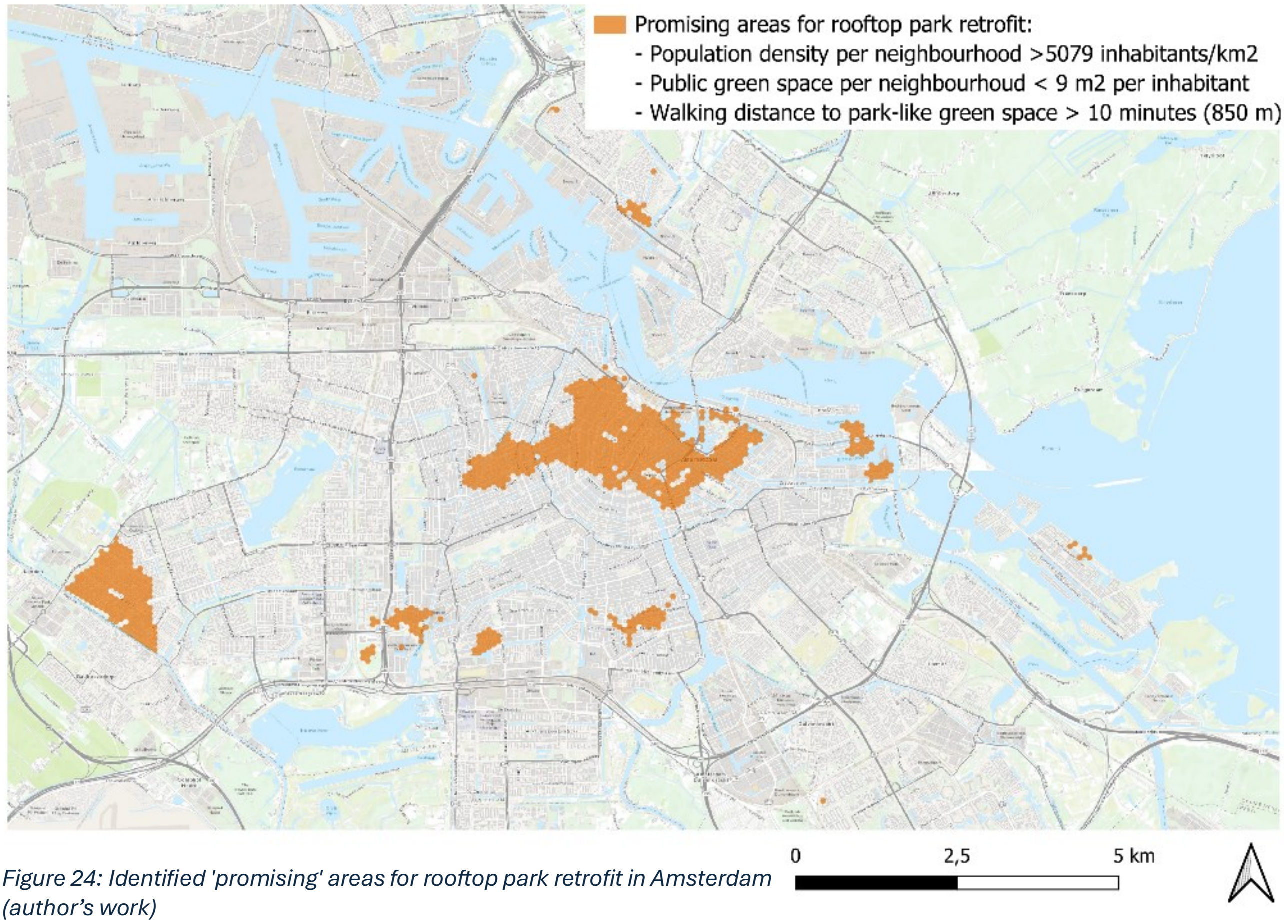


Figure 24: Identified 'promising' areas for rooftop park retrofit in Amsterdam (author’s work)

6.3 Zoom-in: Integrated assessment of selected roofs

Out of the 1322 roofs identified as initially suitable based on the decisive and quantitative filtering in 6.1, further GIS analysis by location extraction revealed that 49 roofs (0.04% of all roofs, approximately 5.7 ha) were located in the promising areas highlighted in Figure 24, and mainly concentrated in the area around the city centre and Amsterdam West. From these 49 roofs, 3 roofs were randomly selected for the integrated zoom-in suitability assessment. Selecting 3 specific locations from this subset for the integrated assessment demonstrates the application of the entire framework while, as aforementioned, yielding insights relevant in terms of space scarcity and pressure on public green spaces.

Each location was evaluated in line with the criteria framework and corresponding indicators outlined in Chapter 5. The assessment involved both quantitative and qualitative analyses to determine the suitability, as described in Table 7. Figure 25 presents the three selected locations in Amsterdam, while Figure 26 provides satellite and 3D images of each site. Tables 11, 12 & 13 present the step-by-step integrated assessment of the suitability of each of the three selected roofs for retrofitting into rooftop parks. **The green and orange cells in the assessment column refer to the colours of the outcome blocks as indicated in the criteria framework** (See Figure 16 in Chapter 5). At the end of this section, a comparison table (Table 14) is provided to highlight key differences and similarities between the three locations. Additional supporting maps used for the assessment can be found in Appendix C.

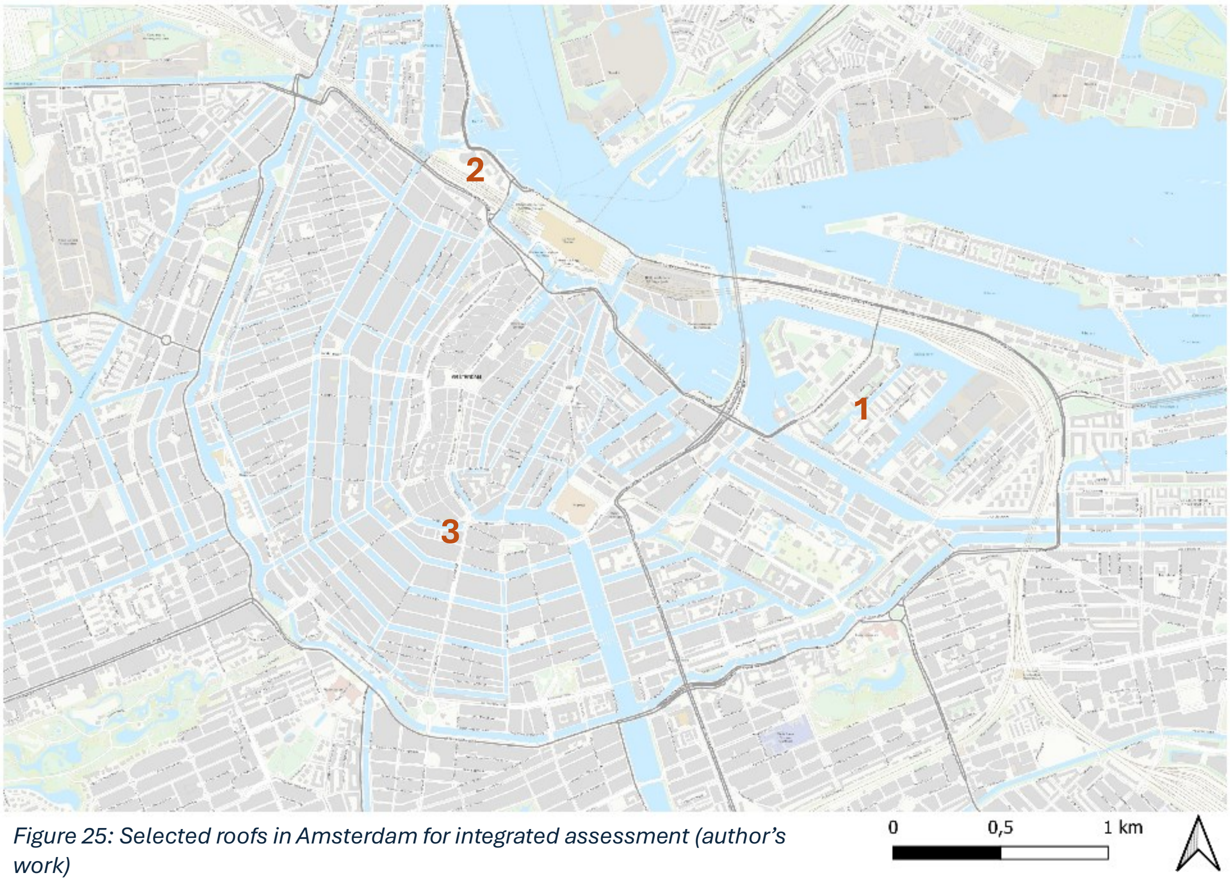
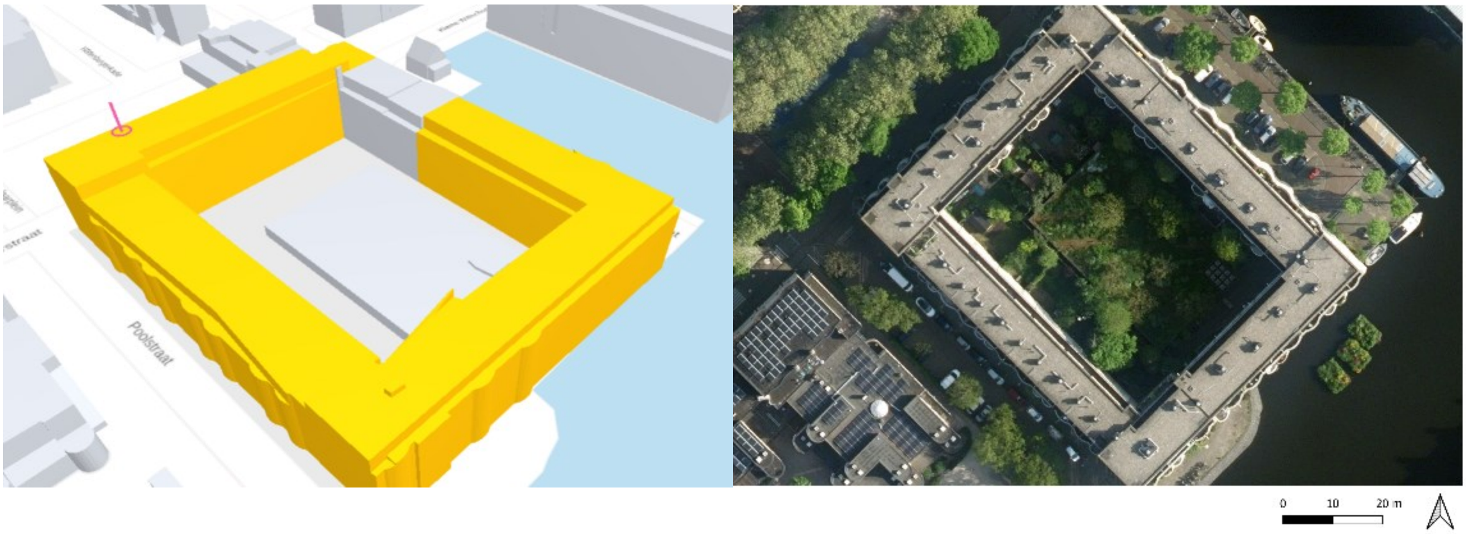
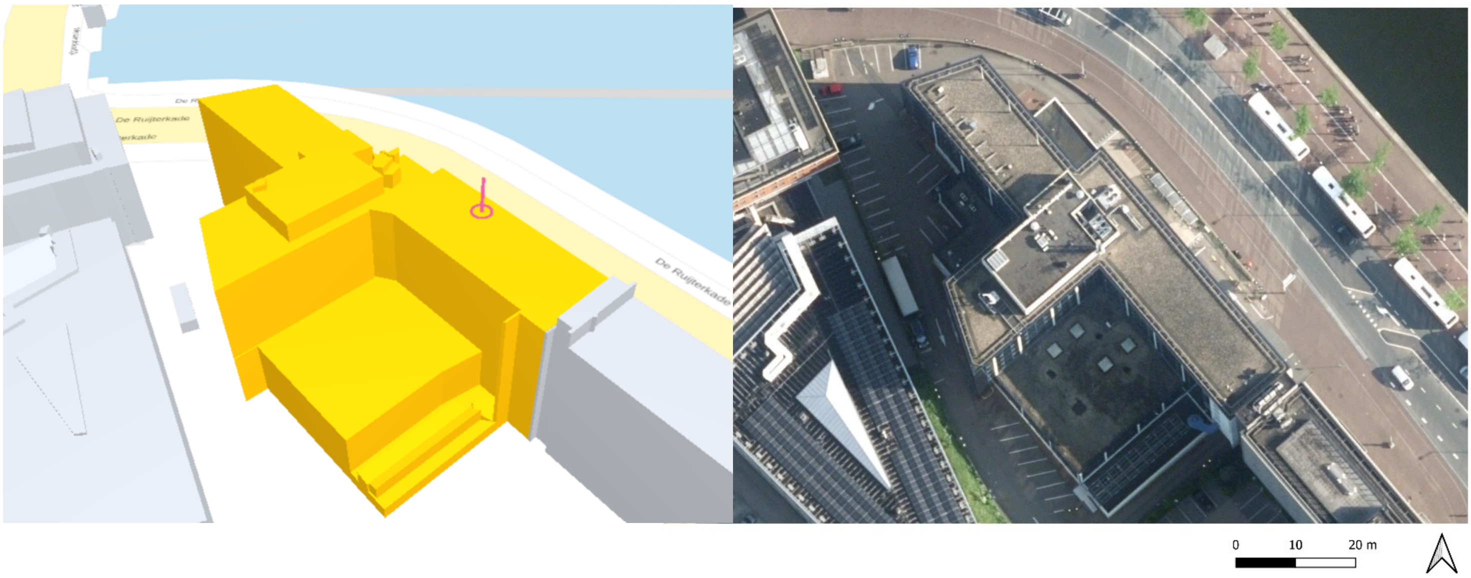


Figure 25: Selected roofs in Amsterdam for integrated assessment (author's work)

Location 1: Kleine Wittenburgerstraat, Oostelijke Eilanden/Kadijken



Location 2: De Ruijterkade, Haarlemmerbuurt



Location 3: Singel, Muntstaete, Grachtengordel-Zuid

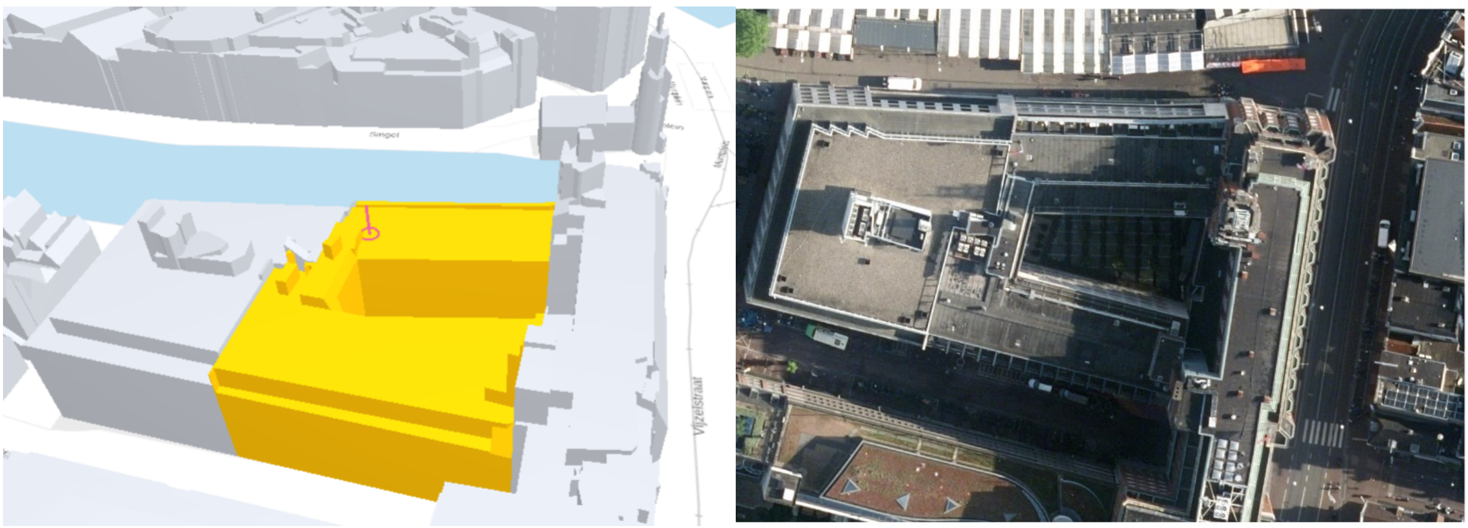


Figure 26: Satellite and 3D image of selected locations for integrated assessment (author's work)

0 10 20 m

Location 1: Kleine Wittenburgerstraat, Oostelijke Eilanden/Kadijken

Criteria	Indicators	Assessment	Explanation
Roof flatness	How large is the flat roof surface?	> 500 m^2	The roof consists of multiple flat horizontal surfaces, with a total flat area over 2089 m^2.
Available roof area			
	Is the roof already in use?	No	Satellite images show about 20 chimneys or ventilation units, but the roof is not currently in use for other functions.
	Is there potential for clustering?		Clustering could further enhance available roof area but it is not required as the individual roof exceeds 500 m^2.
Willingness building stakeholders	Are the stakeholders initially willing for retrofit in direct engagement?		No available data on stakeholder willingness; further research is needed.
	What is the type of ownership?	Other; owner's association	The building appears to be owned by owners' associations, which may be more resistant to change and have less decision-making power, making the retrofit process more complex.
	How many owners are involved?	More than 1	The type of ownership indicates a high number of owners involved, which may require more time for decision-making, making the retrofit process more complex.
Construction capacity	What is the building year?	1960-1990	The building was constructed in 1990.
	What is the building type?	Other; building block	The roof is part of a building block with a flat roof and therefore likely made of concrete.
Urban density	Is the roof located in an highly populated area?	Yes, above average (5079 inhabitants/km2)	The roof is located in Oostelijke Eilanden/Kadijken neighbourhood, an area with an urban density much higher than the urban average (15753 inhabitants/km2).
	Is the roof located in an area with slow traffic flows?	No	Although the building is located along a pedestrian zone, there are no evident large slow traffic flows. For rooftop park retrofit, extra attention should be paid to logical routing.
Compatibility with green infrastructure	Is the roof located in an area with low public green space coverage?	Yes, less than 9m2/inhabitant	The roof is located in an area with about 1.6 m2 of public recreational green space per inhabitant.
	What is the distance to existing public green spaces?	More than 10 minutes walking	The nearest park-like green space over 1 ha is more than a 10-minute walk away (1293 m).
	Can the roof be linked to an ecological corridor?	Yes	The roof can potentially connect to an ecological corridor at the northern side of the neighbourhood.
Compatibility building function	What is the building function?	Other; residential	The building has a residential function, offering little potential to integrate the rooftop park functionalities, and extra measures required to avoid nuisance.
Ease of access	What is the existing type of access to the roof?	Non-existent	Based on satellite images, there is no existing access to the roof, the shared staircase only leads up to the upper floor. There may be space to construct a new access for entrance in the courtyard.
	Does the building have an active frontage?		As there is no existing access to the roof, new construction is required anyway. Therefore, active frontage is not considered.
Roof elevation	Is the roof located at a suitable height?	>15m	The maximum roof height is 18 m. Challenges related to access and environmental performance may exist, but these can be compensated by the quality of the view and the roof's visibility.
Roof visibility	Visual contact from ground level or surrounding buildings	No	The roof is limitedly visible from either street-level or surrounding buildings. There is potential for retrofit, if ease of access is guaranteed.
	Which level of aesthetic standards?	Not protected	The roof is located in an area with a 'special' aesthetic standard, and although it is not protected, relevant regulations should be considered.
	Is the building a recognised landmark?	No	The roof is not located on a recognisable landmark building. As long it is suitable for other criteria regarding accessibility, it can still have potential.
Quality of view	Is the view interesting?	Yes	The variety of waterways, streets and the courtyard may enhance to complexity and new view lines, adding up to an interesting view.
	Is the view unblocked?	Yes	Surrounding buildings are either lower or have an equal elevation; indicating the view is unobstructed.

Table 11: Integrated assessment of Location 1

Location 2: De Ruijterkade, Haarlemmerbuurt

Criteria	Indicators	Assessment	Explanation
Roof flatness	How large is the flat roof surface?	> 500 m^2	The roof consists of multiple flat horizontal surfaces, with a total flat area over 2293m^2.
Available roof area			
	Is the roof already in use?	No	Based on satellite images, there seem to be a couple of installations on the roof, but the roof is not used for other functions yet.
	Is there potential for clustering?		Clustering could further enhance available roof area but it is not required as the individual roof exceeds 500 m^2.
Willingness building stakeholders	Are the stakeholders initially willing for retrofit in direct engagement?		No available data on stakeholder willingness; further research is needed.
	What is the type of ownership?	Commercial	The building appears to be commercially owned, which might simplify decision-making compared to residential or complex ownership structures.
	How many owners are involved?	?	It remains unclear whether the building is owned by one or multiple owners.
Construction capacity	What is the building year?	1960-1990	The building was constructed in 1989.
	What is the building type?	Other; utilities building	The roof is part of a utility building with a flat roof and is likely made of concrete.
Urban density	Is the roof located in a highly populated area?	Yes, above average (5079 inhabitants/km2)	The roof is located in the Haarlemmerbuurt neighbourhood, an area with an urban density much higher than the urban average (17225 inhabitants/km2).
	Is the roof located in an area with slow traffic flows?	Yes	It is located along a busy road to Central Station with high bike traffic and pedestrian activity from nearby touristic boats.
Compatibility with green infrastructure	Is the roof located in an area with low public green space coverage?	Yes, less than 9m2/inhabitant	The roof is located in an area with about 0.01 m2 of public recreational green space per inhabitant.
	What is the distance to existing public green spaces?	More than 10 minutes walking	Data for the walking distance is limited for the building but likely the nearest park-like green space over 1 ha is more than a 10-minute walk away (966 m) based on the closest data cell.
	Can the roof be linked to an ecological corridor?	No	The closest ecological corridor is located on the other side of the IJ river, making direct linkage challenging. Extra attention should be paid to connect the rooftop park to existing corridors
Compatibility building function	What is the building function?	Commercial	The building has a commercial (office) function, which allows for integration of rooftop park functionalities.
Ease of access	What is the existing type of access to the roof?	Non-existent or within building	Based on satellite images, it is unclear whether there is an existing access to the roof from within the building or no existing access is present.
	Does the building have an active frontage?	No	There is no active frontage, and new construction would be required for an entrance to the roof, potentially through the parking space behind the building.
Roof elevation	Is the roof located at a suitable height?	>15m	The maximum roof height is 27 m. Challenges related to access and environmental performance may exist, but these can be compensated by the quality of the view and the roof's visibility.
Roof visibility	Visual contact from ground level or surrounding buildings	No	The roof is limitedly visible from either street-level or surrounding buildings. There is potential for retrofit, if ease of access is guaranteed.
	Which level of aesthetic standards?	Protected	The roof is located in an area with a 'protected' aesthetic standard', therefore may be hindered by regulation. Nevertheless, the building itself does not have a monumental status.
	Is the building a recognised landmark?	Yes	The building could be considered as a landmark, standing out of its surroundings and along the waterfront.
Quality of view	Is the view interesting?	Yes	The view over the IJ river, train tracks, and Central station may enhance to complexity and new view lines, adding up to an interesting view.
	Is the view unblocked?	Yes	There are limited surrounding buildings, which have lower elevation; indicating the view is unobstructed.

Table 12: Integrated assessment of Location 2

Location 3: Singel, Muntstaete, Grachtengordel-Zuid

Criteria	Indicators	Assessment	Explanation
Roof flatness	How large is the flat roof surface?	> 500 m^2	The roof consists of multiple flat horizontal surfaces, with a total flat area over 1617m2.
Available roof area	Is the roof already in use?	No	Based on satellite images, there seem to be a couple of installations on the roof, but the roof is not used for other functions yet.
	Is there potential for clustering?		Clustering could further enhance available roof area but it is not required as the individual roof exceeds 500 m^2.
Willingness building stakeholders	Are the stakeholders initially willing for retrofit in direct engagement?		No available data on stakeholder willingness; further research is needed.
	What is the type of ownership?	Commercial	The building appears to be commercially owned, which might simplify decision-making compared to residential or complex ownership structures.
	How many owners are involved?	?	It remains unclear whether the building is owned by one or multiple owners.
Construction capacity	What is the building year?	1960-1990	The building was constructed in 1965.
	What is the building type?	Other; building block	The roof is part of a building block with a flat roof, and is likely made of concrete.
Urban density	Is the roof located in an highly populated area?	Yes, above average (5079 inhabitants/km 2)	The roof is located in Grachtengordel-Zuid neighbourhood, an area with an urban density higher than the urban average (11209 inhabitants/km2).
	Is the roof located in an area with slow traffic flows?	Yes	It is located along the flower market, a pedestrian and touristy zone in the inner city of Amsterdam.
Compatibility with green infrastructure	Is the roof located in an area with low public green space coverage?	Yes, less than 9m2/inhabitant	The roof is located in an area with about 0.1 m2 of public recreational green space per inhabitant.
	What is the distance to existing public green spaces?	More than 10 minutes walking	The nearest park-like green space over 1 ha is more than a 10-minute walk away (929 m).
	Can the roof be linked to an ecological corridor?	No	There is no ecological corridor in the surrounding areas. Extra attention should be paid to connect the rooftop park to existing corridors.
Compatibility building function	What is the building function?	Commercial	The building offers space for offices, exhibition space and shops.
Ease of access	What is the existing type of access to the roof?	Within building	Based on satellite images, it seems like there are 2 existing accesses to the roof from within the building. As there is an active frontage, either a new construction or creative interventions for access are required for rooftop park retrofit.
	Does the building have an active frontage?	Yes	Among others, an exhibition space is located at the ground-level of the building.
Roof elevation	Is the roof located at a suitable height?	>15m	The maximum roof height is 34 m. Challenges related to access and environmental performance may exist, but these can be compensated by the quality of the view and the roof's visibility.
Roof visibility	Visual contact from ground level or surrounding buildings	Yes	The roof is limitedly visible from street-level but the adjacent building from Vijzelgracht looks out over the roof.
	Which level of aesthetic standards?	Protected	The roof is located in an area with a 'protected' aesthetic standard', therefore may be hindered by regulation. Besides, the building is considered a municipal monument.
	Is the building a recognised landmark?	Yes	The building is located at the heart of the city, next to the flower market and the former savings bank for the City of Amsterdam.
Quality of view	Is the view interesting?	Yes	The building faces the famous floating flower market, as well as the Munttoren and dynamic surroundings.
	Is the view unblocked?	Yes	The view remains mostly unobstructed, as the building is situated directly along the canal with few tall structures nearby.

Table 13: Integrated assessment of Location 3

Comparison of locations

Criteria	Indicators	1	2	3
Roof flatness	How large is the flat roof surface?			
Available roof area				
	Is the roof already in use?			
	Is there potential for clustering?			
Willingness building stakeholders	Are the stakeholders initially willing for retrofit in direct engagement?			
	What is the type of ownership?			
	How many owners are involved?			
Construction capacity	What is the building year?			
	What is the building type?			
Urban density	Is the roof located in an highly populated area?			
	Is the roof located in an area with slow traffic flows?			
Compatibility green infrastructure	Is the roof located in an area with low public green space coverage?			
	What is the distance to existing public green spaces?			
	Can the roof be linked to an ecological corridor?			
Compatibility building function	What is the building function?			
Ease of access	What is the existing type of access to the roof?			
	Does the building have an active frontage?			
Roof elevation	Is the roof located at a suitable height?			
Roof visibility	Is there visual contact from ground level or surrounding buildings?			
	Which level of aesthetic standards?			
	Is the building a recognised landmark?			
Quality of view	Is the view interesting?			
	Is the view unblocked?			

Table 14: Integrated assessment of all selected roofs

Based on the comprehensive integrated analysis, the three locations may all be considered suitable for rooftop park retrofit but to varying degrees. As presented, none of the three locations fully met all the suitability criteria (only green blocks), which means each roof presents various challenges and obstacles, indicated by the orange outcomes (Table 14). As discussed in the criteria framework in 5.3, the greater the number of orange ratings and the higher these orange ratings appear in the table/framework, the lower the overall suitability of the roof for rooftop park retrofit.

Considering the total number of orange blocks and their appearance in the prioritisation (See Table 12), although the roof at Kleine Wittenburgerstraat (Location 1) offers a large roof area, lower protected status, potential for ecological connection and a relatively low roof height, particularly the complex ownership structure as an indicator for the decisive criteria of stakeholder willingness, as well as limited visibility and moderate connection to slow traffic, make its suitability lower compared to the other two locations. Although the roof at the Ruijterkade (Location 2) has a large roof area and strategic positioning in the city, it is affected by uncertainties regarding ownership, potential regulatory constraints for aesthetic standards, and the absence of an ecological connection. The roof at the Singel (location 3) stands out for its iconic location, high pedestrian traffic and high visibility. While monument regulations and height may present challenges, and there is no ecological connection, based on the framework, the overall suitability is highest for this location compared to the other two.

DISCUSSION

Depot Boijmans van Beuningen, Rotterdam
(author's work, 2024)

7 Discussion

Although the municipality of Amsterdam recognises the potential of rooftops to address diverse urban challenges (Gemeente Amsterdam, 2021b, 2023b) and considers green roofs as a central component of its future green infrastructure (Gemeente Amsterdam, 2020), the potential for retrofitting roofs into rooftop parks, which has emerged as an ultimate solution for multifunctional rooftop development (ISSO, 2022), was not yet explored and addressed in this research. This discussion interprets the study´s key findings per SRQ and places them in a broader context by reflecting on the implications for research and practice as well as the study's limitations.

7.1 Interpretations of findings

Defining rooftop parks

Even though real-world examples of rooftop parks exist in various urban settings, no standardised or universally accepted definition exists in the literature, which reflects its novelty. This study addressed this knowledge gap (SRQ1) by formulating an original definition for rooftop parks in the context of Amsterdam: *publicly accessible elevated green spaces of a certain scale, located on building rooftops and designed to function as multifunctional hybrid spaces that offer both environmental and social benefits, complementing existing urban green spaces in densely built areas*.

This definition, and the four guiding principles (multifunctionality, accessibility, environmental performance, and spatial integration) that were outlined emphasise that rooftop parks are unique in relation to existing concepts of public and hybrid urban green spaces, parks and rooftop typologies. In the context of these established concepts, the findings suggest that rooftop parks should be perceived as a new type of multifunctional rooftop usage, incorporating intensive green and red typologies (ISSO, 2022; Kotze et al., 2020; Nationaal Dakenplan, n.d.; Pérez & Coma, 2018). Rather than a replacement, they could form an innovative addition to traditional urban green spaces in Amsterdam. Furthermore, although findings revealed that rooftop parks may fulfil similar environmental and social functions as urban parks at ground level (Konijnendijk et al., 2013), particularly their hybrid character due to their positioning on (private) buildings sets them apart.

Nevertheless, findings also highlight that specific configurations of rooftop parks may eventually likely vary depending on the setting, just like ground-level urban green spaces (Taylor & Hochuli, 2017). The observational study revealed that each case differed significantly in design and function, and also experts had diverse ideas of what a rooftop park would or should be. The latter may be explained by their individual experiences and familiarity with existing examples which shape their perspectives. As a result, the definition and guiding principles developed in this study are necessarily broad to allow for flexible interpretations in different urban settings. Although the definition and guiding principles were primarily developed for Amsterdam, the study also drew on observations in Rotterdam and insights from experts across the Netherlands. Therefore, while space shortage is particularly relevant for Amsterdam and local policies and green space concepts were considered, the definition may also reflect a broader Dutch context.

Criteria development

The findings regarding the criteria development (SRQ2) reveal how multifaceted retrofitting roofs into rooftop parks and assessing the suitability of roofs for this purpose is. Although additional insights could potentially suggest even further criteria than the 11 established in this study, this set strongly reflects the guiding principles as identified and effectively balances insights from theory and practice. This is deemed to underscore completeness and reinforce an overall comprehensive assessment. While urban contextual factors play an essential role, the number and priority of building-level criteria suggest that eventually, possibilities and limitations of the building are most determining, which reflects overall experts' priorities in this study.

Moreover, the findings also highlight the complexity of rooftop park retrofitting and its assessment. Firstly, results revealed more consensus for some criteria and indicators than others. For instance, both roof retrofit and green space literature as well as expert insights widely supported the available roof area as a key criterion. However, perspectives on the importance of roof elevation were more divided. And, while there was consensus on the importance of available roof area, perspectives varied for the appropriate threshold for roof sizes. This highlights the interdisciplinary base for rooftop parks and the multiple lenses through which experts view the phenomenon. Furthermore, defining corresponding indicators and measurable thresholds for some criteria proved challenging. While it was evident that the willingness of building stakeholders and construction capacity was crucial to consider, establishing direct measurement factors was difficult. Proxy indicators such as the type of ownership and building year were identified to address these gaps, nevertheless, for assessment in practice, more in-depth analysis of these criteria is required. Moreover, findings reveal that while most criteria are mutually reinforcing, such as the interlinkage between urban density and the proximity to green spaces, other criteria and indicators may enforce trade-offs. For example, while a lower roof elevation is considered to benefit accessibility and environmental performance, it may limit the quality of the view. Although the applied prioritisation based on the interpretation of the insights gained in this study helps to balance and capture these complexities, it is acknowledged that different interpretations may arise based on additional or other perspectives, and a more thorough weighting could be beneficial.

In terms of the transferability of the framework, the specific tailoring of certain indicators and threshold values, such as the distance to public green space based on municipal goals, indicates that adaptation is required for use in other cities. Nevertheless, the majority of criteria are universally applicable, reinforcing the framework's overall usability.

In light of existing research, this criteria framework is considered innovative because it incorporates perspectives from rooftop retrofitting and urban green space practices. In this way, it extends the scope of existing studies and frameworks on rooftop retrofit potential, which often relied on a limited number of criteria or focused predominantly on quantitative building measures. By integrating more recognised considerations from green retrofit literature, such as the roof flatness and construction capacity (Hong et al., 2019; ISSO, 2022; Joshi et al., 2020; Karteris et al., 2016; Silva et al., 2017; Slootweg et al., 2023; Todeschi et al., 2020; N. Xu et al., 2020), with additional factors that emphasise the role of rooftop parks as accessible urban green spaces, such as the ease of access and compatibility with green infrastructure (Ariff et al., 2023; Gwak et al., 2017; Langemeyer et al., 2020; Talen, 2010; Venter et al., 2021; Willemsen, 2018), the study provides a more holistic view of rooftop retrofit potential, integrating both building-level and urban context considerations.

Application analysis

The application analysis of the criteria framework highlighted its practical potential as well as constraints (SRQ3). The findings gave an initial understanding of which roofs in Amsterdam may be suitable for rooftop park retrofitting and showed that the framework is effective in narrowing down the large pool of roofs to a more manageable set of potential locations. This delivers a useful starting point for stakeholders in practice for further exploration. Besides, the integrated assessment of three roofs demonstrated that the framework is helpful in structurally assessing and comparing the suitability of roofs. Nevertheless, it also suggests that, when considering the holistic combination of criteria, very few buildings in Amsterdam may be highly suitable for rooftop park retrofitting without substantial challenges. This indicates that while the framework offers a useful tool, it might be a little rigid when applied in practice.

Furthermore, the analysis indicates that the criteria and framework, although holistic, are not always straightforward to apply. The findings revealed that data availability was highly varied across criteria and indicators. For some indicators, data was not directly available, such as the type of ownership, and others required visual and subjective assessment. While these subjective assessments are highly relevant, they are time-consuming and slow down the overall assessment approach. Besides, this combination of multiple scales of assessment may hinder its efficient applicability on a city-wide scale and challenge the prioritisation order of criteria application.

While this study focused on providing an overview of initially suitable roofs and demonstrating the applicability of the framework, an alternative approach could have been adopted to find the overall most suitable roofs in Amsterdam according to these criteria. This could involve filtering the dataset further by the additional non-decisive factors on a city-wide scale before integrating any qualitative assessments. However, this would have sacrificed the nuanced prioritisation of the criteria.

Ultimately, the findings underscore that the criteria framework is useful to assess and identify suitable roofs but that additional detailed investigation is eventually required for each site to determine its actual potential for rooftop park retrofit. As findings also suggested that obstacles can be overcome and every opportunity to better utilise rooftop spaces could be valuable, particularly in areas where ground-level space is scarce, this highlights the need for a flexible approach when applying the developed criteria framework.

7.2 Implications for research and practice

By differentiating rooftop parks from established rooftop typologies and traditional ground-level parks and positioning them within the broader context of urban green infrastructure, the study contributes to the existing literature on rooftop greening and offers new perspectives on the potential role of rooftop spaces in cities. In practice, this new knowledge could serve as a base for adding rooftop parks as a new function in Amsterdam's Integrated Rooftop Landscape Manual, which aims to promote the use of rooftops for various purposes. This research also supports the broader integration of rooftop parks as a distinct UGS into the city's broader green infrastructure, highlighting their potential as a valuable addition to Amsterdam's urban green network in the future.

The criteria framework developed in this study provides a holistic and integrated understanding of the factors that determine the suitability of roofs for rooftop park retrofit and their relative importance. The incorporation of perspectives from rooftop retrofitting and urban green space practices deepens the understanding of the potential of roofs to serve as hybrid urban green spaces, expanding their relevance in urban development. In this way, the study enriches the existing literature as it extends the scope of previous studies and frameworks for rooftop retrofit potential.

Apart from theoretical contributions, the criteria framework offers a practical instrument for urban planners, developers, and municipalities to identify opportunities for rooftop park retrofitting in the city. With the help of these criteria, stakeholders can make more informed decisions about where rooftop parks could be potentially integrated and which factors need to be considered. The outcomes of the application analysis may serve as an initial screening and starting point for further investigation in Amsterdam. However, this integrated assessment also implies that the framework may be a little rigid, and flexible use is necessary. Besides, a case-by-case evaluation remains necessary to advance the understanding of these criteria and the real-world potential of roofs. This should also address practical considerations that were beyond the scope of this study, such as financial feasibility and existing regulations.

While retrofitting existing buildings may pose significant challenges, integrating rooftop parks into new urban developments could offer additional opportunities. Although the criteria framework was not designed for new developments, it could serve as a starting point for establishing requirements for integrating rooftop parks into future urban projects. By embedding these considerations early in the planning and design processes, both the municipality and developers could create the conditions necessary for successful rooftop parks, contributing to more scalable and sustainable development.

Overall, the study is considered to pave the way for continuous research on rooftop parks in the future and provides urban stakeholders with a guiding tool to start exploring the broader integration of rooftop parks into urban developments.

7.3 Limitations of the study

While this study provides valuable insights, several limitations should be acknowledged, as also already addressed to some extent above.

Definitional challenges

Firstly, rooftop parks are a relatively new concept with very limited conceptual clarity, and the variable empirical interpretations made it challenging to establish a more precise definition and a comprehensive set of applicable criteria for potential retrofitting. The variability of green space definitions in the literature and the ongoing revision of the Main Green Space Infrastructure in Amsterdam further complicated this process.

Transferability across cities

As aforementioned, while the definition and guiding principles may reflect a broader Dutch context and the majority of suitability criteria are deemed universally applicable, certain indicators and thresholds were specifically aligned with local policies in Amsterdam. Although the definition may be more broadly applicable and the criteria framework can be adapted for use in other cities, implementation strategies for rooftop park retrofit will most likely vary by city. Cities with abundant green spaces may not prioritise rooftop parks in the same way, affecting transferability. Therefore, careful consideration of local circumstances is required when applying the framework elsewhere.

Subjective assessment

The assessment of criteria in the framework based on non-suitable (red), potentially suitable (orange), or highly suitable (green) outcomes provided a straightforward yet binary distinction. While useful, the integrated assessment revealed that more nuance may be required when comparing buildings, and the framework could benefit from additional differentiation. Another limitation to note is the lack of explicit weighting for prioritised criteria. Although the criteria were ranked according to their relative perceived importance, no specific weighting system was assigned to each criterion. This means that the prioritisation process remained somewhat subjective. In the future, a more refined formal ranking could strengthen objectivity. Furthermore, the visual assessments, while useful, were based on subjective observation, which could introduce inconsistencies or biases. Besides, these qualitative assessments are time-consuming, which limits large-scale applications. Therefore, although this approach is comprehensive, it should be regarded as a starting point that requires further refinement.

Data availability and quality

Finally, the study faced challenges concerning the variability in both the availability and quality of data across the identified criteria. While all indicators identified were considered highly relevant, the variability in data availability limited the intended depth of analysis due to time constraints. As a result, filtering of the initial roof set based on decisive criteria for the entire city was incomplete, due to difficulties in obtaining data regarding stakeholder willingness, and the visual assessment required for existing use of the roof and building types. Now, the integrated assessment relied on three case studies, which, while illustrative, do not provide a fully comprehensive picture. Moreover, the roof dataset included missing or incorrect roof data, and building overlap. Additionally, outdated or unofficial classifications in green space mapping affected consistent analysis.

Based on these limitations, and the implications discussed, recommendations for practice and future research are given in the following concluding chapter.

CONCLUSION AND RECOMMENDATIONS

Dakpark Orlyplein, Amsterdam
(author's work, 2024)

8 Conclusion and recommendations

This study aimed to advance the understanding of roof suitability for retrofitting into rooftop parks by assessing the potential of Amsterdam´s rooftops. Through a mixed-method case study approach, guided by three sub-research questions, the study sought to answer the main research question: **“To what extent and based on what criteria are roofs in Amsterdam suitable for potential retrofit as rooftop parks?”**

The findings revealed that a multifaceted and complex interplay of considerations informs the suitability of roofs for rooftop park retrofit in Amsterdam. This led to the development of a holistic prioritised criteria framework, incorporating corresponding indicators and thresholds for the assessment of 7 criteria on a building level (roof flatness, available roof area, willingness of building stakeholders, construction capacity, compatibility of the building function, roof elevation, ease of access) and 4 criteria for the urban context (urban density, compatibility of green infrastructure, roof visibility and quality of view). The roof flatness, available roof area, willingness of building stakeholders and construction capacity were deemed most determining and therefore considered decisive. The remaining criteria provide additional important insights into the degree of suitability for rooftop park retrofitting to various extents, affecting the prioritisation of certain roofs over others.

Based on the application of this framework, the study concludes that roofs in Amsterdam are suitable for potential rooftop park retrofit to a limited extent. A city-wide quantitative analysis found 1233 roofs (0.97% of all roofs in Amsterdam, 231 ha in total) that met fundamental requirements for rooftop park retrofitting to a large extent, equivalent to 4-5 times the size of Vondelpark. However, this initial estimate may decrease significantly when filtering for additional qualitative decisive indicators, including stakeholder willingness, the existing roof use and building type. Further analysis, taking into account the rationale of this study, identified 49 roofs in promising areas where space scarcity and the need for public green spaces are particularly pressing. Assessment of 3 of these roofs showed the practical applicability of the criteria framework and underscored the complexity of retrofitting rooftops into park spaces. While all were considered suitable to varying extents, each presented significant challenges. This highlights that, while the framework provides a useful structured assessment, a flexible and case-specific approach is required for further evaluation.

Despite limitations concerning definitional challenges, transferability across cities, subjective assessment and data availability, the study demonstrated that rooftop parks represent a promising opportunity to address space scarcity in dense urban areas and reduce pressure on existing ground-level public green spaces. Rather than replacing traditional green infrastructure, they form an inspiring addition to future sustainable cities, though they come with numerous challenges. While the criteria framework and its application highlighted how multifaceted and complex retrofitting roofs for this purpose and its assessment is, in practice, obstacles can be overcome and reality is not as clear-cut as the framework suggests. Besides, findings also suggest that each opportunity to better utilise the rooftop landscape could be valuable, particularly in areas where ground-level space is limited.

Overall, by formulating an original definition for rooftop parks in Amsterdam and development and analysis of the criteria framework, this study enhances the understanding of the potential of rooftop spaces within the broader context of urban green spaces and provides a more holistic approach to assessing roof retrofit potential compared to existing studies. In this way, it contributes to the existing literature on rooftop utilisation and enriches the theoretical understanding of (green) roof retrofitting. Moreover, it provides urban planners, developers, and municipalities in Amsterdam and other cities with a valuable initial tool and outcomes for evaluating to what extent rooftops are suitable for retrofitting into parks. This can help to identify promising opportunities and decision-making for future exploration and implementation.

8.1 Recommendations

To further unlock the potential of rooftop parks and make these spaces a valuable and scalable element of sustainable urban development in Amsterdam and other cities, recommendations are provided for practice and future research based on the findings of this research.

To guide urban planners, developers and municipalities in the use of the framework and development of rooftop parks, the following is recommended for practice:

- **Pilot implementation and exploration:** Start with a further exploration of (a selection) of the 49 roofs in promising areas. This could include more detailed evaluations with on-site inspections, discussions with building stakeholders and investigation of additional practical challenges such as financial feasibility and regulations.
- **Maintain flexibility and encourage innovative solutions:** While the framework provides a useful tool, the criteria should not be seen as rigid rules but as a guiding starting point to inform decisions. Flexibility is necessary, as suitability eventually depends on the unique context of each building. In practice, innovative design approaches may create new opportunities even when rooftops do not fully meet the established criteria. It is important to support creative solutions and encourage out-of-the-box thinking to overcome obstacles and open up new possibilities for retrofitting.
- **Foster early stakeholder collaboration:** Considering the hybrid nature of rooftop parks and the importance of the willingness of building stakeholders, close and early collaboration between private building owners, developers, and municipalities is necessary for successful rooftop park retrofitting projects. Municipalities should play an active role to foster and facilitate this collaboration.

In addition to the recommendations for practice, future research could explore several directions to build on the findings of this study:

- **Widen scope and applicability:** Exploring the applicability of the established rooftop park definition, guiding principles and criteria framework in other cities with different green space and urban contexts to draw comparative insights, refining the findings for broader use.
- **Additional weighting**: Refining the criteria framework by introducing additional gradations or a more detailed weighting system to provide more precise guidance on prioritising roofs.
- **Data expansion**: Investigating the use of objective measures such as remote sensing, drone imagery or AI-based analysis to reduce the subjectivity in visual assessments such as the existing use of roofs, and to ensure higher accuracy and consistency of data.
- **Beyond retrofit**: Expanding and modifying the framework's application to new buildings in addition to retrofits, which could help integrate rooftop parks into future urban development.
- **Policy investigation:** Investigating how policies and regulations can be adjusted to facilitate the development of rooftop parks, including structures to encourage public-private collaboration.
- **Impact of rooftop parks:** Assessing the long-term environmental and social benefits of rooftop parks to help quantify their specific value and support their integration into future urban development

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10 Appendices

10.1 Appendix A: Interview guide

- Constructors (C) / Engineers (E): Focus on the building level
- Designers (D): Focus on the building level and potential connection with the urban context
- Municipal officers (M): Focus on the urban context
- Other (O): Focus on urban context/expertise

Introduction	**SH**
Welcome & introduction - Introduction of researcher and the purpose of the research - Short explanation of the research topic: the potential for retrofitting roofs in Amsterdam as rooftop parks - Explanation of the structure of the interview and duration **Background information** - Can you introduce yourself? - What is your background and current role? What do like most about your job? - What is your expertise concerning roofs, green or public space? - What is your experience with roof retrofitting?	All
Definition and context of rooftop parks	
(explanation: I define an urban rooftop park as a vegetated roof with public access.)	All
Understanding rooftop parks - Are you familiar with existing rooftop parks in Amsterdam or other cities? If yes, could you describe them? - Based on your experiences, what does a rooftop park look like? Can you describe what you envision? How would you define an urban rooftop park? (access, attractiveness) - What do you consider the most important functions that rooftop parks (in Amsterdam) could provide? - Do you see any differences with traditional 'ground-level' parks, and what are these differences? (form, functions, people's behaviour, visitors type) **Relevance to Amsterdam** - What makes rooftop parks in Amsterdam different or unique from other cities?	C/E/D/M/O
Building-level criteria for roof suitability	
In this part of the interview, I would like to focus on the building level. The goal is to determine the requirements a building must meet to develop a rooftop park. First, I will discuss the 'green' associated with a rooftop park, and then the 'public' aspect.	
Criteria for park-like vegetated roofs	
- What is the first thing you consider when deciding if a building is suitable for implementing a park-like vegetated roof?	C/E/D
- And how do you measure this? Can you make this concrete, when is/isn't a building suitable? (e.g., minimum load-bearing capacity, building age, height, slope)?	C/E/D
- What else do you consider, and why? - What are (the biggest) challenges or constraints?	C/E/D
Criteria for park-like accessible roofs	
- Apart from vegetation, what factors do you consider to determine if a building is suitable for the development of a publicly accessible rooftop? (e.g., safety regulations, accessibility features, ownership, building function)	C/E/D

- How do you measure this? Can you provide specific examples of what makes a building suitable or unsuitable based on these measurements? (e.g., minimum number of access points, load capacity for large groups)What are (the biggest) challenges or constraints?	C/E/D
Additional factors relevant to Amsterdam	
- Assessing roof suitability for rooftop parks, what are considerations specific to Amsterdam (e.g., historical building preservation, local regulations, urban density) that should be taken into account?	C/E/D/M/O
- What are specific challenges or constraints? (e.g., building regulations, architectural diversity, weather conditions)? And why?	C/E/D/M/O
Prioritisation of roofs	
- Based on the considerations and challenges mentioned, what would be an ideal building (characteristics) to retrofit into a rooftop park? And why?	C/E/D/M/O
Urban context criteria for roof suitability	
Broader considerations beyond building suitability: In this part of the interview, I would like to zoom out to the neighbourhood or city level.	D/M/O
- What impact do you think rooftop parks have or could have on the overall urban landscape/city (e.g., enhancing urban biodiversity, contributing to stormwater management)?	
- Can you explain why the existing rooftop parks in the city are situated at their current locations?	D/M/O
- What would be an ideal site within the city (urban form characteristics) for retrofitting a building roof into a rooftop park? And why? (e.g., proximity to public amenities, visibility, neighbourhood needs)?	D/M/O
- Why this location? Can you provide specific examples of what makes it suitable or unsuitable? (e.g., proximity to public amenities, visibility, neighbourhood needs)	D/M/O
- What urban challenges or obstacles in the surroundings of a building do you foresee (e.g. building height restrictions, surrounding infrastructure) which might affect the suitability of a site for a rooftop park?	D/M/O
- What are considerations or challenges specific to Amsterdam? Why?	M/O
Holistic assessment and applicability of suitability criteria	
Combining building-level and urban context criteria	
- Do you think it is more important first to consider building suitability or site suitability in the city when developing new rooftop parks in Amsterdam? And why?	All
Data availability and applicability	
- When mapping suitable buildings and locations, a lot of data is required. Which data do you think is most important to gather (e.g., building height, roof structure, land use)? And do you foresee any challenges in gathering and applying this data?	
Conclusion	
Final thoughts for rooftop park development	All
- As a final question in this interview, I would like to ask you to share your vision: How do you think the roof landscape and public green spaces will look like in 20 years? How do rooftop parks fit in? - Based on this interview, do you have any final thoughts to add or recommendations for rooftop park development?	
Next steps - Thank the interviewee for their time and insights - Explain the next steps in the research and how the interview input will be used - Offer to share the final research findings with the interviewee if interested - Snowball sampling: any recommendations for other people/organisations to get in contact with? Is introduction possible?	
Closing - Check whether all questions from the interviewee are answered - Stop recording	

10.2 Appendix B: Field observations

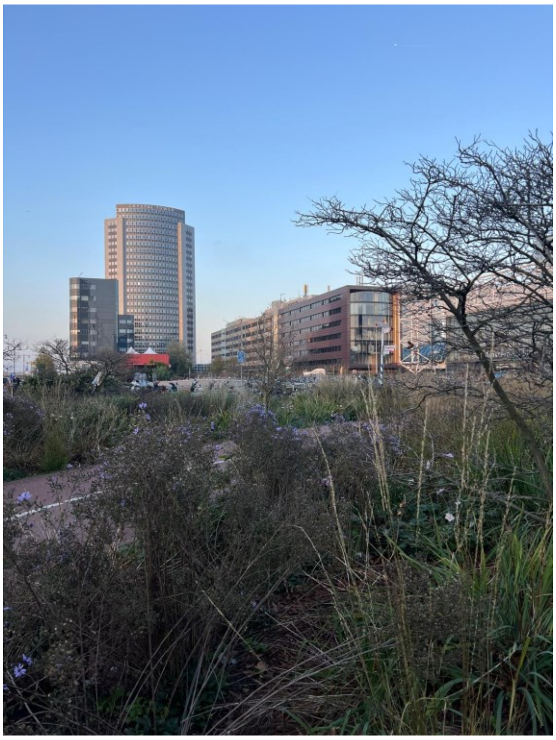
Locations

N#	Name	Location	Date of visit
1	Orlyplein	Amsterdam	09/08/2024
2	Dakpark Vivaldi	Amsterdam	04/09/2024
3	Dakpark de Boel	Amsterdam	04/09/2024
4	Rhapsody Jan van Schaffelaarplantsoen	Amsterdam	04/09/2024
5	Dakpark Vierhavenstrip	Rotterdam	18/09/2024
6	Luchtpark Hofbogen	Rotterdam	18/09/2024
7	De Groene Kaap	Rotterdam	18/09/2024
8	DakAkker	Rotterdam	18/09/2024
9	NEMO	Amsterdam	22/09/2024
10	ROEF Dakpark	Amsterdam	29/09/2024

Observation template

<table>
<tr><td colspan="3">Name & Location: [Rooftop park name and city]
Date of visit: [DD/MM/YYYY]</td></tr>
<tr><td colspan="3">Building level: rooftop use</td></tr>
<tr><td>Key challenges/goals (if known)</td><td colspan="2">[Document any identified constraints or objectives]</td></tr>
<tr><td>Function</td><td>Associated colour</td><td>Description of function (visual)</td></tr>
<tr><td>Vegetated</td><td>Green ☑ / ☒</td><td>Presence, type, form and variety of vegetation</td></tr>
<tr><td>Social</td><td>Red ☑ / ☒</td><td>Accessibility, amenities and users</td></tr>
<tr><td>Other</td><td>☑ / ☒</td><td>Additional observed functions beyond green or red</td></tr>
<tr><td colspan="3">Urban context: surroundings</td></tr>
<tr><td>Description of the urban environment</td><td colspan="2">Connectivity and integration to infrastructure, urban form and surrounding greenery</td></tr>
<tr><td colspan="3">Other remarks</td></tr>
<tr><td colspan="3">Additional qualitative observations</td></tr>
</table>

Name & **Location**: Orlyplein, Amsterdam **Date of visit:** 09/08/2024, 16.15 - 17.00		
Building level: rooftop park properties		
Key challenges/goals	*Drought, extreme weather, heat stress*	
Function	***Associated colour***	***Description of function (visual)***
Vegetated	Green ☑	Variety of vegetation: flowers, shrubs, and smaller trees. Colourful mix. Higher trees along the edges. All in-plant borders.
Social	Red ☑	Multiple cafes/bars in and around the 'park'. Also hotels and a supermarket. Many places to sit down on the station side. Main entrance (same level) from the station. Multiple stairs lead from the lower levels to the park level. Users: people waiting for the train. The majority seem to be tourists. Homeless people are drinking beer. It seems like everyone is just passing through or by. Only one of the bars looks crowded with people for after-work drinks but quite closed off for the park. Large bike parking on the roadside.
Other	☑	Bike parking, entrance to the station
Urban context: surroundings		
Description of urban environment	Station on two sides (main entrance and other tracks), high hotels above the station. 3rd side of the park: large road. North side: High-rise buildings (offices). Biking path going through connecting the square to the city around	
Other remarks		
The rooftop park is not widely used as a park for recreation. The main visitors on the day of observation seem to be tourists transferring or waiting for the train, and homeless people. Questionable whether it is really a rooftop, as it is at the same level as the train station entrance and a road.		



Name & **Location**: Vivaldi Rooftop park, Amsterdam **Date of visit:** 04-09-2024, 11.00 – 11.15		
Building level: rooftop use		
Key challenges/goals	Transform the roof into a rooftop park for all users of the building.	
Function	***Associated colour***	***Description of function (visual)***
Vegetated	Green ☑	Variety of green, mainly lower vegetation with a couple trees. During the visit, the higher vegetation and trees seemed not to be flourishing anymore.
Social	Red ☑	The rooftop park is located on the first floor and the higher floors look out over the roof. The roof has a couple of seating spots and is open to all companies located within the building. You can only enter the roof from inside the building. At the time of the visit, no one was using the rooftop park (11 in the morning and cloudy).
Other	Blue ☑	Polderdaksystem
Urban context: surroundings		
Description of urban environment	The building is surrounded by other office buildings.	
Other remarks		

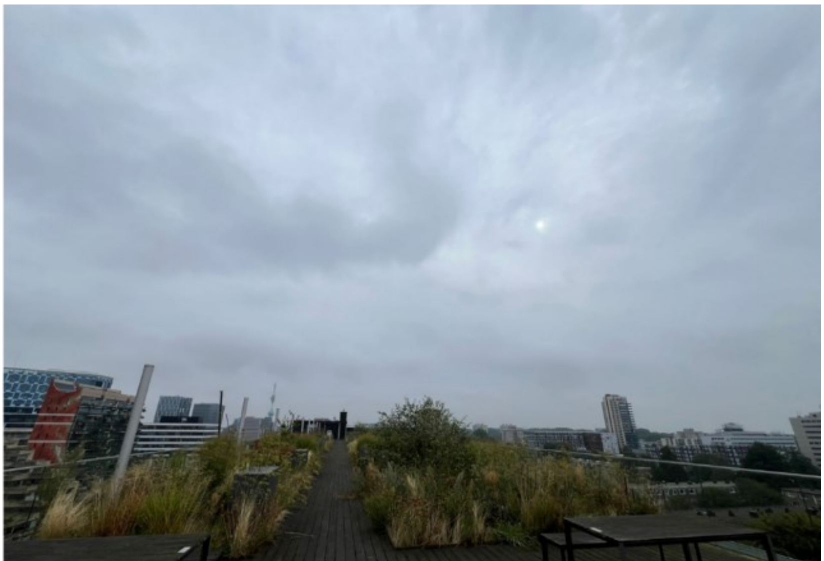

The rooftop park has various seating spots and is located on the first floor


Besides the building users, the rooftop park is also visible from the surrounding buildings. The rooftop park is located in a highly dense business district.


The upper floors of the building look out over the rooftop park. Users of the building can enter the roof via a door in the hallway

Name & **Location**: De Boel, Amsterdam **Date of visit:** 04-09-2024, 10.30 – 10.45		
Building level: rooftop use		
Key challenges/goals	A place for residents of the building to relax. Renovation of the building.	
Function	***Associated colour***	***Description of function (visual)***
Vegetated	Green ☑	Mixed vegetation, mainly a variety of different grasses. Some larger bushes. The vegetation looks quite uniform on the day of visiting. Vesteda's employee mentioned that it has become a little 'wild' over time.
Social	Red ☑	The roof is only accessible to residents of the building with a key and located at the 9^{th} floor. The elevator goes up to the 8^{th} floor. Vesteda is the housing corporation that owns the building and offered me entrance to the roof during the visit. One of the employees accompanied me during the visit and noted that he did not see residents using the space often, as 'it is too much of a hassle to go upstairs'. There are various seating spots on the roof and, as a visitor, you have a great view over the surrounding buildings.
Other	Blue ☑	*Polderdak system*
Urban context: surroundings		
Description of urban environment	Located at the Boelelaan, a large road crossing the Zuidas, business district in Amsterdam. Station Zuid is close by.	
Other remarks		
The rooftop was constructed during the renovation of the building, and was not accessible before.		


The roof offers space to sit between the vegetation


The rooftop park is situated on top of a traditional apartment block and accessible by the residents. The roof is accessible from the main staircase.


From the rooftop park on the 9th floor, residents have a great view of the highly dense surroundings.

Name & **Location**: Rhapsody Jan van Schaffelaarplantsoen, Amsterdam **Date of visit:** 04-09-2024		
Building level: rooftop use		
Key challenges/goals	For the project as a whole: Noise nuisance from the highway	
Function	***Associated colour***	***Description of function (visual)***
Vegetated	Green ☑	High variety of vegetation, different layers and levels.
Social	Red ☑	The elevated inner area is a publicly accessible garden with a community greenhouse, a guest house, and a café that also serves as a living room meeting place. The park is accessible via multiple stair entrances from the ground floor and is open to everyone. Entrances to the apartments are also partly located on the elevated park space, and all apartments in the different blocks look out over the greenery. Beneath the elevated deck, there is a parking garage, storage spaces, utilities, and water storage for the garden.
Other	Blue ☑	Water storage for the garden beneath the elevated park.
Urban context: surroundings		
Description of the urban environment	Located between the A10 highway, the industrial area Westpoort and the busy Bos & Lommerweg.	
Other remarks		


A greenhouse offers activity space for residents between the vegetation

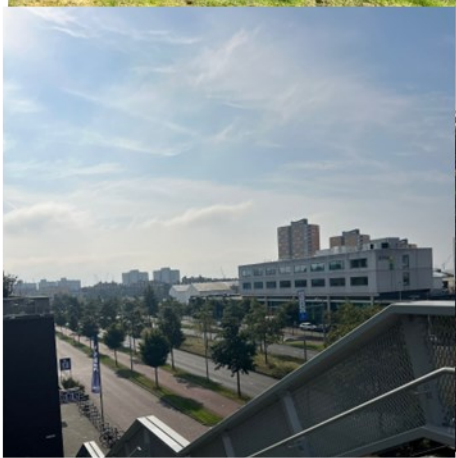

The surrounding apartment blocks look out over the rooftop park


The roof is situated on top of a parking garage and apartments, and stairs from different sides offer free access to the space

Name & **Location**: Dakpark Vierhavenstrip, Rotterdam **Date of visit:** 18/09/2024		
Building level: rooftop use		
Key challenges/goals	To experience and develop urban nature with and for residents of Delfshaven and visitors	
Function	***Associated colour***	***Description of function (visual)***
Vegetated	Green ☑	The park features various sections, including a community garden, grass fields, BBQ areas, a playground, and diverse planting with trees. Limited grass diversity has reportedly affected the rabbit population.
Social	Red ☑	It provides viewpoints over Rotterdam and is accessible via stairs on one side and a gradual slope on the other. It has multiple functions, maintained by local residents. There's a fence with set opening hours and a restaurant. Users include skaters, walkers, and locals. Water feature in the form of a fountain.
Urban context: surroundings		
Description of the urban environment	One side is residential, the other industrial, with a major road. Shops are beneath the park, which slopes up from street level and back down. There are benches and nearby buildings overlook the park.	
Other remarks		
Largest park visited		

The Dakpark offers a diverse mix of functions, from left to right: Neighbourhood garden, a playground, viewing points, a water feature and barbecue/picknick areas



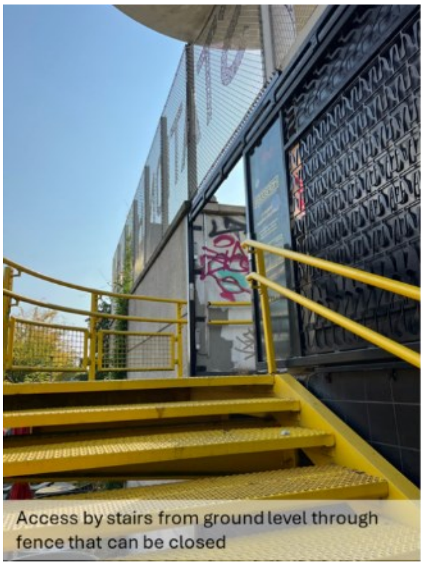




At the side of the neighbourhood, Dakpark has a sloped terrain from ground level, and is accessible by a ramp or stairs. At the other side, there is a steep distinction between the ground level and park. On this side, the space underneath offers room for shops and parking. At one of the ends of Dakpark, apartments blocks are built, in and overlooking, the park area.

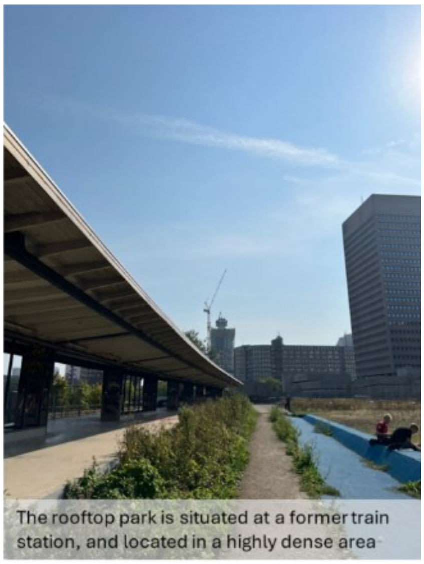
Name & **Location**: Luchtpark Hofbogen, Rotterdam **Date of visit:** 18/09/2024		
Building level: rooftop use		
Key challenges/goals		
Function	***Associated colour***	***Description of function (visual)***
Vegetated	Green ☑	The park includes a community garden, a variety of planting with both trees and low vegetation, and a grass field for events.
Social	Red ☑	There is one street-level entrance with stairs and a gate that can close off the park after opening hours. Residents manage the community garden. Though the entrance from Luchtbogen was closed during the visit, it is generally connected to other parts of Rotterdam. Many students from the nearby Graphic Lyceum use the park. It sits about one story high, on the old railway.
Other	Orange ☑	Connection through Luchtbogensingel
Urban context: surroundings		
Description of the urban environment	The park is in a densely built area near Crooswijk, with the Graphic Lyceum and a tram stop directly by the entrance. Shops are located underneath the park.	
Other remarks		


The luchtsingel connects the luchtpark Hofbogen to other buildings and the surrounding city area

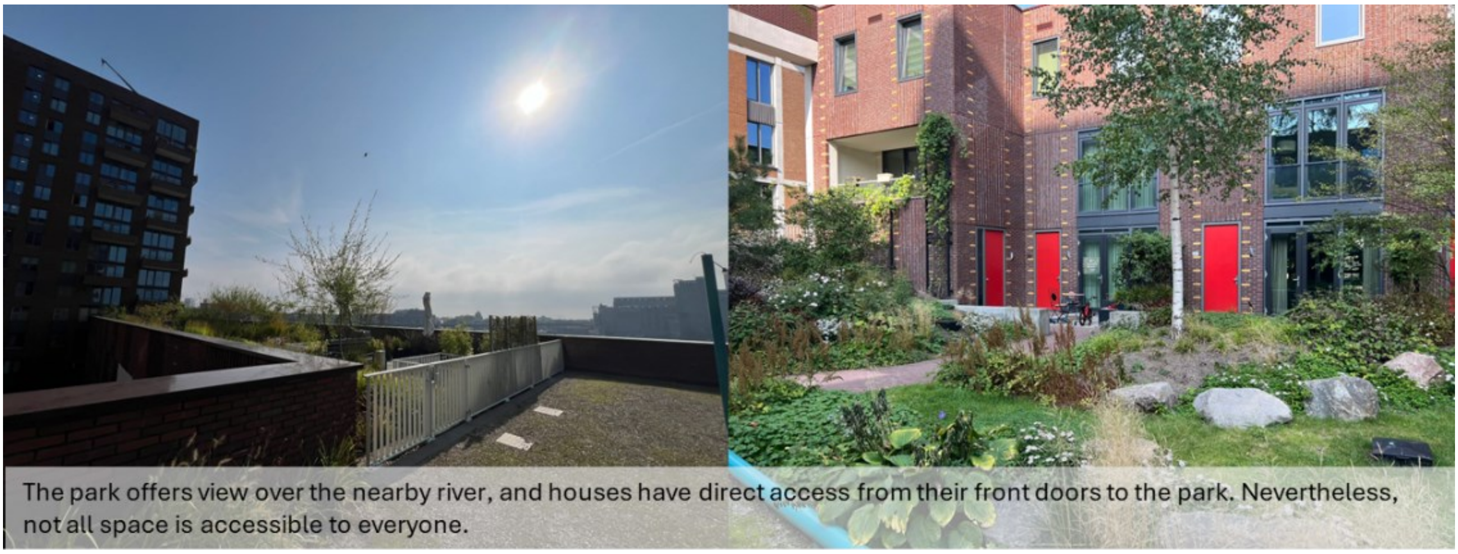
The sign at the entrance gives information about the history, opening hours and park´rules


Access by stairs from ground level through fence that can be closed

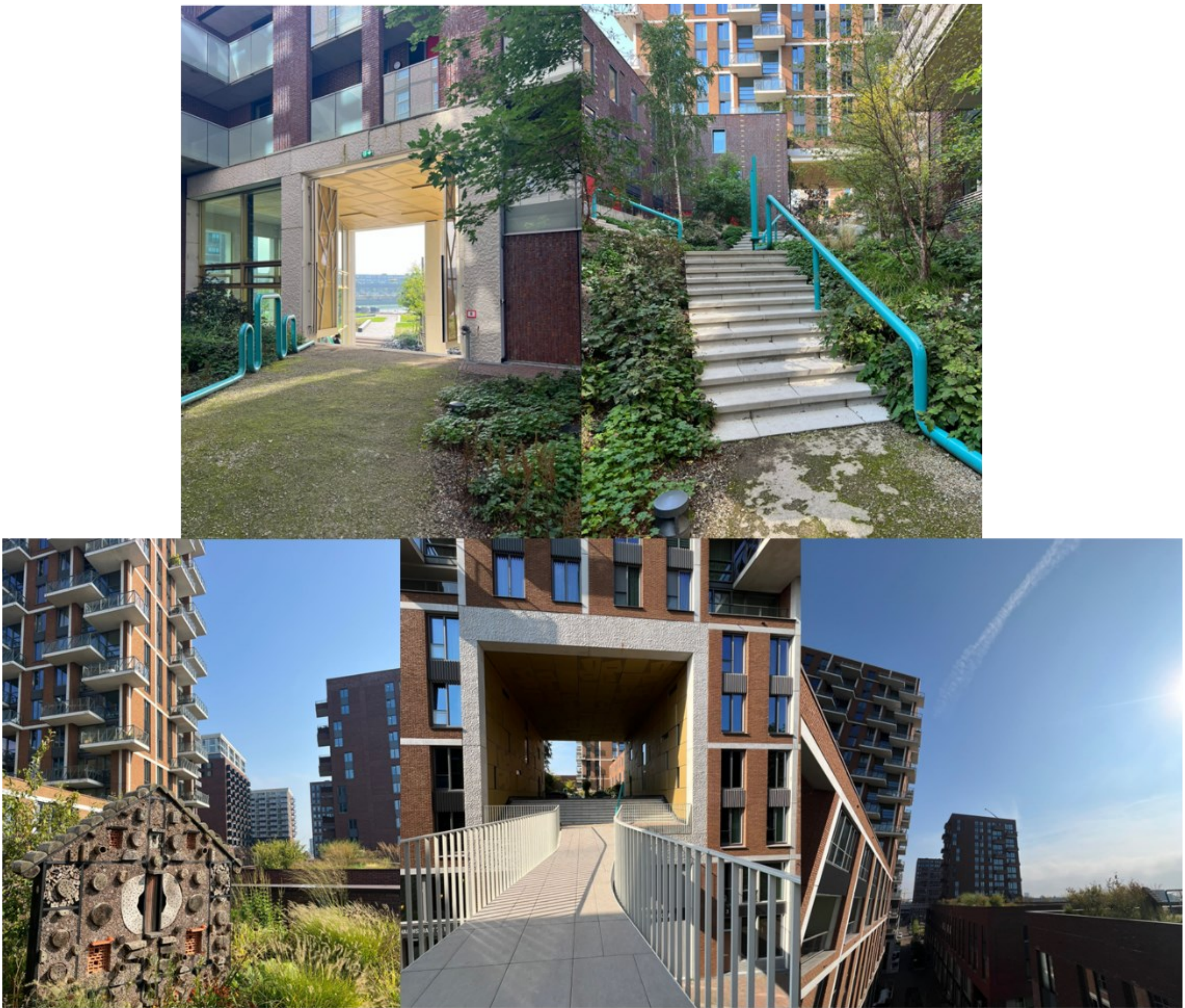

The rooftop park is situated on the first floor, located on top of a variety of shops


The rooftop park is situated at a former train station, and located in a highly dense area

Name & **Location**: De Groene Kaap **Date of visit:** 18-09-2024		
Building level: rooftop use		
Key challenges/goals		
Function	***Associated colour***	***Description of function (visual)***
Vegetated	Green ☑	The park has varied greenery, with different types of trees and vegetation, offering both shaded and sunny areas. There are height differences, adding depth and interest to the landscape.
Social	Red ☑	There is one gated entrance. The buildings are interconnected at various heights, with sections of the park woven throughout. The park is owned by the Homeowners' association (VvE), and some private sections are fenced off. Residents have views of the park from surrounding homes and higher apartments, with a view of the harbour from the park. The area is accessible by stairs (no visible elevator, though possibly inside the buildings). Housing around the park ranges from 3 to 12 stories. During the visit (Wednesday at noon), no users were present. Residents have access tags, and the park is only open to the public on Wednesdays and weekends. There are some nuisances caused by groups near the park, especially by residents who have gardens. Moving the gate to the bottom of the stairs is being considered. A community garden is managed by residents on the back-roof side of the building. The park is mainly used for walking through and as a visual feature for surrounding homes.
Other	☒	
Urban context: surroundings		
Description of the urban environment	Located in a highly urbanized area with lots of high-rise development, the park is near the waterfront and connected to a park along the water.	
Other remarks		
Met a resident, who especially highlighted the view, and remarked that the park is only open on Wednesday and at the weekend because of the nuisance.		



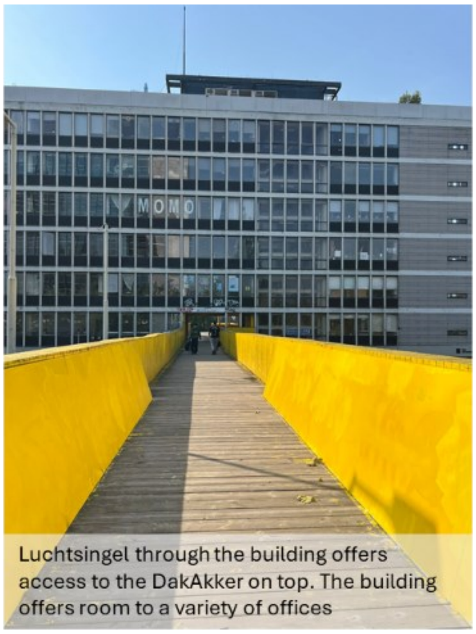
The park offers view over the nearby river, and houses have direct access from their front doors to the park. Nevertheless, not all space is accessible to everyone.



The main entrance (fenced) offers access to the rooftop park. The walking path thorugh the park leads to different housing and apartment blocks, connected by bridges.

Name & **Location**: DakAkker, Rotterdam **Date of visit**: 18/09/2024		
Building level: rooftop use		
Key challenges/goals (if known)	Example for urban rooftop agriculture	
Function	***Associated colour***	***Description of function (visual)***
Vegetated	Green ☑ / ☒	The rooftop is covered with rows of vegetables and fruit-bearing plants, such as tomatoes and herbs. There are distinct farming sections, alongside green spaces with shrubs and flowers to support biodiversity/local bee family.
Social	Red ☑ / ☒	The park is open to the public upon request, you can get a (paid) tour. The restaurant on the roof is open to everyone based on consumption, however, it is not managed by the same organisation. You access the roof (7th floor) by a staircase in the building or the elevator up to the 6th floor). The entrance is connected to the Luchtbogensingel.
Other	Education/blue ☑	The roof facilitates education programmes for schools, and there is a Slimdak water storage test site.
Urban context: surroundings		
Description of the urban environment	Located on top of a commercial building, DakAkker is situated near Rotterdam Central Station. The surrounding urban environment is characterised by high-rise buildings, busy streets, and limited ground-level green spaces. The area has heavy pedestrian and vehicle traffic.	
Other remarks		

Access from the luchtsingel, via staircase or elevator in the building

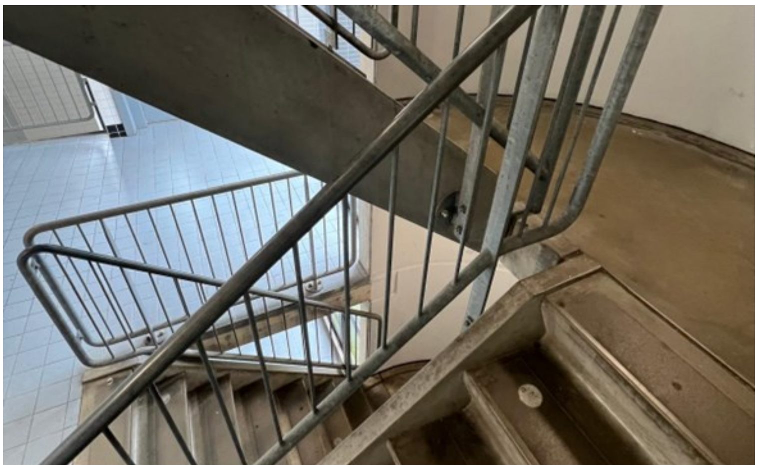


Luchtsingel through the building offers access to the DakAkker on top. The building offers room to a variety of offices

The DakAkker is situated on top of a traditional multi-story office block

Name & **Location**: NEMO, Amsterdam **Date of visit:** 22-09-2024, 15:30-16:00		
Building level: rooftop use		
Key challenges/goals	NEMO architect Renzo Piano envisioned the roof of the building as a Italian piazza (town square).	
Function	***Associated colour***	***Description of function (visual)***
Vegetated	Green ☑	*(Type of green, variety, form)* The extensive green roof (sedum) is separated from the rest of the roof, not accessible and barely visible. The only vegetation on the accessible roof is some individual small (Mediterranean?) trees in big plant pots and bushes on one side of the roof. The vegetation looks very dry (yellow**).** On the day of observation, it is very windy at the top.
Social	Red ☑	The roof has a variety of water play features/playgrounds. On the day of observation (sunny), the playground is full of kids of different ages. On the roof, we find over 20 benches, which are almost all used at the observation time. Visitors are both people that just come to visit the roof, as well as people who visited the museum. At the top of the roof, there is a busy café. Other than that, there are announcements for summer events and wayfinding signs. To get to the top, you can either take the escalator or stairs. The roof offers a great view of the surrounding city: There are many people taking pictures at the moment of observation, and binoculars where people can further explore the view. You can sit in the cafe, but also access the roof and sit down at the other benches without ordering anything. Very busy on the day of observation (200+ people), both tourists and inhabitants. You can access the roof from inside or outside.
Other	☑ / ☒	Water playing features, do they store water?
Urban context: surroundings		
Description of the urban environment	The building is isolated between the water and a big road. Real landmark. Station, and other museums at walking distance. Marine terrain is the closest green.	
Other remarks		
As the vegetation is separated from the green, you can question whether this is a real 'park' or rather a square as the designer envisioned. In 2024, the roof will be renewed and more green will be added, but on the day of visit, the design is not yet presented.		

Name & **Location**: ROEF Dakpark, Amsterdam **Date of visit:** 29/09/2024, 16.00 - 19.00		
Building level: rooftop use		
Key challenges/goals	The temporary rooftop park shows the role rooftops can play in greening cities, and especially that this can be done much faster.	
Function	***Associated colour***	***Description of function (visual)***
Vegetated	Green ☑	The greenery on the rooftop park is based on a modular green system and is supposed to be reused on the roof of the Stopera building in Amsterdam. At the time of visiting, the vegetation in the system was still small, but it was just planted and supposed to grow further in the next weeks. The total area, 350 m2, was supposed to be 1000 m2. Apart from the modular system, some trees are planted in large plant pots.
Social	Red ☑	The rooftop park is temporary and located on the top floor of a parking garage. During opening hours, various events, music and workshops are organised for visitors. You can access the roof via the stairs, the parking garage or the elevator. Entrance to the rooftop park is free, but for some activities, you need to pay an entrance fee. There is a bar, places to sit down and toy vehicles for kids to play with on the roof. The roof offers a view of the surrounding neighbourhood and Westerpark. Visitors at the opening were mainly people involved in the rooftop industry and development, but the park is meant to attract all Amsterdam residents. A sign at the ground floor shows that there is an event upstairs.
Other	☑	*(Type of storage/system)* The modular greenery system collects water, which is directly used to grow the vegetation.
Urban context: surroundings		
Description of urban environment	The location is on the top floor of a parking garage, next to the Westerpark. The parking garage offers space for people to park their cars when they visit the stores around or the surrounding neighbourhood.	
Other remarks		
The space is temporarily and used to demonstrate the possibilities on rooftops (in Amsterdam). Visited during the official opening.		

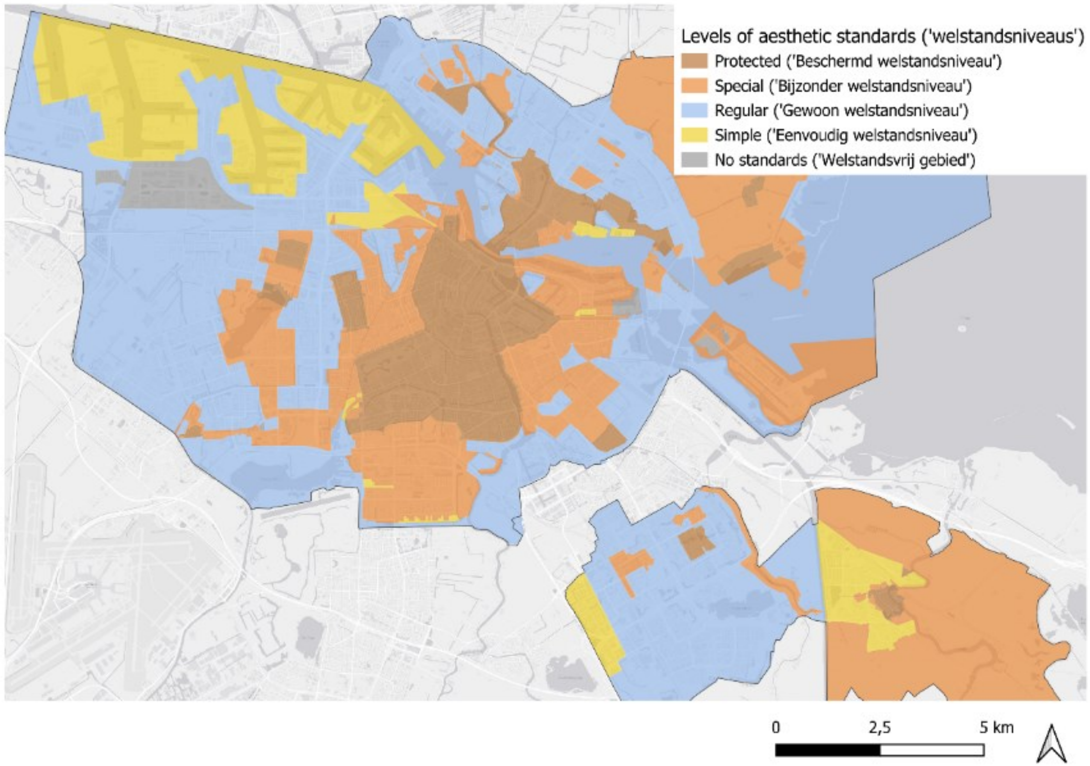


The top deck of the parking garage is accessible via the regular stairs or elevator in the garage.

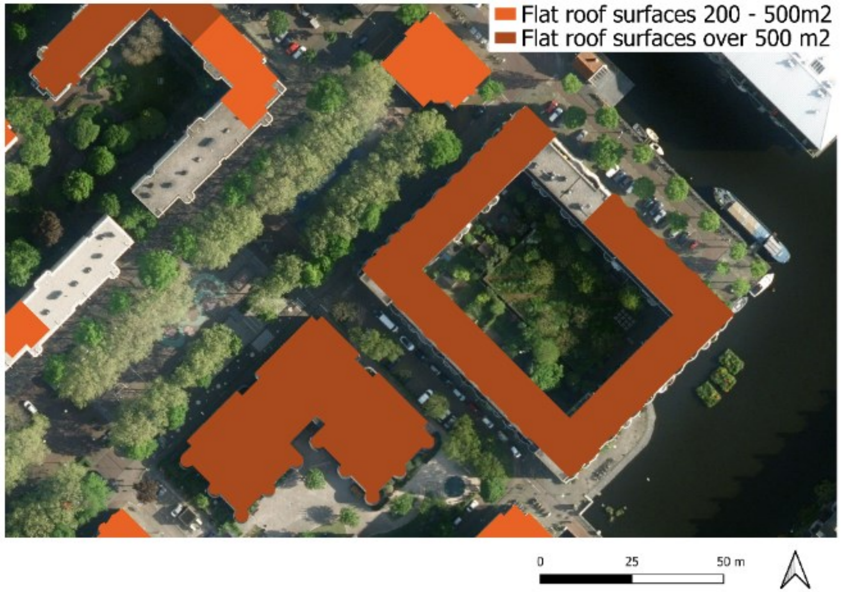
The rooftop park was situated on the top deck of a parking garage and consists of a modular system. Westerpark is located right next to the parking garage. From teh top deck, visitors have a view over the surrounding neighbourhoods and office buildings

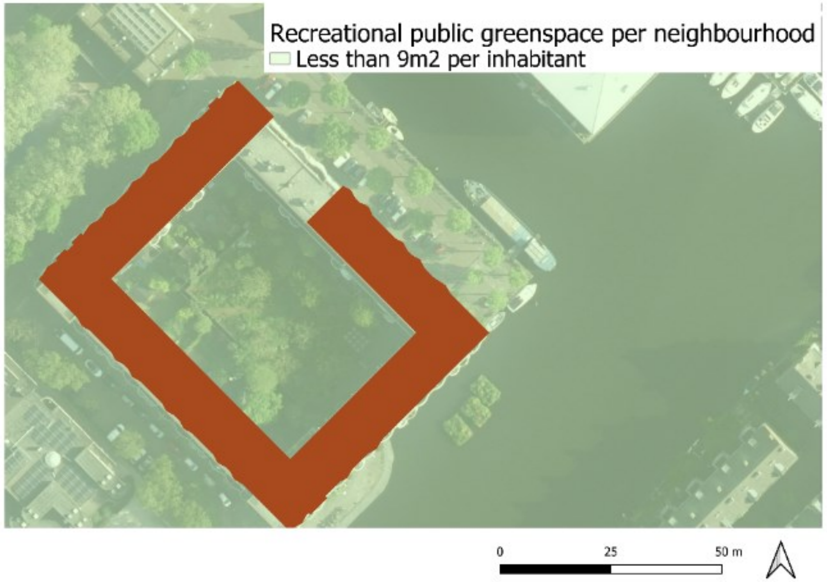
10.3 Appendix C: Supporting visualisations for integrated assessments

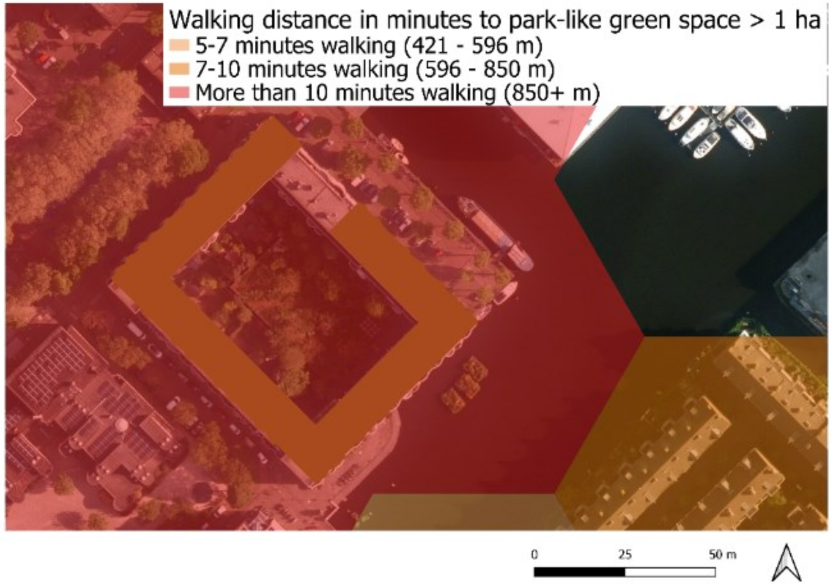
Overview maps: City of Amsterdam



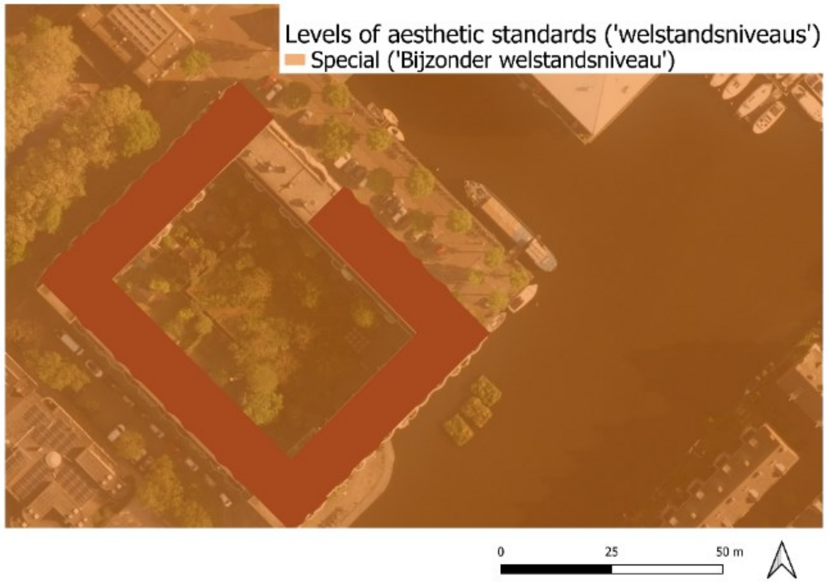
Location 1: Kleine Wittenburgerstraat, Oostelijke Eilanden/Kadijken



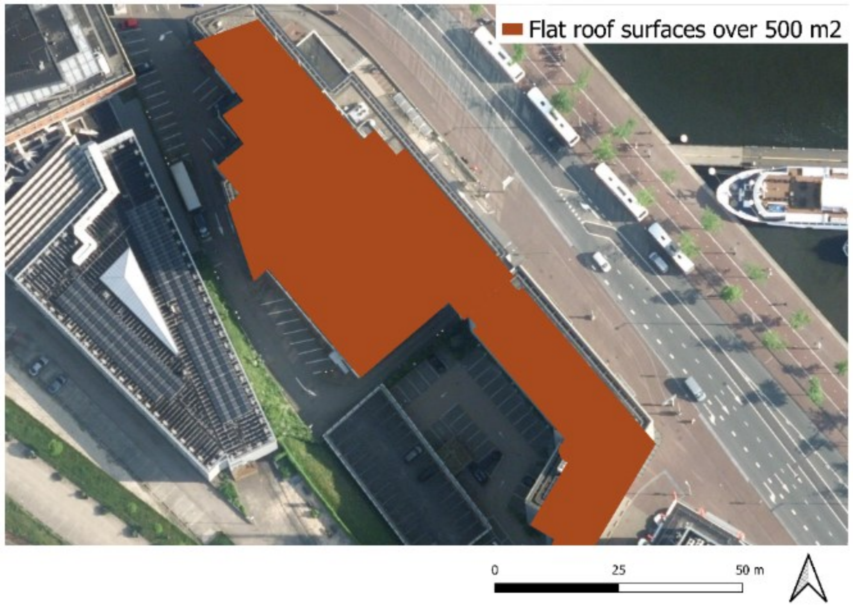

Recreational public greenspace per neighbourhood
Less than 9m2 per inhabitant
0
25
50 m

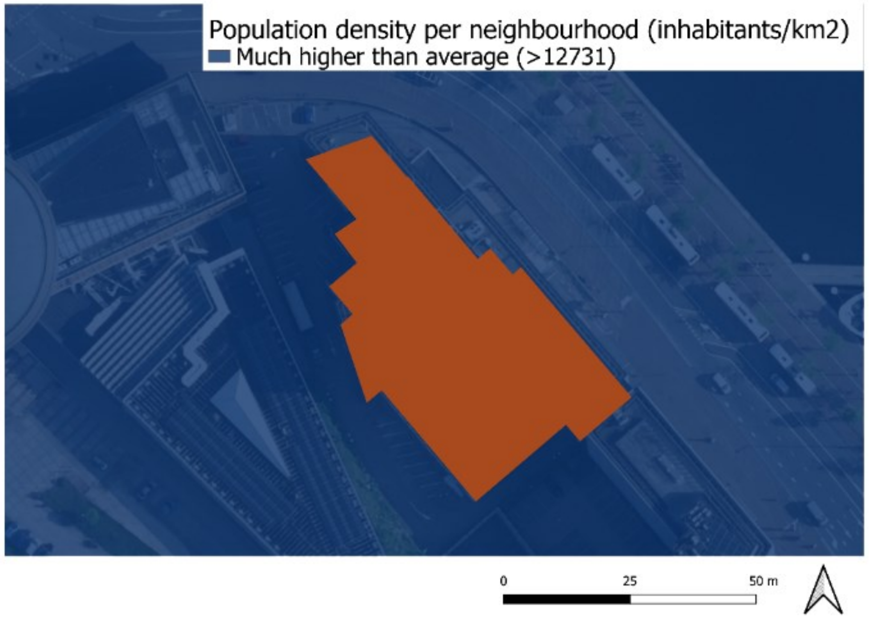

Walking distance in minutes to park-like green space > 1 ha
5-7 minutes walking (421 - 596 m)
7-10 minutes walking (596 - 850 m)
More than 10 minutes walking (850+ m)
0
25
50 m


Ecological corridor
0
100
200 m


Levels of aesthetic standards ('welstandsniveaus')
Special ('Bijzonder welstandsniveau')
0
25
50 m

Location 2: De Ruijterkade, Haarlemmerbuurt

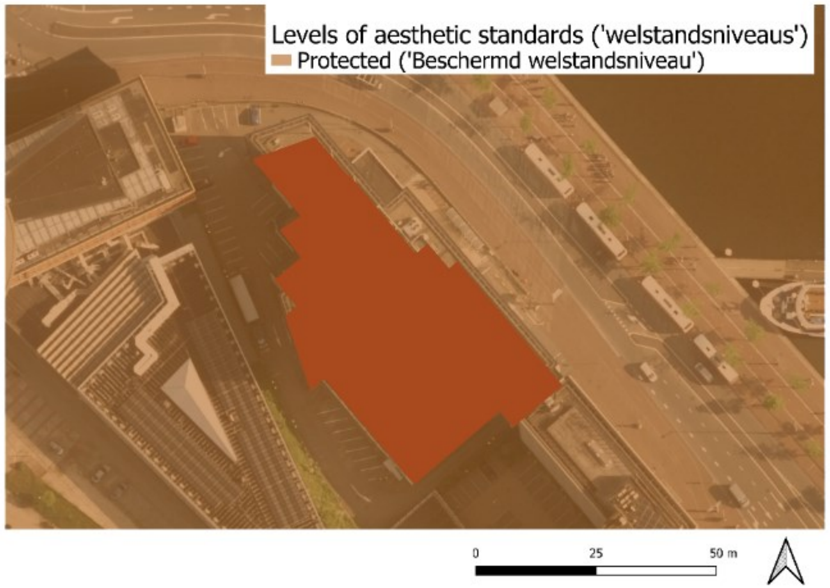




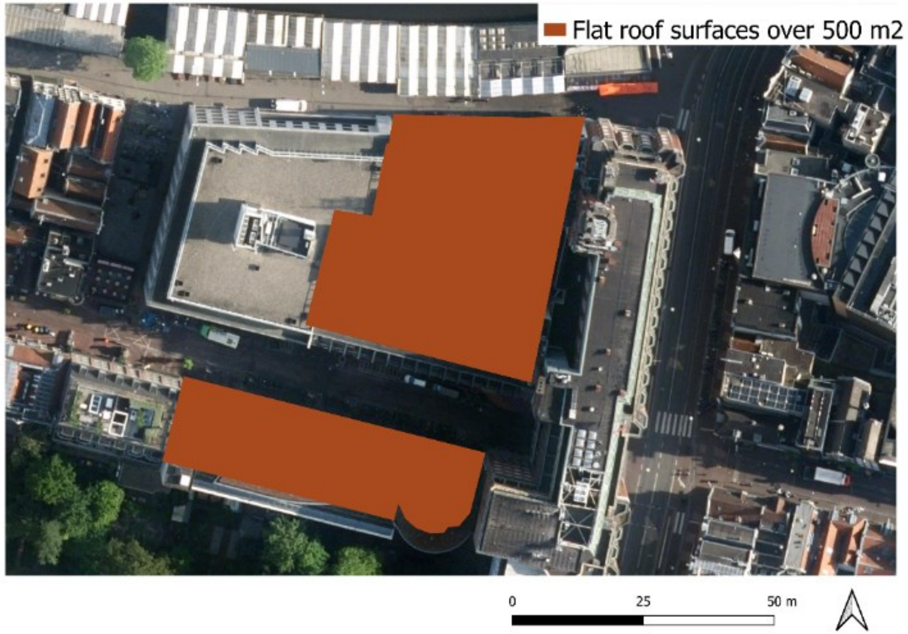

Recreational public greenspace per neighbourhood
Less than 9m2 per inhabitant
0
25
50 m

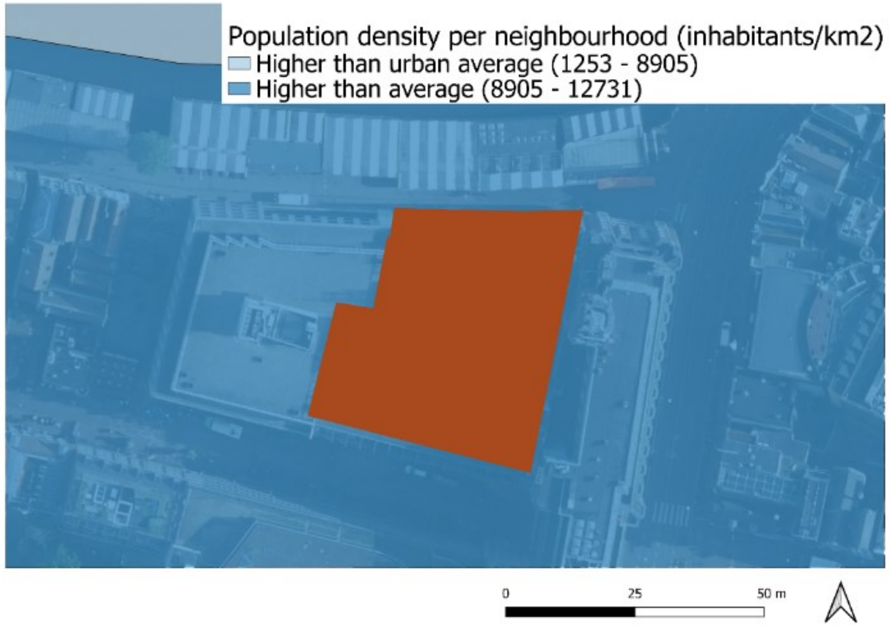

Walking distance in minutes to park-like green space > 1 ha
More than 10 minutes walking (850+ m)
0
25
50 m


Ecological corridor
0
25
50 m


Levels of aesthetic standards ('welstandsniveaus')
Protected ('Beschermd welstandsniveau')
0
25
50 m

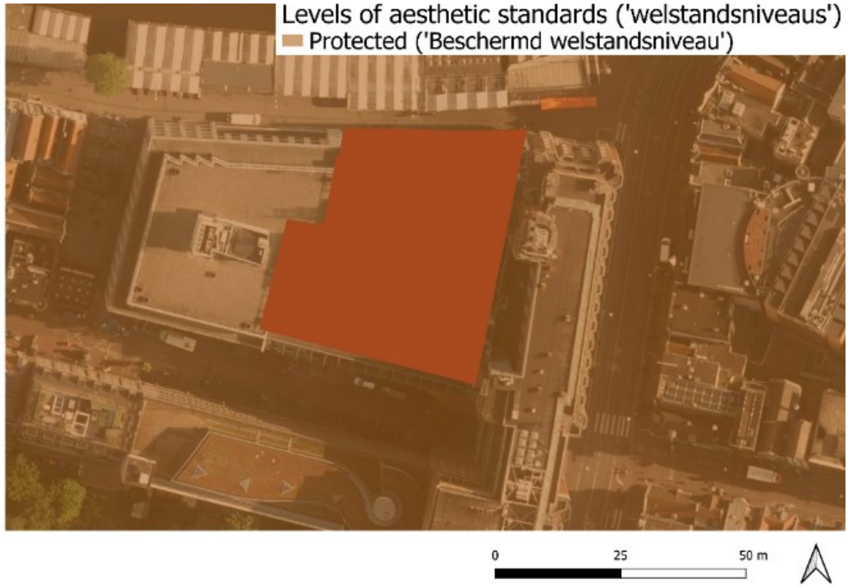
Location 3: Singel, Muntstaete, Grachtengordel-Zuid






Recreational public greenspace per neighbourhood
Less than 9m2 per inhabitant
0
25
50 m


Walking distance in minutes to park-like green space > 1 ha
7-10 minutes walking (596 - 850 m)
More than 10 minutes walking (850+ m)
0
25
50 m


Levels of aesthetic standards ('welstandsniveaus')
Protected ('Beschermd welstandsniveau')
0
25
50 m