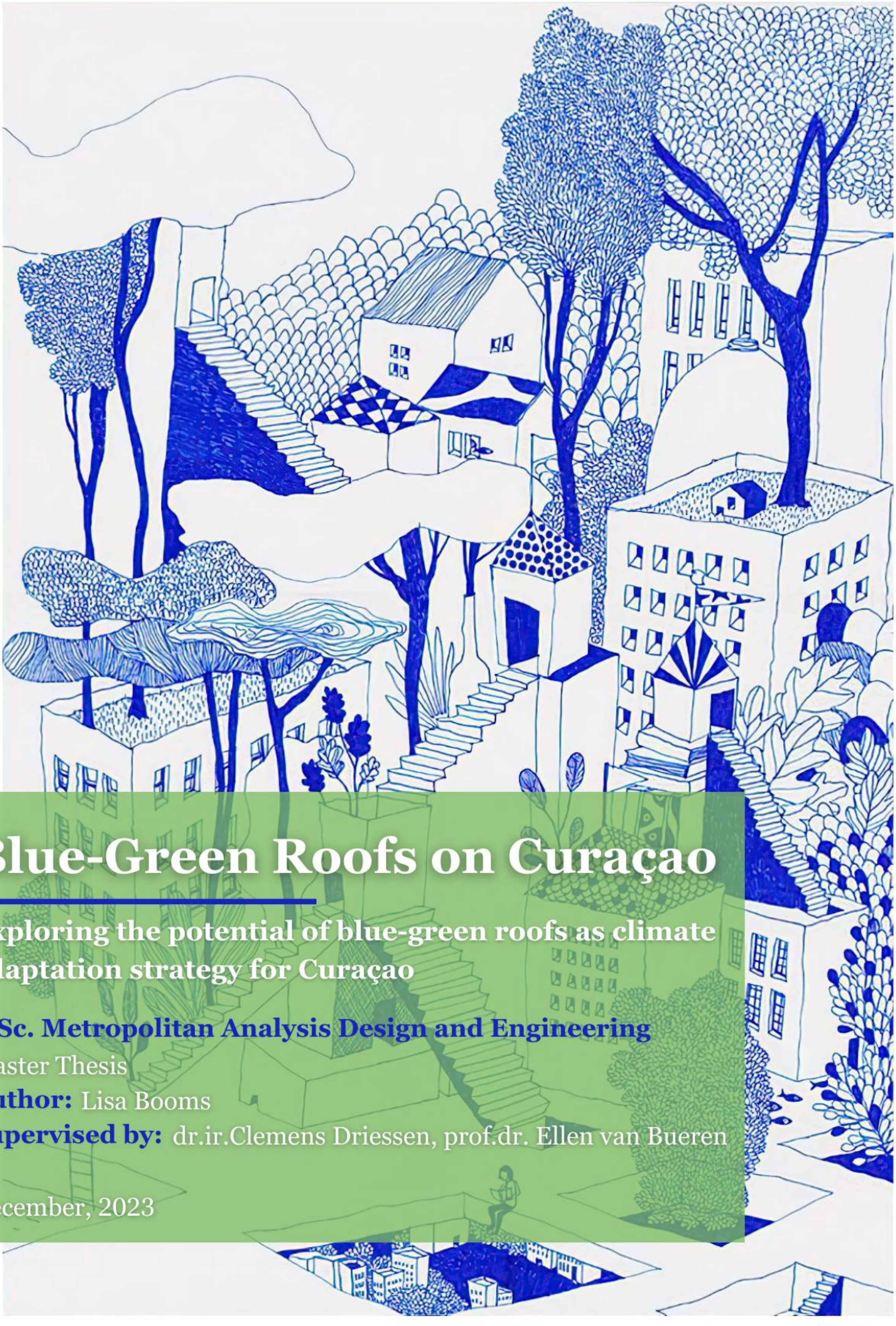

Blue-Green Roofs on Curaçao

Exploring the potential of blue-green roofs as climate adaptation strategy for Curaçao

MSc. Metropolitan Analysis Design and Engineering

Master Thesis

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Abstract

While Curaçao's contribution to greenhouse gas emissions that cause global climate change is negligible, the island suffers significantly as a result of environmental challenges such as intense heatwaves and heavy rainfall. This severely impacts the environmental and living conditions, as well as the physical and psychological well-being of the local community. Enhancing resilience through climate-adaptive innovations in the built environment seems crucial, and blue-green roofs (BGRs) offer an interesting opportunity due to their numerous co-benefits. Nevertheless, there are a number of technical and social barriers that make the implementation of climate adaptation strategies on Curaçao difficult. Moreover, it is not feasible to replicate the design and development process of regions where BGRs are effectively implemented due to substantial differences in environmental, political, and living factors. Curaçao currently lacks knowledge and has limited examples to explore the potential of BGRs as a climate adaptation strategy. Hence, this exploratory research investigates the potential of implementing blue-green roofs as a climate adaptation strategy on Curaçao.

This study identified the context of BGR implementation on Curaçao by developing a sociotechnical framework of multi-level aspects, visualising these aspects in system diagrams, and conducting a supplementary multifaceted stakeholder analysis. Following that, insights were gathered through stakeholder interviews conducted during a field visit to the island, using the network of a case study developing a new neighbourhood. This was supplemented by literature review, resulting in a holistic framework on all system dynamics of BGR implementation on Curaçao, including information on various topics, multiple scales, and the involvement of relevant stakeholders. The findings indicate that there are several system dynamics that support the potential of BGR implementation on Curaçao. However, the more pressing results are the system dynamics that are currently limiting this potential. These include safety concerns, minimal effects on stormwater management, and a lack of interest and financial resources from the local community.

The findings emphasise that the potential for BGR implementation on Curaçao exists and provide sufficient knowledge and tools to realise this potential. With the exception of the community acceptance and engagement principle, all established principles for BGR implementation on Curaçao can be met by utilising the insights gathered in this study. However, these insights are insufficient to make BGRs an effective stormwater management practice for the island or to gain acceptance from the local community. This study emphasises the importance of conducting further research into these two aspects in the context of climate adaptation strategies before pursuing the potential of BGR implementation on Curaçao.

Keywords: Blue-Green Roofs, Curaçao, Climate Adaptation Strategies, Stakeholder Engagement, Sociotechnical Development.

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I would like to thank all the interviewees who took part in this research, particularly Chris van Grieken. He holds the unique experience of having the only green roof of the island, but regrettably without achieving success. Nonetheless, he maintained confidence in my study and the potential of blue-green roofs, serving as a strong source of motivation.

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Masha danki,
Lisa Booms

List of Abbreviations

AMS	Advanced Metropolitan Solutions (in: AMS Institute)
ANG	Antillean guilder
BGR	Blue-green roof
GDP	Gross domestic product
GR	Green roof
IPCC	Intergovernmental Panel on Climate Change
MADE	Metropolitan Analysis Design and Engineering
NBS	Nature-based solutions
SIDS	Small Island Development States
WMC	Wechi Management Company
QH	Quadruple Helix (in: QH approach)

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1. Introduction

The motivation for this research originates in the urgency to address the pressing environmental challenges faced by Curaçao, particularly in light of recent climatic extremes such as intense heatwaves and heavy rainfall. The relevance of this research is emphasised by the effects of these climatic extremes, including power disruptions, landslides, severe damage to homes and infrastructure, and a negative impact on the mental and physical health of the local community. In light of these challenges, it is important to investigate the potential of implementing sustainable urban solutions such as blue-green roofs (BGRs). This approach serves as a proactive measure and contributes to broader initiatives aimed at promoting sustainability and resilience in response to the island's changing environment. This research originated from an invitation extended by a Curaçao-based project developer, who aims to create a sustainable neighbourhood by incorporating the consultation of students based in the Netherlands. By addressing the challenges presented in this case study and considering the broader context of environmental issues on the island, this research centres on examining the potential of implementing BGRs as part of climate adaptation strategies on Curaçao.

1.1. Climate Change and Adaptation on the Caribbean SIDS

1.1.1. Climate Change on the Caribbean SIDS

Curaçao, known as Kòrsou in the native tongue Papiamentu, is an island located 70 km off the coast of Venezuela. It is an overseas country that is part of the Kingdom of the Netherlands. The island is a part of the Caribbean region and is classified as one of the Small Island developing states (SIDS). SIDS are a specific group of countries located across the entire globe that encounter unique social, economic, and environmental vulnerabilities. The 1992 United Nations Conference on Environment and Development, which took place in Rio de Janeiro, Brazil, acknowledged SIDS as a special case due to their distinctive environmental conditions and their role in the context of development (United Nations, n.d.).

According to literature, the interconnectedness of social, economic, and ecological systems affects the vulnerability of SIDS. Any negative changes in these systems can increase a country's vulnerability and reduce its ability to recover, thereby having a detrimental effect on its sustainable development (Mohan, 2023; Metcalfe & Bennett, 2023). The vulnerability of the economies, societies, and natural ecosystems of SIDS in the Caribbean to external disturbances is well documented, not only in the literature on sustainable development, climate change, and risk management but also in the psyche of Caribbean residents.

While the Caribbean’s contribution to greenhouse gas emissions that cause global climate change is negligible, the region has already suffered and is expected to suffer even more from intense hurricanes, changes in rainfall patterns, and rising sea levels if global warming exceeds 1.5 °C (Mohan, 2023; Metcalfe & Bennett, 2023). Factors like small population size, remoteness from international markets, high transportation costs, vulnerability to exogenous economic shocks, and fragile land and marine ecosystems make SIDS particularly vulnerable to biodiversity loss and climate change because they lack economic alternatives. Biodiversity is an important issue for the livelihood of many SIDS, as industries like tourism and fisheries can constitute over half of the GDP of small island economies (United Nations, n.d.). However, the importance of natural resources extends beyond the economy; biodiversity holds aesthetic and spiritual value for many island communities. This value is threatened to disappear due to the effects of climate change and urbanisation. Although Curaçao may not be characterised by extensive urbanisation, even modest urbanisation trends, as highlighted by Metcalfe & Bennett (2023), present serious challenges for Caribbean governments today when combined with the inherent challenges of smallness, geographic isolation, and social, economic, and environmental vulnerability.

1.1.2. Barriers and Enablers to Climate Adaptation on the Caribbean SIDS

Effectively managing urbanisation necessitates adopting a comprehensive strategy to tackle the complexities and possibilities linked to inclusive, resilient, and sustainable development (Metcalfe & Bennett, 2023). Various strategies and initiatives are being suggested for climate adaptation in SIDS, including the United Nations National Adaptation Programme of Action. Researchers agree (UN-OHRLLS, 2009; Robinson, 2020; Mohan, 2023; Metcalfe & Bennett, 2023) that to meet adaptation needs properly, there needs to be a considerable increase in adaptation efforts, as well as better capacity building and technology transfer from other countries. Robinson's (2018) study showed that one major barrier to developing resilience to climate change in Caribbean SIDS is the absence of adequate technical expertise. Recent emigration trends in the Caribbean indicate that individuals from the islands are moving to metropolitan areas in the Netherlands, the United States, Canada, and the United Kingdom primarily for economic and educational reasons (Thomas & Benjamin, 2018). As a result, there is a scarcity of proficient experts who possess the necessary qualifications to address the environmental and engineering challenges presented by climate change (Mercer et al., 2012). Although there are technological approaches to combat climate change, they predominantly consist of "hard" engineering solutions. These solutions aim to prevent damage and disruptions to the islands caused by predictable events. However, they may not adequately protect communities against future events that deviate from the prevailing trends (Metcalfe & Bennett, 2023).

Related to this technical barrier, a research barrier exists. Even if there is the technical capacity to do research on different climate adaptation and mitigation strategies, it is often small-scale because of a lack of financing. In the Caribbean SIDS, investment in research is less than ½% of GDP (Robinson, 2018). This financial barrier is felt, especially in the Caribbean SIDS, where a significant climate finance gap exists. These countries are principally classified as high- or upper-middle-income countries, while other SIDS are primarily low- or lower-middle-income countries. Given that a large share of finance comes from traditional bilateral aid, Caribbean SIDS receive comparatively less international climate finance (Watson & Schalatek, 2019; Pauw et al., 2019; Mohan, 2023). Moreover, only a handful of Caribbean SIDS qualify for concessional borrowing from international donors (Mohan, 2023). The bidding process for projects funded by international agencies may be biassed towards large engineering firms from outside the Caribbean that prefer "hard" engineering solutions because they are more widely accepted and can be implemented over shorter timescales (Metcalfe & Bennett, 2023). The Caribbean SIDS' reliance on international climate finance places them in a precarious position, forcing them to pursue more innovative and diverse options.

In addition to the aforementioned technical, research, and financial barriers, there also appear to be cognitive and cultural barriers. The presence of cognitive barriers appears through the lack of attention given to climate change and adaptation strategies in everyday life, resulting in a lack of understanding (Kuruppu & Willie, 2015). To maintain control over the integration of island-based knowledge into broader adaptation planning and policy at different spatial scales, it is necessary to develop new approaches for producing knowledge that combine island-based and scientific knowledge (Lazrus, 2012; Kuruppu & Willie, 2015). The main cultural barriers pertain to the insufficient attention given in adaptation strategies to the significance of traditional knowledge, rituals, and cultural meanings in communities (Kuruppu & Willie, 2015). Additionally, a significant cultural barrier was the lack of educational resources and other forms of communication specifically addressing climate change adaptation and disaster management in the local language(s). As a result, there is a lack of trust in climate change information and a lack of responsibility in implementing national adaptation initiatives.

While extensive studies have been conducted on the five barriers to climate adaptation across the Caribbean SIDS mentioned above and potential strategies to address them, fewer studies have focused on the factors that facilitate this adaptation process. This is an area of concern that the

Intergovernmental Panel on Climate Change (IPCC), a United Nations organisation responsible for evaluating scientific research on climate change, is actively engaged in. The IPCC's 6th assessment report on effects, adaptation, and vulnerability provides an extensive list of factors that enable climate change adaptation, with a specific focus on SIDS (IPCC, 2022). The enablers are summarised in Table 1.1 and connected to the aforementioned barriers to demonstrate areas of overlap. According to Table 1.1, the enablers that facilitate climate adaptation strategy implementation in Caribbean SIDS are primarily related to cognitive and cultural obstacles. This suggests that by addressing these two barriers, most of the enablers for implementing climate adaptation strategies in Caribbean SIDS can be considered.

Table 1.1

Enabling factors (left) for implementing climate change strategies on SIDS (according to the IPCC 6th Assessment Report) are linked to literature-identified barriers (right).

Enablers	Barriers				
	T	R	F	Co	Cu
Better governance and legal reforms.					x
Improving justice, equity, and gender considerations.				x	x
Building human resource capacity.	x			x	
Increased finance and risk transfer mechanisms.		x	x		
Education and awareness programs.				x	x
Increased access to climate information.				x	x
Adequately down-scaled climate data.		x			
Embedding indigenous knowledge and local knowledge.	x			x	x
Integrate cultural resources into decision-making.				x	x

Note. T = technical barrier, R = research barrier, F = financial barrier, Co = Cognitive barrier, Cu = cultural barrier.

Robinson (2020) supports the incorporation of social variables to develop a holistic perspective. She acknowledges a UN initiative that highlights the potential for enhanced benefits and resilience in SIDS through the combination of adaptation measures, disaster risk reduction, and community-based development approaches. Metcalfe & Bennett (2023) advocate for a holistic approach, stating that Caribbean SIDS should develop a culture of resilience that is deeply embedded in the resilience of individuals, businesses, and institutions. To strengthen the resilience of small islands like Curaçao, it is vital to design sustainable strategies that connect the physical, environmental, and economic aspects with the values and needs of the community. This research will primarily focus on adopting nature-based solutions (NBS) as a promising approach.

1.2. Blue-Green Roofs (BGRs) as Nature-Based Solutions (NBS)

1.2.1. Nature-Based Solutions (NBS)

Nature-based solutions (NBS) harness the inherent strengths of nature to enhance various circumstances. NBS can be employed to safeguard communities and ecosystems from the impacts of climate change by utilising the diverse range of services offered by the natural environment. NBS are attracting global interest as practical and cost-effective methods for addressing climate-induced stressors. Given the scale and urgency of these stressors, there is a need for inventive and comprehensive solutions that can address multiple challenges in the built environment simultaneously (Larsen et al., 2016; Cook & Larsen, 2021), and NBS present an opportunity in this regard. An important challenge that the Caribbean SIDS encounter is the increasing severity of extreme weather events. Stormwater management drainage systems in urban areas frequently maintain designs that are "against nature", intending to withstand the impact of Mother Nature (Pasi, 2016). According to Pumo et al. (2023), we have reached a point where these systems are no longer capable of efficiently handling the ongoing changes in stormwater runoff patterns. The effectiveness of NBS in reducing pluvial floods and improving urban resilience has been demonstrated in several studies (Pelorosso et al., 2018; Oral et al., 2020; Recanatesi & Petroselli, 2022; Calheiros & Stefaniskis, 2021; Cristiano et al., 2022). Through the imitation of natural ecosystems, rainwater can be collected at the location where it lands, stored in plants and soil to support plant development during dry seasons, and the evaporation of stored rainwater helps to regulate the temperature inside the system (Gunawardena et al., 2017). Moreover, NBS, particularly in the form of blue-green roofs (BGRs), offer a chance to view rainwater as a useful local resource rather than an inconvenience, promoting the development of sustainable and efficient urban settings.

1.2.2. Blue-Green Roofs (BGRs)

The implementation of these NBS requires finding adequate space within cities, where green infrastructure is gradually disappearing. Rooftops in urban areas offer a promising solution, as they are often underutilized spaces that can be effectively reclaimed for stormwater management combined with plant growth (Wilkinson & Orr, 2018). Blue-green roofs (BGRs) are roofing systems that incorporate both vegetation and water storage elements. They can provide multiple ecosystem services (Williams et al., 2010; Bianchini & Hewage, 2012; Saadatian et al., 2013; Vijayaraghavan, 2016; Cook & Larsen, 2021), including reducing stormwater runoff (Berndtsson, 2010), decreasing urban temperature (Santamouris, 2014), diminishing the energy consumption of dwellings (Castleton et al., 2010), and increasing the efficiency of rooftop solar panels due to their cooling effect (Chemisana, 2014; Cirkel, 2023). BGRs also have the capacity to improve biodiversity (Brenneisen, 2006; Lepczyk et al., 2017), sequester CO_2 (Li et al., 2010), reduce air pollution (Yang & Gong, 2008; Rowe, 2011), dampen noise (Renterghem & Botteldooren, 2008; Yang et al., 2012), and improve building insulation and efficiency (Sailor, 2008). BGRs are particularly appreciated and accepted by society because of the possibility of private realisations (Vijayaraghavan, 2016; Pumo et al., 2023).

Figure 1.1

Example structure of a blue-green roof (BGR with a visible layer for water storage).

Note. Adapted from ICB-Projects (UK). CC BY-NC.

BGRs are different from regular green roofs (GRs) because they have extra storage space under the vegetation layer. This facilitates water reuse and increases the ability to hold, slow down, and lower stormwater volumes (Pumo et al., 2023; Figure 1.1). This technology proves particularly suitable for arid and semi-arid climates (such as part of the Caribbean SIDS), where water conservation is paramount and traditional green roof implementations face challenges in sustaining vegetation. BGRs offer a continuous water supply for plants during periods of drought, encouraging various plant species to thrive and consequently supporting a diverse range of insect species, enhancing biodiversity year-round (Cirkel et al., 2018; Permavoid, 2020).

1.3. Problem Statement

As Larsen et al. (2016) mentioned, due to the scale and urgency of climate change stressors, innovative and integrated solutions that can offer solutions to multiple challenges at once are welcomed. Studies by Williams et al. (2010) and Versini et al. (2015) tell us that BGRs are increasingly adopted in the last decades for this reason, yet especially in developed countries. The multiple benefits of BGRs on the scale of the local dwelling as for a broader community, are relevant decision factors that could make the implementation of BGRs as climate adaptation strategy attractive for Caribbean SIDS as well. However, literature unveils a list of barriers making it difficult to implement climate adaptation strategies in the Caribbean SIDS (Table 1.1). Looking at the comparison of the barriers against the enablers (Table 1.1) for this process, focussing on the cognitive and cultural barriers seems to hold a promising potential. Therefore, the focus of this research will be on the technical as well as the social (cognitive and cultural) barriers in the context of BGR implementation. By focusing on these three barriers, this research can offer practical and context-specific insights that can serve as a foundation for addressing the other barriers, which can be more effectively tackled once the region's unique challenges and opportunities are well-understood and accounted for.

The technological barrier and two social barriers are currently restraining the successful implementation of BGRs in the Caribbean SIDS. Moreover, mimicking the design and implementation process of regions where BGRs occur to be successful is difficult because of a difference in climate and living circumstances. At this moment in time, Curaçao has limited knowledge of BGR implementation and a lack of examples specifically tailored to the local conditions, both of which are needed to explore BGRs as a climate adaptation strategy.

1.4. Research Objectives and Questions

1.4.1. Research Objectives

The main objective of this research is to explore the potential of blue-green roofs (BGRs) as a climate adaptation strategy for Caribbean SIDS, especially the island of Curaçao. This could motivate local urban planners and policymakers to either include or exclude this innovation in their climate adaptation strategies. Within this main objective, the first objective is to establish a framework of multi-level aspects that are important to explore for implementing BGRs as a climate adaptation strategy on Curaçao, related to relevant stakeholders. The second objective is to find out if the current knowledge on these aspects is contributing to or hindering the potential of BGR implementation on Curaçao. By addressing these two objectives, this research could provide a kick-start in BGR implementation for urban planners, policymakers, architects, and other relevant stakeholders related to climate adaptation on Curaçao. Additionally, the findings of this research can be seen as a manual where a variety of relevant knowledge on these topics is collated in a comprehensive and systematic manner.

1.4.2. Research Questions

Based on the research objectives, the following main research question is formulated:

"What is the potential of implementing blue-green roofs (BGRs) on Curaçao[1], and how to realise[3] this potential by engaging local stakeholders[2]?"

To answer this question, it is divided into three sub-questions, each thoroughly focusing on a different aspect.

Sub question 1: What are important technical and social factors to consider for effective BGR implementation on Curaçao?

Sub question 2: Who are relevant stakeholders in the process of BGR implementation on Curaçao and how do they influence this process?

Sub question 3: How can a holistic framework, combining the important factors and relevant stakeholders, be used to realise the potential of BGR implementation on Curaçao?

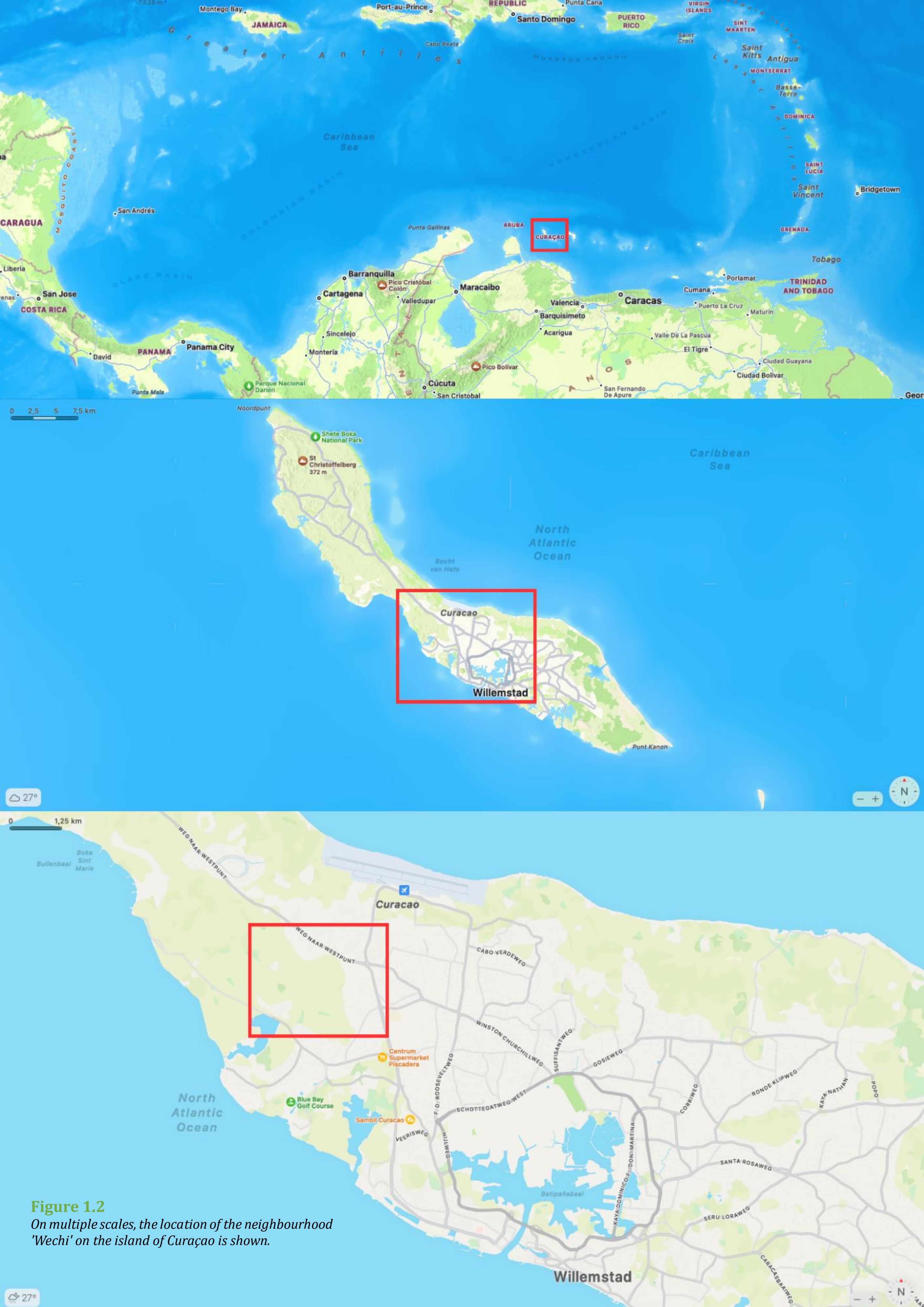


Figure 1.2
On multiple scales, the location of the neighbourhood 'Wechi' on the island of Curaçao is shown.

1.5. Case study: Wechi on Curaçao

Situated between 68–70 degrees West and 12–13 degrees North, Curaçao falls within the Southern Caribbean Dry Zone, characterised by a semi-arid to arid climate. The most recent climate change predictions for the Caribbean region, conducted by the Meteorological Department (Meteo) under the commission of the Intergovernmental Panel on Climate Change (IPCC), reveal concerning outcomes, indicating that the islands of the Dutch Caribbean will undergo profound environmental changes in the coming century. These climate change impacts will significantly affect the living conditions of the entire community on Curaçao, indicating the necessity for smart adaptation strategies.

One organisation on Curaçao displaying a commitment to investing in small-scale adaptation strategies for climate change is Wechi Management Company (WMC). A local newspaper article in 2022 highlighted that there were approximately 8.000 people on the waiting list for social housing services (Nu.cw, 2022). In an effort to alleviate this demand, WMC acquired a parcel of 134 hectares in the heart of the island to develop a new neighbourhood (see Figure 1.2 and 1.3). Wechi is envisioned to become a sustainable, safe, and liveable neighbourhood for inhabitants from all different socioeconomic backgrounds, as emphasised by urban designer Cees van de Sande (Antilliaans Dagblad, 2010). The community is expected to accommodate around 4,000 residents and provide essential amenities and a diverse range of building types and apartments. Currently in its initial phase of development, the project involves a dedicated team collaborating with various stakeholders, including contractors, landscape architects, construction workers, sustainability experts, and government agencies. To gain a better understanding of building a sustainable neighbourhood, a team from WMC went on an inspirational visit to the Marine Terrain in Amsterdam, where they got in touch with the AMS Institute. The AMS Institute develops a deep understanding of cities to design solutions for their challenges and integrate these into the city of Amsterdam and beyond (AMS Institute, n.d.). During this visit, the team drew inspiration from the concept of blue-green roofs (BGRs). This research aligns with WMC to explore the potential of BGRs on Curaçao.

Figure 1.3

Visual representation of a segment of the future neighbourhood Wechi.

Note. Adapted from Wechi Management Company (https://www.wechi.info). CC BY-NC.

1.6. Potential Ethical Dilemmas

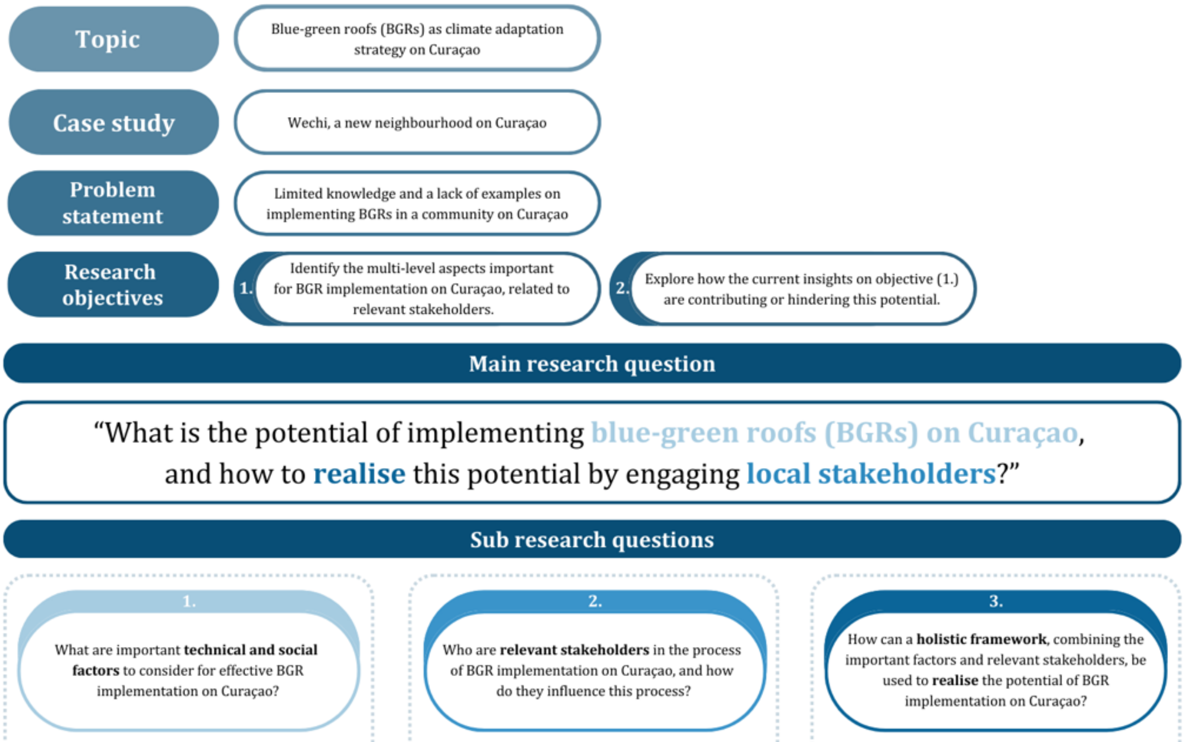
Given that this research is being conducted in an unfamiliar area and community, it is important to remain aware of the associated risks. The main concerns involve culture imposition, where researchers may unintentionally prioritise their own values and beliefs when investigating an environment characterised by different cultural values and beliefs. This can result in circumstances where the researchers' viewpoint surpasses the unique cultural setting being studied. Hence, it is crucial to remain alert in order to avoid a lack of understanding and appreciation for the knowledge, practices, or traditions of the community. The island has a diverse population from different cultural and social backgrounds. Hence, it is imperative for the researchers to maintain cultural sensitivity and exhibit respect for local norms and traditions while refraining from any cultural biases. Remaining conscious of potential power imbalances is crucial, since they can lead to the exploitation of local communities when the researcher extracts knowledge and experiences for their own advantage without offering equitable benefits or addressing the community's needs. It is essential to undertake this study with a dedication to ethical principles and practices that give priority to the safety, well-being, and autonomy of the community and the environment of Curaçao. Simultaneously, it is crucial to prioritise the inclusion of different points of view and voices in the research. There should be extra motivation to incorporate local knowledge and skills into the research. It is crucial to approach the research with cultural sensitivity, avoid generalisations, and ensure that findings are accurately presented in a nuanced manner that respects the complexities of the community's perspective and practices. It is crucial to approach the research with cultural sensitivity, avoid generalisations, and ensure that findings are accurately presented in a nuanced manner that respects the complexities of the community's perspective and practices.

1.7. Reading Guide

To address both the main and sub-questions, this thesis starts with an overview of the theories employed and essential contextual considerations, detailed in the theoretical framework (Chapter 2). Chapter 3 provides an overview of the research methodology, introducing the three subsequent research phases and the various methods employed within each phase. Chapters 4 and 5 present the results of Phases 1 and 2, which together form the basis for Phase 3. The findings of Phase 3 are then reported in Chapter 6. The results of the third phase serve as the primary input for the conclusive findings presented in Chapter 8, where the main research question is addressed. Yet, first, Chapter 7 delves into a comprehensive discussion of the results from all three phases, along with an exploration of the used methods, leading to suggestions for future research.

Figure 1.4

Part of the research design including the topic, case study, problem statement, research objectives, main research question and sub research questions.



Note. The overview of the entire research design can be found in *Appendix 1 – Research Design.*

2. Theoretical and Contextual Framework

To provide answers to the main and sub-research questions, this study relies on a few theories derived from literature and some contextual considerations. These theories and context will guide the research methodology and explain the rationale behind the choices that are made during the research process.

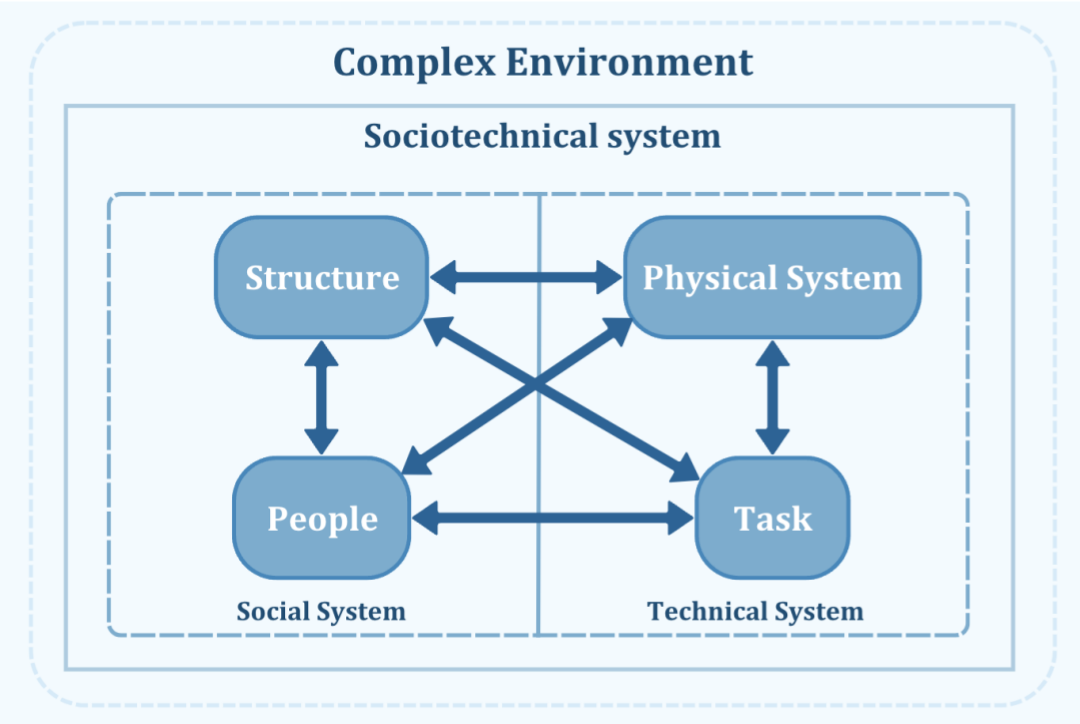
2.1. Socio-Technical Systems Design

The first sub-question aims to identify technical and social factors, and to scope these two broad terms within the field of sustainable urban development, the Socio-Technical Systems Design (STSD) framework is used in this study.

Baxter & Sommerville (2010) argue that there is a general consensus that adopting a socio-technical approach in system development results in solutions that are more easily accepted by end-users and provide greater value to stakeholders. The term socio-technical system is currently used to describe various complex systems, and Badham et al. (2000) provide a concise summary of its five major characteristics. These encompass (1) the interconnected components of the system; (2) the connection to external surroundings; (3) the various interrelated social and technical subcomponents of the internal environment; (4) the equifinality of the system; and (5) the dependence on the simultaneous optimisation of the technical and social subcomponents of the system. STSD methods were developed to facilitate the design of such systems, and one of these methods was visualised by Bostrom and Heinen (1977), as shown in Figure 2.1. The perspective presented by Bostrom and Heinen (1977) is used as the foundational framework for this research on BGR implementation. The technical subsystem is characterised as a physical system that encompasses specific features, whereas the task refers to the particular activities being performed (Bostrom & Heinen, 1977). The social subsystem consists of people and an organisational structure that incorporates cognitive elements and the methods in which these people interact.

Figure 2.1

The Socio-Technical Systems Design approach including the elements of the complex environment, sociotechnical system, structure, physical system, people, and task.



Note. Diagram adapted from Bostrom & Heinen (1977). CC-BY NC

Using the STSD framework allows for the thorough assessment of blue-green roofs (BGRs) beyond their technical structure, encompassing social, cultural, economic, and ecological dynamics as well, resembling the nature of the barriers explained in the literature (Section 1.1.2.). By using STSD, it is also ensured that the local context is considered, and the needs of the community can be met, as is stated to be an important factor in addressing potential ethical dilemmas (Section 1.6.). Moreover, STSD emphasises the involvement of stakeholders from various disciplines and backgrounds within the decision-making process.

Within this research, the different segments of the framework by Bostrom and Heinen will be defined. In addition, the arrows in the framework will be defined as well since the functioning of a socio-technical system relies on the interrelations between the different subsystems (Badham et al., 2000; Baxter & Sommersville, 2010).

2.2. Quadruple Helix Approach

As part of the main research question and second sub-question, stakeholder engagement is a key element in this research. Metcalfe & Bennett (2023) argued that in order to establish a resilience culture to climate change in Caribbean Small Island Development States (SIDS), there is a need for a holistic approach rooted in citizens, businesses, and institutions. This fits with the quadruple helix (QH) approach, which will be the starting point of the stakeholder analysis and engagement in this research.

Until the 1990s, most innovation systems operated on the belief that scientific discoveries and inventions would inherently result in economic growth and, consequently, societal progress (Schütz et al., 2019). Nevertheless, other opposing points of view have become more prominent in the past twenty years. The triple helix method involves a combination of universities, businesses, and public sector institutions to promote innovation and expand university-industry interactions. The quadruple helix approach has added the wider community as an additional actor group. Engaging societal actors is anticipated to realign research trajectories with public preferences and result in more desirable and sustainable solutions (von Hippel, 1988; Chesbrough, 2003; Schraudner & Wehking, 2012; Park, 2014; Schütz, 2019). Schütz and colleagues (2019) argue that there is still uncertainty regarding the extent of the societal aspect of the QH approach. They suggest that the focus of this approach should be on comprehending and ensuring mutual understanding of all roles within the QH. This is of lesser importance for the current research, as stakeholder participation will be examined but not implemented. Still, the significance of this will increase as stakeholders actively participate in the possible process of BGR implementation.

The problem statement of this research relates to five distinct barriers: technical, research, financial, cognitive, and cultural barriers. The QH approach can assist in addressing, investigating, and potentially resolving these barriers by encouraging interdisciplinary research and advocating for diverse perspectives. The QH approach will be employed to identify the distinct challenges and possibilities faced by businesses, higher educational institutions, governmental organisations, and various other community groups in relation to the potential implementation of BGR on Curaçao.

2.3. Contextual Considerations

The third sub-question concerns the potential implementation of BGRs on Curaçao. However, without a comprehensive understanding of the context in which this implementation is taking place, its effectiveness may be diminished or rapidly declining. The uniqueness of Curaçao's context originates from its climate and political conditions, its building traditions, and the intrinsic motifs regarding sustainable development. Prior to examining the potential deployment of BGR, it is crucial to comprehend these conditions.

2.3.1. Climate Considerations

Situated between 68–70 degrees West and 12–13 degrees North, Curaçao falls within the Southern Caribbean Dry Zone, characterised by a semi-arid to arid climate (Köppen classification: BS). The island experiences a distinct dry season from February to May and a rainy season from October to January, with intermittent months between June and September. Curaçao is characterised by warm tropical and constant temperatures (Figure 2.2). January has the lowest average temperature of 26.5 °C, while September has the highest average temperature of 28.9 °C. The annual mean maximum temperature is 32.1 °C. Projections suggest that the air temperature is likely to rise by 1.4 °C by the year 2100, according to the Meteorological Department of Curaçao (Meteo).

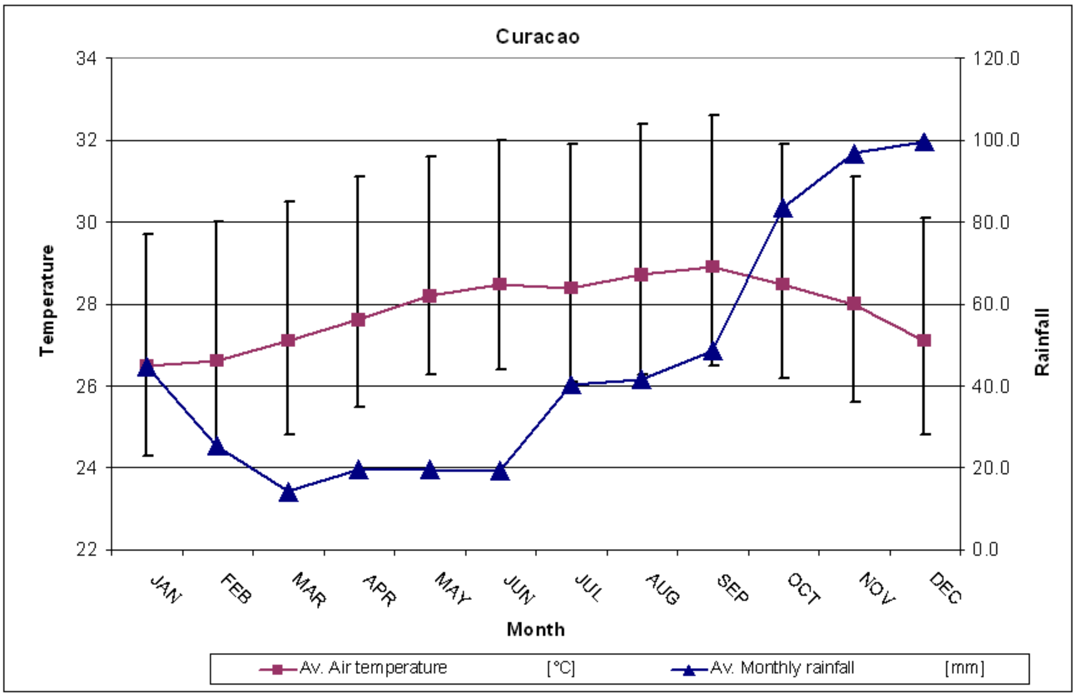
Throughout the year, there are significant variations in the rainfall patterns (Figure 2.2). The annual average precipitation is 550 mm, reaching its highest points from October (84 mm) to December (100 mm). In the rainy season, precipitation usually takes place in the early morning or evening. Nevertheless, the climate of the island sets itself apart from other areas at similar latitudes because of the frequently light and unpredictable nature of the rain. Precipitation is limited during the spring and summer of the northern hemisphere. This is caused by the proximity to the southern mainland and the presence of neighbouring islands.

The island's plant evaporation rates are influenced by average temperatures and rainfall patterns. The evaporation rate, often measured in millimetres per day, is a crucial factor for the BGR design since it informs the designers about the required water amount for optimal vegetation growth and, consequently, the ideal height of the retention layer. The mean evaporation rate in Curaçao is 6.9 millimetres per day and 2500 millimetres per year, which is somewhat higher in comparison to other surrounding areas.

Curaçao is situated outside the hurricane belt; however, it is sporadically impacted by these natural calamities. According to researchers, the island experiences major storms around once every 28.8 years (Meteo, n.d.). Hurricane Felix (2007) and Omar (2008) were the most recent storms to affect Curaçao.

Figure 2.2

Climate summary with the average air temperature (red) and the average precipitation (blue) per month.



Note. This diagram was adapted from the meteorological department of Curaçao (Meteo). CC-BY NC

2.3.2. Legal and Governmental Policy Considerations

Curaçao is not part of EU territory, meaning that they have the rights of EU citizenship but do not need to adhere to EU laws. These rights make the island eligible for European fundings and EU-wide cooperation agreements.

The absence of comprehensive regulations and guidelines governing climate change on Curaçao is another crucial aspect to understand the context of this research. While the government of Curaçao addresses the challenges of climate change (Ministerie van Infrastructuur en Waterstaat, 2022), research conducted by Bruijn and Dieperink (2022) indicates that the adaptation governance of Curaçao falls short. Their findings reveal deficiencies in government effectiveness, accountability, and connectivity, as well of a lack of urgency. In his podcast "De Vergeten Klimaatcrisis" (The forgotten climate crisis) John Samson adds the current emphasis on Curaçao on research and education rather than action. Despite plans for collaboration between the Netherlands and Curaçao in the realm of sustainable energy (Government of the Netherlands, 2022), the lack of tangible action emphasizes the relevance of exploring small-scale adaptation strategies that can be initiated by the community itself, semi-bypassing the inertia of the government.

The legal framework for spatial development and environmental protection on the island primarily relies on the Island Development plan (1995), which was updated in 2016. At that same moment, a draft for National Ordinance on Environmental Management Principles was developed, intending to require development projects to submit environmental impact reports. However, as of now, this regulation has not been implemented, resulting in many projects proceeding without consideration of environmental impact and corresponding mitigation measures (United Nations, 2018). Experts emphasize the urgency of accelerating legislative processes for processing, approving, and enacting legislation, as well as updating existing laws and regulations to establish a coherent and effective environmental policy framework (Algemene Rekenkamer Curaçao, 2015). The main reasons for the absence of a solid policy framework include a shortage of human and financial capital, along with a deficiency in specialised expert knowledge related to climate adaptation strategies.

To address these challenges, the Roadmap for SDG implementation in Curaçao (2018) proposes a comprehensive plan, developed at the request of the Government, aimed at informing the Ministries responsible for achieving the 2030 Agenda.

Finally important to understand the political culture of the island, it is important to recognise the importance of power relations on Curaçao. Curaçao is a small island, where most influential people know each other, where many matters are handled informally, family ties are strong and there are many conflicts of interest as a result (Schotborgh-Van De Ven, 2019).

2.3.3. Structural Building Traditions

To comprehend the potential integration of BGRs into urban design on Curaçao, it is crucial to delve into the local construction practices. The architectural landscape of this region is mainly shaped by the island's local geography, which influences the climate affecting buildings and the availability of construction materials.

As described in Section 2.3.1., the climate of Curaçao substantially influences the construction, placement, and design of dwellings due to the presence of severe weather patterns. Factors such as solar radiation, high wind speeds, and salt in the air pose challenges to building condition. Consequently, adaptive design strategies should enhance the resilience of dwellings against these influences. For instance, maintaining a cool environment can be achieved by optimising ventilation and shading, and a solution frequently implemented on Curaçao involves incorporating a courtyard in the centre of the dwelling, facilitating natural ventilation (Early, 2014). Furthermore, placement and structural design of dwellings play a crucial role in protection against hurricane damage. Buildings are usually positioned in a specific way to avoid direct damage from prevailing hurricane winds and have hurricane shutters and reinforced structures and roofs. Notably, constructing dwellings with flat roofs is a recognized solution for mitigating hurricane winds.

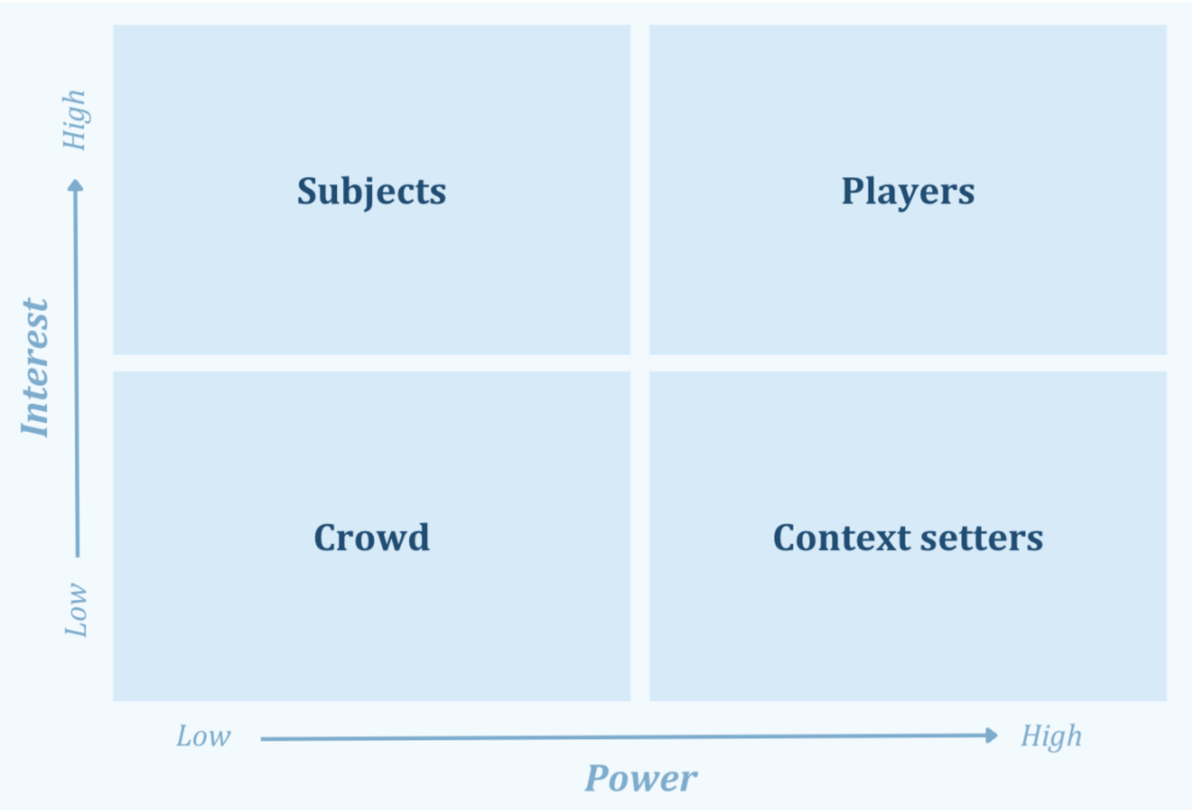
Given the limited local resources available on the island, a substantial part of construction materials needs to be imported, potentially increasing both costs and construction timelines. However, the use of concrete and natural indigenous stone materials helps alleviate this by reducing the reliance on imported materials. Consequently, concrete emerges as a primary material in various construction projects on Curaçao (Tissink, 2023).

2.3.4. Motifs for Sustainable Urban Development

As previously stated, the literature recognises community-based development approaches as an opportunity to improve resilience in SIDS (Robinson, 2020). However, it is essential to first comprehend the particular motifs of the community before implementing a community-based approach and engaging stakeholders. The degree of involvement in sustainable urban development varies among stakeholders and is frequently influenced by multiple factors. To build a full understanding of each stakeholder, this study will initially profile them based on their power and interest in sustainable urban development. Additionally, individuals might exhibit distinct drivers, motivations, and barriers that they can encounter in relation to this matter. A classification of stakeholders according to their power, interest, drivers, motivations, and barriers will be utilised to enhance the QH approach in addressing the second sub-question and discussing the third sub-question.

Figure 2.3

The Power/Interest grid with the four categories of subjects, players, crowd, and context setters.



Note. Adapted from Eden & Ackermann (1998).

Eden and Ackerman (1998) developed a structured approach to stakeholder profiling that is based on assessing the power and interests of stakeholders. The authors suggest using a two-dimensional grid to categorise stakeholders into four distinct categories, as shown in Figure 2.3.

'Players' possess significant power over sustainable urban development and demonstrate a strong interest in its activities. It is crucial to closely manage these groups or individuals, actively engage them in initiatives and decision-making processes on a regular basis, and maintain a strong relationship with them. The 'subjects' have little power but are interested. It is crucial to ensure that these stakeholders are kept informed and that their opinions are acknowledged. 'Context setters' have significant power over sustainable urban development; however, they do not generate much interest. Frequent engagement and consultation with these stakeholders is crucial, as their lack of interest poses a risk to sustainable urban development. Finally, the 'crowd' has both limited power and little interest in sustainable urban development, which means these stakeholders could be engaged on a lower level (Eden & Ackermann, 1998).

The interests of stakeholders could originate from different characteristics. Within this study, the drivers, motivations, and barriers associated with sustainable urban development are defined. Drivers are factors or conditions that can convince stakeholders to act and are often viewed from an external standpoint. Motivations are internal factors or goals that different stakeholders want to achieve through sustainable urban development. Barriers can be both internal and external factors constraining stakeholders to be involved actively and positively (Zhang & He, 2021). Drivers are factors or conditions that can convince stakeholders to act and are often viewed from an external standpoint. Motivations are internal factors or goals that different stakeholders want to achieve through sustainable urban development. Barriers can be both internal and external factors constraining stakeholders to be involved actively and positively (Zhang & He, 2021). The drivers (Table 2.1) and motivations (Table 2.2) for stakeholder engagement with BGR implementation on Curaçao in this study are derived from the research conducted by Zhang & He (2021). The barriers presented in Table 2.3 are derived from this research as well, along with the barriers mentioned in Section 1.1.2.

Table 2.1

Drivers for stakeholders to engage in BGR implementation on Curaçao.

No.	Drivers	Examples
1.	Policy pressure	- Incentive programs by municipalities to include sustainable building practices. - Regulations in building codes that demand to incorporate runoff cor constructional design. - Policies focused on preserving biodiversity.
2.	Economical pressure	- Cost savings for dwelling owners and municipalities through energy efficient design. - Funding by governmental or private stakeholders. - Increased property value for property sellers.
3.	Reputational pressure	- Sustainability certifications that companies can obtain by including sustainable design. - Positive media recognition for companies contributing to sustainable design.
4.	Innovation and technology advancement	- Research and development constantly improving sustainable innovations. - Collaboration with forerunner tech companies.

Table 2.2

Motivations for stakeholders to engage in BGR implementation on Curaçao.

No.	Motivations	Examples
5.	Energy efficiency	- Cost savings for dwelling owners and municipalities. - Cutting electricity crisis with economic benefits for governments. - Beneficial for sustainable development.

6.	Urban heat island mitigation	- Beneficial effect on mental health for all citizens. - Cost savings for governments.
7.	Roof longevity prolongation	- Postponement of high maintenance or roof system replacement, and thereby reduced costs.
8.	Solar panel enhancement	- Improvement of energy efficiency of the dwelling. - Long-term return on investment on energy bills.
9.	Air purification	- Reduction of air pollutants from industrial emissions.
10.	Runoff control	- Alleviating the pressure on the drainage systems of the built environment. - Prevent floods and therefore damage due to weather events.
11.	Water purification	- Reduction of water pollutants from acid rains and construction materials.
12.	Noise reduction	- Reduce noise from outside sounds to inside the dwelling.
13.	Biodiversity increase	- Creating green zones as settlement for wildlife species.
14.	Recreation and aesthetics	- Providing conducive spaces for mental relaxation and energy recovery. - Providing spaces for social activities.
15.	Property value enhancement	- Adding market value of a dwelling.
16.	Employment improvement	- Creating a niche in architectural, constructional, engineering, and vegetation fields. - Generating employment across diverse socioeconomic and educational strata.

Table 2.3

Barriers for stakeholders to engage in BGR implementation on Curaçao.

No.	Barriers	Examples
17.	Technological barrier	- Shortage of trained professionals with the qualities to address environmental challenges. - Lack of knowledge and expertise on BGR implementation. - Lack of examples on BGR implementation.
18.	Research barrier	- Small-scaled research because of a lack of financing. - Small-scaled research because of a lack of academics specialized on topics related to BGRs.
19.	Financial barrier	- Investment in research is a small portion of GDP. - Receiving little international climate finance. - Not qualified to borrow from international donors. - Preference for cheaper hard-engineering solutions over more expensive sustainable innovations.
20.	Cognitive barrier	- Absence of attention towards the topic of climate change and adaptation strategies. - Lack of understanding these topics by the local community.
21.	Cultural barrier	- Limited consideration given in adaptation planning to the role of traditional knowledge. - Paucity of education material and other communication outputs in local dialects.
22.	Lack of government policy	- Lack of guidelines and regulations on sustainable urban development. - Lack of incentives for design and construction companies to include sustainable practices.
23.	Individual unwillingness	- Lack of a complete cost-benefit analysis. - Individuals unwilling to pay the investment costs of a BGR over a grey roof. - Lack of promotion from the public sector to the private sector and the local community.

2.4. Assumptions

Before exploring the potential of implementing BGR on Curaçao, this study establishes a few assumptions to frame its scope. The assumptions are based on the theoretical framework and contextual factors, and they have been validated through literature. The assumptions of this research are as follows:

1. Curaçao is experiencing urbanisation patterns, which may result in challenges related to heat island effects and stormwater runoff.
2. The benefits and relevance of blue-green roof implementation, established in global studies, are applicable to the context of Curaçao.
3. A modest but increasing consciousness of environmental concerns is observed within the population of Curaçao. This will make this research useful.
4. Blue-green roof implementation involves stakeholders from all four categories that underpin the Quadruple Helix approach.
5. The integration of blue-green roofs in urban planning would align with existing or developing policy frameworks on Curaçao.

There is sufficient availability of relevant data for conducting a meaningful study on the potential of BGRs in Curaçao.

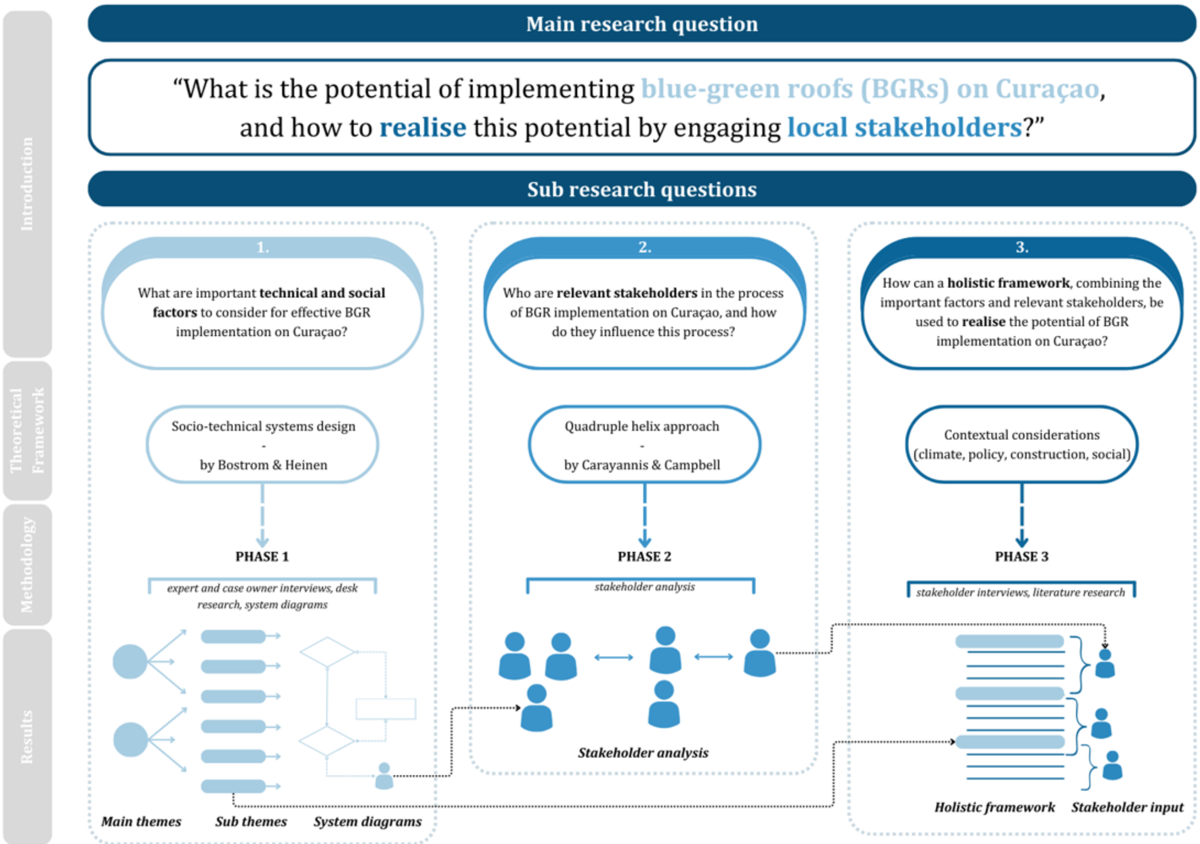
3. Methodology

3.1. Exploratory Research

To address both the main and sub-research questions, an exploratory study has been conducted. Blue-green roofs (BGRs) are systems that combine multiple technical and social functionalities and should be considered as part of broader systems on different scales. This makes their development and implementation complex, making exploratory research instrumental for comprehending the entire system and its context. The flexibility of exploratory research methodologies made it particularly fitting for this study, given that they allowed the approach to be adapted to the wide scope of the subject and the changing direction of the study along with the insights and knowledge gaps being uncovered. Qualitative methods were used, allowing this research to explore the richness and complexity of human experiences in the given context (Madjar et al., 2002; Booth, 2006).

Figure 3.1

A section of the research design including the research questions, the research phases, the methods used and the expected outcomes.



Note. The overview of the complete research design can be found in Appendix 1 – Research Design.

3.2. Three Research Phases

To provide a thorough answer to the main research question and the different sub-questions, this research was divided into three distinct phases. The overarching objective of this research was to explore the potential of BGRs as a climate adaptation strategy on Curaçao. Shaping the three phases of this study, the aim was to: (1) identify the multi-level factors essential for the implementation process; (2) associate the relevant stakeholders of this process; and (3) connect these factors and stakeholders in a holistic framework. The output of the first phase became a component of the input for the second phase. Following this, the input for the third phase was composed of the outputs from both the first and second phases (Figure 3.1). The sections that follow describe each phase in detail, explaining why these methods were chosen, what part of the theoretical and contextual framework guided this phase, and what outcomes were expected.

3.2.1. Phase 1: Identifying Factors for BGR Implementation

Phase 1, referred to as the 'identifying factors' phase, focused on answering the first sub-question: *"What are important technical and social factors to consider for effective BGR implementation on Curaçao?"* The methods employed during this phase included framework adaptation, conducting interviews, performing desk research, and system diagramming. The findings of Phase 1 are presented in Chapter 4 and discussed upon in Section 7.1.

Phase 1.1: Socio-Technical System Design framework

In the first phase, the objective was to establish a foundational understanding of the key factors that influence the process of BGR implementation, specifically on Caribbean SIDS as Curaçao. To achieve this, the Socio-Technical System Design (STSD) framework developed by Bostrom and Heinen (1977) was applied. The STSD framework (Section 2.1., Figure 2.1) was chosen because it provides a holistic perspective, allowing to synthesise the complex interplay between social, organisational, and technical aspects.

The approach of this method was to adapt the original framework to the context of BGR implementation on Curaçao, translating every arrow in the diagram to address the unique challenges and opportunities. The input for this method came from setting the problem statement (Section 1.3.) and the case study (Section 1.5.).

The expected output of this phase was a set of overarching themes, which serve as a foundational framework for understanding the critical aspects influencing BGR implementation. This output was used in the future stages of Phase 1 and was reflected upon in Phase 3.

Phase 1.2: Expert and case owner interviews, and desk research

To further elaborate on the themes identified in Phase 1.1, a combination of research methods was employed, including an expert interview, desk research, and a case owner interview. These methods facilitated the expansion of the understanding of the identified themes by creating a detailed network for each of them.

The approach to this method involved interviewing two individuals. A researcher from Wageningen University & Research (WUR) was interviewed as an expert on BGRs. He has over twenty years of experience in the field from both the organisational and academic points of view specified in the Dutch and European conditions. The project developer of Wechi was interviewed as the case owner of the case study to explore their rationale behind the project. Desk research was carried out to supplement the insights from the two interviews. To identify, review, and report on the technical and social aspects of the research, the STARLITE principles were applied (**s**ampling strategy, **t**ype of study, **a**pproaches, **r**anges of year, **l**imits, **i**nclusion and exclusions, **t**erms used, **e**lectronic sources) (Booth, 2006; Table 3.1). This principle is designed for qualitative, systematic literature review and allows for easy replication of the research method (Booth, 2006). Following Berrang-Ford et al. (2015), who noted that a reviewer must place limits on the scope of the literature included, the desk research in this phase included around 5–10 articles from the first fifty results.

The expected output of this phase was a detailed overview of all the main factors and sub-factors under the overarching themes previously identified. Moreover, a first overview of the connections between these factors and potential stakeholders was expected. This provided a more nuanced perspective on the aspects influencing BGR implementation. The output of this phase was used as the foundation for Phase 1.3 and as input for Phase 3. The output related to the potential stakeholders was used as input for Phase 2.

Table 3.1

The STARLITE principle applied to the desk research of Phase 1.2.

Systematic review of multi-level factors of BGRs	
Sampling strategy	**Selective**: Studies relevant to the technical and social aspects of BGR systems worldwide.
Type of the study	**Partially reported:** Any qualitative, quantitative, or mixed methods study.
Approaches	Electronic subject searching and citation snowballing.
Range of years	**No restrictions:** To the beginning of each candidate database – to the end of 2023.
Limits	English or Dutch.
Inclusion and exclusions	**Inclusion:** Studies with case studies on SIDS or other places with a tropical climate similar to Curaçao. **Exclusion:** Studies with case studies on SIDS with an extreme cold climate.
Terms used	**Partially present:** • 'green roofs' OR 'blue-green roofs'; AND • 'SIDS' OR 'Curaçao' OR 'semi-arid climate' OR 'tropical climate' … appearing in titles, abstracts, and keywords.
Electronic sources	Google Scholar.

Phase 1.3: System diagrams

The themes identified in Phase 1.1 and the comprehensive network of factors in Phase 1.2 were systematically interconnected using the system diagramming method. The primary objective of visualising this elaborate network of information was to uncover potential interrelations and illustrate how changes in one segment of the system can impact other components.

The approach of this method was to employ system diagramming techniques at two distinct levels: individual dwellings and neighbourhoods. The system diagrams encompassed both technical aspects of BGRs and the organisational structures guiding the implementation process. Components featured in the diagrams included inputs, outputs, technical components, potential stakeholders, processes, and actions. In the absence of existing BGR system diagrams, the input for developing these diagrams was derived from results of Phase 1.1, supplemented with the insights gathered in Phase 1.2.

The expected output of this phase included two distinct system diagrams at the dwelling level and two at the neighbourhood level. These diagrams are effective tools for displaying potential BGR implementation strategies on Curaçao and could be used as a starting point when exploring this. They served as inputs for Phase 2 and Phase 3.

3.2.2. Phase 2: Associating Stakeholders for BGR Implementation

Phase 2, titled the 'associating stakeholders' phase, addressed the second sub-question: *"Who are relevant stakeholders in the process of BGR implementation on Curaçao and how do they influence this* *process?"* The method employed during this phase was a multifaceted stakeholder analysis. The results of Phase 2 are presented in Chapter 5 and discussed in Section 7.1.

Phase 2.1: Stakeholder analysis

The objective of Phase 2 was to relate the factors identified in Phase 1 to the specific context of Curaçao by conducting a multifaceted stakeholder analysis. This aimed at identifying key individuals or groups essential for BGR implementation at all different stages. This analysis contributed to the understanding of the roles different stakeholders can perform in this process and what their motives, challenges, and drivers are. Moreover, the stakeholder analysis aimed at disclosing the interrelationships and co-dependencies between the different actors.

The approach of this method was to perform this stakeholder analysis following a few steps, including the Quadruple Helix (QH) approach (Section 2.2.), chosen for its holistic character matching this research. This approach considers stakeholders from various sectors, including industry, community, government, and academia. As a first step in this stakeholder analysis, a list of important stakeholders was generated. This list was derived from relevant literature (Zhang & He, 2021) and complemented by the expert and case owner interviews from Phase 1.2. Then the stakeholders were divided into the four categories underpinning the QH approach: academia, industry (private sector), government (public sector), and societal actors. The third step in this stakeholder analysis included placing all the identified stakeholders on the Power/Interest grid (Eden & Ackermann, 1998). Finally, for each stakeholder, drivers, motivations, and barriers were established in order to generate a complete picture of the stakeholders and their roles. Drivers are factors or conditions that can convince stakeholders to act and are often viewed from an external standpoint. Motivations are internal factors or goals that different stakeholders want to achieve through BGR implementation. Barriers can be both internal and external factors that constrain stakeholders from being involved in the BGR implementation actively and positively. Input for these drivers, motivations, and barriers stemmed from literature (Zhang & He, 2021) and the output of Phase 1.

The expected output of this phase was a comprehensive list of important and necessary stakeholders and their characteristics, who were further engaged in Phase 3.

3.2.3. Phase 3: Connecting Factors and Stakeholders for BGR Implementation

Phase 3, referred to as the 'connecting factors and stakeholders' phase, addressed the third sub-question: *"How can a holistic framework, combining the important factors and relevant stakeholders, be used to realise the potential of BGR implementation on Curaçao?"* The methods employed during this phase include conducting stakeholder interviews and performing scientific and grey literature review. The results of Phase 3 are presented in Chapter 6 and discussed in Section 7.1.

Phase 3.1: Stakeholder interviews

The aim of Phase 3 was to establish a holistic understanding of how the various factors of BGR implementation identified in Phase 1 interrelate with the stakeholders associated in Phase 2. This holistic understanding was placed within the specific socioeconomic and environmental landscape of Curaçao and potentially other SIDS. This phase allowed for connecting the factors to each other, the system, its stakeholders, and the context to establish a complete picture and allow for uncovering the interdependencies that may exist. To create these connections, deeper understandings were gained of the specific factors identified in Phases 1.1 and 1.2. Moreover, to link them to the stakeholders identified in Phase 2.2, stakeholder interviews were conducted. The interviews allowed for delving into specific topics and factors while identifying the individuals who can contribute to BGR implementation on Curaçao.

The approach of to method was a six-week field study on Curaçao, involving semi-structured interviews with relevant stakeholders. These stakeholders were contacted beforehand and defined partly through the case owner interview and partly through the stakeholder analysis (Section 5.1.). The structure of the interviews was determined by the results of the previous phases. The interviews were transcribed with *Good Tape* (mygoodtape.com) and coded in *ATLAS.ti,* where they were structurally analysed and summarised in coherent overarching themes.

The expected output of this phase included valuable and validated insights into all the themes identified in Phase 1, highlighting any knowledge gaps that may emerge. Furthermore, an expected output of this phase were strategies for the utilisation of the established holistic framework, discussed in Section 7.1 on the interpretation of the results.

Phase 3.2: Scientific and grey literature review

To build upon the insights gained from stakeholder interviews, further scientific and grey literature review was done. This step enhanced the understanding of the factors and their context by drawing from existing theoretical and practical knowledge. The findings either confirmed or contradicted statements from the stakeholder interviews, providing valuable context in either scenario.

As in Phase 1.2, the STARLITE principles were applied to identify, review, and report on the multi-level aspects of BGR implementation on Curaçao (Booth, 2006; Table 3.1). All aspects were the same as in Phase 1.2, except for the terms. The terms used were this time supplemented with the outcomes from Phase 1 (Table 3.2). Following Berrang-Ford et al. (2015), who noted that a reviewer must place limits on the scope of the literature included, the desk research in this phase included around 15-20 articles from the first 50–100 results.

The expected output of this phase was additional insights into the main and sub-factors and the possibility to identify and fill any other gaps in the understanding of the potential of BGR implementation on Curaçao. Moreover, anticipated outputs were concrete strategies for stakeholders to effectively implement this holistic framework.

Table 3.2

The STARLITE principle applied to the scientific and grey literature review of Phase 3.2.

Additional search terms used in the systematic review of multi-level factors of BGRs.		
Terms used	**Partially present:** • 'green roofs' OR 'blue-green roofs'; AND • 'SIDS' OR 'Curaçao' OR 'semi-arid climate' OR 'tropical climate'; AND	*

	• 'technical design' AND
	  ○ 'irrigation system' OR 'vegetation' OR 'structural considerations' OR 'layers' OR 'solar'…
	• OR 'larger system' AND
	  ○ 'stormwater management' OR 'reuse of greywater' OR 'green infrastructure' OR 'blue infrastructure' OR 'recreation'…
	• OR 'evaluation' AND 'improvement' AND
	  ○ 'responsibilities' OR 'community of practice'…
	• OR 'education' AND
	  ○ 'methods' OR 'collaboration' OR 'subjects'…
	• OR 'community engagement' AND
	  ○ 'education'…
	• OR 'ownership' AND
	  ○ 'responsibilities' OR 'community of practice' OR 'engagement' OR 'education'…
	• OR 'local knowledge' AND 'skills' AND
	  ○ 'education'…
	
	… appearing in titles, abstracts, and keywords.
		**

* These terms were left out of the search if the results turned out too specifically focused on that region.
** These terms are the result from Phase 1.1. and Phase 1.2. To understand where they originate from, first read the result chapters on these phases (Chapter 4).

4. Identifying Factors for Blue-Green Roof (BGR) Implementation (Phase 1)

This chapter relates to the first phase of this research, addressing sub-question 1: *"What are important technical and social factors to consider for effective BGR implementation on Curaçao?"* This first phase aimed at identifying the key factors shaping the process of BGR implementation on Caribbean SIDS such as Curaçao.

To achieve this, the initial approach involved the application of the Socio-Technical Systems Design (STSD) framework to the research context of BGR implementation on Curaçao. The STSD Framework's elements were systematically identified (Table 4.1), and the connections between these elements were subsequently specified (Figure 4.1). These connections resemble the interplay between the elements preferred for effective BGR implementation. As a result, these connections were identified as the seven principles essential for effective BGR implementation on Curaçao, marking the first output of this phase.

These findings were validated and supplemented through expert and case owner interviews, along with desk research. This resulted in further elaboration of the seven principles into 26 main factors and 68 sub-factors. The expert interview facilitated the generation of this comprehensive overview of aspects. Conversely, the interview with the case owner served to identify factors that emerge as particularly urgent or relevant within the context of the Curaçao case. This thorough analysis provided a conclusive response to the first sub-question.

To expand the understanding of the identified technical and social factors influencing BGR implementation on Curaçao even further, the research employed system diagrams. These diagrams served to visually represent the technical system of BGRs and the organisational structures essential to the implementation stages. Within these system diagrams, key elements such as inputs, outputs, physical components, processes, actions, and stakeholders were visualised. This facilitated a holistic comprehension of the BGR context, offering a comprehensive answer to the first sub-question.

In the following sections, a detailed exploration of the results obtained in Phase 1 will be provided.

4.1. STSD Framework Application to BGRs

At first, the BGR implementation context and the Wechi case study were used to look at different elements of the STSD framework (Table 4.1, Figure 4.1). This resulted in the following translations: The 'complex environment' was identified as the neighbourhood or a specific area within it, as this is where BGR implementation takes place. Following that, since this is the topic of this study, the 'sociotechnical system' was recognised as the BGR itself, and the 'physical system' as the technical component of the BGR system. The 'task' of the framework was defined as the different stages of system implementation, inspired by Zhang and He (2021): initiation, site analysis, design, construction, and evaluation and improvement. A promotion stage was added to the Wechi case, as BGR innovation is still unknown within the local community, necessitating promotion in policy and urban planning areas (Zhang & He, 2021). Based on input from the expert and case owner interviews, the 'structure' was identified as a community of practice around BGRs, representing a new niche community in the case of Wechi. A community of practice entails a group of people who share a concern or passion and learn to enhance their practices through interaction (Wenger-Trayner & Wenger-Trayner, 2021). Lastly, informed through the case owner and expert interviews as well, the 'people' involved were defined as the project developer, end-users, and different teams in the stages (design, construction, research, and maintenance). Specific stakeholders for BGR implementation on Curaçao were identified in the stakeholder analysis in Phase 2.1. (Section 5.1.).

Table 4.1

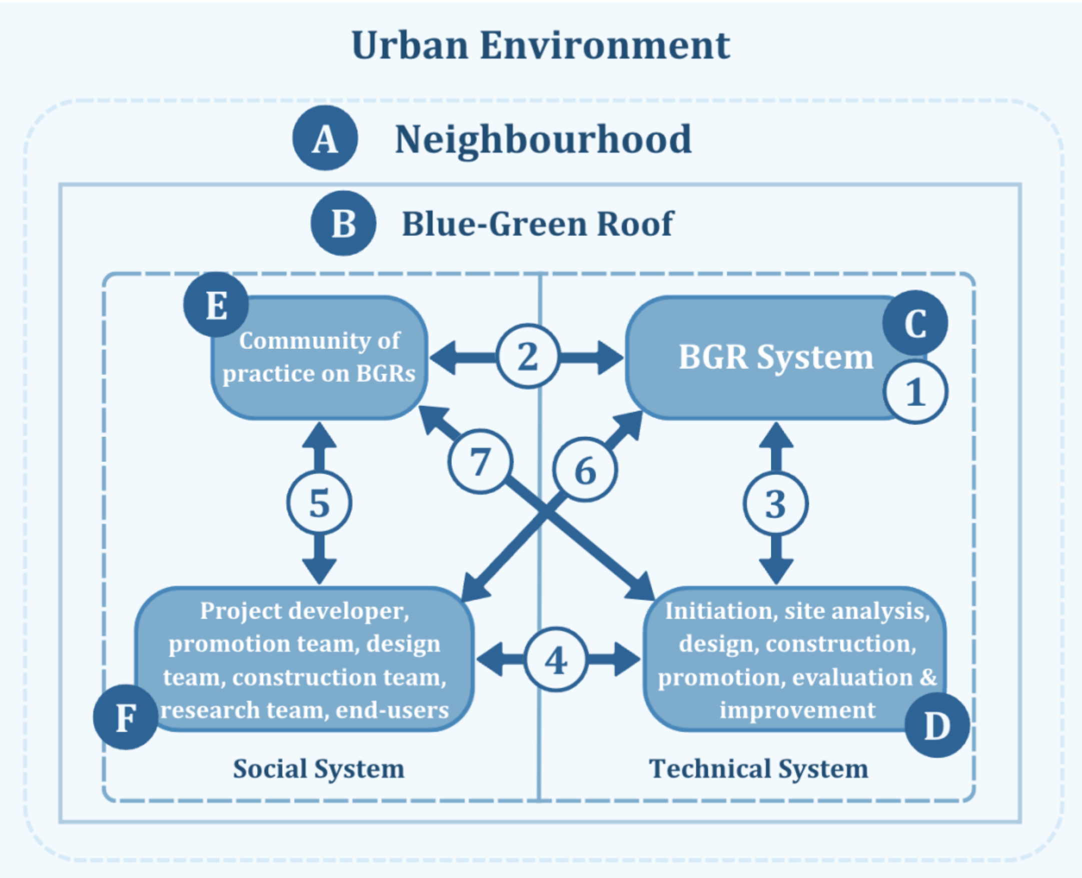
The six elements of the STSD framework by Bostrom & Heinen (1977) applied to the context of BGR implementation in general (second column) and more specific in Wechi on Curaçao (third column).

Elements		Applied to the context of...	
		BGR implementation (general)	BGR implementation (Wechi, Curaçao)
A.	Complex environment	(Part of a) neighbourhood	Wechi
B.	Sociotechnical system	Blue-Green Roof (BGR)	Blue-Green Roof (BGR)
C.	Physical system	BGR system	BGR system
D.	Task	Initiation, site analysis, design, construction, evaluation & improvement	Initiation, site analysis, design, construction, <u>promotion</u>, evaluation & improvement
E.	Structure	Community of practice on BGRs	New niche community of practice on BGRs
F.	People	Project developer, designer team, construction team, research team, end-users	Wechi MC, designer team*, construction team*, research team*, residents of Wechi

* To be further determined in the stakeholder analysis (see *Section 5.1*).

Figure 4.1

The STSD framework by Bostrom & Heinen (1977) adapted to the context of BGR implementation.



Note. *Own work (October 2023). CC-BY NC.*

By identifying these six elements within the context of BGR implementation, the BGR multi-level sociotechnical framework took shape. As a next step, the arrows between the different elements were translated to the context of BGRs and Wechi (Figure 4.1). These arrows in the diagram illustrate the interconnections between the various elements of the STSD framework, and translating these arrows resulted in the principles of how BGR implementation on Curaçao can be effective. The expert and case owner interviews validated and supported this list of principles. Keeping in mind that there is no specific hierarchical order or timeline in this list, these principles are as follows:

1. **Technical design.**
   The technical design of the BGR adapts to the contextual conditions of Curaçao, including political, environmental, structural, and social factors.
2. **Connections to larger context.**
   The BGR is integrated into the larger technical blue- and green infrastructures present on the island.
3. **Iterative innovation design.**
   Continuous improvement of the BGR system design.
4. **Transferring knowledge.**
   Learning from successful BGR implementations worldwide and drawing from their experiences.
5. **Community acceptance and engagement.**
   Social acceptance, interest in the innovation, willingness to participate, and engagement from the local community of Curaçao with the concept of BGRs.
6. **A sense of ownership and commitment.**
   End-users and/or project developers have a sense of ownership of the BGRs, and there is a commitment by the design, construction, and research teams.
7. **Local skills and knowledge.**
   Utilisation of local skills and knowledge present on Curaçao in order to implement and maintain the BGRs.

4.2. Elaborating the Framework with Multi-level Aspects

The expert and case owner interviews also contributed to further elaborating the STSD framework, revealing all sociotechnical aspects related to BGR implementation. By consulting the expert on specific technical elements and focusing on social aspects with the case owner, various subject matters emerged. This information, combined with data from desk research, was structured by breaking down the seven identified principles of BGR implementation ([1] technical design, [2] connections to a larger context, [3] iterative innovation design, [4] transferring knowledge, [5] community acceptance and engagement, [6] sense of ownership and commitment, and [7] local skills and knowledge) into different main factors and sub-factors.

Furthermore, these identified factors were related to potential stakeholders in BGR implementation. These stakeholders were further defined in Phase 2 of this research, and therefore they were at first classified as the 'people' element of the STSD framework: the project developer or end-user, the design team, the construction team, the research team, the maintenance team, and other stakeholders. This facilitated the structuring of the stakeholder interviews in the third phase of the research.

The definite framework comprises seven sections, reflecting the list of principles from Section 4.1., with 26 main factors and 68 sub-factors, as detailed in Appendix 2. It is worth noting that certain main factors and sub-factors extend across diverse sections, thereby highlighting the inherent interconnectedness of the sociotechnical system. Throughout the subsequent phases of the research, the list of themes was consistently used as a point of reference. It served as the foundational basis for the formulation of system diagrams, guided the structuring of the stakeholder interviews, and informed the literature review.

4.3. Creating System Diagrams of BGR Implementation

The multi-level factors identified in Phase 1 served as a starting point for constructing the system diagrams. These diagrams illustrate the technical system of BGRs and the organisational structures underpinning the implementation stages. Within the system diagrams, elements such as inputs, outputs, physical components, processes, actions, and stakeholders were defined.

4.3.1. Technical System Diagrams on the Dwelling and Neighbourhood Levels

In Section 4.1, the principle 'The BGR is integrated in larger technical infrastructures' was identified as essential for effective BGR implementation on Curaçao. This led to the decision to visualise system diagrams at both the dwelling and neighbourhood scales. Another crucial principle emphasised that 'the technical design of the BGR adapts to contextual conditions, including political, environmental, and structural factors'. Adapting to the environmental context of Curaçao, this resulted in an additional differentiation made to account for the distinct characteristics of the rainy and dry seasons.

The outputs from applying and elaborating on the STSD framework were used to generate the technical system diagrams. Drawing insights from desk research (Braithwaite, 2012; Rowe et al., 2014; Jim, 2015; Nektarios, 2018; Penkova, 2020; Permavoid, 2020; ICJB-Projects, n.d.; Meteo, n.d.) and the expert interview, a conceptual technical setup for the BGR system was developed. During the rainy season from October through January (Figure 4.2), main inputs would include precipitation and water from the main water grid, which flows into the irrigation system, distributing water over the BGR. In contrast, during the dry season from February through May (Figure 4.3), the main input would be from the main water grid, occasionally supplemented by precipitation. Both water inputs will be stored within the vegetation and the retention layer. Water would exit the system through evaporation by the vegetation and controlled release via the smart valve. According to the expert interview, the smart valve, responsive to sensory weather input such as upcoming rainstorms, could regulate the water flow into the drainage system of the dwelling. The case owner expressed the wish to include solar panels on the roof of each dwelling, allowing this element to be included in the system diagrams, powering the electrical pump of the irrigation system.

One of the main goals for the development of Wechi, as stated by the case owner, is to connect the dwellings to a centralised water treatment plant in the neighbourhood. Therefore, ideally, the drainage system of the BGR would connect to a cistern, itself linked to this water treatment plant (Figure 4.4). This cistern would have its own emergency overflow system that transports the water to the drain when the retention container reaches its maximum capacity. If there is no rainfall and a demand for water in the BGR system, the water would cycle back from the cistern to the irrigation system, completing the loop.

Beyond providing treated domestic greywater to the BGRs, the centralised water treatment plant could serve multiple purposes, including supporting agriculture and industry with water (Rainproof, n.d.). Sludge could be used in agriculture, while the generated energy would contribute to the main energy grid system, subsequently powering components of the BGR system. Finally, the effluent water produced by the centralised water treatment plant proves ideal for water management innovations like BGRs, infiltration wells, wadis, and various emerging solutions (Rainproof, n.d.). These innovations could collectively play a crucial role in alleviating pressure on the primary drainage systems within the neighbourhood.

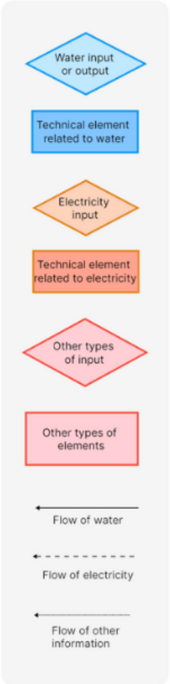


Figure 4.2

Proposed technical system diagram at the dwelling level during the rainy season (October through January).

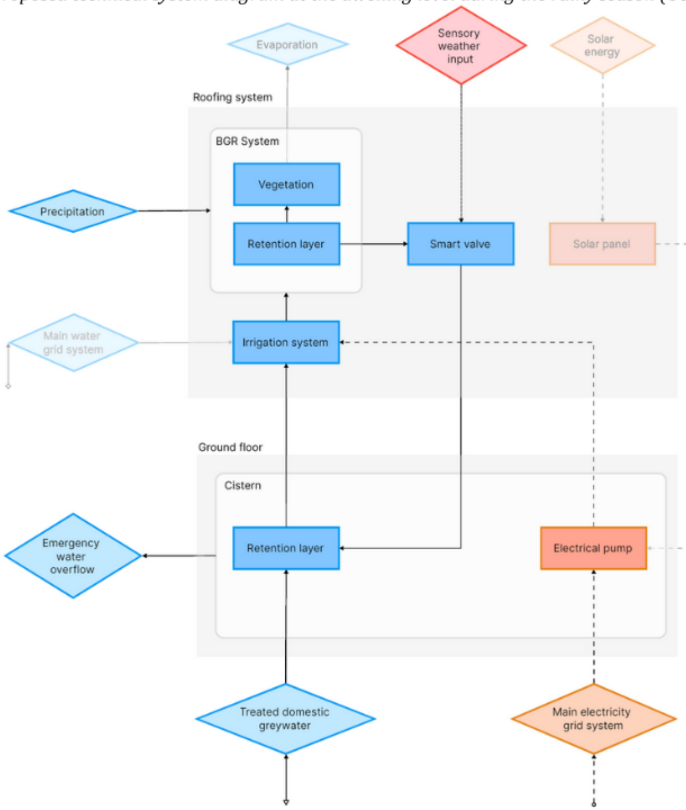


Figure 4.3

Proposed technical system diagram at the dwelling level during the dry season (February through May).

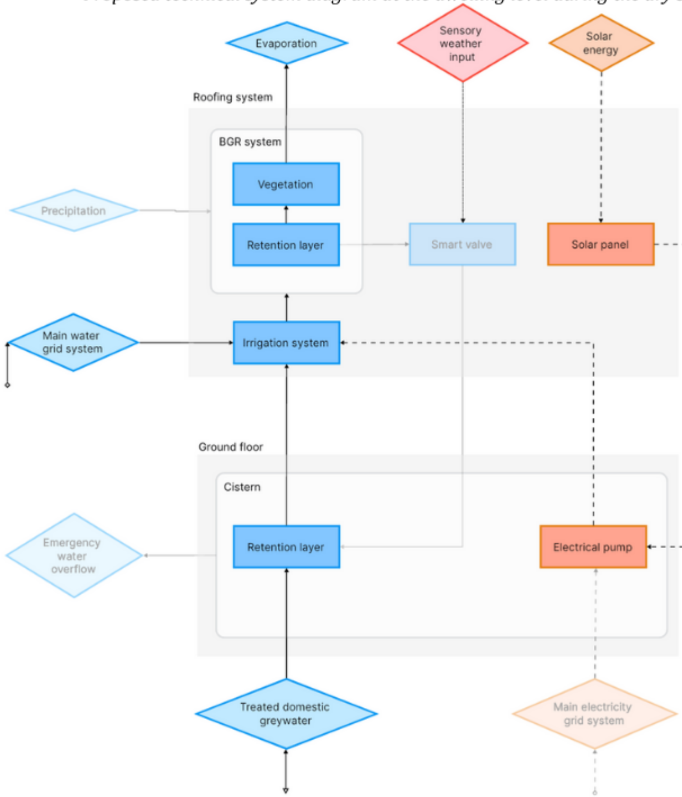


Figure 4.4

Proposed technical system diagram at the neighbourhood level, independent of seasonal variations.

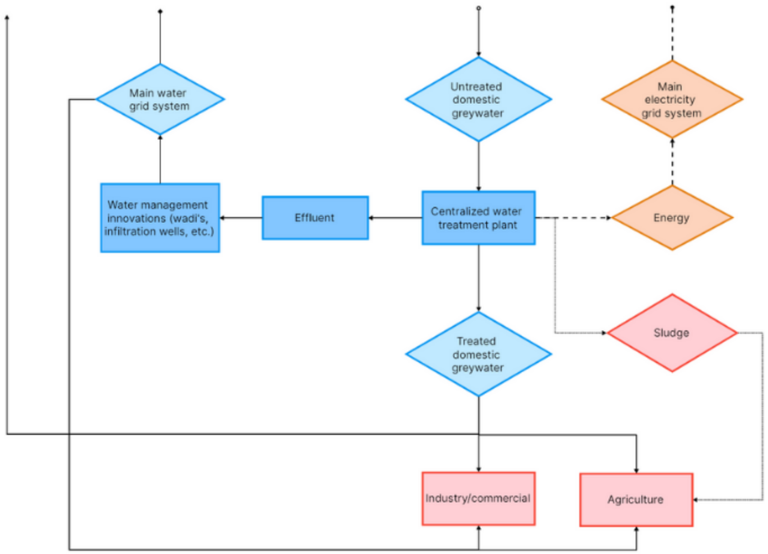
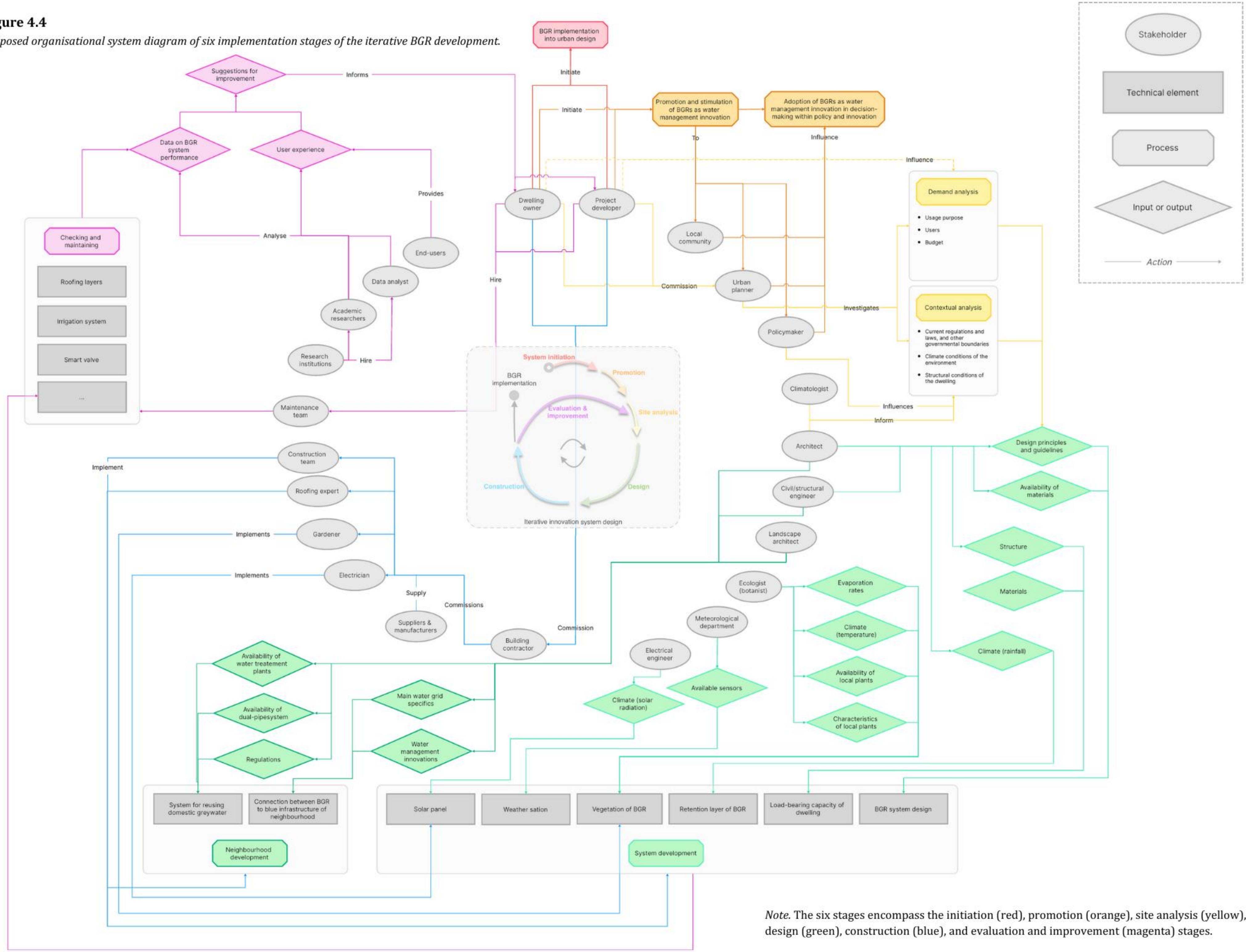


Figure 4.4

Proposed organisational system diagram of six implementation stages of the iterative BGR development.



Note. The six stages encompass the initiation (red), promotion (orange), site analysis (yellow), design (green), construction (blue), and evaluation and improvement (magenta) stages.

Note. Own work (October 2023).

4.3.2. Organisational System Diagrams on the Neighbourhood Level

By visualising the technical system, it became evident which elements and structures require development for BGR implementation on Curaçao. The next step involved integrating these elements and structures with social and organisational factors, and this became the input for the organisational system diagram.

In Section 4.1., the six different stages of system implementation were defined, following Zhang & He (2021): initiation, promotion, site analysis, design, construction, and evaluation and improvement. The expert interview confirmed that these six stages represent the BGR implementation process on Curaçao. The interview with the case owner revealed that in the case of Wechi, the initiation stage has passed, and the next step would indeed be to promote the BGRs to different relevant stakeholders on Curaçao. At the same time that the project's architect was creating the initial design for the BGR, the site analysis process was launched. This showed that the different implementation stages intermingle timewise; nonetheless, they were visualised in the organisational system diagram as how they would take place one after the other.

The process of BGR implementation on Curaçao would begin with dwelling owners or project developers, referred to as the initiators, initiating the implementation of BGRs into the urban environment (Figure 4.5-red).

In environments where BGRs are unfamiliar, a promotional phase would follow (Figure 4.5-orange). The promotion of this innovation is a prerequisite before its development and implementation (Zhang & He, 2021). BGRs should be advocated towards urban planners to incorporate them into their designs. Simultaneously, the concept of BGRs should be promoted to end-users, encouraging their motivation to financially support them. Additionally, promotion efforts should target policymakers to establish a framework of guidelines and regulations for development and implementation. The initiators could actively promote the BGR concept to these three stakeholder groups. Upon successful persuasion, these groups could then play a pivotal role in influencing the adoption of BGRs as a water management innovation in decision-making processes related to policy and innovation. According to the case owner, at this moment, the promotion stage is lacking for Wechi. Therefore, this could be a primary focus when considering effective BGR implementation for their neighbourhood design.

Once regulations will be in place and there would be support from urban planners and policymakers, a site analysis should be conducted that could inform the design stage (Figure 4.5-yellow). The initiators could commission an urban planner tasked with conducting a site analysis, which should be further divided into a demand and a context analysis. With input from the initiators, the demand analysis should delve into the purpose, users, and financial considerations of the BGR system. Meanwhile, the context analysis should explore current regulations, laws, governmental constraints, environmental climate conditions, and structural aspects of the specific dwellings. Policymakers could contribute to the analysis, influencing the former, while climatologists and architects could contribute insights into the latter two aspects. This comprehensive site analysis, encompassing both demand and context analyses, would result in a set of design principles and guidelines that could inform the subsequent stage. According to the case owner of this study, a general site analysis has been performed and resulted in 'The Masterplan of Wechi'. The urban planner that Wechi Management Company (WMC) hired performed an environmental analysis and included it in this report. However, the Masterplan still lacks information on other contextual analyses that could have been performed, and it is missing understandings of potential climate adaptation strategies such as BGRs. Essentially, this entire research can be seen as the contextual analysis part of the site analysis stage for Wechi and Curaçao.

Separated into dwelling (Figure 4.2/4.3) and neighbourhood (Figure 4.4) levels, this design stage could involve collaboration among various stakeholders, guided by design principles and guidelines established in the previous stage. The architect, civil engineer, and landscape architect would be central figures in this stage (Figure 4.5-green). They should integrate information on materials, dwelling structures, rainfall, evaporation rates, temperatures, and indigenous plants. They should also utilise specifics on the main water grid and existing water management innovations to connect the BGR system to the broader blue infrastructure, incorporating information on greywater reuse regulations, dual-pipe systems, and water treatment possibilities. Collaboration with an ecologist and meteorological department could aid in vegetation and weather station design. Working with an electrical engineer, solar panel design could allow for the incorporation of information on solar radiation. According to the case owner of this study, the architect involved in the project at Wechi was already busy with a design for the BGR system. As this is the fourth stage of the implementation process, it seemed important to reflect this design against the previous stages and see how this design would be adapted regarding them.

Upon finalising the design, the initiators should commission a building contractor to oversee the BGR implementation's construction stage (Figure 4.5-blue). The contractor, in turn, should engage construction experts to manufacture various BGR system components. Suppliers and manufacturers could contribute by providing essential materials. Installation tasks could include an electrician fitting the solar panel on the roof, a gardener planting roof vegetation, and a construction team, along with roofing experts, implementing the remaining elements in both the system and neighbourhood development.

When the BGR system is established, continuous monitoring would be essential. The gathered data could play an important role in the evaluation and improvement stage (Figure 4.5-magenta) by capturing feedback from both the system and the end-users. Initiators could enlist a maintenance team to conduct regular checks on various system elements, including the smart valve, irrigation system, and roofing layers. Research institutions could engage academic researchers and data analysts to examine the maintenance data along with user feedback. The outcome would be a set of improvement suggestions that inform the initiators. Given the iterative nature of innovative system design, this information could serve as motivation for design adjustments, structural modifications, and subsequent rounds of evaluation and improvement.

4.4. Concluding Phase 1 and Starting Phase 2

This phase aimed to identify the key factors influencing the implementation of BGRs on Curaçao. Employing the STSD framework along with expert and case owner interviews and desk research resulted in an elaborate framework of **seven principles** for effective BGR implementation on Curaçao, further divided into **26 main factors** and **68 sub-factors**. All themes were visualised in **technical and organisational system diagrams**, where inputs, outputs, technical and social elements, and stakeholder types were clarified over six different BGR implementation stages.

These results serve as the main response to the first sub-question and define the scope for the remaining research. It illustrates the presence of multi-level aspects in both the social and technical dimensions of the BGR system. Moreover, it highlights that the multi-level aspects can be categorised into different sections while remaining interconnected. This emphasises the importance of using innovation implementation methods that involve experts from various disciplines in the early stages of the process. The Quadruple Helix (QH) method aligns with this approach and was applied in Phase 2 of the research to categorise the stakeholders. The first step for identifying relevant stakeholders was made while establishing the system diagrams. Now, Phase 2 will build upon this result to further associate the relevant stakeholders with BGR implementation on Curaçao.

5. Associating Stakeholders for Blue-Green Roof (BGR) Implementation (Phase 2)

This chapter focuses on Phase 2 of the research and addresses sub-question 2: *"Who are relevant stakeholders in the process of BGR implementation on Curaçao and how do they influence this process?"* The aim of this phase was to build upon the stakeholder types identified in the system diagrams of Phase 1 and to associate them with the specific context of Wechi and Curaçao.

To accomplish this, a multifaceted stakeholder analysis was employed. The first step involved generating a list of key stakeholders identified through the expert interview, desk research, and system diagrams (Chapter 4). This resulted in a compilation of 24 relevant stakeholders for BGR implementation on Curaçao, further specified in the context of Wechi through insights gathered from the case owner interview (Table 5.1).

The stakeholders' categorization into the four groups supporting the Quadruple Helix (QH) approach (Table 5.1) helped to refine this list. This classification revealed 5 academic stakeholders, 13 industry (private sector) stakeholders, 3 government (public sector) stakeholders, and 3 societal actors. This classification offered a comprehensive response to the first part of the second sub-question, unfolding the identities of relevant stakeholders and their respective domains.

The second part of the second sub-question was addressed by positioning the stakeholders on a Power/Interest grid, illustrating how various stakeholders could exert influence on the process of BGR implementation on Curaçao (Figure 5.1). The findings indicated that among stakeholders with significant power over BGR implementation, none were societal actors, with the majority having ties to the government or industry domains. Stakeholders exhibiting high interest in BGR implementation were mainly societal actors and those from the industry domain.

Additionally, an exploration of drivers, motivations, and barriers was conducted for all stakeholders, shedding light on reasons for their engagement or disengagement with BGR implementation. This analysis unveiled clusters of stakeholders with similar characteristics, further contributing to answering the second sub-question.

In the following sections, a detailed exploration of the results obtained in each part of the stakeholder analysis is provided.

5.1. Listing Relevant Stakeholders Categorized by the QH approach

A multifaceted stakeholder analysis was conducted to contextualise BGR implementation on Curaçao. The initial step involved generating a list of key stakeholders identified through the expert interview, desk research, and system diagrams in Phase 1 (Chapter 4). The list encompassed a diverse range of stakeholders, including: the initiators (dwelling owner and project developer), the local community, urban planners, policymakers, climatologists, architects, civil and structural engineers, landscape architects, ecologists (botanists), the meteorological department, electrical engineers, building contractors, suppliers and manufacturers, electricians, gardeners, roofing experts, a construction team, a maintenance team, research institutions, academic researchers, data analysts, and the end-users of the BGRs.

To ensure a more comprehensive representation, stakeholders from Zhang & He's (2021) framework were incorporated. Government agents and NGOs were added, recognising their roles in policy implementation, capacity building, funding research, and raising awareness.

The case owner interview performed in Phase 1 further refined the stakeholder list, adapting it to the context of Curaçao. Efforts were made to ensure applicability beyond Wechi, aiming for representation across the entire island. Given the small community size, certain stakeholders were assigned predefined names or organisations due to their exclusive presence on the island.

Table 5.1

Overview of stakeholders of the BGR implementation on Curaçao supplemented with examples of the context of Curaçao.

Stakeholders	Context of Curaçao
Academia	
1. Climatologists	Meteo*
2. Ecologists (botanists)	***
3. Research institutions	University of Curaçao, CBHRI, CARMABI, foreign institutions.
4. Academic researchers	***
5. Data analysts	EcoVision*
Industry (private sector)	
6. The initiators (dwelling owner, project developer)	Wechi MC*, Hofi Vidanova*
7. Urban planners	ProGaya*
8. Architects	***
9. Civil and structural engineers	CCM Engineering*
10. Landscape architects	ProGaya*
11. Electrical engineers	***
12. Building contractors	N.A.b.*, MNO Vervat, Betonbouw
13. Suppliers and manufacturers	***
14. Electricians	***
15. Gardeners	***
16. Roofing experts	ARG Gropu NV (i.e., Chirs van Grieken)*
17. Construction team	***
18. Maintenance team	***
Government (public sector)	
19. Policymakers	Minister of… … health, environment, and nature (GMN). … of education, science, culture, and sport (VWS). … of traffic, transport, and spatial planning (VVRP).
20. Meteorological department	Meteo*
21. Government agents	***
Societal actors	
22. Local community	**
23. End-users	**
24. NGOs	Stichting Uniek Curaçao*

* Exempli gratia based on experiences within this study. ** Case specific stakeholders. *** No information.

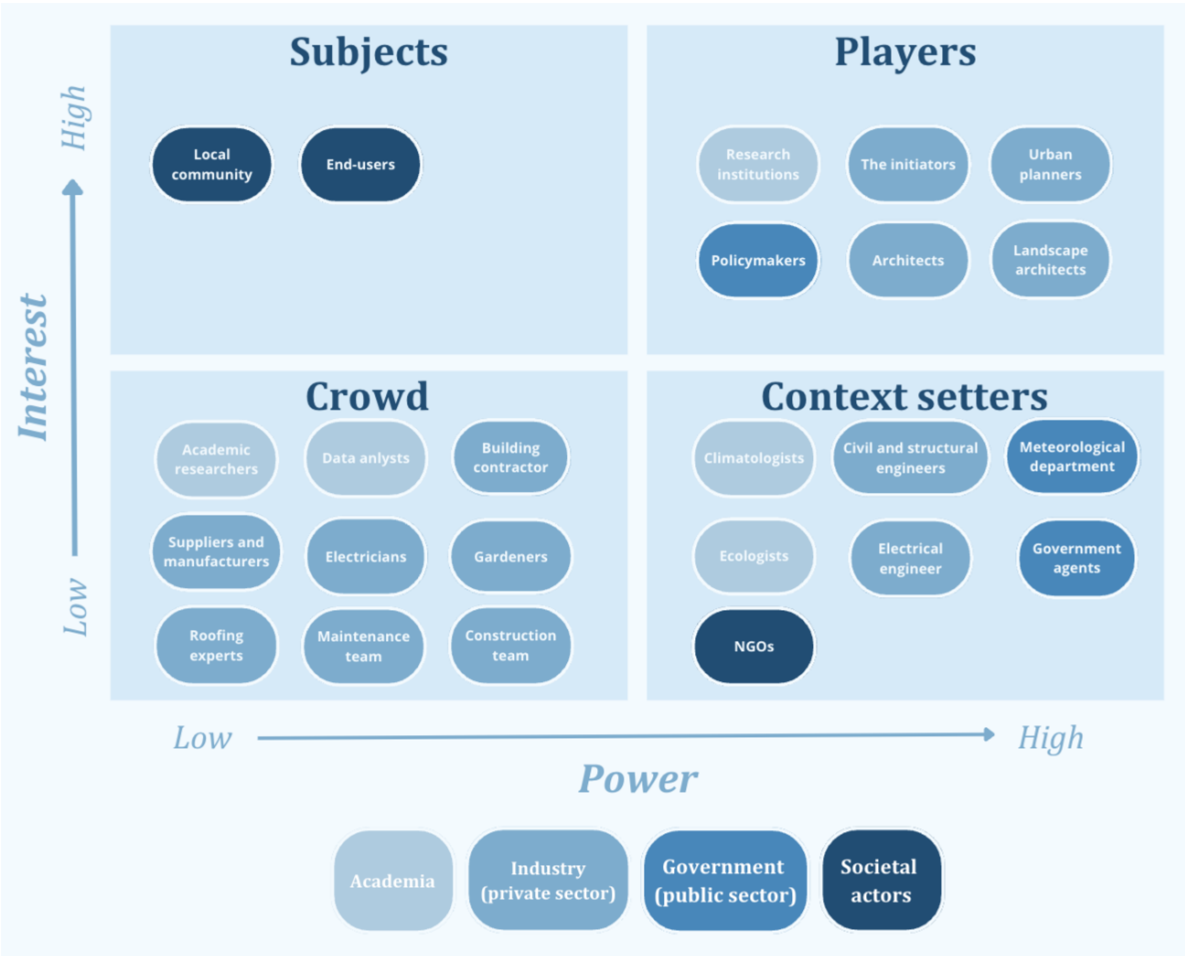
As previously mentioned, the BGR implementation process involves diverse areas of expertise and stakeholders from various professional backgrounds. To understand this diversity, the Quadruple Helix (QH) approach was employed, categorising stakeholders into four key domains: academia, industry (private sector), government (public sector), and societal actors (Table 5.1). Notably, Chris van Grieken, the only known individual with experience in constructing a BGR on Curaçao, stands out. Table 5.1 shows that the industry category stands out with a higher number of stakeholders compared to the other three categories, which exhibit a relatively comparable, lower amount.

5.2. Summarizing Stakeholders' Power, Interest, Drivers, Motivations, and Barriers

The following step of the stakeholder analysis involved plotting the stakeholders on a Power/Interest grid (Eden & Ackermann, 1998). Figure 5.1 illustrates stakeholders' categorization based on their power and interest in BGR implementation.

Figure 5.1

The Power/Interest grid with the stakeholders distributed over the four categories: subjects, players, crowd, and context setters.



Note. Own work (September 2023), diagram adapted from Eden & Ackermann (1998). CC-BY NC.

Characterised by low power and low interest, the 'crowd' consists of the building contractor, suppliers and manufacturers, gardeners, electricians, the roofing experts, the maintenance team, the construction team, the academic researchers, and the data analyst. They are minimally involved in or affected by the BGR implementation process and are mainly operational and task-oriented. Generally, communication efforts with this group may be more generalised and less detailed.

The ‘context setters’, with high power but low interest, were identified as the civil and structural engineers, the climatologists, the meteorological department, the electrical engineers, the ecologists (botanists), government agents, and the NGOs. While they have considerable power owing to their expertise and influence on design, their interest may be more concentrated on specific project aspects. Hence, it is crucial to keep these stakeholders well-informed to prevent unexpected challenges.

On the other hand, stakeholders with low power but high interest, the 'subjects' were identified as the local community and the end-users. Although they lack direct decision-making authority, their opinions and perspectives deserve consideration. Engaging with these stakeholders is crucial for gaining support and effectively managing perceptions.

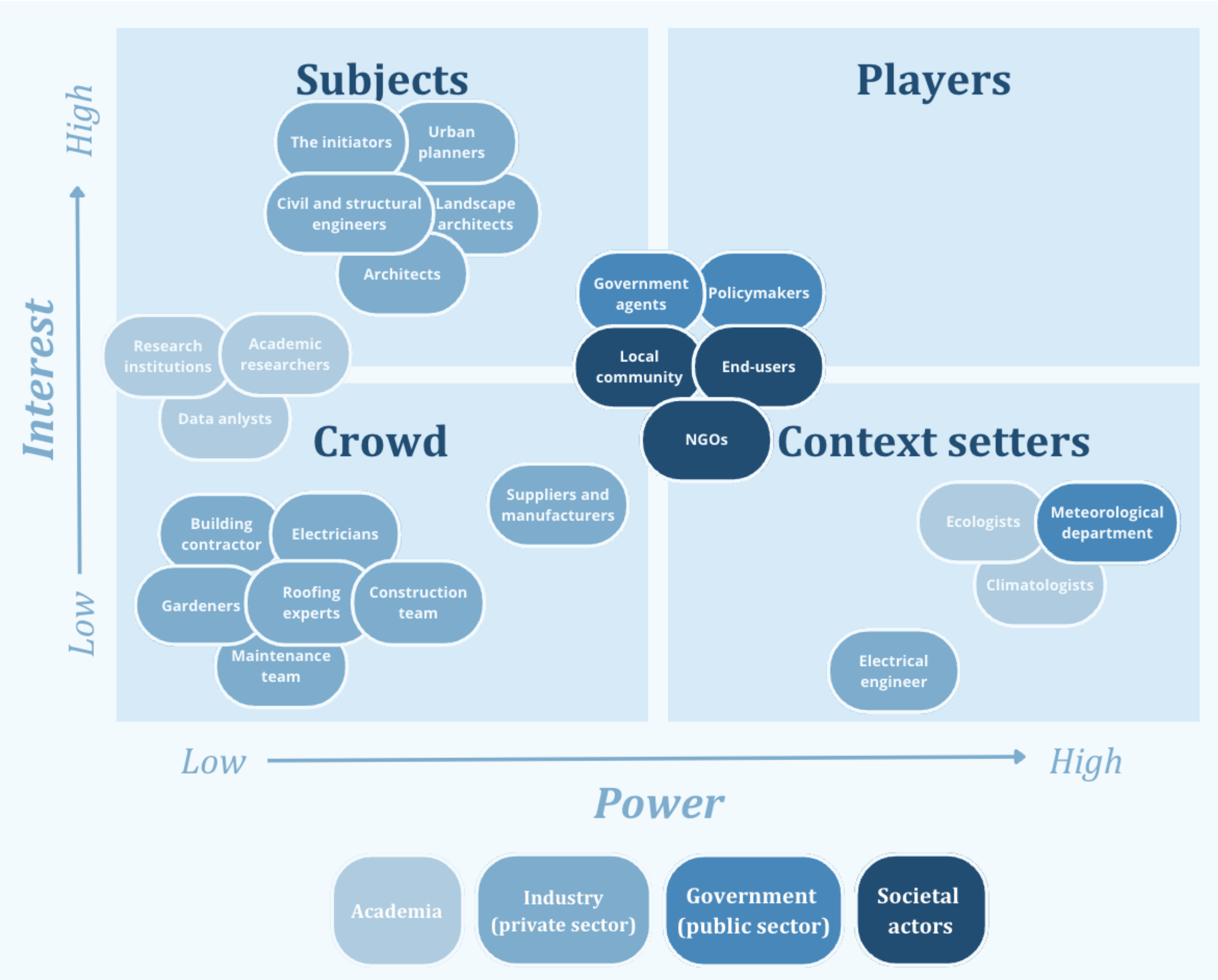
Finally, the initiators (dwelling owner and project developer), urban planner, architect, landscape architect, research institutions, and policymakers were identified as the 'players', who exhibited both high power and interest. These stakeholders are actively engaged in the BGR implementation processes, making key decisions, and influencing outcomes. Close collaboration and regular communication with them are essential.

The final step of the stakeholder analysis involved creating a comprehensive overview of drivers, motivations, and barriers. Drivers are factors or conditions that can convince stakeholders to act and are often viewed from an external standpoint. Motivations are internal factors or goals that different stakeholders want to achieve through BGR implementation. Barriers can be both internal and external factors that constrain stakeholders from being involved in the BGR implementation actively and positively. Examining these aspects provided valuable insights into the factors influencing stakeholder engagement. The drivers for BGR implementation were identified as policy pressure, economic pressure, reputational pressure, and innovation and technological advancement. Motivations were recognised as different ecosystem services and other advantages of BGR implementation documented in the literature, encompassing energy efficiency, urban heat island mitigation, roof longevity prolongation, solar panel enhancement, air purification, runoff control, water purification, noise reduction, biodiversity increase, recreation and aesthetics, property value enhancement, and employment improvement. Barriers included technological, research, financial, cognitive, and cultural barriers, as stated in Section 1.1.2. This list was expanded with barriers related to a lack of government policy and individual unwillingness, drawing from Zhang & He (2021).

An overview detailing how stakeholders relate to different drivers, motivations, and barriers can be found in Appendix 3. Recognising similarities between stakeholders based on these characteristics facilitated grouping stakeholders. Subsequently, these clusters were repositioned on the Power/Interest grid (Figure 5.2). Furthermore, within the previously established Power/Interest grid (Figure 5.1), stakeholders were reorganised based on these similarities, resulting in a new Power/Interest grid (Figure 5.3).

Figure 5.2

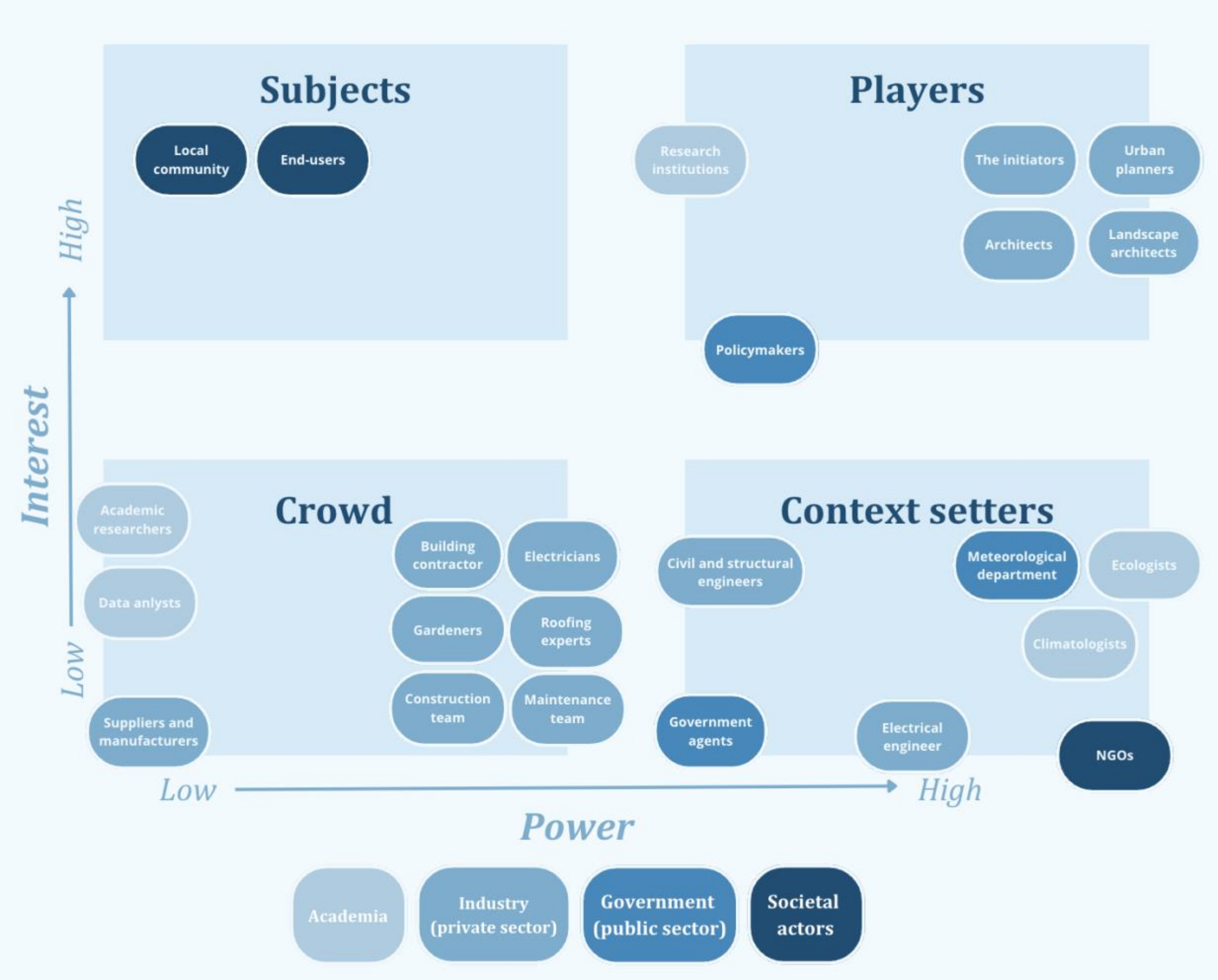
The Power/Interest grid with clusters of stakeholders grouped on their similarities in drivers, motivations, and barriers/



Note. Own work (September 2023), diagram adapted from Eden & Ackermann (1998). CC-BY NC.

Figure 5.3

Stakeholders grouped on their similarities in drivers, motivations, and barriers within the different categories of the Power/Interest grid.



Note. Own work (September 2023), diagram adapted from Eden & Ackermann (1998). CC-BY NC.
There is no meaning of higher power nor interest based on placing of the stakeholders within each category (square). Diagram adapted from Eden & Ackermann (1998).

5.2. Concluding Phase 2 and Starting Phase 3

This phase aimed to identify and associate relevant stakeholders involved in BGR implementation on Curaçao through a multifaceted stakeholder analysis. By generating a list based on insights from Phase 1 and relevant literature, a list of 24 stakeholders was obtained, categorised according to the four dimensions of the QH approach, which are academia, industry, government, and societal actors. This provided an answer to the first part of the second sub-question and underscored the multidisciplinary nature of this research topic.

The latter half of the second sub-question, focusing on how these stakeholders exert influence on BGR implementation, was addressed by employing the Power/Interest grid and exploring drivers, motivations, and barriers. The outcomes revealed both similarities and distinctions in how various stakeholders perceive BGR implementation, emphasising the necessity for adapted engagement strategies for each stakeholder.

To further align the standpoints of the stakeholders with the context of BGR implementation on Curaçao, Phase 3 established a holistic framework of all insights combined. This provided the opportunity to connect the results of the multi-level framework and system diagrams (Phase 1) with the opinions and knowledge contributed by the identified relevant stakeholders (Phase 2).

6. Connecting Factors with Stakeholders for Blue-Green Roof (BGR) Implementation (Phase 3)

This chapter corresponds to the third phase of this research, addressing sub-question 3: *"How can a holistic framework, combining the important factors and relevant stakeholders, be used to realize the potential of BGR implementation on Curaçao?"* The third phase aimed at establishing an in-depth holistic framework where the multi-level factors influencing BGR implementation on Curaçao (Phase 1) were connected to relevant stakeholders (Phase 2).

To achieve this integration, stakeholder interviews were conducted during a six-week field visit to Curaçao and Wechi. The insights gained from these interviews, summarised in Appendix 4, were validated and supplemented by a scientific and grey literature review. These efforts led to the generation of a manual that comprehensively outlines the system dynamics that were proposed for BGR implementation on Curaçao, serving as the main output of this phase. This manual delved into all multi-level aspects, categorising the discussions of system dynamics under design dynamics and social dynamics. Essentially, the manual provided part of the answer to the third sub-question, serving as the holistic framework.

In the upcoming sections, a detailed exploration of the results obtained in Phase 3 will be provided.

6.1. Establish a Manual of System Dynamics

In Phase 1, one of the results was the development of a list of seven principles considered essential for the successful implementation of BGRs (Section 4.1.). This list of principles, further expanded in Appendix 2, served as a structured interview guide for the third phase. Moreover, it contributed to the categorization of the findings of Phase 3 into two distinct sub-sections. These sections were dedicated to exploring the design dynamics and social dynamics of BGR implementation. The section on design dynamics covered the principles of [1] technical design, [2] connections to a larger context, [3] iterative innovation design, and [7] local skills and knowledge. Meanwhile, the section on social dynamics delved into the principles of [4] transferring knowledge, [5] community acceptance and engagement, and [6] sense of ownership and commitment. Each subsection outlined the principles it addresses, specified the relevant scales (dwelling, neighbourhood, or island), and identified the involved stakeholders.

6.2. Design Dynamics

6.2.1. Dwelling Structure Supporting the BGR

When examining the BGR system, it is crucial to take into account the underlying structure of the house. Primarily, it is preferable for the rooftop to possess a flat surface, ideally exhibiting a gradient of less than 7 degrees (van der Meulen, 2019).

In addition, the dwelling and the roof must possess a sufficient load-bearing capacity to withstand the substantial weight of the BGR system. The typical weight of a saturated BGR system is between 160 and 220 kilogrammes per square metre. A local roofing specialist argued that this would not pose a significant problem for Curaçao.

> *"Curaçao is characterised by a significant number of structures and rooftops made of concrete. Each square metre of concrete rooftop is counted for an additional weight of 350 kilogrammes." – Local roofing expert*

Bauder (n.d.) also advocated using reinforced concrete as the main material supporting the BGR system in dwellings. Calculations should be done in advance, considering system weight, plant and growing media weight, and loads caused by individuals accessing the system for maintenance purposes. For these calculations, it is recommended to take into account European standards due to the lack of Caribbean norms and the similarity to Dutch governmental situations. Other BGR companies often used British Standard EN 1991-1-1 and EN 1991-1-4 (Bauder, n.d.). Figure 6.1 depicts a support structure in the case study of Wechi, which employed reinforced concrete and additional wooden beams for added support on the rooftop.

Figure 6.1

Rooftop construction on Wechi including reinforced concreate (left) and supporting wooden beams (right).

Note. Own work (May 2023). CC-BY NC.

The installation of a Building Green Roof (BGR) system on an existing building requires a significant financial investment, often with a minimal or negative return on investment (van der Meulen, 2019). As the structural integrity of the building has already been established, a Dutch expert on BGRs provided a comprehensive evaluation.

> *"The additional expenses required to enhance the initial building's framework are negligible. [...] Oftentimes, this entails reinforcing the concrete to a greater extent. In a recent project I participated in, the additional expenses for construction amounted to €2.45 (4.76 ANG) per square metre. On the other hand, the process of retrofitting a building can result in additional expenses amounting to tens of thousands of euros." – Dutch BGR expert*

Curaçao's vulnerability to natural calamities like hurricanes and seismic events is expected to increase with climate change (Mohan, 2023; Metcalfe & Bennett, 2023). To make the BGR system hurricane-proof, a combination of low-height vegetation and robust structural construction can be used. High wind speeds can cause negative pressure forces, which the system's weight can counteract (Bauder, n.d.). A retention layer for water storage can enhance the substrate layer's resilience during seismic events, potentially promoting the use of a blue-green roof over a green roof when this is considered important (Carmody et al., 2009).

Finally, a local construction superintendent emphasised the need for the building structure to be able to support the weight of the BGR system by strategically positioning the vegetation on the roof. When questioned on this matter, a local roofing expert affirmed:

> *"Ensure that the areas with the most dense vegetation and substrate on the BGR are positioned directly above the inner walls. At these specific spots, the structure exhibits maximum strength and is capable of withstanding the greatest loads." – local roofing expert*

Moreover, he argued that no compromises on the structural design of the dwelling supporting the BGR should be made to ensure safety.

Relevant principles	Scales	Stakeholders involved
• Technical design • Local skills and knowledge	• Dwelling	• Architects • Civil and structural engineers • Roofing experts • Meteorological department

6.2.2. Materials for the BGR

The materials used for BGR systems differ in terms of their prices, durability, aesthetic appeal, and availability on the island. When selecting materials, there will always be a trade-off between these factors. It is recommended to determine in advance which materials need to be of sufficient quality, such as the irrigation system and retention layer.

Curaçao primarily depends on the importation of a wide range of products. Although the objective is to generate a substantial amount of materials within the local area, this is frequently challenging to do due to insufficient demand or expertise. The local contractor encounters numerous challenges in relation to this matter:

> *"Curaçao does not engage in any manufacturing. We import all goods from foreign countries. We are constantly conducting a global investigation to determine the availability and specifications of various materials. Due to the need for container shipment, the item must be able to fit within the container. You consider: What is the most cost-effective method to acquire it? What is the final price? The costs must be weighed against the benefits." - Local contractor*

According to a local roofing specialist, local roofing firms may have part of the required materials for the BGR system, but they do not have enough for large-scale production to supply a whole neighbourhood with BGRs. Curaçao Customs provides a comprehensive description of customs fees for several categories of cargo[1].

The materials that make up the various possible levels of a BGR system are arranged in the following order (Figure 6.2):

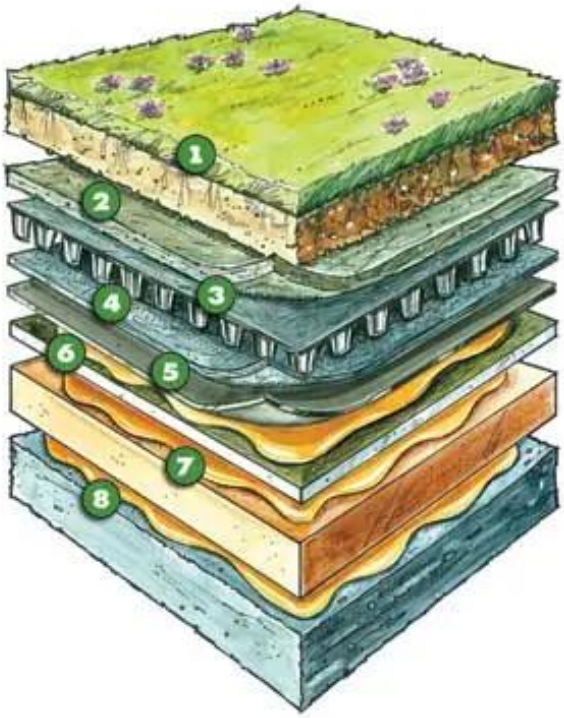
- **Sensors and a meteorological station** (Section 6.2.8.).
- **The irrigation system** (Section 6.2.4).
- **Vegetation (Figure 6.2-1)** (Section 6.2.3).
- **Growing media (Figure 6.2-1)** (Section 6.2.3.).
- **Filter fabric (Figure 6.2-2).** This permeable fabric enables the passage of water and roots while obstructing the accumulation of small particles that could obstruct the drainage system. Geotextile, commonly known as this fabric, stabilises unconsolidated soil and mitigates erosion.

[1] https://douane.cw/zakelijk/inklaring-en-invoer/

- **Retention layer (Figure 6.2-3).** A layer designed for drainage and water storage, which incorporates capillary cones. The water stored in this layer is supplied to the plants through capillary action, which occurs via the capillary fibre columns. Plants have access to water as per their requirement, in a natural and energy-free manner, similar to how it occurs in nature (Permavoid, 2020).
- **Root barrier (Figure 6.2-4).** A root barrier is used to prevent the roots of vegetation from penetrating the waterproof layer.
- **Waterproof layer (Figure 6.2-5).** A waterproof membrane that prevents water from seeping through and damaging the roof structure. Typically, materials such as TPO (ThermoPlastic Olefin), EPDM (Ethylene Propylene Diene Monomer), or PVC (PolyVinyl Chloride) are utilised.
- **Roof structure (Figure 6.2-6,7)** (Section 6.2.1.), preferably made out of concrete and possibly enhanced with extra insulation material.
- **Extra materials**: edge material, for instance gravel; maintenance tools for pruning, weeding, and general maintenance; and safety equipment (Section 6.2.7.) such as a safety harness, gloves, and protective wear.

Figure 6.2

Layers of a BGR system illustrated



Note. Adapted from Carlisle Construction Materials. CC-BY NC.

According to a roofing specialist, the subsequent elements can be manufactured locally on Curaçao: the irrigation system, vegetation, growth media, the filter fabric, the root barrier, the waterproof layer, concrete, and safety and maintenance supplies. A Dutch BGR specialist recommended importing the essential capillary cone, a key component of the retention layer, to Curaçao. It was suggested that this cone can be included in the design with a locally available material that serves the same function as the crates in the retention layer but is less expensive.

If the retention layer of the BGR system is omitted from the design, for instance, due to financial constraints, the irrigation system will depend entirely on the main water grid. In this scenario, alternative sustainable methods for irrigation could be explored. An example that appeared to be of preference to local stakeholders is the utilisation of domestic greywater (Section 6.2.4.) for reuse purposes.

Relevant principles	Scales	Stakeholders involved
• Technical design • Local skills & knowledge	• Dwelling • Island (or abroad)	• Architects • Civil and structural engineers • Building contractors • Suppliers and manufacturers • Roofing experts

6.2.3. Vegetation Layer of the BGR

A roofing expert suggested that locally produced growing media and vegetation for a Building Green Roof (BGR) can save money and promote an indigenous ecosystem.

Penkove et al. (2020) state that in tropical regions, a minimum growing media depth of 200 mm is necessary for efficient stormwater management. A local contractor suggested using diabase, an abundant and finely textured substance found on Curaçao, which could be transformed into rockwool. Rockwool enhances aeration, augments water retention capacity, and has a lightweight nature (Wong & Jim, 2014).

Implementing xeriscaping principles in the vegetation design of the BGR minimises the requirement for irrigation. An essential element of xeriscaping involves selecting plant species that are well-suited to the specific climatic conditions of Curaçao, typically consisting of a variety of cactus, prickly bushes, and evergreen plants (Van Der Burg et al., 2012). Local interviewees recommended utilising *Aloe barbadensis miller* (Aloe vera), *Ananas comosus* (pineapple plant), and *Arachis glabrata* (perennial peanut). The latter exhibits a significant ability to retain moisture, complements rockwool effectively, requires no maintenance, possesses an appealing look, and attracts bees and butterflies (Jim, 2015). A local roofing specialist advised avoiding sedums, as they can easily catch fire in the local climate. He recommended utilising indigenous species that will spread across the entire roof, such as *Bidens alba*, *Nephrolepis biseratta*, *Momordica charantia*, *Portulaca oleracea*, and *Portulaca Pilosa*. When selecting vegetation for the BGRs, the database containing information on indigenous species can provide guidance on the locations where these plants can be found[2].

Once the BGR is established, the maintenance of vegetation and growing media does not require significant expenses (Setherton, 2023). However, it is necessary to periodically remove leaves from the roof in Curaçao, particularly due to the windy circumstances (see Figure 6.3).

Relevant principles	Scales	Stakeholders involved
• Technical design • Local skills & knowledge	• Dwelling • Island	• Ecologists (botanists) • Architects • Gardeners

[2] http://speciesdistribution.dcbd.nl

Figure 6.3

Example of maintenance on rooftops on Curaçao due to windy conditions.

Note. Own work (May 2023). CC-BY NC.

6.2.4. Irrigating the BGR

In the dry season of semi-arid climates like that of Curaçao, the BGR can be left 'brown' (Figure 6.4) or irrigated constantly. Based on the statements of a local constructor and a local roofing expert, the BGR still offers a significant insulating capacity when its vegetation desiccates. Nevertheless, it is recommended to maintain a high level of greenery in the BGR, as it offers numerous advantages in terms of roof longevity and the energy efficiency of the structure.

The irrigation system has the capability of distributing water through various methods, such as an overhead system, a drip system, or a capillary system that is linked to the retention layer. The overhead system is more efficient as it covers the entire roof area (Rowe et al., 2014); however, it is limited to irrigating the BGR with water from the main grid. Capillary cones allow uniform irrigation without requiring any electricity (Permavoid, 2020), but only work when water is present in the retention layer of the BGR. Drip irrigation systems have reduced pressure demands, reduced vulnerability to wind-induced infections, and improved water efficiency compared to overhead irrigation (Walsh & Jolly, 2020). According to a local contractor, this made the drip-type system the preferred choice when considering the reuse of wastewater for irrigation purposes. Both the overhead and drip systems require a low flow trajectory to effectively address the issue of wind gusts (Nektarios, 2018).

Furthermore, the quantity and frequency of irrigation should be determined in advance (Nektarios, 2018). The irrigation demands vary depending on the vegetation type, the nature of the growing medium, and the soil depth. In 2018, Nektarios stated that xerophytic plants can adequately grow in BGRs that provide irrigation at a rate equivalent to 30% of the daily evaporation. Moreover, Nektarios (2018) stated that most plants have the capacity to tolerate drought for a period of 10 to 15 days, whereas succulents are capable of enduring even longer durations of drought. It is recommended to divide the quantity of irrigation water into portions and distribute them at more frequent intervals, especially in locations with semi-arid climates such as Curaçao.

Speaking from experience, a local roofing expert stated that it is essential to irrigate the BGR system continuously. Nevertheless, the island of Curaçao continues to face challenges related to the limited availability of water. This requires the investigation of intelligent, environmentally friendly alternatives, and one encouraging advancement is the possibility of reusing domestic greywater for irrigation purposes. This is also depicted in the system diagrams (Section 4.3.1). Prior to considering the use of domestic greywater for BGR irrigation, it is crucial to initially determine the origins of domestic wastewater. According to a Dutch BGR expert, water from baths and showers, which has minimal soap concentrations, may be the most appropriate supply. In addition, the gathering of household greywater requires the implementation of a dual-pipe system during the building process of the residences. Although this technique does not require immediate segregation of wastewater streams, it allows for the possibility of separating them in the future. A local contractor is confident that linking a septic tank to the BGR irrigation system will be adequate, taking into account the average daily water use of residents in Curaçao. An alternative method entails channelling treated household greywater straight into the BGR retention layer. An interviewee with expertise in water management regulations on the island emphasised the significance of implementing a thorough wastewater management strategy to address the issue of limited freshwater resources. This aspect is already being taken into account in the island's water policy planning. Furthermore, it is of extreme significance to provide end-users with education regarding potential health hazards. Disseminating information to people regarding the technical system and possible health risks may effectively prevent accidents.

Figure 6.4

GR on Curaçao without irrigation during the dry season.

Note. Own work (May 2023).

Relevant principles	Scales	Stakeholders involved
• Technical design • Connection to larger context	• Dwelling • Neighbourhood	• Architects • Landscape architects • Civil and structural engineers • Policymakers

6.2.5. Solar Panels on the BGR

Curaçao's frequent power blackouts and intense solar radiation make it an ideal location for photovoltaic modules, also referred to as solar panels (Kawepraek et al., 2021). According to literature, the installation of solar panels on a BGR can increase energy outputs by 2 to 4% (Kaewpraek et al., 2021; Arenandan et al., 2022; van der Roest et al., 2023). The rationale is as follows:

> *"Plants evaporate water, which has a greater effect in tropical climates, keeping the solar panel significantly cooler and allowing the panel to produce more electricity."*
> *– local architect*

A study by Arenandan et al. (2022) recommended placing solar panels in tropical environments at a lower height on the roof for increased efficiency and safety. Vegetation on a BGR enhances the energy efficiency of the solar panel. Conversely, the solar panels enhance the growing conditions for the vegetation (Schindler et al., 2018).

A local civil engineer revealed that solar panels on the BGR system can power public facilities like street lighting. Moreover, he indicated that maintenance of solar panels is currently primarily handled by professionals, making solar panel acquisition unaffordable and inaccessible to a large part of the local community.

Relevant principles	Scales	Stakeholders involved
• Technical design • Connection to larger context	• Dwelling • Neighbourhood	• Architects • Electrical engineers

6.2.6. Stormwater Management

BGRs not only provide benefits to the building but also serve as a component of urban stormwater management plans to alleviate stress on the sewers (Permavoid, 2020). This makes BGRs integral components of the broader blue infrastructure, as was also depicted in the system diagrams (Section 4.3.1). BGRs integrate water retention for vegetation irrigation, and detention for temporary storage and regulated release. Retention involves the long-term gathering, containment, and utilisation of stormwater on the roof, while detention temporarily collects and stores rainwater for release into sewers or groundwater. According to a local contractor, however, the population of Curaçao does not typically have a mindset focused on retaining and detaining.

> *"The current mindset is to quickly divert rainwater to the ocean. Precipitation can contain a significant amount of sediment, which can have damaging impacts on coral reefs. Simultaneously, the availability of freshwater is diminishing, making this all even more frustrating." – Local contractor*

This was confirmed by a local water resource management expert who established a comprehensive sustainable water management plan for Curaçao, however, experiences a lot of resistance from the government.

A local civil engineer explained that dams and trenches were constructed in Wechi to retain rainwater within the neighbourhood. He suggested a higher retention layer to be able to cope with the heavy rainfall on Curaçao. According to a local meteorological expert, the average rainfall during a downpour is 10 mm per hour. By considering the average daily evaporation rate of 6.9 mm, it is possible to determine an optimal height. Using the equations provided by Busker et al. (2022), it is possible to assess the performance of the BGR system in terms of water management.

$$Performance_{buffer} = \frac{Total\ rainfall\ captured\ (mm)}{Total\ rainfall\ (mm)} * 100 \quad (1)$$

$$Performance_{ET} = \frac{ETa\ (mm)}{PET\ (mm)} * 100 \quad (2)$$

$$Performance_{droughts} = \left(1 - \frac{\#\ drought\ events}{\#\ years\ analysed}\right) * 100 \quad (3)$$

$Performance_{buffer}$, as defined by equation (1), represents the proportion of total precipitation that is captured by the BGR. Any variation less than 100 indicates a case of undesired overflow. $Performance_{ET}$ (Eq. (2)) quantifies the ratio of actual evapotranspiration (Eta) to daily prospective evapotranspiration (PET), therefore indicating both water stress and evaporative cooling. The $Performance_{drought}$, as defined by equation (3), aims to limit the occurrence of water depletion from the vegetation layer over an extended period of time. A drought episode is characterised as a consecutive period of 28 days during which the amount of water present in the vegetation is less than 10 mm (Busker et al., 2022). Busker et al (2022) found that there is a trade-off between the performance indicator described in Eq. (1) and the indicators in Eq. (2) and Eq. (3). In order to optimise buffer capacity, it is necessary for the retention layer to have minimal content, while a fully saturated vegetation layer is ideal for cooling and drought resistance. The most effective early-drainage techniques rely on finding the right balance between the expenses associated with increased overflow and the resulting rise in pluvial flood risks, which is particularly important in the case of Curaçao, and the costs of reduced evaporation and the subsequent decrease in evaporative cooling.

Relevant principles	Scales	Stakeholders involved
• Connection to a larger context	• Neighbourhood • Island	• Civil and structural engineers • Landscape architects • Meteorological department

6.2.7. Safety and Maintenance of the BGR

The first division where safety issues may arise is in structural safety, linked to the structural considerations for the dwelling (Section 6.2.1.). A local contractor stated that choices in material for the structure of the BGR and in vegetation should be made so that they increase safety as much as possible. In order to avoid costs later, it is crucial to take safety into account in the design phase of the project. Next to the load-bearing structural considerations, it is important to consider lightning protection just as you would on a regular rooftop.

The second category of safety considerations that is of high importance is fire safety. Since greenery is incorporated into the design, it is more prone to fire spreading compared to a regular grey roof. Experts recommended that, in view of fire safety, at least 60% of roof vegetation should come from a sedum family or groundcover plantings (Clagett, 2019). It is also advised to avoid using grasses and mosses, which can easily dry out. In her product case study, Clagett (2019) also advises establishing a fire break by creating border zones around the greenery. Maintenance is a large part of fire safety, since a lack of it may lead to a lot of dead and dormant organic material on the roof (Figure 6.3). This can fuel a fire quite easily.

Safety issues also rise in a third category, which is maintenance and inspection. Because the roofs are self-sustaining, this doesn't mean that there is no maintenance required on them. Just like regular roofs that require periodic inspections and check-ups, blue-green roofs also demand attention and care. Tasks such as checking for leaks into the dwelling, inspecting the irrigation system, and tending to the greenery, including weeding, should be carried out at least once or twice every six months (Godfrey, 2020). The contractor believes that the maintenance of the BGR is the responsibility of the roof owners themselves. He believes that residents should be responsible for their own safety during maintenance checks, deeming it a matter of 'common sense' to stay away from the roof's edge. Other locals argue that accidents due to maintenance could result in a ban on BGRs across the entire island. For the landscape architect, this safety concern is the main reason to place the BGRs on public-owned buildings rather than private-owned houses. This will make it a collective responsibility to maintain the BGR, possibly leading to the involvement of a professional maintenance team. Maintaining gardens on the island is already a challenge for a lot of residents, let alone managing a garden on a roof, the roofing expert stressed. An additional service agreement is envisioned, similar to the operation of solar panel companies, which perform maintenance once in a while in exchange for a monthly fee. However, the landscape architect is anticipating resistance since Curaçao residents value their privacy and control over their own property.

Relevant principles	Scales	Stakeholders involved
• Technical design	• Dwelling	• Architects • Policymakers • Government agents

6.2.8. Monitoring the BGR System Performance

To achieve optimal operation of the BGR system, the local roofing expert recommended monitoring and enhancing it by utilising user feedback and data collected from rooftop sensors. System performance monitoring could promptly identify weaknesses in the BGR system, avoiding potential high costs or safety issues in the future. Additionally, it could enable the system to respond to upcoming meteorological conditions, such as rainfall, in order to prevent system overflow (RESILIO, 2022).

A comprehensive list of potential principles to evaluate was produced through interviews with several local stakeholders, including an architect, contractor, roofing expert, and contractor. A weather station could be installed on the roof to measure the ambient temperature, humidity, pressure, rainfall, and wind. Additionally, it is advisable to assess the levels of soil moisture, salt, and temperature. Other variables that could be assessed include the water level in the retention layer and the electrical output of the solar panel. Furthermore, it was suggested to install sensors that detect any shortcomings in the irrigation system, as this plays an essential part in the BGR system. Additionally, a local architect had proposed that the user experience be taken into consideration as well.

Based on insights from a local project developer, the firm in Curaçao that currently holds a monopoly on the water and power networks possesses a substantial amount of data but is unwilling to make it accessible. Consequently, she held the belief that monitoring these factors would be beneficial and proposed connecting these projects with data analysts or university research institutions to gain more insights.

Relevant principles	Scales	Stakeholders involved
• Technical design • Iterative innovation design	• Dwelling	• Research institutions • Academic researchers • Data analysts • Urban planner • The initiators • End-users • Maintenance team

6.2.9. Local Knowledge and Skills

According to a local contractor, there is a lack of knowledge regarding BGRs on Curaçao. He expressed a need for foreign information, which is in line with the motivation behind this research. Nevertheless, a local advocate for sustainability stated that many residents of Curaçao are implementing small-scale sustainable measures in their houses as a means of achieving financial savings. This suggests the existence of knowledge on the island pertaining to sustainable urban development.

The local contractor expressed confidence in the proficiency of the local skills. He indicated that a significant number of residents in Curaçao will have the capacity and time to acquire knowledge about the details of BGR implementation when it is requested.

"On Curaçao, everything is about demonstrating" — Local sustainability enthusiast

Regarding roofing techniques, a roofing expert noted that many residents possess the expertise to effectively insulate their roofs to protect against heat. While many organisations have expertise in insulating techniques, the concept of BGRs remains unfamiliar to a significant number of them. The roofing specialist proposed that the personnel of the roofing firms could help in the installation and construction of the BGRs, as they hold expertise with regard to safety and have knowledge about the specific requirements for roof installations on Curaçao.

Regarding the vegetation, a local expert noted that only a few of Curaçao's residents possess a genuine interest in gardening. He reasoned that this could be related to the opposition against the historical period of colonisation and the institution of slavery on the plantations. A local contractor affirmed that there will be a sufficient number of specialists on the island who have expertise in supplying native flora and possess the necessary understanding for maintaining it.

A local construction manager proposed that including BGRs might create a new niche sector for the construction industry of Curaçao. This would integrate expertise in gardening, roofing, and water management, possibly providing support to unemployed youth. Nevertheless, the significance of education and training cannot be undermined, while the current allocation of responsibilities for this remains unclear.

Relevant principles	Scales	Stakeholders involved
• Local skills & knowledge	• Island	• *All industry related stakeholders* • Academic researchers • Research institutions • Local community • NGOs

6.3. Social Dynamics

6.3.1. Promotion to the Local Community

Within the context of Curaçao, one of the most significant social dynamics appeared to be the promotion of BGRs to the local community. The concept of BGRs is unfamiliar to the residents, and when BGRs are implemented on privately owned buildings (see Section 6.3.2.), it will be the responsibility of the building owners to finance the implementation. Regarding this economical issue, a local contractor expressed:

"People on Curaçao are too busy with surviving; they don't have the time to make strategies for the future." – Local contractor

Several local residents agreed. They noticed there is a lack of enthusiasm for sustainable development, as individuals are preoccupied with guaranteeing their own and their families' survival.

Nevertheless, urban planners expressed their willingness to adopt cost-effective sustainable solutions, as they eventually lead to financial savings.

Hence, the majority of local interviewees expressed that the primary factors to emphasise while promoting the concept of BGRs are the economic advantages for the end-users, followed by the environmental benefits. A local sales manager advised against discussing the complicated functioning of the system, as it could discourage the local community by creating the perception that it is overly complex to manage.

According to local interviewees engaged in the sustainable development of Curaçao, the most effective approach to persuading the local population is to spend time in the neighbourhoods. According to the local water resource manager's expertise, a small subset of people will be easily persuaded, while the majority will exhibit resistance. Identify individuals who are already passionate about sustainable development, cultivate their enthusiasm for BGRs, and they will subsequently propagate what they have learned, she recommended.

"Find activities that the local community engages in every day. Show them how these activities will be enhanced when incorporating a BGR into their homes. Subsequently, demonstrate to them how they can implement this, where to find information, and let them join activities. This will convince and teach them." – Local sustainability enthusiast

As previously stated, the main considerations that the local community prioritised were the cost-effectiveness of the system and the benefits it would bring to them. Following a collaborative session with a project developer, sales manager, and construction experts from the case study, it was proposed to install a BGR on a public building in Wechi. This would allow individuals to come visit and personally witness the system's impacts. The users will perceive the system's cooling effect and will be able to visually observe the return on investment by comparing the energy bills. When applied to privately owned buildings, the local project developer maintained the belief that only the island's upper class could afford the investment.

A sales manager provided valuable information regarding the promotional practices in Curaçao. She observed a significant number of individuals from diverse backgrounds and varying socioeconomic statuses using social media. She recommended investing in accessible online resources that provide explanations, which can be accessed for free and at any time. An example from the case study is that Wechi used a WhatsApp channel to keep anyone interested informed on the most recent developments in the community. This was regarded as an accessible method to connect with the local community. In connection with this topic, the local sales manager emphasised the significance of having promotional and communication materials accessible in the native language, Papiamentu, as well as in English and Dutch.

Related principles	Scales	Stakeholders involved
• Community engagement	• Neighbourhood • Island	• Local community • NGOs • Initiators

6.3.2. Ownership Over the Rooftops and the BGRs

Based on experience from a local sales manager, when end-users develop a sense of ownership towards the BGR system, it fosters a sense of ownership in their homes and neighbourhoods. This will enhance the value of the neighbourhood and prove beneficial for its market value.

Nevertheless, owning a BGR holds certain responsibilities, and when BGRs are implemented on privately owned buildings, the primary responsibilities fall upon the end-users. In order to mitigate this pressure, the project developer could arrange a contractual agreement to guarantee regular inspections with a dedicated maintenance team, as well as a type of insurance coverage to address any potential damages, accidents, or other BGR-related difficulties. A local construction manager stated that he thinks a single accident with an end-user of a BGR will lead to widespread opposition towards the system. He explained that this results from a culture where nothing escapes attention and information spreads quickly among the small community.

This was the key incentive for the local urban planner to imagine placing BGRs on public buildings, including schools, community centres, shopping malls, and sports facilities. In addition to mitigating safety concerns and reducing investment costs (see Section 6.3.1.), this will significantly expand the operational area of the BGR, hence enhancing its overall effectiveness (Busker et al., 2022). Busker et al. (2022) state that, in order to be economically feasible, BGRs must have a minimum size of 200 m^2. However, implementing BGRs on public buildings, stated by a local urban planner, will probably decrease the feeling of ownership.

Related principles	Scales	Stakeholders involved
• Sense of ownership	• Dwelling • Neighbourhood	• Local community • Initiators • End-users • Policymakers

6.3.3. Education and Engagement of BGR End-Users

After the implementation of BGRs in the urban planning of Curaçao, it is important to educate end-users on the functioning and maintenance of the system. Furthermore, a local contractor emphasised the need for a clear explanation of the health concerns associated with using treated domestic greywater for irrigation purposes. Engaging end-users might yield several advantages in addition to their education.

"I believe you should include end-users in education (of the BGR system). [...] You will make inhabitants proud of their homes, giving the neighbourhood added value."
– Local urban planner

One approach to educating the end-users of the BGRs was proposed in the form of an informational brochure, which would be provided along with other materials received upon contract signing. An alternative approach involved constructing a scaled-down replica of the BGR system or a cross-sectioned representation to visually demonstrate it at community events, workshops, or open house days. A resident who incorporated numerous little ecological practices into his own home emphasised the significance of demonstrating the functioning and maintenance practises. He believed that by demonstrating the functioning and maintenance of the system, the inhabitants learn the most. A local roofing expert, however, had a pessimistic view regarding the education of end-users. He was convinced that they would not be interested, and the better choice would be to make sure that the entire process of installation and maintenance should be out of their hands.

Related principles	Scales	Stakeholders involved
• Transferring knowledge • Community engagement	• Dwelling • Neighbourhood	• End-users • Initiators • Urban planners

6.2.4. Community of Practice Around BGRs

"We all know what we want, that we want it, and why we want it, but not how to execute this wish. Therefore, we need to figure this out together, and a community of practice facilitates this process." – local project developer talking about BGR implementation.

Communities of practice are collectives of individuals who share common interests or passions for a certain activity or subject matter. Through regular interaction, these communities engage in the process of enhancing their skills and knowledge to improve their performance (Wenger, 2009). Creating communities of practice is beneficial for addressing problems, finding information, sharing experiences, coordinating efforts, fostering collaboration among stakeholders, documenting projects, and discovering gaps in knowledge. Given the lack of familiarity with BGRs on Curaçao, establishing a community of practice focused on this topic would be beneficial, according to a local project developer. A local architect supported the inclusion of stakeholders from several disciplines. She also recommended including end-users in the early project stages to incorporate their preferences and requirements. A local sales manager emphasised the significant impact of social media on Curaçao, and she concluded that establishing a platform to support this community of practice would be highly promising. The community of practice could include end-users, persons from the local community who are interested, NGOs relevant to the topic, and all stakeholders from the industry sector.

According to a roofing expert, the community of practice could also help in learning and the acquisition of skills, enabling individuals in the local community to enhance their proficiency in the job sector of BGRs. Implementing BGRs as a component of a sustainable transition can lead to an increase in employment prospects and a reduction in job market challenges, as is seen in the current situation in Curaçao (Kazi, 2013; Cedefop, 2021). As suggested by the local roofing expert, engaging in networking activities within the professional community can also foster collaborative initiatives and collaborations, perhaps leading to substantial projects and the generation of additional employment opportunities. He suggested that the community of practice on BGR implementation could possibly be integrated with one on solar panels or other sustainable practices on the island.

Related principles	Scales	Stakeholders involved
• Community engagement • Sense of ownership • Transferring knowledge	• Neighbourhood • Island	• End-users • Local community • NGOs • *All industry related stakeholders*

6.4. Concluding Phase 3

This phase aimed at establishing an in-depth holistic framework where multi-level factors influencing BGR implementation on Curaçao were connected to relevant stakeholders. The process of conducting stakeholder interviews and conducting literature review helped to identify **nine design dynamics** and **four social dynamics**, together forming the **system dynamics**, providing in-depth information on the implementation of BGR in the specific context of Curaçao. This made it possible to make conclusions on the essential requirements for possibly realising the potential of BGR implementation on Curaçao. This answered the third sub-question and in combination with the results obtained from Phase 1 and Phase 2, this third phase provides the necessary information to address the main research question.

7. Discussion

7.1. Interpretation of the Results

By the end of this research on blue-green roof (BGR) implementation in Curaçao, a holistic framework had been developed. This framework encompasses an extensive range of relevant factors and the corresponding stakeholders involved. The first part of this section explains how the holistic framework, consisting of the system dynamics, assists with assessing the potential of BGR on Curaçao. Subsequently, the engagement of stakeholders in relation to the system dynamics is considered. Following that, the introduction's definition of the enablers and barriers of climate adaptation strategies in Small Island Developing States (SIDS) is analysed in the context of system dynamics. Throughout this section, suggestions are made for effectively approaching the potential implementation of BGRs for the relevant stakeholders.

7.1.1. System Dynamics That Support or Hinder the Potential of BGR Implementation on Curaçao

This study demonstrated that certain design dynamics contribute to the potential of implementing BGRs on Curaçao, while others appear to hinder this process. Some examples are given in this section.

One unexpected finding was that a substantial amount of the essential materials required for the technical system can be manufactured on the island. This contributes to the potential of realising BGRs on Curaçao. Nevertheless, the need to import crucial components such as capillary cones for the retention layer may present a significant obstacle due to their high cost. As a result, it is critical to be creative when choosing materials, and designers must be creative by using local alternative materials whenever possible.

Regarding the choices to be made for vegetation, in general, the consensus among local interviewees was that there are an adequate number of gardening experts with the requisite expertise and knowledge to select appropriate vegetation for the BGRs.

Nevertheless, continuous irrigation is essential to prevent the plants from desiccating and causing the BGRs to lose their visual appeal. This hinders the potential of BGR implementation, as continuous irrigation is costly, and the availability of freshwater is limited on the island. The potential lies in the utilisation of treated domestic greywater. An innovative method that has been used by several project developers on the island. The legislation is currently insufficient, and it is crucial to set clear guidelines and standards on this matter.

Another unexpected finding was that the significance of safety seems to be a crucial element that could possibly impede the potential of BGR adoption on Curaçao. A noteworthy discovery was that local inhabitants indicated that a single safety concern could result in resistance towards BGRs across the entire island.

Another important discovery in relation to the potential of BGRs on Curaçao is that, although there is a lack of local knowledge regarding BGRs, there is confidence that the expertise of local roofing and gardening professionals can be utilised to successfully implement BGRs. It has the potential to establish a distinct market niche within the construction industry and maybe alleviate the pressure on Curaçao's job market.

It is crucial to highlight that the islands' blue infrastructure does not currently prioritise efficient stormwater management. A single BGR implementation will not mitigate the pressure on the sewer systems. Hence, in order to take advantage of BGRs for stormwater management, the primary objective should be to install BGRs on large rooftops with substantial surface areas and to install several BGRs across the neighbourhood. Only then can the BGRs be utilised to their maximum capacity and effectively manage stormwater.

Concluding upon all the design dynamics, they are related to the principles for effective BGR implementation established in Phase 1 of the research (Table 7.1). According to the results of Phase 3, the first requirement is partially met. The presence of knowledge, resources, and expertise allows for the adaptation of the BGR design to suit the specific environmental and structural conditions on Curaçao. However, political factors are currently limiting the implementation of BGRs. To begin with, the absence of any established regulations and the lack of government financing or other incentives now make the implementation of BGR challenging. The second principles can be met by employing treated domestic greywater and implementing many BGRs in close range, hence contributing to stormwater management approaches. The third principle can be met by establishing connections with educational institutions and can be optimised by leveraging data-driven user experiences. However, this principle becomes significant only when the other requirements are initially met. Finally, the seventh requirement can be met by embracing the expertise of local individuals in gardening and roofing fields on the island and integrating this with the newly acquired information on BGR implementation in Curaçao, as presented in this research.

Considering the social dynamics, this study showed that most of them are contributing to the potential of BGR implementation on Curaçao.

It was discovered that through the active involvement of the end-users of the BGRs, individuals develop a sense of ownership and influence over their homes and the BGR system in particular. This will lead to a sense of pride among the residents, ultimately contributing to an increase in the neighbourhood's value. Nevertheless, it is crucial to emphasise the need for a balanced distribution of responsibilities concerning BGR maintenance. The sense of ownership is likely to diminish when BGRs are installed in public buildings, a discovery that should be considered when selecting properties designated for BGR implementation.

Approaches related to the education of end-users suggested in this study will also enhance the potential of implementing BGR on Curaçao. Utilising materials such as informational folders, cross-sections, or miniature models will effectively facilitate the communication of the system's functioning. Nevertheless, the primary emphasis was placed on demonstrating the practices and allowing the local population to experience the tangible impact. It was clarified that this has the potential to instantly persuade individuals, alongside the reduction in energy expenses, by showcasing the difference in energy bills.

The effectiveness of a community of practice in facilitating knowledge transfer and fostering collaboration among stakeholders from diverse disciplines was determined. The culture of Curaçao seemed to be well-suited for engagement online and through social media. A proposal was presented to create a platform for a community of individuals who are engaged in various practices, such as solar panels or other sustainable practices. This idea of a community of practice enhanced the potential for implementing BGR on Curaçao.

Among all the contributions of social dynamics to the potential of BGR implementation on Curaçao, one particular dynamic emerged as a significant obstacle. This was the promotion of BGRs targeting the local community and was deemed challenging due to the prevailing lack of interest and financial constraints faced by a significant portion of the community. Although multiple suggestions were proposed regarding the promotional strategy, the primary issue seemed to be the insufficient financial resources to initiate the investment in the BGR system. The support of funds is crucial alongside an effective community strategy.

Reflecting on all the social dynamics, they were related to the principles for effective BGR implementation (Table 7.1). According to the results of Phase 3, the fourth requirement may be met, and this study provides this by synthesising all relevant details derived from local as well as global contexts. Meeting the fifth principle will be challenging, as it is envisioned that the involvement of the local community will be limited to social acceptance, as previously said. According to the findings of this study, the local population will possibly accept BGRs that are installed on the island's public buildings, as long as they don't have to deal with any financial or maintenance obligations. This poses a challenge to fostering community engagement and participation, despite being seen as a crucial element by numerous local interviewees. According to the findings of this study, it appears that the sixth principle can be met by involving end-users in decision-making processes. However, it was found to be less significant in comparison to the other principles.

Table 7.1

Principles for effective BGR implementation divided over the different system dynamics.

System dynamics	
Design dynamics	Social dynamics
1. Technical design *The technical design of the BGR adapts to contextual conditions, including political, environmental, and structural factors.*	**4. Transferring knowledge** *Learning from successful BGR implementations worldwide and drawing from their experiences.*
2. Connections to larger context *The BGR is integrated in larger technical infrastructures.*	**5. Community acceptance and engagement** *Social acceptance, interest in the innovation, willingness to participate, and engagement from the local community with the concept of BGRs.*
3. Iterative innovation design *The BGR is integrated in larger technical infrastructures.*	**6. Sense of ownership and commitment** *End-users and/or project developers have a sense of ownership, and there is a commitment by the design, construction, and research team.*
7. Local skills and knowledge *Utilisation of local skills and knowledge to implement and maintain the BGRs.*	

Note. Own work (December 2023).

7.1.2. System Dynamics and the Involvement of Stakeholders

As indicated in this research, some stakeholders appear to be involved in a lot of system dynamics. These key stakeholders with significant influence on system dynamics are architects, civil and structural engineers, and urban planners. In line with the Power/Interest theory presented in the theoretical and contextual framework, these individuals are crucial stakeholders who should be involved at all stages of BGR implementation in order to fully realise its potential. Furthermore, it is important to incorporate stakeholders who hold little influence yet are involved in numerous system dynamics in order to include their insights and offer them a voice. This encompasses roofing experts, the local community, and end-users. It should be noted that the roofing experts are showing a low level of interest on the Power/Interest grid (see Section 5.2. and Figure 5.1). Next to this, although initial indications suggested a strong local community interest in BGR implementation, the interviews found that this was not correct.

The current obstacles to the effective implementation of BGR on Curaçao (Section 7.1.1.) are the need to import necessary and costly materials, the limited impact on stormwater management, safety concerns, and ineffective promotion to the local community. Further investigation into these processes necessitates engaging with the relevant stakeholders.

The process of importing materials includes multiple stakeholders, such as architects, building contractors, suppliers, and manufacturers. Engaging in discussions with these local stakeholders could provide valuable information regarding the availability of local alternatives for the materials or the feasibility of initiating local manufacturing of the essential materials on the island. Regarding the power and interest of these stakeholders identified in this study, it is worth mentioning that the building contractors and suppliers were categorised as the crowd, while the architects were classified as the players. Thus, it may be concluded that architects, who possess significant influence and interest in relation to BGR implementation that is lacking by the other two, should take the lead in initiating these discussions. These three stakeholders were recognised as potentially facing comparable drivers and barriers, which could facilitate the alignment of goals.

Safety concerns should be evaluated with policymakers, and regulations should be established. Nevertheless, as illustrated by the results of this study, policymakers may encounter technological barriers. Given that safety problems are not primarily influenced by climate conditions, it is feasible to draw on the experiences and policy frameworks related to safety concerns of BGRs from other locations abroad.

In order to develop a thorough water management strategy that includes BGRs, it is necessary for landscape architects, civil engineers, and the meteorological department to get together. It is noteworthy to point out that the findings of this research indicate that all of these stakeholders hold considerable power in the implementation of BGR. It suggests that assembling these stakeholders is a promising approach for the development of an improved water management strategy. This is supported by the fact that these stakeholders encounter contrasting barriers, indicating that collaboration may help in overcoming these barriers through active involvement. The local expert on water resource management has suggested that this procedure has begun, although it is progressing slowly due to the government's inadequate involvement.

Promotion of BGR implementation among the local community could be investigated further by examining the role that NGOs can play in this regard and by allowing BGR implementation initiators to consult with the local community in order to align their desires and objectives. Looking back at the results of this research on the levels of power and interest of NGOs and the local community, it reveals opposite profiles. NGOs may empower the local community by representing their voice, but conversely, they can reach a large share of the local community to propagate the advantages of BGRs. This suggests that they could play a significant role in promoting the implementation of BGRs on Curaçao.

7.1.3. System Dynamics Related to the Barriers and Enablers of Climate Adaptation Strategies on SIDS

The study conducted by Metcalfe & Bennet (2023) and the IPCC's assessment report (2022) provide valuable insights into the barriers and enablers of climate adaptation strategies in SIDS. The barriers that might prevent the implementation of BGR on Curaçao were identified as technological, research, financial, cognitive, and cultural barriers.

This study demonstrated that the presence of a technical barrier on the island, where there is limited knowledge and expertise in BGR systems, can be overcome by leveraging knowledge from abroad and integrating expertise from various fields, including roofing, gardening, and stormwater management. The study demonstrated that the existing knowledge on the island encompasses both information on available materials and the irrigation system.

In this study, the research barrier relates to the process of monitoring the performance of the BGR system design. However, it was deemed less important to prioritise when seeking ways to maximise the potential of BGRs in Curaçao. The suggestion put forth by the Wechi case study to establish a BGR on their office as a test setup could serve as a solution to overcome the research obstacle. This will provide researchers with a free experimental setting where various technical BGR elements can be examined and assessed.

The findings of this study presented possibilities for integrating cultural elements into the design and social dynamics of BGRs, with the aim of overcoming cultural barriers. An example of this is offering promotional and instructional materials in multiple languages. This study provides little insight on how the implementation of BGR might incorporate traditional rituals and cultural meanings, as was considered important by Kuruppu and Willie (2015). Nevertheless, the use of indigenous expertise about vegetation, structural factors, and traditional roofing methods was demonstrated and determined to enhance the potential of implementing BGRs on Curaçao.

This investigation strongly supported the cognitive barrier that Kuruppu and Willie (2015) identified. The local interviewees unanimously expressed that there is a noticeable neglect of the subject of climate change and the implementation of methods for adaptation. Conquering this obstacle is considered difficult and ineffective if the government continues to disregard these subjects. This obstacle extends well beyond the implementation of BGRs on Curaçao and affects all subjects linked to sustainability. This implies that it is essential to prioritise all efforts towards climate adaptation first and thereafter consider the possibilities of BGRs.

While this study did not prioritise the financial barrier, it was inevitable to ignore this issue. The majority of the system dynamics, encompassing both design and social dynamics, are intricately linked to the financial aspects of the island in some way. Importing necessary materials makes significant expenses; the recruitment of a maintenance crew entails additional costs; and although the adoption of BGRs will eventually result in energy (bill) savings, the initial investment costs are projected to be exceedingly expensive for the local population to consider. This study demonstrated that the ability to overcome the financial obstacle can be achieved through additional investigation into funding options or by limiting the adoption of BGRs to exclusively public buildings.

The enablers for implementing climate change strategies on SIDS mentioned in the 6th IPCC assessment report are connected to the obstacles mentioned before (Table 1.1). The findings of this study indicated that several of these enablers are within reach: *Building human capacity*, *Integrate cultural resources into decision-making*, and *Embedding indigenous knowledge and local knowledge*. Prior to possibly implementing BGRs on Curaçao, it is essential to address certain enablers that aim to create a supportive environment for sustainable development practices. These enablers include: *Better governance and legal reforms*, *Increased finance and risk transfer mechanisms*, and *Education and awareness programmes*.

7.2. Validity and Reliability

7.2.1. Validity

The application of the STSD framework in Phase 1, in the context of BGR implementation on Curaçao, compromised the face validity of this research phase. This is because the framework is primarily intended for assessing computer systems rather than urban innovations. To address this concern, interviews with the case owner and an expert were conducted in order to validate the findings obtained by using this framework. Furthermore, the inclusion of experts with both technological and contextual expertise improved the internal validity of Phase 1. The system diagrams produced in Phase 1 contributed to the external validity of this research by being applicable to a broader scope beyond the case study.

The stakeholder analysis used four different methods, which were used both individually and in combination, to improve the content validity of this research phase.

During Phase 3, stakeholder interviews were conducted on-site during a field visit to Curaçao, taking place in the work environments of the stakeholders. This method enhanced the ecological validity of this research phase, particularly in the case of the roofing expert and the project developer, where both interviews were complemented by on-site demonstrations. Nevertheless, the research phase's external validity was undermined due to the restricted limitation of interviewing only one individual per stakeholder type, which may have resulted in conclusions that are subjective to the interviewees. To address this issue, two additional methodologies were utilised, namely scientific and grey literature review, which further enhanced the internal validity in Phase 3.

7.2.2. Reliability

Ensuring the reliability of this research involved efforts to achieve replicability and transparency. In order to ensure transparency, a comprehensive audit trail was maintained, documenting all notes generated over the research period. These notes were derived from engagements with supervisors, experts, and the case owner, as well as from stakeholder interviews, and reflections and discoveries made during the research process. In addition, the inclusion of transcripts from all interviews enhanced the capacity to replicate the research. The researcher can provide the audit trail and interview transcripts upon request; however, they are not included in this study.

7.3. Limitations

This research has several limitations that require consideration when interpreting the conclusions drawn from the results. The limitations primarily stem from the stakeholder interviews conducted during the field visit to Curaçao and from the cultural barriers encountered during the study.

Firstly, a limitation in time was inherent in the Curaçao field visit. Although six weeks were initially counted for the field visit of the third phase, practical considerations and unforeseen circumstances reduced the actual time for interviews to three weeks. The preference of the case owner to contact stakeholders upon arrival, together with the laid-back nature of the local community, contributed to this compressed timeline for the stakeholder interviews. Post-field visit, communication with stakeholders stagnated due to various reasons, further impacting the depth of the interviews. In hindsight, the field visit should have been open-ended, allowing sufficient time for comprehensive stakeholder engagement, potentially including multiple interviews with the same individuals.

Another limitation relates to the exclusive reliance on the Wechi Management Company (WMC) network for interviewing stakeholders from the industry sector (Table 5.1). This could introduce results that are biased, as stakeholders might have been acquainted with the motivations of WMC to commission this research. To mitigate this, interviews with stakeholders from the Hofi Vida Nova sustainable neighbourhood development could have provided a more diverse perspective on the subject.

Thirdly, the limitations above contributed to a small sample size for stakeholder interviews. Not all identified stakeholders crucial for BGR implementation on Curaçao could be interviewed, and the singular perspective of one person per stakeholder type may not capture the full spectrum of visions and opinions. Addressing this could involve expanding interviews beyond the network of WMC and allocating more time to investigate a broader range of perspectives.

Fourth, a limitation was found in reaching the local community. As properties in Wechi were mostly unsold at the moment of the field visit, it was impossible to reach future residents. WMC's cautious approach to sharing contact details of current residents further hindered outreach. Attempts were made to involve the local community through NGOs focused on sustainability, but this resulted in subjective views from individuals already engaged with the topic. A more fruitful approach would have been direct engagement with community members unaware of climate change effects and potential adaptation strategies.

Lastly, there was a limitation in employing research methods uncommon to Curaçao. Co-creation was proposed as a method to collaboratively design an ideal BGR system. According to the case owner, this encountered resistance because brainstorming sessions are not commonplace in their culture. Reasons for this were indicated as time and financial constraints and a lack of experience with it. Despite this, a successful brainstorm session with the WMC team underscored the potential value of such methods.

In conclusion, the limitations in time spent on Curaçao and in reaching the local community had the most significant impact on this research, contributing to a limited perspective on BGR implementation on Curaçao. Addressing these limitations could have enriched the findings and conclusions.

7.4. Suggestions for Future Research

Based on the conclusions of this research and the identified limitations, several suggestions for future research emerge. Looking back at the initial part of the main research question concerning the potential of BGR implementation on Curaçao, the first obvious suggestion is to delve deeper into the details of this potential. While the findings of Phase 3 provide comprehensive information on various factors related to this topic, certain areas call for a more thorough investigation. For instance, the reuse of domestic greywater, explored in this research and already a known innovation on the island, could be further examined to conceptualise its potential across the entire island. Future research could involve calculations on the impact of this innovation on water savings, for example.

Expanding on the exploration of the BGR potential, future research could elaborate on the seven principles for successful BGR implementation established in Phase 1. The fourth principle, focusing on knowledge transfer, could serve as the foundation for a global study examining successful BGR cases worldwide. By synthesising this knowledge, researchers can identify shared aspects that different regions can learn from due to similarities. Another interesting principle for future research is community acceptance and engagement, which could be subjected to practical experiments testing various engagement methods with the local community of Curaçao and other Caribbean SIDS.

Transitioning to the second part of the main research question—how to realise the potential of BGR implementation on Curacao—future research could involve an in-depth investigation into the promotion stage of BGR implementation. Developing and establishing tools for promoting BGRs to the local community, end-users, design teams, and policymakers could be a valuable focus. Subsequently, these tools could be tested for their effectiveness.

Finally, an additional suggestion for future research is to explore the application of co-creation as a function for addressing sustainable urban development, extending beyond BGR implementation. Employing co-creation methodologies to develop climate adaptation strategies for Curaçao has the potential to yield inventive solutions that are grounded in diverse perspectives on the subject. Furthermore, these methods have the potential to provide valuable strategies regarding the barriers and enablers of climate adaptation on Caribbean SIDS, which have been extensively discussed in this study.

7.5. Impacts and Relevancies

7.5.1. Implications for Wechi

Wechi Management Company (WMC) is dedicated to establishing an inclusive and diverse neighbourhood that encourages community building while offering a green, sustainable, pleasant, and safe living environment (WMC, n.d.). To achieve this vision, the findings of this research can serve as a comprehensive guide for WMC on implementing BGRs on Curaçao.

The results from Phase 1 outline the key factors for success that WMC should aim to meet during BGR implementation. Phase 2 identifies the stakeholders who should be involved and outlines the organisational aspects of the BGR implementation process. A recommended strategy for WMC is to facilitate a co-creation session involving relevant stakeholders from the design, construction, and evaluation stages (see Figures 4.8, 4.9, and 4.10). This collaborative effort could lead to interdisciplinary solutions, initiate a community around BGRs, and encourage open collaboration and participation. The findings from Phase 3 provide WMC with detailed, hands-on information about these three stages. One of the ideas arising from the brainstorm session with WMC employees is to transform their new office into an innovation hub. This hub could serve as a testing ground for various sustainable innovations, promoting them to potential end-users. Considering the positive responses from stakeholders in various disciplines, it is recommended to implement this idea.

While these implications primarily apply to Wechi, they could be extended to benefit the broader community of Curaçao. However, it's crucial to acknowledge that there need to be initiators, such as WMC, to kickstart the process. By embracing the outcomes of this research, Wechi has the potential to become an exemplary model for other locations on Curaçao and beyond. This aligns with addressing the problem statement (Section 1.3.) of limited knowledge and a lack of examples regarding BGR implementation within a community on Curaçao.

7.5.2. Scientific Relevance of the Research

Understanding and addressing the socio-technical challenges and opportunities of implementing BGRs on Curaçao can lead to the development of new technologies and innovative solutions to mitigate the effects of climate change, particularly in Caribbean SIDS and other tropical and semi-arid regions. This research combines knowledge and skills from multiple disciplines, such as engineering, ecology, and social sciences, to investigate and develop suitable suggestions for the BGR implementation process that may also be applied to other environments with similar features. As a result, this research has relevance beyond Curaçao. When actively participating, the disciplines involved in this research can benefit from the results, providing them with new insights and putting the contextual considerations into perspective (Section 2.3.).

7.5.3. Societal Relevance of the Research

By researching and addressing the socio-technical challenge of implementing BGRs on Curaçao, it is possible to enhance sustainable development and climate adaptation strategies. Next to the benefits for end-users of BGRs, such as energy efficiency and isolation enhancement, the rest of the local community benefits from increased resilience to the effects of climate change on the island. This can be experienced in the form of urban heat mitigation, air and water purification, runoff control, noise reduction, and biodiversity increase. Next to this BGR implementation on the island, there could be an improvement in employment. All this could lead to Curaçao being a more sustainable and liveable place for current and future generations and potentially higher the market value of the neighbourhood and island itself. Furthermore, by involving the community in these efforts, a sense of ownership and empowerment will be fostered, which can lead to a more united and engaged society around these climate adaptation strategies.

7.5.3. Reflection on the Potential Ethical Dilemmas

The main risk associated with conducting research in an unfamiliar environment and community is the potential bias of prioritising the researcher's own values and beliefs over the cultural values and beliefs in the research context. Throughout conducting the interviews and the subsequent analysis, the perspectives of the interviewees were consistently regarded as the starting point. Additionally, one of the principles for successful BGR implementation on Curaçao was identified as including local skills and knowledge in the process.

As previously mentioned, the challenge of reaching the local community posed a limitation to this research. To ensure that this stakeholder group had a voice in this research, the concluding question in all interviews invited participants to describe their ideal green roof. By framing the question in this manner, the aim was to capture the opinions of stakeholders as local residents of Curaçao, distinct from their professional expertise.

During the field visit to Curaçao, deliberate efforts were made to assimilate into the local community. This involved residing with locals and working daily from the Wechi MC office, providing an opportunity to closely experience cultural values and beliefs. Embracing the tranquillity of the community was a significant aspect of this. Demonstrating sensitivity and respect for local customs, it was an attempt to adapt to the community's pace of life, which presented a challenge for a Dutch person.

7.5. Reflection on the Interdisciplinarity of the Research

The interdisciplinary nature of this research is evident across all three research phases. The first phase underscores the sociotechnical aspect of the study, emphasising the interconnectedness of social and technical elements. In the second phase, stakeholders from diverse disciplines and various categories of the QH approach are identified and engaged. Finally, the third phase builds upon the multidisciplinary topics and stakeholders identified in the previous phases. While interdisciplinarity is fundamental to this research, the balance among various disciplines might be slightly off due to specific research limitations (Section 7.3) and the research's initiation by a private stakeholder. A restoration of this balance across all disciplines is anticipated as BGR implementation processes on Curaçao approach their full potential.

8. Conclusion

The pressing environmental challenges that Curaçao is currently facing, particularly in light of recent climate events like intense heatwaves and heavy rainfall, served as the motivation for this study. The significance of this research is emphasised by the consequences of these extreme climatic events, which include power outages, landslides, substantial damage to buildings and infrastructure, and a detrimental impact on the emotional and physical well-being of the local population. Given these issues, it is important to investigate the possibilities of sustainable urban solutions like blue-green roofs (BGRs). This is a vital step towards promoting sustainability and resilience in response to the island's changing environment. In recent decades, there has been a growing adoption of BGRs, particularly in developed countries. The multiple benefits make the implementation of BGRs as a climate adaptation strategy appealing for Caribbean Small Island Development States (SIDS) as well. Nevertheless, literature reveals an array of barriers that hinder the implementation of climate adaptation approaches in the Caribbean SIDS, such as Curaçao. Replicating the design and execution process of places where BGRs emerge to have success is challenging due to differences in climate and living conditions. Currently, Curaçao has insufficient knowledge and lacks the examples necessary to investigate BGRs as a climate adaptation strategy.

Hence, this study aimed to investigate the potential of BGRs as a climate adaptation strategy for Curaçao and possibly other Caribbean SIDS. The main research question posed was:

"What is the potential of implementing blue-green roofs (BGRs) on Curaçao[1], and how to realize[3] this potential by engaging local stakeholders[2]?"

This question was broken down into three sub-questions, which scoped the three stages of the research. The initial stage of the research centred on the concept of 'blue-green roofs (BGRs) on Curaçao' and produced visual representations in the form of system diagrams illustrating the potential design of a BGR system on Curaçao, taking into account variations between the dry and rainy seasons. Furthermore, this phase led to the development of a set of seven principles that can be pursued to effectively implement BGR on Curaçao. The emphasis on the multidisciplinary character of these principles highlights the significance of employing innovation implementation approaches that include stakeholders from diverse disciplines, hence driving the second phase.

The second phase of the study focused on the part of the question 'local stakeholders' and successfully identified these stakeholders, falling into four distinct categories: industry (private sector), government (public sector), academia, and societal actors. This phase also highlighted both similarities and disparities in how different stakeholders may perceive BGR implementation, underscoring the need for adapted strategies for engagement for each stakeholder.

The third phase centred on the 'realization' aspect and integrated the findings from the other two phases through a six-week field study on Curaçao. This involved gathering insights from interviews with local experts, which were supplemented by relevant literature. The resulting holistic framework, referred to as the system dynamics of BGR implementation in Curaçao, consists of nine design dynamics and four social dynamics. These dynamics can be used to evaluate the potential raised in the main research question.

The findings of this study emphasise that the potential for BGR implementation on Curaçao can be recognised in various aspects of the design and social dynamics. The potential can be recognised in particular in the utilisation of domestic greywater for irrigation, the incorporation of local xerophytic vegetation, the integration of solar panels into the system, the creation of a community of practice platform, and the emphasis on demonstrational practices to educate end-users. However, it appeared especially important to examine the aspects in which the potential was lacking. The absence of laws and guidelines may give rise to safety issues, possibly resulting in a complete ban on innovation throughout the entire island. Furthermore, the impact of a single BGR on stormwater management is restricted, reducing the efficacy of BGRs as a climate adaptation strategy for the entire community of Curaçao. The most significant barrier to the potential of BGRs was found to be the absence of interest and financial resources amongst the local community in pursuing the development. These three factors collectively suggest the use of BGR systems on publicly owned buildings to shift the responsibility of investment and maintenance away from the local community while also enabling the establishment of larger operational areas. In this manner, the implementation of BGRs on Curacao can reach high potential as a strategy for climate adaptation.

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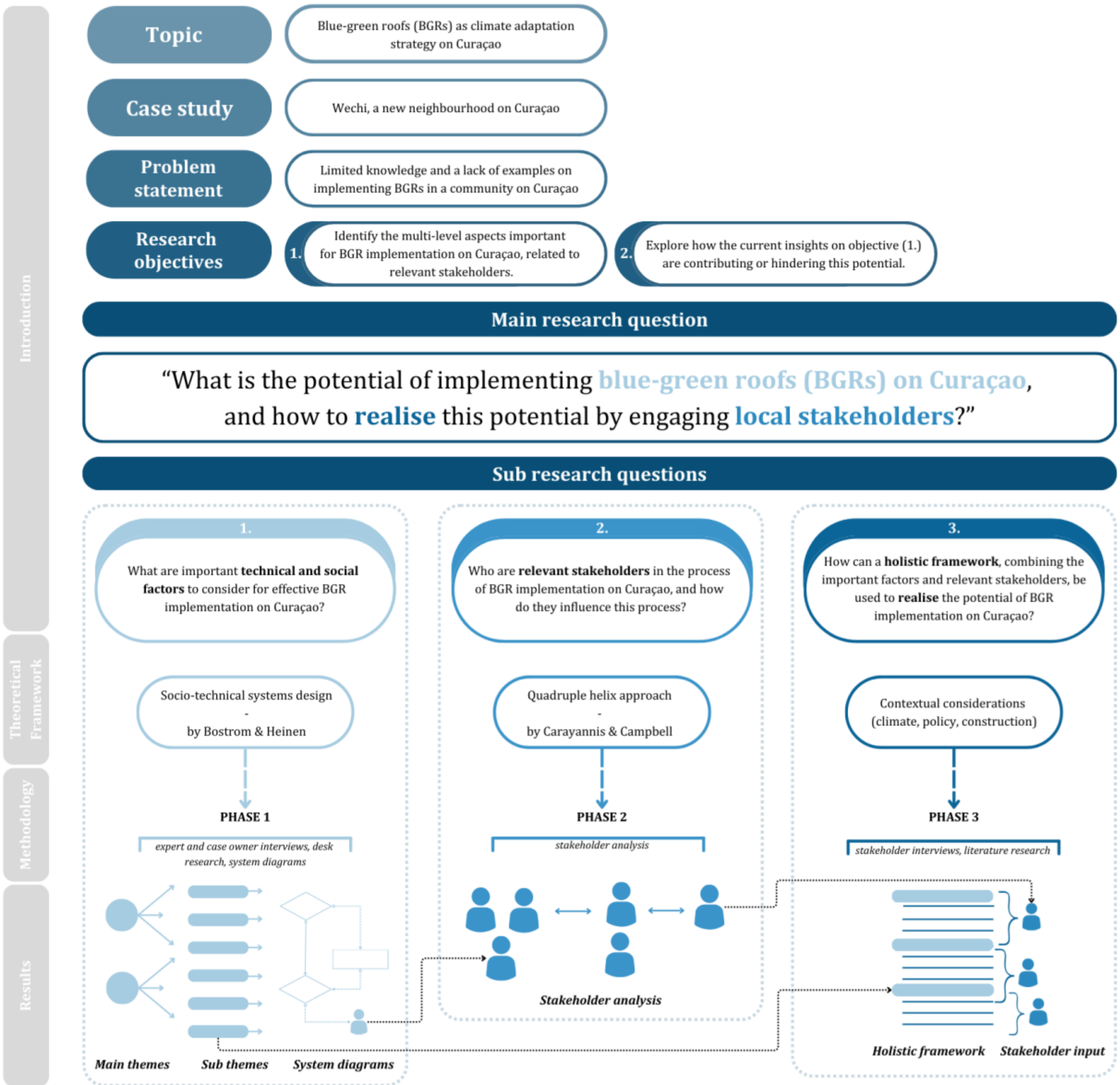
10. Appendix

10.1. Appendix 1 – Research Design



10.2. Appendix 2 – Multi-Level Factors Related to BGR Implementation

The seven sections of BGR implementation ([1] technical design, [2] connections to larger context, [3] iterative innovation design, [4] transferring knowledge, [5] community acceptance and engagement, [6] sense of ownership and commitment, and [7] local skills and knowledge) are specified into several main themes and sub themes. Furthermore, the sub themes are related to potential stakeholders of BGR implementation. These stakeholders are now classified as: project-developer or end-user, design team, construction team, research team, maintenance team and other stakeholders.

1. *Technical Design*

Main themes	**Sub themes**	**Stakeholders related to themes**					
		Project-developer or end-user	Design team	Construction team	Research team	Maintenance team	Other
Structural considerations	Additional weight • Load distribution • Suited to which dwellings		X				
	Access to roof • Maintenance • Safety		X			X	
	Fire safety		X			X	
	Seismic events		X				X[1]
	Wind uplift • Climate considerations • Design specifics		X				X[1]
	Moisture issues		X				
Vegetation	Types of plants		X	X		X	
	Diversity of different plants		X				
	Soil • Depth (mm) • Substrate composition • Materials 　○ Origin 　○ Lightweight 　○ Water retention		X	X			

	Maintenance • Human resource capacity • Responsibility	X	X				
Irrigation system	Capillary system • Permavoid example		X				
	Water distribution over roof		X				
	Smart flow control • Emergency overflow • Valve		X				
	Extreme drought • Main water grid • Reusing domestic water • Other sustainable innovations		X				X[1]
Extra layers	Waterproofing • Materials • Origin • Local knowledge		X				
	Root resistant • Materials • Origin • Local knowledge • Geotextile		X				
	Filter mat • Materials • Origin • Local knowledge		X				
Solar	Placement • Load • Wind • Sun		X	X		X	
	Battery placement		X	X		X	
	Roof penetrations. • Waterproof		X	X	X		
	Possibilities to link solar panel directly to irrigation system.		X	X			

[1] *Meteorological department.*

2. Connection to Larger Context

Main themes	Sub themes	Stakeholders related to themes					
		Project-developer or end-user	Design team	Construction team	Research team	Maintenance team	Other
Connectivity of blue	Blue infrastructure • Current situation • New possibilities		X		X		
	Water management innovations • Current situation • New possibilities	X	X	X	X		X[1]
	Regulations						X[2]
Connectivity of green	Green in the neighbourhood • Public • Private	X	X		X		
	Urban green innovations		X		X		
Connectivity to recreation	Connection to education • Primary/high schools • University • Workshops	X			X		
	Connection to other recreation • Resting area • Community garden						
	Social benefits						X[3]
Stormwater management	Extreme rainfall periods • How much • When						X[1]
	Drainage system • Dwelling level • Neighbourhood level		X	X			
Reuse of domestic grey water	Dual pipe system • Retrofitting vs. new		X	X			
	Regulations						X[2]

[1] *Meteorological department.* [2] *Policymaker.* [3] *Sustainable innovation expert.*

3. Iterative Innovation Design

Main themes	Sub themes	Stakeholders related to themes					
		Project-developer or end-user	Design team	Construction team	Research team	Maintenance team	Other
Evaluators ('who')	Public versus private	X	X		X		
	Local knowledge and skills	X	X		X		X[4]
Evaluation ('what')	Technical design • System structure • New materials		X		X		
	Vegetation		X		X		
	Irrigation system		X		X		
	Solar panel		X		X		
	Connection to blue infrastructure • Reuse of domestic grey water • Water management innovations		X		X		
Data gathering ('how')	Maintenance checks	X				X	
	Performance monitoring	X			X	X	
	User experience	X			X		
	Data analysis	X			X		

[4] *Local community.*

4. Transferring Knowledge

Main themes	Sub themes	Stakeholders related to themes					
		Project-developer or end-user	Design team	Construction team	Research team	Maintenance team	Other
Topics ('what')	Functioning of the system	X	X	X	X	X	X[5]
	Benefits • Environmental • Financial	X					X[5]
	Management and maintenance	X				X	X[5]
Strategies ('how')	Network for community • Application	X					X[4,5]
	Community events • Cargo-bike method by Rooftop Revolution* • Tour through dwelling and on roof	X					X[4,5]
	Workshops • Functioning of BGRs. • Co-creation sessions	X					X[4,5]
	Social Media • Website • Visual information • Multiple languages	X					X[4,5]
	Information signs on site • Visual information • Multiple languages	X					X[4,5]
Partnerships and collaborations		X	X	X	X	X	X[5]

[4] Local community. [5] Promotion and educational team.
** Rooftop Revolution©*

5. Community Acceptance and Engagement

Main themes	Sub themes	Stakeholders related to themes					
		Project-developer or end-user	Design team	Construction team	Research team	Maintenance team	Other
Target group ('who')	By whom • Community organisation • Project developer	X					X[3,4,5]
	For whom • Local community • End-users • Recreational partners • Other partners	X					X[3,4,5]
Community approaches ('how')	Events • Cargo-bike method of Rooftop Revolution* • Environmental organisations • Tours • Lectures at schools	X					X[3,4,5]
	Transparent communication • Decision-making processes • Multiple languages • Regular updates on entire process	X	X				X[3,4,5]
Timeline ('when')	From start of process • Input • Decision-making processes	X	X				X[3,4,5]
	Long-term • User experience	X			X		X[3,4,5]

[3] Sustainable innovation expert. [4] Local community. [5] Promotion and educational team.

6. Sense of Ownership and Commitment

Main themes	Sub themes	Stakeholders related to themes					
		Project-developer or end-user	Design team	Construction team	Research team	Maintenance team	Other
Responsibilities	Maintenance • By who? • Instructions	X				X	
	Communication • Clear roles • Guidelines • Agreements	X				X	X[4]
	Performance monitoring • Users • Research	X			X		
*Education***							
*Engagement****							
Community of practice		X	X	X	X	X	X[1,2,4,5]

[1] Meteorological department. [2] Policymaker. [3] Sustainable innovation expert. [4] Local community. [5] Promotion and educational team.
*** Identical to theme [4]. *** Identical to theme [5].*

7. Local Knowledge and Skills

Main themes	Sub themes	Stakeholders related to themes					
		Project-developer or end-user	Design team	Construction team	Research team	Maintenance team	Other
Current state	Design		X				
	Construction			X			
	Research				X		
	Maintenance					X	
Norms and values	Roofing	X	X				X[4]
	Gardening	X	X				X[4]
	Water Management	X	X				X[4]
*Education***							

[4] Local community.
*** Identical to theme [4].*

10.3. Appendix 3 – Stakeholder Drivers, Motivations, and Barriers

10.3.1. Stakeholder Overview

Overview with drivers, motivations, and barriers to implementing BGRs on Curaçao for the different stakeholders.

Stakeholders	Drivers	Motivations	Barriers	Similarities
	1 t/m 4	5 t/m 16	17 t/m 23	
Academia				
1. Climatologists	4	6, 9, 11, 13	17, 18, 19	Ecologists [2], meteorological department [20]
2. Ecologists (botanists)	4	5, 6, 8, 9, 10, 11, 12, 13, 14	17, 18, 19, 21, 22	Climatologists [1]
3. Research institutions	1, 4	7, 15, 16	17, 18, 19	Academic researchers [4], data analysts [5]
4. Academic researchers	1, 4	7, 15, 16	17, 18, 19	Research institutions [3], data analysts [5]
5. Data analysts	1, 4	7, 15, 16	17, 18, 19, 20, 21, 23	Research institutions [3], academic researchers [4]
Industry (private sector)				
6. The initiators (dwelling owner, project developer)	1, 2, 3	5, 7, 8, 9, 10, 11, 12, 13, 14, 15	17, 19, 20, 21, 22, 23	Urban planners [7], architects [8], civil and structural engineers [9], landscape architects [10]
7. Urban planners	1, 3, 4	5, 6, 7, 8, 9, 10, 11, 12, 13, 14	17, 19, 20, 21, 22	The initiators [6], architects [8], civil and structural engineers [9], landscape architects [10]
8. Architects	1, 3, 4	5, 6, 7, 8, 9, 10, 11, 12, 13, 14	17, 20, 21, 22	The initiators [6], urban planners [7], civil and structural engineers [9], landscape architects [10]
9. Civil and structural engineers	1, 3, 4	5, 6, 7, 8, 9, 10, 11, 12, 13, 14	17, 20, 21, 22	The initiators [6], urban planners [7], architects [8], landscape architects [10]
10. Landscape architects	1, 3, 4	5, 6, 7, 8, 9, 10, 11, 12, 13, 14	17, 20, 21, 22	The initiators [6], urban planners [7], architects [8], civil and structural engineers [9]
11. Electrical engineers	1, 4	5, 6, 8	17, 22	-
12. Building contractors	1, 3, 4	7, 10,15, 16	17, 19, 20, 21, 22	Initiators [6], electricians [14], gardeners [15], roofing experts [16], construction team [17], maintenance team [18]
13. Suppliers and manufacturers	1, 3, 4	7	17, 19, 23	-
14. Electricians	1, 3, 4	7, 8, 16	17, 21	Building contractors [12], gardeners [15], roofing experts [16], construction team [17], maintenance team [18]
15. Gardeners	1, 3, 4	13, 14, 16	17, 21	Building contractors [12], electricians [14], roofing experts [16], construction team [17], maintenance team [18]

16.	Roofing experts	1, 3, 4	7, 16	17, 20, 21	Building contractors [12], electricians [14], gardeners [15], construction team [17], maintenance team [18]
17.	Construction team	1, 3, 4	7, 16	17, 21	Building contractors [12], electricians [14], gardeners [15], roofing experts [16], maintenance team [18]
18.	Maintenance team	1, 4	7, 16	17, 21, 22	Building contractors [12], electricians [14], gardeners [15], roofing experts [16], construction team [17]
Government (public sector)					
19.	Policymakers	1, 3	5, 6, 8, 9, 10, 11, 13, 14, 16	17	Government agents [21], local community [22], end-users [23], NGOs [24]
20.	Meteorological department	1, 4	6, 9, 10, 11	17, 18, 19, 20, 21	Climatologists [1]
21.	Government agents	1, 4	5, 10, 13	17, 22	Policymakers [21]
Societal actors					
22.	Local community	1, 4	6, 9, 10, 11, 12, 13, 14, 16	20, 21, 23	Policymakers [19], end-users [23], NGOs [24]
23.	End-users	1, 2, 4	5, 6, 7, 8, 9, 10, 11, 12, 13, 14	17, 19, 20, 21, 23	Policymakers [19], local community [22], NGOs [24]
24.	NGOs	1, 2, 3, 4	6, 9, 10, 11, 12, 13, 14, 16	17, 18, 19, 20, 21, 22, 23	Policymakers [19], local community [22], end-users [23]

Note. Drivers: 1. Policy pressure, 2. Economical pressure, 3. Reputational pressure, 4. Innovation and technology advancement. Motivations: 5. Energy efficiency, 6. Urban heat island mitigation, 7. Roof longevity prolongation, 8. Solar panel enhancement, 9. Air purification, 10. Runoff control, 11. Water purification, 12. Noise reduction, 13. Biodiversity increase, 14. Recreation and aesthetics, 15. Property value enhancement, 16. Employment improvement.
Barriers: 17. Technological barrier, 18. Research barrier, 19. Financial barrier, 20. Cognitive barrier, 21. Cultural barrier, 22. Lack of government policy, 23. Individual unwillingness.

10.4. Appendix 4 – Main Takeaways from Stakeholder Interviews

The stakeholder type refers to the different stakeholders identified in Section 5.1. The drivers, motivations, and barriers refer to the motifs that stakeholders could have for their engagement with sustainable urban development (Section 2.3.4.). The themes discussed refer to the set of 7 principles guiding effective BGR implementation, displayed in Appendix 2.

10.4.1. Interview 1 – Local Contractor

Name:	Daan Hoogendijk
Function:	Technical director, contractor.
Company:	N.A.b. (Nederlands Antilliaans bouwbedrijf).
Stakeholder type:	Building contractors.
Drivers:	Policy pressure (1.) Reputational pressure (3.) Innovation and technology advancement (4.)
Motivations:	Roof longevity prolongation (7.) Runoff control (10.) Property value enhancement (15.) Employment improvement (16.)
Barriers:	Technological barrier (17.) Financial barrier (19.) Cognitive barrier (20.) Cultural barrier (21.) Lack of government policy (22.)
Themes discussed:	▪ Technical design ▪ Connection to a larger system ▪ Local skills and knowledge ▪ Transferring knowledge
Main takeaways:	▪ Daan is convinced that the technical design of BGRs can be effectively adjusted to the contextual considerations. ▪ He believes the hardest part will be to import materials and to convince the local community. ▪ Daan states that possible end-users will be convinced for the investment in a BGR system when they sense the difference in heating load or see the difference in energy bills. ▪ He did not make a plan regarding possible safety issues.
Ideal blue-green roof:	A roof where Daan can include permaculture into the design.

10.4.2. Interview 2 – Local Civil and Structural Engineer

Name:	Martin Koopman
Function:	Owner of a civil and structural engineering firm.
Company:	CCM Engineering.
Stakeholder type:	Civil and structural engineers.
Drivers:	Policy pressure (1.) Reputational pressure (3.) Innovation and technology advancement (4.)

Motivations:	Energy efficiency (5.) Urban heat island mitigation (6.) Roof longevity prolongation (7.) Solar panel enhancement (8.) Air purification (9.) Runoff control (10.) Water purification (11.) Noise reduction (12.) Biodiversity increase (13.) Recreation and aesthetics (14.)
Barriers:	Technological barrier (17.) Cognitive barrier (20.) Cultural barrier (21.) Lack of government policy (22.)
Themes discussed:	▪ Connection to a larger system ▪ Technical design ▪ Iterative innovation design
Main takeaways:	▪ Martin explained the working on the blue infrastructure of the island. Currently the main idea is to bring the stormwater to the sea as quickly as possible. ▪ He thinks more construction companies are leaning towards sustainable building practices. He admits that this might be the bubble he lives in. ▪ Martin explained the possibility for the reuse of domestic greywater through a dual-pipe system.
Ideal blue-green roof:	A roof where Martin can grow his oregano to make the famous local oregano punch.

10.4.3. Interview 3 – Local Promoters of Sustainability

Name:	Frensel Marcelina and Theo van der Giessen
Function:	Director and volunteer.
Company:	Uniek Curaçao.
Stakeholder type:	Local community.
Drivers:	Policy pressure (1.) Innovation and technologicy advancement (4.)
Motivations:	Urban heat island mitigation (6.) Air purification (9.) Runoff control (10.) Water purification (11.) Noise reduction (12.) Biodiversity increase (13.) Recreation and aesthetics (14.) Employment improvement (16.)
Barriers:	Cognitive barrier (20.) Cultural barrier (21.) Individual unwillingness (23.)
Themes discussed:	▪ Community acceptance and engagement ▪ Transferring knowledge

Main takeaways:

- Frensel explained how many people are not having the financial resources for such big investments as BGRs.
- He explained all sorts of smart innovations the local community can implement on small and cheap scale.
- Theo explained that it is important to look into climate justice.
- He also beliefs in education on a young age in order to make a lasting impression.
- Frensel and Theo both agreed you need to become part of the community in order to try to understand the motifs of the local community and to possibly persuade them to make the investments in BGRs.

Ideal blue-green roof: A place where a lot of people can come together. Frensel envisions a pineapple plant on his roof.

10.4.4. Interview 4 – Local Architect and Urban Planner

Name: Zarja Garmers

Function: Director of an architecture firms, urban planner, landscape architect.

Company: ProGaya, ZARJA architects.

Stakeholder type: Architect, landscape architect, urban planner

Drivers:
Policy pressure (1.)
Reputational pressure (3.)
Innovation and technology advancement (4.)

Motivations:
Energy efficiency (5.)
Urban heat island mitigation (6.)
Roof longevity prolongation (7.)
Solar panel enhancement (8.)
Air purification (9.)
Runoff control (10.)
Water purification (11.)
Noise reduction (12.)
Biodiversity increase (13.)
Recreation and aesthetics (14.)

Barriers:
Technological barrier (17.)
Financial barrier (19.)
Cognitive barrier (20.)
Cultural barrier (21.)
Lack of government policy (22.)

Themes discussed:

- Connection to a larger system
- Technical design
- Iterative innovation design

Main takeaways:

- Zarja states that she thinks the potential lies in implementing BGRs on publicly owned buildings due to safety and responsibility concerns.
- She explained a lot on the establishment of the Masterplan for Wechi and the necessary site analysis that was performed. This encompasses multiple researches into aspect such as water management, trash, ground quality, etc.
- Zarja favours the idea of reusing domestic greywater.

Ideal blue-green roof: A roof for herbs and that provides space for recreation and relaxation.

10.4.5. Interview 5 – Local Expert on Water Resource Management

Name:	Pedzi Girigori
Function:	Chief Operations Officer.
Company:	Meteorological Department of Curaçao (Meteo).
Stakeholder type:	Meteorological department.
Drivers:	Policy pressure (1.) Innovation and technology advancement (4.)
Motivations:	Urban heat island mitigation (6.) Air purification (9.) Runoff control (10.) Water purification (11.)
Barriers:	Technological barrier (17.) Research barrier (18.) Financial barrier (19.) Cognitive barrier (20.) Cultural barrier (21.)
Themes discussed:	▪ Connection to a larger system ▪ Technical design ▪ Iterative innovation design
Main takeaways:	▪ Pedzi made a policy plan including the implementation of BGRs already in 2020. This plan is only recently reviewed and partly approved. ▪ Pedzi gave a lot of insights in the climate considerations of Curaçao such as prevailing rainfall patterns. ▪ She believes that a community-based approach is necessary.
Ideal blue-green roof:	A roof with a lot of flowers and edible plants, so the roof has even more functions.

10.4.6. Interview 6 – Local Roofing Expert

Name:	Chris van Grieken
Function:	Director of roofing company.
Company:	ARG Group.
Stakeholder type:	Roofing expert.
Drivers:	Policy pressure (1.) Reputational pressure (3.) Innovation and technology advancement (4.)
Motivations:	Roof longevity prolongation (7.) Employment improvement (16.)
Barriers:	Technological barrier (17.) Cognitive barrier (20.) Cultural barrier (21.)
Themes discussed:	▪ Connection to a larger system ▪ Technical design ▪ Iterative innovation design

Main takeaways:

- Chris showed the green roof system he employed a few years ago. It turned all brown. However, according to Chris, is green during the rainy season. He explained he tried everything regarding irrigation systems.
- Chris sees potential in adding a retention layer under the vegetation, so plants have access to water when they are in need of it.
- Chris gave some insights on the important materials to include, such as TPO and a root barrier.
- He also provided some construction insights and building traditions.

Ideal blue-green roof: A roof that stays green throughout the year.

10.4.7. Interview 7 – Dutch Blue-Green Roof expert

Name: Joris Voeten

Function: Researcher Nature-based solutions

Company: Wageningen Environmental Research

Stakeholder type: N/A

Drivers: N/A

Motivations: N/A

Barriers: N/A

Themes discussed:

- Technical design
- Connection to a larger context
- Iterative innovation design
- Transferring knowledge

Main takeaways:

- Joris provided useful insights in the factors essential for considering the potential of BGR implementation.

Ideal blue-green roof: A roof that retains stormwater throughout the entire year.

10.4.8. Brainstorm session – Local Project Developer, Local Construction Manager, Local Construction Superintendent, and Local Sales Manager

Name: Carine Ghazzi, Roger de Lanooi, Ralph Cijntje, Tasha Reina York.

Function: Project developer, construction manager, superintendent, sales manager.

Company: Wechi Management Company

Stakeholder type: Initiator.

Drivers: Policy pressure (1.)
Economical pressure (2.)
Reputational pressure (3.)

Motivations:
Energy efficiency (5.)
Roof longevity prolongation (7.)
Solar panel enhancement (8.)
Air purification (9.)
Runoff control (10.)
Water purification (11.)
Noise reduction (12.)
Biodiversity increase (13.)
Recreation and aesthetics (14.)
Property value enhancement (15.)

Barriers:
Technological barrier (17.)
Financial barrier (19.)
Cognitive barrier (20.)
Cultural barrier (21.)
Lack of government policy (22.)
Individual unwillingness (23.)

Themes discussed:

- Technical design
- Iterative innovation design
- Transferring knowledge
- Community acceptance and engagement
- Sense of ownership and commitment
- Local knowledge and skills

Main takeaways:

- During this brainstorm the idea arose to turn the office of WMC into an innovation hub where multiple sustainable urban innovations can be tested. One of these could be a BGR. People could then come by to feel and see the difference compared to a regular grey roof.
- Multiple suggestions regarding promotion BGRs to the local community were made. One of them was to actively use social media. Another entailed the demonstrating approach.

Ideal blue-green roof:
A roof promoting a green, safe, and pleasant environment for everyone.